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Classic Shell Scripting

By [Nelson H.F. Beebe](#), [Arnold Robbins](#)

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Overview

An essential skill for Unix users and system administrators, shell scripts let you easily crunch data and automate repetitive tasks, offering a way to quickly harness the full power of any Unix system. This book provides the tips, tricks, and organized knowledge you need to create excellent scripts, as well as warnings of the traps that can turn your best efforts into bad shell scripts.

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Foreword

Surely I haven't been doing shell scripting for 30 years?!? Well, now that I think about it, I suppose I have, although it was only in a small way at first. (The early Unix shells, before the Bourne shell, were very primitive by modern standards, and writing substantial scripts was difficult. Fortunately, things quickly got better.)

In recent years, the shell has been neglected and underappreciated as a scripting language. But even though it was Unix's first scripting language, it's still one of the best. Its combination of extensibility and efficiency remains unique, and the improvements made to it over the years have kept it highly competitive with other scripting languages that have gotten a lot more hype. GUIs are more fashionable than command-line shells as user interfaces these days, but scripting languages often provide most of the underpinnings for the fancy screen graphics, and the shell continues to excel in that role.

The shell's dependence on other programs to do most of the work is arguably a defect, but also inarguably a strength: you get the concise notation of a scripting language plus the speed and efficiency of programs written in C (etc.). Using a common, general-purpose data representation—lines of text—in a large (and extensible) set of tools lets the scripting language plug the tools together in endless combinations. The result is far more flexibility and power than any monolithic software package with a built-in menu item for (supposedly) everything you might want. The early success of the shell in taking this approach reinforced the developing Unix philosophy of building specialized, single-purpose tools and plugging them together to do the job. The philosophy in turn encouraged improvements in the shell to allow doing more jobs that way.

Shell scripts also have an advantage over C programs—and over some of the other scripting languages too (naming no names!)-of generally being fairly easy to read and modify. Even people who are not C programmers, like a good many system administrators these days, typically feel comfortable with shell scripts. This makes shell scripting very important for extending user environments and for customizing software packages.

Indeed, there's a "wheel of reincarnation" here, which I've seen on several software projects. The project puts simple shell scripts in key places, to make it easy for users to customize aspects of the software. However, it's so much easier for the *project* to solve problems by working in those shell scripts than in the surrounding C code, that the scripts steadily get more complicated. Eventually they are too complicated for the users to cope with easily (some of the scripts we wrote in the C News project were notorious as stress tests for shells, never mind users!), and a new set of scripts has to be provided for user customization...

For a long time, there's been a conspicuous lack of a good book on shell scripting. Books on the Unix programming environment have touched on it, but only briefly, as one of several topics, and the better books are long out-of-date. There's reference documentation for the various shells, but what's wanted is a novice-friendly tutorial, covering the tools as well as the shell, introducing the concepts gently, offering advice on how to get the best results, and paying attention to practical issues like readability. Preferably, it should also discuss how the various shells differ, instead of trying to pretend that only one exists.

This book delivers all that, and more. Here, at last, is an up-to-date and painless introduction to the first and best of the Unix scripting languages. It's illustrated with realistic examples that make useful tools in their own right. It covers the standard Unix tools well enough to get people started with them (and to make a useful reference for those who find the manual pages a bit forbidding). I'm particularly pleased to see it including basic coverage of *awk*, a highly useful and unfairly neglected tool which excels in bridging gaps between other tools and in doing small programming jobs easily and concisely.

I recommend this book to anyone doing shell scripting or administering Unix-derived systems. I learned things from it; I think you will too.

Henry Spencer

SP Systems

Preface

The user or programmer new to Unix^[1] is suddenly faced with a bewildering variety of programs, each of which often has multiple options. Questions such as "What purpose do they serve?" and "How do I use them?" spring to mind.

[1] Throughout this book, we use the term *Unix* to mean not only commercial variants of the original Unix system, such as Solaris, Mac OS X, and HP-UX, but also the freely available workalike systems, such as GNU/Linux and the various BSD systems: BSD/OS, NetBSD, FreeBSD, and OpenBSD.

This book's job is to answer those questions. It teaches you how to combine the Unix tools, together with the standard shell, to get your job done. This is the art of *shell scripting*. Shell scripting requires not just a knowledge of the shell language, but also a knowledge of the individual Unix programs: why each one is there, and how to use them by themselves and in combination with the other programs.

Why should you learn shell scripting? Because often, medium-size to large problems can be decomposed into smaller pieces, each of which is amenable to being solved with one of the Unix tools. A shell script, when done well, can often solve a problem in a mere fraction of the time it would take to solve the same problem using a conventional programming language such as C or C++. It is also possible to make shell scripts *portable*-i.e., usable across a range of Unix and POSIX-compliant systems, with little or no modification.

When talking about Unix programs, we use the term *tools* deliberately. The Unix *toolbox approach* to problem solving has long been known as the "Software Tools" philosophy.^[2]

[2] This approach was popularized by the book *Software Tools* (Addison-Wesley).

A long-standing analogy summarizes this approach to problem solving. A Swiss Army knife is a useful thing to carry around in one's pocket. It has several blades, a screwdriver, a can opener, a toothpick, and so on. Larger models include more tools, such as a corkscrew or magnifying glass. However, there's only so much you can do with a Swiss Army knife. While it might be great for whittling or simple carving, you wouldn't use it, for example, to build a dog house or bird feeder. Instead, you would move on to using *specialized* tools, such as a hammer, saw, clamp, or planer. So too, when solving programming problems, it's better to use specialized software tools.

Intended Audience

This book is intended for computer users and software developers who find themselves in a Unix environment, with a need to write shell scripts. For example, you may be a computer science student, with your first account on your school's Unix system, and you want to learn about the things you can do under Unix that your Windows PC just can't handle. (In such a case, it's likely you'll write multiple scripts to customize your environment.) Or, you may be a new system administrator, with the need to write specialized programs for your company or school. (Log management and billing and accounting come to mind.) You may even be an experienced Mac OS developer moving into the brave new world of Mac OS X, where installation programs are written as shell scripts. Whoever you are, if you want to learn about shell scripting, this book is for you. In this book, you will learn:

Software tool design concepts and principles

A number of principles guide the design and implementation of good software tools. We'll explain those principles to you and show them to you in use throughout the book.

What the Unix tools are

A core set of Unix tools are used over and over again when shell scripting. We cover the basics of the shell and regular expressions, and present each core tool within the context of a particular kind of problem. Besides covering what the tools do, for each tool we show you *why* it exists and why it has particular options.

Learning Unix is an introduction to Unix systems, serving as a primer to bring someone with no Unix experience up to speed as a basic user. By contrast, *Unix in a Nutshell* covers the broad swath of Unix utilities, with little or no guidance as to when and how to use a particular tool. Our goal is to bridge the gap between these two books: we teach you how to exploit the facilities your Unix system offers you to get your job done quickly, effectively, and (we hope) elegantly.

How to combine the tools to get your job done

In shell scripting, it really is true that "the whole is greater than the sum of its parts." By using the

shell as "glue" to combine individual tools, you can accomplish some amazing things, with little effort.

About popular extensions to standard tools

If you are using a GNU/Linux or BSD-derived system, it is quite likely that your tools have additional, useful features and/or options. We cover those as well.

About indispensable nonstandard tools

Some programs are not "standard" on most traditional Unix systems, but are nevertheless too useful to do without. Where appropriate, these are covered as well, including information about where to get them.

For longtime Unix developers and administrators, the software tools philosophy is nothing new. However, the books that popularized it, while still being worthwhile reading, are all on the order of 20 years old, or older! Unix systems have changed since these books were written, in a variety of ways. Thus, we felt it was time for an updated presentation of these ideas, using modern versions of the tools and current systems for our examples. Here are the highlights of our approach:

- Our presentation is POSIX-based. "POSIX" is the short name for a series of formal standards describing a portable operating system environment, at the programmatic level (C, C++, Ada, Fortran) and at the level of the shell and utilities. The POSIX standards have been largely successful at giving developers a fighting chance at making both their programs and their shell scripts portable across a range of systems from different vendors. We present the shell language, and each tool and its most useful options, as described in the most recent POSIX standard.
- The official name for the standard is IEEE Std. 1003.1-2001.^[3] This standard includes several optional parts, the most important of which are the *X/Open System Interface* (XSI) specifications. These features document a fuller range of historical Unix system behaviors. Where it's important, we'll note changes between the current standard and the earlier 1992 standard, and also mention XSI-related features. A good starting place for Unix-related standards is <http://www.unix.org/>.^[4]

^[3] A 2004 edition of the standard was published after this book's text was finalized. For purposes of learning about shell scripting, the differences between the 2001 and 2004 standard don't matter.

^[4] A technical frequently asked questions (FAQ) file about IEEE Std. 1003.1-2001 may be found at http://www.opengroup.org/austin/papers/posix_faq.html. Some background on the standard is at <http://www.opengroup.org/austin/papers/backgrounder.html>.

- The home page for the Single UNIX Specification is <http://www.unix.org/version3/>. Online access

to the current standard is available, but requires registration at <http://www.unix.org/version3/online.html>.

- Occasionally, the standard leaves a particular behavior as "unspecified." This is done on purpose, to allow vendors to support historical behavior as *extensions*, i.e., additional features above and beyond those documented within the standard itself.
- Besides just telling you how to run a particular program, we place an emphasis on *why* the program exists and on what problem it solves. Knowing why a program was written helps you better understand when and how to use it.
- Many Unix programs have a bewildering array of options. Usually, some of these options are more useful for day-to-day problem solving than others are. For each program, we tell you which options are the most useful. In fact, we typically do not cover all the options that individual programs have, leaving that task to the program's manual page, or to other reference books, such as *Unix in a Nutshell* (O'Reilly) and *Linux in a Nutshell* (O'Reilly).

By the time you've finished this book, you should not only understand the Unix toolset, but also have internalized the Unix mindset and the Software Tools philosophy.

What You Should Already Know

You should already know the following things:

- How to log in to your Unix system
- How to run programs at the command line
- How to make simple pipelines of commands and use simple I/O redirectors, such as `<` and `>`
- How to put jobs in the background with `&`
- How to create and edit files
- How to make scripts executable, using *chmod*

Furthermore, if you're trying to work the examples here by typing commands at your terminal (or, more likely, terminal emulator) we recommend the use of a POSIX-compliant shell such as a recent version of *ksh93*, or the current version of *bash*. In particular, `/bin/sh` on commercial Unix systems may not be fully POSIX-compliant.

[Chapter 14](#) provides Internet download URLs for *ksh93*, *bash*, and *zsh*.

Chapter Summary

We recommend reading the book in order, as each chapter builds upon the concepts and material covered in the chapters preceding it. Here is a chapter-by-chapter summary:

Chapter 1

Here we provide a brief history of Unix. In particular, the computing environment at Bell Labs where Unix was developed motivated much of the Software Tools philosophy. This chapter also presents the principles for good Software Tools that are then expanded upon throughout the rest of the book.

Chapter 2

This chapter starts off the discussion. It begins by describing compiled languages and scripting languages, and the tradeoffs between them. Then it moves on, covering the very basics of shell scripting with two simple but useful shell scripts. The coverage includes commands, options, arguments, shell variables, output with *echo* and *printf*, basic I/O redirection, command searching, accessing arguments from within a script, and execution tracing. It closes with a look at internationalization and localization; issues that are increasingly important in today's "global village."

Chapter 3

Here we introduce text searching (or "matching") with regular expressions. We also cover making changes and extracting text. These are fundamental operations that form the basis of much shell scripting.

Chapter 4

In this chapter we describe a number of the text processing software tools that are used over and over again when shell scripting. Two of the most important tools presented here are *sort* and

uniq, which serve as powerful ways to organize and reduce data. This chapter also looks at reformatting paragraphs, counting text units, printing files, and retrieving the first or last lines of a file.

Chapter 5

This chapter shows several small scripts that demonstrate combining simple Unix utilities to make more powerful, and importantly, more flexible tools. This chapter is largely a cookbook of problem statements and solutions, whose common theme is that all the solutions are composed of linear pipelines.

Chapter 6

This is the first of two chapters that cover the rest of the essentials of the shell language. This chapter looks at shell variables and arithmetic, the important concept of an exit status, and how decision making and loops are done in the shell. It rounds off with a discussion of shell functions.

Chapter 7

This chapter completes the description of the shell, focusing on input/output, the various substitutions that the shell performs, quoting, command-line evaluation order, and shell built-in commands.

Chapter 8

Here we demonstrate combinations of Unix tools to carry out more complex text processing jobs. The programs in this chapter are larger than those in [Chapter 5](#), but they are still short enough to digest in a few minutes. Yet they accomplish tasks that are quite hard to do in conventional programming languages such as C, C++, or Java©.

Chapter 9

This chapter describes the essentials of the *awk* language. *awk* is a powerful language in its own right. However, simple, and sometimes, not so simple, *awk* programs can be used with other programs in the software toolbox for easy data extraction, manipulation, and formatting.

Chapter 10

This chapter introduces the primary tools for working with files. It covers listing files, making temporary files, and the all-important *find* command for finding files that meet specific criteria. It looks at two important commands for dealing with disk space utilization, and then discusses different programs for comparing files.

Chapter 11

Here we tie things together by solving an interesting and moderately challenging task.

Chapter 12

This chapter uses the problem of doing spellchecking to show how it can be solved in different ways. It presents the original Unix shell script pipeline, as well as two small scripts to make the freely available *ispell* and *aspell* commands more usable for batch spellchecking. It closes off with a reasonably sized yet powerful spellchecking program written in *awk*, which nicely demonstrates the elegance of that language.

Chapter 13

This chapter moves out of the realm of text processing and into the realm of job and system management. There are a small number of essential utilities for managing processes. In addition, this chapter covers the *sleep* command, which is useful in scripts for waiting for something to happen, as well as other standard tools for delayed or fixed-time-of-day command processing. Importantly, the chapter also covers the *trap* command, which gives shell scripts control over Unix signals.

Chapter 14

Here we describe some of the more useful extensions available in both *ksh* and *bash* that aren't in POSIX. In many cases, you can safely use these extensions in your scripts. The chapter also looks at a number of "gotchas" waiting to trap the unwary shell script author. It covers issues involved when writing scripts, and possible implementation variances. Furthermore, it covers download and build information for *ksh* and *bash*. It finishes up by discussing shell initialization

and termination, which differ among different shell implementations.

Chapter 15

In this chapter we provide a cursory introduction to shell scripting security issues.

Appendix A

This chapter describes how to write a manual page. This necessary skill is usually neglected in typical Unix books.

Appendix B

Here we describe the Unix byte-stream filesystem model, contrasting it with more complex historical filesystems and explaining why this simplicity is a virtue.

Appendix C

This chapter provides several lists of Unix commands. We recommend that you learn these commands and what they do to improve your skills as a Unix developer.

Bibliography

Here we list further sources of information about shell scripting with Unix.

Glossary

The Glossary provides definitions for the important terms and concepts introduced in this book.

Conventions Used in This Book

We leave it as understood that, when you enter a shell command, you press Enter at the end. Enter is labeled Return on some keyboards.

Characters called Ctrl-*X*, where *X* is any letter, are entered by holding down the Ctrl (or Ctl, or Control) key and then pressing that letter. Although we give the letter in uppercase, you can press the letter without the Shift key.

Other special characters are newline (which is the same as Ctrl-J), Backspace (the same as Ctrl-H), Esc, Tab, and Del (sometimes labeled Delete or Rubout).

This book uses the following font conventions:

Italic

Italic is used in the text for emphasis, to highlight special terms the first time they are defined, for electronic mail addresses and Internet URLs, and in manual page citations. It is also used when discussing dummy parameters that should be replaced with an actual value, and to provide commentary in examples.

Constant Width

This is used when discussing Unix filenames, external and built-in commands, and command options. It is also used for variable names and shell keywords, options, and functions; for filename suffixes; and in examples to show the contents of files or the output from commands, as well as for command lines or sample input when they are within regular text. In short, anything related to computer usage is in this font.

Constant Width Bold

This is used in the text to distinguish regular expressions and shell wildcard patterns from the text to be matched. It is also used in examples to show interaction between the user and the shell;

any text the user types in is shown in **Constant Width Bold**. For example:

```
$ pwd                                User typed this
/home/tolstoy/novels/w+p                System printed this
$
```

Constant Width Italic

This is used in the text and in example command lines for dummy parameters that should be replaced with an actual value. For example:

```
$ cd directory
```



This icon indicates a tip, suggestion, or general note.

This icon indicates a warning or caution.

References to entries in the Unix User's Manual are written using the standard style: *name*(N), where *name* is the command name and N is the section number (usually 1) where the information is to be found. For example, *grep*(1) means the manpage for *grep* in section 1. The reference documentation is referred to as the "man page," or just "manpage" for short.

We refer both to Unix system calls and C library functions like this: `open()`, `printf()`. You can see the manpage for either kind of call by using the *man* command:

```
$ man open                            Look at open(2) manpage
$ man printf                          Look at printf(3) manpage
```

When programs are introduced, a sidebar, such as shown nearby, describes the tool as well as its significant options, usage, and purpose.

Example

Usage

```
whizprog [ options ... ] [ arguments ... ]
```

This section shows how to run the command, here named *whizprog*.

Purpose

This section describes *why* the program exists.

Major options

This section lists the options that are important for everyday use of the program under discussion.

Behavior

This section summarizes what the program does.

Caveats

If there's anything to be careful of, it's mentioned here.

Code Examples

This book is full of examples of shell commands and programs that are designed to be useful in your everyday life as a user or programmer, not just to illustrate the feature being explained. We especially encourage you to modify and enhance them yourself.

The code in this book is published under the terms of the GNU General Public License (GPL), which allows copying, reuse, and modification of the programs. See the file `COPYING` included with the examples for the exact terms of the license.

The code is available from this book's web site: <http://www.oreilly.com/catalog/shellsrptg/index.html>.

We appreciate, but do not require, attribution. An attribution usually includes the title, author, publisher, and ISBN. For example: "*Classic Shell Scripting*, by Arnold Robbins and Nelson H.F. Beebe. Copyright 2005 O'Reilly Media, Inc., 0-596-00595-4."

Unix Tools for Windows Systems

Many programmers who got their initial experience on Unix systems and subsequently crossed over into the PC world wished for a nice Unix-like environment (especially when faced with the horrors of the MS-DOS command line!), so it's not surprising that several Unix shell-style interfaces to small-computer operating systems have appeared.

In the past several years, we've seen not just shell clones, but also entire Unix environments. Two of them use *bash* and *ksh93*. Another provides its own shell reimplementations. This section describes each environment in turn (in alphabetical order), along with contact and Internet download information.

Cygwin

Cygnus Consulting (now Red Hat) created the *cygwin* environment. First creating *cygwin.dll*, a shared library that provides Unix system call emulation, the company ported a large number of GNU utilities to various versions of Microsoft Windows. The emulation includes TCP/IP networking with the Berkeley socket API. The greatest functionality comes under Windows/NT, Windows 2000, and Windows XP, although the environment can and does work under Windows 95/98/ME, as well.

The *cygwin* environment uses *bash* for its shell, GCC for its C compiler, and the rest of the GNU utilities for its Unix toolset. A sophisticated *mount* command provides a mapping of the Windows `C:\path` notation to Unix filenames.

The starting point for the *cygwin* project is <http://www.cygwin.com/>. The first thing to download is an installer program. Upon running it, you choose what additional packages you wish to install. Installation is entirely Internet-based; there are no official *cygwin* CDs, at least not from the project maintainers.

DJGPP

The DJGPP suite provides 32-bit GNU tools for the MS-DOS environment. To quote the web page:

DJGPP is a complete 32-bit C/C++ development system for Intel 80386 (and higher) PCs running MS-DOS. It includes ports of many GNU development utilities. The development tools require an 80386 or newer computer to run, as do the programs they produce. In most cases, the programs it produces can be sold commercially without license or royalties.

The name comes from the initials of D.J. Delorie, who ported the GNU C++ compiler, `g++`, to MS-DOS, and the text initials of `g++`, GPP. It grew into essentially a full Unix environment on top of MS-DOS, with all the GNU tools and `bash` as its shell. Unlike `cygwin` or UWIN (see further on), you don't need a version of Windows, just a full 32-bit processor and MS-DOS. (Although, of course, you can use DJGPP from within a Windows MS-DOS window.) The web site is <http://www.delorie.com/djgpp/>.

MKS Toolkit

Perhaps the most established Unix environment for the PC world is the MKS Toolkit from Mortice Kern Systems:

MKS Canada - Corporate Headquarters
410 Albert Street
Waterloo, ON
Canada N2L 3V3
1-519-884-2251
1-519-884-8861 (FAX)
1-800-265-2797 (Sales)
<http://www.mks.com/>

The MKS Toolkit comes in various versions, depending on the development environment and the number of developers who will be using it. It includes a shell that is POSIX-compliant, along with just about all the features of the 1988 Korn shell, as well as more than 300 utilities, such as `awk`, `perl`, `vi`, `make`, and so on. The MKS library supports more than 1500 Unix APIs, making it extremely complete and easing porting to the Windows environment.

AT&T UWIN

The UWIN package is a project by David Korn and his colleagues to make a Unix environment available under Microsoft Windows. It is similar in structure to `cygwin`, discussed earlier. A shared library, `posix.dll`, provides emulation of the Unix system call APIs. The system call emulation is quite complete. An interesting twist is that the Windows registry can be accessed as a filesystem under `/reg`. On top of the Unix API emulation, `ksh93` and more than 200 Unix utilities (or rather, reimplementations) have been compiled and run. The UWIN environment relies on the native Microsoft Visual C/C++ compiler, although the GNU development tools are available for download and use with UWIN.

<http://www.research.att.com/sw/tools/uwin/> is the web page for the project. It describes what is available, with links for downloading binaries, as well as information on commercial licensing of the UWIN package. Also included are links to various papers on UWIN, additional useful software, and links to other, similar packages.

The most notable advantage to the UWIN package is that its shell *is* the authentic *ksh93*. Thus, compatibility with the Unix version of *ksh93* isn't an issue.



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Arnold Robbins

Nelson H.F. Beebe

Chapter 1. Background

This chapter provides a brief history of the development of the Unix system. Understanding where and how Unix developed and the intent behind its design will help you use the tools better. The chapter also introduces the guiding principles of the Software Tools philosophy, which are then demonstrated throughout the rest of the book.

1.1. Unix History

It is likely that you know something about the development of Unix, and many resources are available that provide the full story. Our intent here is to show how the environment that gave birth to Unix influenced the design of the various tools.

Unix was originally developed in the Computing Sciences Research Center at Bell Telephone Laboratories.^[1] The first version was developed in 1970, shortly after Bell Labs withdrew from the Multics project. Many of the ideas that Unix popularized were initially pioneered within the Multics operating system; most notably the concepts of devices as files, and of having a command interpreter (or *shell*) that was intentionally not integrated into the operating system. A well-written history may be found at <http://www.bell-labs.com/history/unix>.

^[1] The name has changed at least once since then. We use the informal name "Bell Labs" from now on.

Because Unix was developed within a research-oriented environment, there was no commercial pressure to produce or ship a finished product. This had several advantages:

- The system was developed by its users. They used it to solve real day-to-day computing problems.
- The researchers were free to experiment and to change programs as needed. Because the user base was small, if a program needed to be rewritten from scratch, that generally wasn't a problem. And because the users were the developers, they were free to fix problems as they were discovered and add enhancements as the need for them arose.
- Unix itself went through multiple research versions, informally referred to with the letter "V" and number: V6, V7, and so on. (The formal name followed the edition number of the published manual: First Edition, Second Edition, and so on. The correspondence between the names is direct V6 = Sixth Edition, and V7 = Seventh Edition. Like most experienced Unix programmers, we use both nomenclatures.) The most influential Unix system was the Seventh Edition, released in 1979, although earlier ones had been available to educational institutions for several years. In particular, the Seventh Edition system introduced both *awk* and the Bourne shell, on which the POSIX shell is based. It was also at this time that the first published books about Unix started to appear.
- The researchers at Bell Labs were all highly educated computer scientists. They designed the system for their personal use and the use of their colleagues, who also were computer scientists. This led to a "no nonsense" design approach; programs did what you told them to do, without being chatty and asking lots of "are you sure?" questions.

- Besides just extending the state of the art, there existed a quest for *elegance* in design and problem solving. A lovely definition for elegance is "power cloaked in simplicity."^[2] The freedom of the Bell Labs environment led to an *elegant* system, not just a *functional* one.

^[2] I first heard this definition from Dan Forsyth sometime in the 1980s.

Of course, the same freedom had a few disadvantages that became clear as Unix spread beyond its development environment:

- There were many inconsistencies among the utilities. For example, programs would use the same option letter to mean different things, or use different letters for the same task. Also, the regular-expression syntaxes used by different programs were similar, but not identical, leading to confusion that might otherwise have been avoided. (Had their ultimate importance been recognized, regular expression-matching facilities could have been encoded in a standard library.)
- Many utilities had limitations, such as on the length of input lines, or on the number of open files, etc. (Modern systems generally have corrected these deficiencies.)
- Sometimes programs weren't as thoroughly tested as they should have been, making it possible to accidentally kill them. This led to surprising and confusing "core dumps." Thankfully, modern Unix systems rarely suffer from this.
- The system's documentation, while generally complete, was often terse and minimalistic. This made the system more difficult to learn than was really desirable.^[3]

^[3] The manual had two components: the reference manual and the user's manual. The latter consisted of tutorial papers on major parts of the system. While it was possible to learn Unix by reading all the documentation, and many people (including the authors) did exactly that, today's systems no longer come with printed documentation of this nature.

Most of what we present in this book centers around processing and manipulation of *textual*, not binary, data. This stems from the strong interest in text processing that existed during Unix's early growth, but is valuable for other reasons as well (which we discuss shortly). In fact, the first production use of a Unix system was doing text processing and formatting in the Bell Labs Patent Department.

The original Unix machines (Digital Equipment Corporation PDP-11s) weren't capable of running large programs. To accomplish a complex task, you had to break it down into smaller tasks and have a separate program for each smaller task. Certain common tasks (extracting fields from lines, making substitutions in text, etc.) were common to many larger projects, so they became standard tools. This was eventually recognized as being a good thing in its own right: the lack of a large address space led to smaller, simpler, *more focused* programs.

Many people were working semi-independently on Unix, reimplementing each other's programs. Between version differences and no need to standardize, a lot of the common tools diverged. For example, *grep* on one system used *-i* to mean "ignore case when searching," and it used *-y* on another

variant to mean the same thing! This sort of thing happened with multiple utilities, not just a few. The common small utilities were named the same, but shell programs written for the utilities in one version of Unix probably wouldn't run unchanged on another.

Eventually the need for a common set of standardized tools and options became clear. The POSIX standards were the result. The current standard, IEEE Std. 1003.1-2004, encompasses both the C library level, and the shell language and system utilities and their options.

The good news is that the standardization effort paid off. Modern commercial Unix systems, as well as freely available workalikes such as GNU/Linux and BSD-derived systems, are all POSIX-compliant. This makes learning Unix easier, and makes it possible to write portable shell scripts. (However, do take note of [Chapter 14](#).)

Interestingly enough, POSIX wasn't the only Unix standardization effort. In particular, an initially European group of computer manufacturers, named X/Open, produced its own set of standards. The most popular was XPG4 (X/Open Portability Guide, Fourth Edition), which first appeared in 1988. There was also an XPG5, more widely known as the UNIX 98 standard, or as the "*Single UNIX Specification*." XPG5 largely included POSIX as a subset, and was also quite influential.^[4]

^[4] The list of X/Open publications is available at <http://www.opengroup.org/publications/catalog/>.

The XPG standards were perhaps less rigorous in their language, but covered a broader base, formally documenting a wider range of existing practice among Unix systems. (The goal for POSIX was to make a standard formal enough to be used as a guide to implementation from scratch, even on non-Unix platforms. As a result, many features common on Unix systems were initially excluded from the POSIX standards.) The 2001 POSIX standard does double duty as XPG6 by including the *X/Open System Interface Extension* (or XSI, for short). This is a formal extension to the base POSIX standard, which documents attributes that make a system not only POSIX-compliant, but also XSI-compliant. Thus, there is now only one formal standards document that implementors and application writers need refer to. (Not surprisingly, this is called the Single Unix Standard.)

Throughout this book, we focus on the shell language and Unix utilities as defined by the POSIX standard. Where it's important, we'll include features that are XSI-specific as well, since it is likely that you'll be able to use them too.

1.2. Software Tools Principles

Over the course of time, a set of core principles developed for designing and writing software tools. You will see these exemplified in the programs used for problem solving throughout this book. Good software tools should do the following things:

Do one thing well

In many ways, this is the single most important principle to apply. Programs that do only one thing are easier to design, easier to write, easier to debug, and easier to maintain and document. For example, a program like *grep* that searches files for lines matching a pattern should *not* also be expected to perform arithmetic.

A natural consequence of this principle is a proliferation of smaller, specialized programs, much as a professional carpenter has a large number of specialized tools in his toolbox.

Process lines of text, not binary

Lines of text are the universal format in Unix. Datafiles containing text lines are easy to process when writing your own tools, they are easy to edit with any available text editor, and they are portable across networks and multiple machine architectures. Using text files facilitates combining any custom tools with existing Unix programs.

Use regular expressions

Regular expressions are a powerful mechanism for working with text. Understanding how they work and using them properly simplifies your script-writing tasks.

Furthermore, although regular expressions varied across tools and Unix versions over the years, the POSIX standard provides only two kinds of regular expressions, with standardized library routines for regular-expression matching. This makes it possible for you to write your own tools that work with regular expressions identical to those of *grep* (called *Basic Regular Expressions* or BREs by POSIX), or identical to those of *egrep* (called *Extended Regular Expressions* or EREs by POSIX).

Default to standard I/O

When not given any explicit filenames upon which to operate, a program should default to reading data from its standard input and writing data to its standard output. Error messages should always go to standard error. (These are discussed in [Chapter 2](#).) Writing programs this way makes it easy to use them as *datafilters*-i.e., as components in larger, more complicated pipelines or scripts.

Don't be chatty

Software tools should not be "chatty." No *starting processing, almost done, or finished processing* kinds of messages should be mixed in with the regular output of a program (or at least, not by default).

When you consider that tools can be strung together in a pipeline, this makes sense:

```
tool_1 < datafile | tool_2 | tool_3 | tool_4 > resultfile
```

If each tool produces "yes I'm working" kinds of messages and sends them down the pipe, the data being manipulated would be hopelessly corrupted. Furthermore, even if each tool sends its messages to standard error, the screen would be full of useless progress messages. When it comes to tools, no news is good news.

This principle has a further implication. In general, Unix tools follow a "you asked for it, you got it" design philosophy. They don't ask "are you sure?" kinds of questions. When a user types `rm somefile`, the Unix designers figured that he knows what he's doing, and *rm* removes the file, no questions asked.^[5]

^[5] For those who are really worried, the *-i* option to *rm* forces *rm* to prompt for confirmation, and in any case *rm* prompts for confirmation when asked to remove suspicious files, such as those whose permissions disallow writing. As always, there's a balance to be struck between the extremes of never prompting and always prompting.

Generate the same output format accepted as input

Specialized tools that expect input to obey a certain format, such as header lines followed by data lines, or lines with certain field separators, and so on, should produce output following the same rules as the input. This makes it easy to process the results of one program run through a different program run, perhaps with different options.

For example, the *netpbm* suite of programs^[6] manipulate image files stored in a Portable BitMap format.^[7] These files contain bitmapped images, described using a well-defined format. Each tool reads PBM files, manipulates the contained image in some fashion, and then writes a PBM format file back out. This makes it easy to construct a simple pipeline to perform complicated image processing, such as scaling an image, then rotating it, and then decreasing the color depth.

[6] The programs are not a standard part of the Unix toolset, but are commonly installed on GNU/Linux and BSD systems. The WWW starting point is <http://netpbm.sourceforge.net/>. From there, follow the links to the Sourceforge project page, which in turn has links for downloading the source code.

[7] There are three different formats; see the *pnm(5)* manpage if *netpbm* is installed on your system.

Let someone else do the hard part

Often, while there may not be a Unix program that does *exactly* what you need, it is possible to use existing tools to do 90 percent of the job. You can then, if necessary, write a small, specialize program to finish the task. Doing things this way can save a large amount of work when compared to solving each problem fresh from scratch, each time.

Detour to build specialized tools

As just described, when there just isn't an existing program that does what you need, take the time to build a tool to suit your purposes. However, before diving in to code up a quick program that does exactly your specific task, stop and think for a minute. Is the task one that other people are going to need done? Is it possible that your specialized task is a specific case of a more general problem that doesn't have a tool to solve it? If so, think about the general problem, and write a program aimed at solving that. Of course, when you do so, design and write your program so it follows the previous rules! By doing this, you graduate from being a tool user to being a *toolsmith*, someone who creates tools for others!

1.3. Summary

Unix was originally developed at Bell Labs by and for computer scientists. The lack of commercial pressure, combined with the small capacity of the PDP-11 minicomputer, led to a quest for small, elegant programs. The same lack of commercial pressure, though, led to a system that wasn't always consistent, nor easy to learn.

As Unix spread and variant versions developed (notably the System V and BSD variants), portability at the shell script level became difficult. Fortunately, the POSIX standardization effort has borne fruit, and just about all commercial Unix systems and free Unix workalikes are POSIX-compliant.

The Software Tools principles as we've outlined them provide the guidelines for the development and use of the Unix toolset. Thinking with the Software Tools mindset will help you write clear shell programs that make correct use of the Unix tools.

Chapter 2. Getting Started

When you need to get some work done with a computer, it's best to use a tool that's appropriate to the job at hand. You don't use a text editor to balance your checkbook or a calculator to write a proposal. So too, different programming languages meet different needs when it comes time to get some computer-related task done.

Shell scripts are used most often for system administration tasks, or for combining existing programs to accomplish some small, specific job. Once you've figured out how to get the job done, you can bundle up the commands into a separate program, or *script*, which you can then run directly. What's more, if it's useful, other people can make use of the program, treating it as a *black box*, a program that gets a job done, without their having to know *how* it does so.

In this chapter we'll make a brief comparison between different kinds of programming languages, and then get started writing some simple shell scripts.

2.1. Scripting Languages Versus Compiled Languages

Most medium and large-scale programs are written in a *compiled* language, such as Fortran, Ada, Pascal, C, C++, or Java. The programs are translated from their original *source code* into *object code* which is then executed directly by the computer's hardware.^[1]

^[1] This statement is not quite true for Java, but it's close enough for discussion purposes.

The benefit of compiled languages is that they're efficient. Their disadvantage is that they usually work at a low level, dealing with bytes, integers, floating-point numbers, and other machine-level kinds of objects. For example, it's difficult in C++ to say something simple like "copy all the files in this directory to that directory over there."

So-called scripting languages are usually *interpreted*. A regular compiled program, the *interpreter*, reads the program, translates it into an internal form, and then executes the program.^[2]

^[2] See <http://foldoc.doc.ic.ac.uk/foldoc/foldoc.cgi?Ousterhout's+dichotomy> for an attempt to formalize the distinction between compiled and interpreted language. This formalization is not universally agreed upon.

2.2. Why Use a Shell Script?

The advantage to scripting languages is that they often work at a higher level than compiled languages, being able to deal more easily with objects such as files and directories. The disadvantage is that they are often less efficient than compiled languages. Usually the tradeoff is worthwhile; it can take an hour to write a simple script that would take two days to code in C or C++, and usually the script will run fast enough that performance won't be a problem. Examples of scripting languages include *awk*, Perl, Python, Ruby, and the shell.

Because the shell is universal among Unix systems, and because the language is standardized by POSIX, shell scripts can be written once and, if written carefully, used across a range of systems. Thus, the reasons to use a shell script are:

Simplicity

The shell is a high-level language; you can express complex operations clearly and simply using it.

Portability

By using just POSIX-specified features, you have a good chance of being able to move your script, *unchanged*, to different kinds of systems.

Ease of development

You can often write a powerful, useful script in little time.

2.3. A Simple Script

Let's start with a simple script. Suppose that you'd like to know how many users are currently logged in. The `who` command tells you who is logged in:

```
$ who

george      pts/2          Dec 31 16:39      (valley-forge.example.com)
betsy       pts/3          Dec 27 11:07      (flags-r-us.example.com)
benjamin    dtlocal       Dec 27 17:55      (kites.example.com)
jhancock    pts/5          Dec 27 17:55      (:32)
camus       pts/6          Dec 31 16:22
tolstoy     pts/14         Jan  2 06:42
```

On a large multiuser system, the listing can scroll off the screen before you can count all the users, and doing it manually is painful anyway. This is a perfect opportunity for automation. What's missing is a way to count the number of users. So, that, we use the `wc` (word count) program, which counts lines, words, and characters. In this instance, we use `wc` to count just lines:

```
$ who | wc -l          Count users

6
```

The `|` (pipe) symbol creates a pipeline between the two programs: `who`'s output becomes `wc`'s input. The number shown by `wc -l`, is the number of users logged in.

The next step is to make this pipeline into a separate command. You do this by entering the commands into a file and then making the file executable, with `chmod`, like so:

```
$ cat > nusers          Create the file, copy terminal input
                        Program text
who | wc -l
^D                       Ctrl-D is end-of-file
```

```
$ chmod +x nusers
```

Make it executable

```
$ ./nusers
```

Do a test run

6

Output is what we expect

This shows the typical development cycle for small one- or two-line shell scripts: first, you experiment directly at the command line. Then, once you've figured out the proper incantations to do what you want, you put them in a script and make the script executable. You can then use that script directly from now on.



2.4. Self-Contained Scripts: The #! First Line

When the shell runs a program, it asks the Unix kernel to start a new process and run the given program in that process. The kernel knows how to do this for compiled programs. Our *nusers* shell script isn't a compiled program; when the shell asks the kernel to run it, the kernel will fail to do so, returning a "not executable format file" error. The shell, upon receiving this error, says "Aha, it's not a compiled program, it must be a shell script," and then proceeds to start a new copy of `/bin/sh` (the standard shell) to run the program.

The "fall back to `/bin/sh`" mechanism is great when there's only one shell. However, because current Unix systems have multiple shells, there needs to be a way to tell the Unix kernel which shell to use when running a particular shell script. In fact, it helps to have a general mechanism that makes it possible to directly invoke *any* programming language interpreter, not just a command shell. This is done via a special first line in the script file—one that begins with the two characters `#!`.

When the first two characters of a file are `#!`, the kernel scans the rest of the line for the full pathname of an interpreter to use to run the program. (Any intervening whitespace is skipped.) The kernel also scans for a *single* option to be passed to that interpreter. The kernel invokes the interpreter with the given option, along with the rest of the command line. For example, assume a *cs*h script^[3] named `/usr/ucb/whizprog`, with this first line:

^[3] `/bin/csh` is the C shell command interpreter, originally developed at the University of California at Berkeley. We don't cover C shell programming in this book for many reasons, the most notable of which are that it's universally regarded as being a poorer shell for scripting, and because it's not standardized by POSIX.

```
#! /bin/csh -f
```

Furthermore, assume that `/usr/ucb` is included in the shell's search path (described later). A user might type the command `whizprog -q /dev/tty01`. The kernel interprets the `#!` line and invokes *cs*h as follows:

```
/bin/csh -f /usr/ucb/whizprog -q /dev/tty01
```

This mechanism makes it easy to invoke *any* interpreted language. For example, it is a good way to invoke a standalone *awk* program:

```
#! /bin/awk -f
```


awk program here

Shell scripts typically start with `#!/bin/sh`. Use the path to a POSIX-compliant shell if your `/bin/sh` isn't POSIX compliant. There are also some low-level "gotchas" to watch out for:

- On modern systems, the maximum length of the `#!` line varies from 63 to 1024 characters. Try to keep it less than 64 characters. (See [Table 2-1](#) for a representative list of different limits.)
- On some systems, the "rest of the command line" that is passed to the interpreter includes the full pathname of the command. On others, it does not; the command line as entered is passed to the program. Thus, scripts that look at the command-line arguments cannot portably depend on the full pathname being present.
- Don't put any trailing whitespace after an option, if present. It will get passed along to the invoked program along with the option.
- You have to know the full pathname to the interpreter to be run. This can prevent cross-vendor portability, since different vendors put things in different places (e.g., `/bin/awk` versus `/usr/bin/awk`).
- On antique systems that don't have `#!` interpretation in the kernel, some shells will do it themselves, and they may be picky about the presence or absence of whitespace characters between the `#!` and the name of the interpreter.

[Table 2-1](#) lists the different line length limits for the `#!` line on different Unix systems. (These were discovered via experimentation.) The results are surprising, in that they are often not powers of two.

Table 2-1. `#!` line length limits on different systems

Vendor platform	O/S version	Maximum length
Apple Power Mac	Mac Darwin 7.2 (Mac OS 10.3.2)	512
Compaq/DEC Alpha	OSF/1 4.0	1024
Compaq/DEC/HP Alpha	OSF/1 5.1	1000
GNU/Linux ^[4]	Red Hat 6, 7, 8, 9; Fedora 1	127
HP PA-RISC and Itanium-2	HP-UX 10, 11	127
IBM RS/6000	AIX 4.2	255

Vendor platform	O/S version	Maximum length
Intel x86	FreeBSD 4.4	64
Intel x86	FreeBSD 4.9, 5.0, 5.1	128
Intel x86	NetBSD 1.6	63
Intel x86	OpenBSD 3.2	63
SGI MIPS	IRIX 6.5	255
Sun SPARC, x86	Solaris 7, 8, 9, 10	1023

[4] All architectures.

The POSIX standard leaves the behavior of `#!` "unspecified." This is the standardese way of saying that such a feature may be used as an extension while staying POSIX-compliant.

All further scripts in this book start with a `#!` line. Here's the revised *nusers* program:

```
$ cat nusers           Show contents
#! /bin/sh -          Magic #! line

who | wc -l           Commands to run
```

The bare option `-` says that there are no more shell options; this is a security feature to prevent certain kinds of spoofing attacks.

2.5. Basic Shell Constructs

In this section we introduce the basic building blocks used in just about all shell scripts. You will undoubtedly find them from your interactive use of the shell.

2.5.1. Commands and Arguments

The shell's most basic job is simply to execute commands. This is most obvious when the shell is being used to execute commands one at a time, and the shell executes them, like so:

```
$ cd work ; ls -l whizprog.c
-rw-r--r--      1  tolstoy   devel           30252 Jul   9  22:52 whizprog.c
$ make
...
```

These examples show the basics of the Unix command line. First, the format is simple, with *whitespace* (spaces) separating the different components involved in the command.

Second, the command name, rather logically, is the first item on the line. Most typically, options follow, and arguments to the command follow the options. No gratuitous syntax is involved, such as:

```
COMMAND=CD , ARG=WORK
```

```
COMMAND=LISTFILES , MODE=LONG , ARG=WHIZPROG.C
```

Such command languages were typical of the larger systems available when Unix was designed. The free-format command language was a real innovation in its time, contributing notably to the readability of shell scripts.

Third, options start with a dash (or minus sign) and consist of a single letter. Options are optional, and may be grouped together: e.g., `ls -l whizprog.c` (which works, but requires more typing).

Long options are increasingly common, particularly in the GNU variants of the standard utilities, as well as in the X Window System (X11). For example:


```
$ cd whizprog-1.1
```

```
$ patch --verbose --backup -p1 < /tmp/whizprog-1.1-1.2-patch
```

Depending upon the program, long options start with either one dash, or with two (as just shown). (The `<` is an I/O redirection. It causes *patch* to read from the file `/tmp/whizprog-1.1-1.2-patch` instead of from one of the fundamental topics covered later in the chapter.)

Originally introduced in System V, but formalized in POSIX, is the convention that two dashes (`--`) should be used for long options. Any other arguments on the command line that look like options are instead to be treated the same way as filenames (for example, treated as filenames).

Finally, semicolons separate multiple commands on the same line. The shell executes them sequentially. If a command is followed by a semicolon, the shell runs the preceding command in the *background*, which simply means that it does not wait for the command to finish before continuing to the next command.

The shell recognizes three fundamental kinds of commands: built-in commands, shell functions, and external commands.

- Built-in commands are just that: commands that the shell itself executes. Some built-in commands change the directory, or *read* to get input from the user (or a file) into a shell variable. Other built-in commands improve efficiency. Most typically, these include the *test* command (described later in Section 6.2.4), which is used for testing, and I/O commands such as *echo* or *printf*.
- Shell functions are self-contained chunks of code, written in the shell language, that are invoked in the same way as external commands. We delay discussion of them until Section 6.5. At this point, it's enough to know that they're invoked, and that they're treated as external commands.
- External commands are those that the shell runs by creating a separate process. The basic steps are:
 1. Create a new process. This process starts out as a copy of the shell.
 2. In the new process, search the directories listed in the `PATH` variable for the given command. `/bin:/usr/bin:/usr/X11R6/bin:/usr/local/bin` might be a typical value of `PATH`. (The path search name contains a slash character, `/`.)
 3. In the new process, execute the found program by replacing the running shell program with the new program.
 4. When the program finishes, the original shell continues by reading the next command from the terminal or in the script. This is illustrated in Figure 2-1.

Figure 2-1. Program execution

That's the basic process. Of course, the shell can do many other things for you, such as variable and wildcard arithmetic substitution, and so on. We'll touch on these topics as we progress through the book.

2.5.2. Variables

A *variable* is a name that you give to a particular piece of information, such as `first_name` or `driver_license`. All programs have variables, and the shell is no exception. Every variable has a *value*, which is the contents or information stored in the variable. In the case of the shell, variable values can be, and often are, empty—that is, they contain no characters. Empty values are common, and useful. Empty values are referred to as *null*, and we'll use that term a lot in the rest of the book.

Shell variable names start with a letter or underscore, and may contain any number of following letters, digits, or underscores. There is no limit on the number of characters in a variable name. Shell variables hold string values, and there is also no limit on the length of the string that they may hold. (The Bourne shell was one of the few early Unix programs to follow a "no arbitrary line length" rule.) Here's an example:

```
$ myvar=this_is_a_long_string_that_does_not_mean_much      Assign a variable
$ echo $myvar                                               Print the value
this_is_a_long_string_that_does_not_mean_much
```

As you can see, variables are assigned values by writing the variable name, immediately followed by an equals sign and the value, without any intervening spaces. Shell variable *values* are retrieved by prefixing the variable's name with a dollar sign. Here's an example assigning a literal value that contains spaces:

```
first=isaac middle=bashevis last=singer      Multiple assignments allowed
fullname="isaac bashevis singer"           Use quotes for whitespace
oldname=$fullname                          Quotes not needed to preserve spaces
```

As shown in the previous example, double quotes (discussed later in "Section 7.7") aren't necessary around the value when used as the new value of a second variable. Using them, though, doesn't hurt either, and is necessary when the value contains spaces:

```
fullname="$first $middle $last"           Double quotes required here
```

2.5.3. Simple Output with echo

We just saw the *echo* command for printing out the value of `myvar` , and you've probably used it at the command line to produce output, either for prompting or to generate data for further processing.

The original *echo* command simply printed its arguments back to standard output, with each one separated and terminated with a newline:

```
$ echo Now is the time for all good men
```

```
Now is the time for all good men
```

```
$ echo to come to the aid of their country.
```

```
to come to the aid of their country.
```

echo

Usage

```
echo [ string ... ]
```

Purpose

To produce output from shell scripts.

Major options

None.

Behavior

echo prints each argument to standard output, separated by a single space and terminated by a newline. It also recognizes escape sequences within each string that represent special characters and also control its behavior.

Caveats

Historical differences in behavior among Unix variants make it difficult to use *echo* portably for all kinds of output.

Many versions support a *-n* option. When supplied, *echo* omits the final newline from its output. This is useful for printing prompts. However, the current POSIX-standard version of *echo* does not include this option. This is discussed in the text.

Unfortunately, over time, different versions of *echo* developed. The BSD version accepted a first argument that suppresses the trailing newline. For example (the underscore represents the terminal's cursor):

```
$ echo -n "Enter your name: "          Print prompt
Enter your name: _                    Enter data
```

The System V version interpreted special escape sequences (explained shortly) within the arguments. For example, *echo* should not print the final newline:

```
$ echo "Enter your name: \c"          Print prompt
Enter your name: _                    Enter data
```

Escape sequences are a way to represent hard-to-type or hard-to-see characters within a program. When *echo* prints the corresponding character. The valid escape sequences are listed in Table 2-2 .

Table 2-2. echo escape sequences

Sequence	Description
<code>\a</code>	Alert character, usually the ASCII BEL character.
<code>\b</code>	Backspace.
<code>\c</code>	Suppress the final newline in the output. Furthermore, any characters left in the argument, and any characters following, are ignored (not printed).

Sequence	Description
<code>\f</code>	Formfeed.
<code>\n</code>	Newline.
<code>\r</code>	Carriage return.
<code>\t</code>	Horizontal tab.
<code>\v</code>	Vertical tab.
<code>\</code>	A literal backslash character.
<code>\0 ddd</code>	Character represented as a 1- to 3-digit octal value.

When shell scripting, the `\a` sequence is most useful for getting a user's attention. The `\0 ddd` sequence is for character manipulation by sending terminal escape sequences, but we don't recommend this.

Since many systems still default to the BSD behavior for `echo`, we only use its simplest form throughout the book for complicated output.

2.5.4. Fancier Output with `printf`

The differences between the two versions of `echo` led to one of the most infamous of the Unix-variant portability round of standardization for POSIX, the committee members could not agree on how to standardize `echo`, so they reached a compromise. While `echo` was part of the POSIX standard, the standard didn't specify the behavior if the first argument contained escape sequences. Instead the behavior was left as *implementation-defined*, meaning that each implementation documents what its version of `echo` does.^[5] In effect, `echo` could be used portably only if it was used in the same way as the `printf` command from the Ninth Edition Research Unix system. This command is more flexible than `echo` but adds some added complexity.

^[5] Interestingly enough, the current version of the standard has `echo` being essentially the same as the System V version, which treats the first argument specially and does not treat `-n` specially.

The `printf` command is modeled after the `printf()` library routine from the C library. It closely duplicates the manual pages for `printf(3)`, and it's likely that if you've done any programming in C, C++, `awk`, Perl, or Python, you know the basics. Of course, there are a few quirks specific to the shell-level version.

The `printf` command can output a simple string just like the `echo` command:

```
printf "Hello, world\n"
```

The main difference that you will notice immediately is that, unlike `echo`, `printf` does not automatically suppress trailing spaces or newlines; you must specify them explicitly as `\n`. The full syntax of the `printf` command has two parts:


```
printf format-string [arguments ...]
```

The first part is a string describing the desired output; this is best supplied as a string constant in quotes. Text to be printed literally, and *format specifications*, which are special placeholders that describe how to print

The second part is an argument list, such as a list of strings or variable values, that correspond to the format arguments than format specifications, *printf* cycles through the format specifications in the format string, reading arguments. A format specification is preceded by a percent sign (%) and the specifier is one of the characters described in the following table. The main format specifiers are %s for strings and %d for decimal integers.

Within the format string, regular characters are printed verbatim. Escape sequences, similar to those of *echo*, are printed as the corresponding character. Format specifiers, which begin with the character % and end with one of a set of characters, are used to format the output of the following corresponding arguments. For example, %s is used for strings:

```
$ printf "The first program always prints '%s, %s!'\n" Hello world
```

```
The first program always prints 'Hello, world!'
```

All the details on *printf* are given in Section 7.4.

2.5.5. Basic I/O Redirection

Standard I/O is perhaps the most fundamental concept in the Software Tools philosophy.^[6] The idea is that a program should have a source, a data sink (where data goes), and a place to report problems. These are referred to by the names *standard input*, *standard output*, and *standard error*, respectively. A program should neither know, nor care, what kind of device lies behind these names: terminals, tape drives, network connections, or even another running program! A program can expect these devices to be open and ready to use when it starts up.

^[6] "Standard I/O," as used here, should not be confused with the C library's standard I/O library, whose interface is defined in `stdio.h` and is to provide this abstraction to C programs.

Many, if not most, Unix programs follow this design. By default, they read standard input, write standard output, and write standard error. Such programs are called *filters*, for reasons that will become clear shortly. The default device for standard input and standard error is the terminal. This can be seen with *cat*:

```
$ cat                                     With no arguments, read standard input

now is the time                          Typed by the user

now is the time                          Echoed back by cat

for all good men
```


for all good men

to come to the aid of their country

to come to the aid of their country

^D

Ctrl-D, End of file

You may be wondering, who initializes standard input, output, and error for a running program? After all, it's for any given program, even the interactive shell that each user sees at login!

The answer is that when you log in, Unix arranges the default place for standard input, output, and error to be the process by which you, at the terminal interactively, or from within a shell script, then arrange to characterize which input comes or to which output goes.

2.5.5.1 Redirection and pipelines

The shell provides several syntactic notations for specifying how to change the default I/O sources and destinations; later we'll provide the full story. Moving from simple to complex, these notations are as follows:

Change standard input with <

Use `program < file` to make `program`'s standard input be `file` :

```
tr -d '\r' < dos-file.txt ...
```

Change standard output with >

Use `program > file` to make `program`'s standard output be `file` :

```
tr -d '\r' < dos-file.txt > unix-file.txt
```

This `tr` invocation removes *ASCII* carriage-return characters from `dos-file.txt`, placing the transformed original data in `unix-file.txt` is not changed. (The `tr` command is discussed in more detail in Chapter 5.)

The `>` redirector creates the destination file if it doesn't exist. However, if the file does exist, then it is *truncated* and its contents are lost.

Append to a file with >>

Use `program >> file` to send `program`'s standard output to the end of `file`.

Like `>`, the `>>` operator creates the destination file if it doesn't exist. However, if it already exists, any new data generated by the running program is *appended* to the end of the file:

```
for f in dos-file*.txt
do
    tr -d '\r' < $f >> big-unix-file.txt
done
```

(The `for` loop is described in Section 6.4.)

Create pipelines with |

Use `program1 | program2` to make the standard output of `program1` become the standard input of `program2`.

Although `<` and `>` connect input and output to *files*, a pipeline hooks together two or more running *programs*. The first program becomes the standard input of the second one. In favorable cases, pipelines can run similar code using temporary files. Most of this book is about learning how to hook together the various programs, increasing complexity and power. For example:

```
tr -d '\r' < dos-file.txt | sort > unix-file.txt
```

This pipeline removes carriage-return characters from the input file, and then sorts the data, sending the result to a new file.

tr

Usage

```
tr [ options ] source-char-list replace-char-list
```

Purpose

To transliterate characters. For example, converting uppercase characters to lowercase. Options let ; characters and compress runs of identical characters.

Major options

-c

Complement the values in *source-char-list* . The characters that *tr* translates then become those *source-char-list* . This option is usually used with one of *-d* or *-s* .

-C

Like *-c* but work on (possibly multibyte) characters, not binary byte values. See *Caveats* .

-d

Delete characters in *source-char-list* from the input instead of transliterating them.

-s

"Squeeze out" duplicate characters. Each sequence of repeated characters listed in *source-char-li* with a single instance of that character.

Behavior

Acts as a filter, reading characters from standard input and writing them to standard output. Each in *source-char-list* is replaced with the corresponding character in *replace-char-list* . POSIX-equivalence classes may be used, and *tr* also supports a notation for repeated characters in *replace*· the manual pages for *tr* (1) for the details on your system.

Caveats

According to POSIX, the `-c` option operates on the binary byte values, whereas `-C` operates on characters by the current locale. As of early 2005, many systems don't yet support the `C` option.

When working with the Unix tools, it helps to visualize data as being similar to water in a pipeline. Untreated water enters a processing plant and passes through a variety of filters, until the final output is water fit for human consumption.

Similarly, when scripting, you often have raw data in some defined input format, and you need processed data (which can mean any number of things: sorting, summing and averaging, formatting for printing, etc.) You start with the raw data and construct a pipeline, step by step, where each stage in the pipeline further refines the data.

If you're new to Unix, it may help your visualization if you look at `<` and `>` as data "funnels"-data goes into the large end and out the small end.



A final tip: when constructing pipelines, try to write them so that the amount of data is reduced early in the pipeline. In other words, if you have two steps that could be done in either order relative to each other, do the one that reduces the amount of data first. This improves the overall efficiency of your pipeline. You have to move less data between programs, and each program in turn will have less work to do.

For example, use `grep` to choose interesting lines before using `sort` to sort them; this way

2.5.5.2 Special files: `/dev/null` and `/dev/tty`

Unix systems provide two special files that are particularly useful in shell programming. The first file, `/dev/null`, is a "black hole" or "bit bucket." Data sent to this file is thrown away by the system. In other words, a program writing data to this file is successful, but in practice, nothing is done with it. This is useful when you need a command to run successfully (see Section 6.2) but not its output. For example, to test if a file contains a pattern:

```
if grep pattern myfile > /dev/null
then
    ...    Pattern is there
else
    ...    Pattern is not there
fi
```

In contrast to writes, reading from `/dev/null` always returns end-of-file immediately. Reading from `/dev/programming`, but it's important to know how the file behaves.

The other special file is `/dev/tty`. When a program opens this file, Unix automatically redirects it to the real serial port, or pseudoterminal for network and windowed logins) associated with the program. This is particularly important for programs that *must* come from a human, such as a password. It is also useful, although less so, for generating error messages.

```
printf "Enter new password: "      Prompt for input
stty -echo                        Turn off echoing of typed characters
read pass < /dev/tty              Read password
printf "Enter again: "           Prompt again
read pass2 < /dev/tty            Read again for verification
stty echo                          Don't forget to turn echoing back on
...
```

The `stty` (set tty) command controls various settings of your terminal (or window).^[7] The `-echo` option turns off (echoing) of every character you type; `stty echo` restores it.

^[7] `stty` is possibly the most baroque and complicated Unix command in existence. See the `stty` (1) manpage for the gory details.

2.5.6. Basic Command Searching

Earlier, we mentioned that the shell searches for commands along the search path, `$PATH`. This is a colon-separated list of directories in which commands are found. Commands may be compiled executables or shell scripts; there's no real distinction between the two.

The default path varies from system to system. It will contain at least `/bin` and `/usr/bin`. It might contain `/usr/local/bin` for programs that your local system administrator has installed.

```
$ echo $PATH
```

```
/bin:/usr/bin:/usr/X11R6/bin:/usr/local/bin
```

The term "bin" for directories that hold executables is short for binary. However, you can also think of it as meaning-a place to hold things; in this case, executable programs.

When you write your own scripts, it would be nice to have your own bin in which to place them, and have the shell find them. This is easy to do. Just create your own `bin` directory and add it to the list in `$PATH`:

\$ cd	<i>Change to home directory</i>
\$ mkdir bin	<i>Make a personal "bin" directory.</i>
\$ mv nusers bin	<i>Put our script there</i>
\$ PATH=\$PATH:\$HOME/bin	<i>Append our bin directory to P.</i>
\$ nusers	<i>Test it out</i>
6	<i>The shell finds it</i>

To make the change permanent, add your `bin` directory to `$PATH` in your `.profile` file, which is read every time you log in. Add the following line to the end of the file:

```
PATH=$PATH:$HOME/bin
```

Empty components in `$PATH` mean "the current directory." An empty component can be designated by two empty components, or by a leading or trailing colon, which puts the current directory first or last, respectively, in the search path.

```
PATH=:/bin:/usr/bin:/usr/X11R6/bin:/usr/local/bin      Current directory first
```

```
PATH=/bin:/usr/bin:/usr/X11R6/bin:/usr/local/bin:      Current directory last
```

```
PATH=/bin:/usr/bin:/usr/X11R6/bin::/usr/local/bin     Current directory in middle
```

If you wish to include the current directory in the search path, it is preferable to use an explicit dot in `$PATH` rather than an empty component. This way, the reader of your program knows what's going on.

In our testing, we found two versions of the same system that did not correctly support supplying an empty component. Empty components thus represent a minor portability problem.

In general, you should not have the current directory in your path *at all*. It represents a security problem (see Chapter 15 for more information.) We describe empty components only so that you understand how they work.

< Day Day Up >

2.6. Accessing Shell Script Arguments

The so-called *positional parameters* represent a shell script's command-line arguments. They also represent a function's arguments within shell functions. Individual arguments are named by integer numbers. For historical reasons, you have to enclose the number in braces if it's greater than nine:

```
echo first arg is $1
echo tenth arg is ${10}
```

Special "variables" provide access to the total number of arguments that were passed, and to all the arguments at once. We provide the details later, in [Section 6.1.2.2](#).

Suppose you want to know what terminal a particular user is using. Well, once again, you could use a plain *who* command and manually scan the output. However, that's difficult and error prone, especially on systems with lots of users. This time what you want to do is search through *who*'s output for a particular user. Well, anytime you want to do searching, that's a job for the *grep* command, which prints lines matching the pattern given in its first argument. Suppose you're looking for user *betsy* because you *really* need that flag you ordered from her:

```
$ who | grep betsy           Where is betsy?
betsy      pts/3             Dec 27 11:07      (flags-r-us.example.com)
```

Now that we know *how* to find a particular user, we can put the commands into a script, with the script's first argument being the username we want to find:

```
$ cat > finduser           Create new file
#!/bin/sh

# finduser --- see if user named by first argument is logged in

who | grep $1
```

```
^D                                     End-of-file

$ chmod +x finduser                   Make it executable

$ ./finduser betsy                    Test it: find betsy

betsy      pts/3                       Dec 27 11:07    (flags-r-us.example.com)

$ ./finduser benjamin                Now look for good old Ben

benjamin   dtlocal                     Dec 27 17:55    (kites.example.com)

$ mv finduser $HOME/bin              Save it in our personal bin
```

The line beginning with `# finduser ...` is a *comment*. The shell ignores everything from the `#` to the end of the line. (This is serendipitous; the special `#!` line described earlier acts as a comment when the shell reads a script.) Commenting your programs is always a good idea. It will help someone else, or you a year from now, to figure out what you were doing and why. Once we see that the program works, we move it to our personal `bin` directory.

This program isn't perfect. What happens if we don't give it any arguments?

```
$ finduser
```

```
Usage: grep [OPTION]... PATTERN [FILE]...
```

```
Try 'grep --help' for more information.
```

We will see in [Section 6.2.4](#), how to test the number of command-line arguments and take appropriate action when the right number isn't supplied.

2.7. Simple Execution Tracing

Because program development is a human activity, there will be times when your script just doesn't do what you want it to do. One way to get some idea of what your program is doing is to turn on *execution tracing*. This causes the shell to print out each command as it's executed, preceded by "+ "-that is, a plus sign followed by a space. (You can change what gets printed by assigning a new value to the `PS4` shell variable.) For example:

```
$ sh -x nusers                                Run with tracing on
+ who                                           Traced commands
+ wc -l
      7                                         Actual output
```

You can turn execution tracing on within a script by using the command `set -x`, and turn it off again with `set +x`. This is more useful in fancier scripts, but here's a simple program to demonstrate:

```
$ cat > trace1.sh                               Create script
#! /bin/sh
set -x                                           Turn on tracing
echo 1st echo                                   Do something
set +x                                           Turn off tracing
echo 2nd echo                                   Do something else
^D                                               Terminate with end-of-file
```



```
$ chmod +x trace1.sh
```

Make program executable

```
$ ./trace1.sh
```

Run it

```
+ echo 1st echo
```

First traced line

```
1st echo
```

Output from command

```
+ set +x
```

Next traced line

```
2nd echo
```

Output from next command

When run, the `set -x` is not traced, since tracing isn't turned on until after that command completes. Similarly, the `set +x` is traced, since tracing isn't turned off until after it completes. The final `echo` isn't traced, since tracing is turned off at that point.

2.8. Internationalization and Localization

Writing software for an international audience is a challenging problem. The task is usually divided into two parts: *internationalization* (*i18n* for short, since that long word has 18 letters between the first and last), and *localization* (*l10n* for short, since that long word has 10 letters between the first and last).

Internationalization is the process of designing software so that it can be adapted for specific user communities without having to change or recompile the code. At a minimum, this means that all character strings must be wrapped in calls that handle runtime lookup of suitable translations in message catalogs. Typically, the translations are ordinary text files that accompany the software, and then are compiled by *genmsg* or *msgfmt* into compact binary catalogs organized for fast lookup. The compiled message catalogs are then installed in a system-specific directory: the GNU conventional `/usr/share/locale` and `/usr/local/share/locale`, or on commercial Unix systems `/usr/lib/nls` or `/usr/lib/locale`. Details can be found in the manual pages for *setlocale* (3), *catgets* (3), and *catgets* (3C).

Localization is the process of adapting internationalized software for use by specific user communities. This involves translating software documentation, and all text strings output by the software, and possibly changing the format of currency, dates, numbers, times, units of measurement, and so on, in program output. The character set used also has to be changed, unless the universal *Unicode* character set can be used, and different fonts may be used for some languages, the writing direction has to be changed as well.

In the Unix world, ISO programming language standards and POSIX have introduced limited support for addressing these problems, but much remains to be done, and progress varies substantially across the various flavors of Unix. The feature that controls which language or cultural environment is in effect is called the *locale*, and one or more of the *environment variables* shown in Table 2-3.

Table 2-3. Locale environment variables

Name	Description
LANG	Default value for any <code>LC_XXX</code> variable that is not otherwise set
LC_ALL	Value that overrides all other <code>LC_XXX</code> variables
LC_COLLATE	Locale name for collation (sorting)
LC_CTYPE	Locale name for character types (alphabetic, digit, punctuation, and so on)
LC_MESSAGES	Locale name for affirmative and negative responses and for messages; POSIX only

Name	Description
<code>LC_MONETARY</code>	Locale name for currency formatting
<code>LC_NUMERIC</code>	Locale name for number formatting
<code>LC_TIME</code>	Locale name for date and time formatting

In general, you set `LC_ALL` to force a single locale, and you set `LANG` to provide a fallback locale. In most cases you should avoid setting any of the other `LC_XXX` variables. For example, although it might appear to be more precise to set `LC_COLLATE` when you use the `sort` command, that setting might conflict with a setting of `LC_CTYPE`, or be entirely overridden if `LC_ALL` is set.

Only a single standard locale name, `C`, is prescribed by the ISO C and C++ standards: it selects traditional C-oriented behavior. POSIX specifies one additional locale name, `POSIX`, which is equivalent to `C`.

Apart from the names `C` and `POSIX`, locale names are not standardized. However, most vendors have adopted not identical, naming conventions. The locale name encodes a language, a territory, and optionally, a codeset modifier. It is normally represented by a lowercase two-letter ISO 639 language code,^[8] an underscore, and a two-letter ISO 3166-1 country code,^[9] optionally followed by a dot and the character-set encoding, and an optional modifier word. Language names are sometimes used as well. You can list all of the recognized locale names in your system like this:

^[8] Available at <http://www.ics.uci.edu/pub/ietf/http/related/iso639.txt>.

^[9] Available at http://userpage.chemie.fu-berlin.de/diverse/doc/ISO_3166.html.

```
$ locale -a                                List all locales
...
français
fr_BE
fr_BE@euro
fr_BE.iso88591
fr_BE.iso885915@euro
fr_BE.utf8
fr_BE.utf8@euro
```



```
fr_CA
fr_CA.iso88591
fr_CA.utf8
...
french
...
```

You can query the details of a particular locale variable by defining a locale in the environment (here, as a command) and running the *locale* command with the *-ck* option and an *LC_XXX* variable. Here is an example from a Solaris system that reports information about the Danish time locale:

```
$ LC_ALL=da locale -ck LC_TIME           Get locale information for D
LC_TIME
d_t_fmt="%a %d %b %Y %T %Z"
d_fmt="%d-%m-%y"
t_fmt="%T"
t_fmt_ampm="%I:%M:%S %p"
am_pm="AM" ; "PM"
day="søndag" ; "mandag" ; "tirsdag" ; "onsdag" ; "torsdag" ; "fredag" ; "lørdag"
abday="søn" ; "man" ; "tir" ; "ons" ; "tor" ; "fre" ; "lør"
mon="januar" ; "februar" ; "marts" ; "april" ; "maj" ; "juni" ; "juli" ; "august" ; \
    "september" ; "oktober" ; "november" ; "december"
abmon="jan" ; "feb" ; "mar" ; "apr" ; "maj" ; "jun" ; "jul" ; "aug" ; "sep" ; "okt" ; \
    "nov" ; "dec"
era=""
era_d_fmt=""
```

```
era_d_t_fmt=" "
```

```
era_t_fmt=" "
```

```
alt_digits=" "
```

The number of available locales varies widely. A survey of about 20 flavors of Unix found none at all on E X systems (they lack the *locale* command), as few as five on some systems, and almost 500 on recent GNU. Locale support may be an installation option at the discretion of the system manager, so even the same operating release on two similar machines may have differing locale support. We found filesystem requirements for locales approaching 300MB^[10] on some systems.

^[10] MB = megabyte, approximately 1 million bytes, where one byte is now conventionally eight bits (binary digits), although and smaller byte sizes have been used in the past. Despite the metric prefix, in computer use, M usually means $2^{20} = 1,048,576$.

Several GNU packages have been internationalized, and localization support has been added for many locales. For example, in an Italian locale, GNU *ls* offers help like this:

```
$ LC_ALL=it_IT ls --help           Get help for GNU ls in Italian
```

```
Uso: ls [OPZIONE]... [FILE]...
```

```
Elenca informazioni sui FILE (predefinito: la directory corrente).
```

```
Ordina alfabeticamente le voci se non è usato uno di -cftuSUX oppure --
```

```
" "
```

```
Mandatory arguments to long options are mandatory for short options too
```

```
-a, --all           non nasconde le voci che iniziano con .
```

```
-A, --almost-all  non elenca le voci implicite . e ..
```

```
    --author        stampa l'autore di ogni file
```

```
-b, --escape       stampa escape ottali per i caratteri non g
```

```
    --block-size=DIMENS  usa blocchi lunghi DIMENS byte
```

```
...
```

Notice that when a translation is unavailable (fifth output line), the fallback is to the original language, English.

names and option names are not translated, because that would destroy software portability.

There is currently little support on most systems for the shell programmer to address the issues of internationalization. However, shell scripts are often affected by locales, notably in collation order, and in bracket-character ranges in regular expressions. Although we describe character classes, collating symbols, and equivalence classes in Section 3.2.1, it appears to be quite difficult on most Unix systems to determine from locale documentation exactly what characters are members of the character and equivalence classes, and what collating symbols. This reflects the immaturity of locale support on current systems.

When the GNU *gettext* package^[11] is installed, it is possible to use it to support the internationalization and localization of shell scripts. This is an advanced topic that we do not cover in this book, but you can find the details in the *Shell Scripts for Internationalization* section of the *gettext* manual.

[11] Available at <ftp://ftp.gnu.org/gnu/gettext/>.

The wide variations in locale support, and the lack of standardized locale names, make it hard to do much portable shell scripts, other than force the traditional locale by setting `LC_ALL` to `C`. We do that in some of the examples in this book when locale dependence could otherwise produce unexpected results.

< Day Day Up >

2.9. Summary

The choice of compiled language versus scripting language is usually made based on the need of the application. Scripting languages generally work at a higher level than compiled languages, and the loss in performance is often more than made up for by the speed with which development can be done and the ability to work at a higher level.

The shell is one of the most important and widely used scripting languages in the Unix environment. Because it is ubiquitous, and because of the POSIX standard, it is possible to write shell programs that will work on many different vendor platforms. Because the shell functions at a high level, shell programs have a lot of bang for the buck; you can do a lot with relatively little work.

The `#!` first line should be used for all shell scripts; this mechanism provides you with flexibility, and the ability to write scripts in your choice of shell or other language.

The shell is a full programming language. So far we covered the basics of commands, options, arguments, and variables, and basic output with *echo* and *printf*. We also looked at the basic I/O redirection operators, `<`, `>`, `>>`, and `|`, with which we expect you're really already familiar.

The shell looks for commands in each directory in `$PATH`. It's common to have a personal `bin` directory in which to store your own private programs and scripts, and to list it in `PATH` by doing an assignment in your `.profile` file.

We looked at the basics of accessing command-line arguments and simple execution tracing.

Finally, we discussed internationalization and localization, topics that are growing in importance as computer systems are adapted to the computing needs of more of the world's people. While support in this area for shell scripts is still limited, shell programmers need to be aware of the influence of locales on their code.

Chapter 3. Searching and Substitutions

As we discussed in [Section 1.2](#), Unix programmers prefer to work on lines of text. Textual data is more flexible than binary data, and Unix systems provide a number of tools that make slicing and dicing text easy.

In this chapter, we look at two fundamental operations that show up repeatedly in shell scripting: text *searching*-looking for specific lines of text-and text *substitution*-changing the text that is found.

While you can accomplish many things by using simple constant text strings, *regular expressions* provide a much more powerful notation for matching many different actual text fragments with a single expression. This chapter introduces the two regular expression "flavors" provided by various Unix programs, and then proceeds to cover the most important tools for text extraction and rearranging.

3.1. Searching for Text

The workhorse program for finding text (or "matching text," in Unix jargon) is *grep*. On POSIX systems, *grep* supports either of the two regular expression flavors, or match simple strings.

Traditionally, there were three separate programs for searching through text files:

grep

The original text-matching program. It uses Basic Regular Expressions (BREs) as defined by POSIX. The details of BREs are described later in the chapter.

egrep

"Extended *grep*." This program uses Extended Regular Expressions (EREs), which are a more powerful regular expression notation. The cost of EREs is that they can be more computationally expensive to use. On PDP-11s this was important; on modern systems, there is little difference.

fgrep

"Fast *grep*." This variant matches fixed strings instead of regular expressions using an algorithm optimized for fixed-string matching. The original version was also the only variant that could match multiple strings. In other words, *grep* and *egrep* could match only a single regular expression, whereas *fgrep* used a different algorithm that could match multiple strings, effectively testing each input line for a match against all the requested strings.

The 1992 POSIX standard merged all three variants into one *grep* program whose behavior is controlled by options. The POSIX version can match multiple patterns, even for BREs and EREs. Both *fgrep* and *egrep* were still available, but they were marked as "deprecated," meaning that they would be removed from a subsequent standard. Indeed, the 2001 POSIX standard only includes the merged *grep* command. However, in practice, both *egrep* and *fgrep* continue to be available on all Unix and Unix-like systems.

grep

Usage

```
grep [ options ... ] pattern-spec [ files ... ]
```

Purpose

To print lines of text that match one or more patterns. This is often the first stage in a pipeline that does further processing on matched data.

Major options

-E

Match using extended regular expressions. `grep -E` replaces the traditional `egrep` command.

-F

Match using fixed strings. `grep -F` replaces the traditional `fgrep` command.

-e pat-list

Usually, the first nonoption argument specifies the pattern(s) to match. Multiple patterns can be supplied by quoting them and separating them with newlines. In the case that the pattern starts with minus sign, `grep` could get confused and treat it as an option. The `-e` option specifies that its argument is a pattern, even if it starts with a minus sign.

-f pat-file

Read patterns from the file *pat-file* .

-i

Ignore lettercase when doing pattern matching.

-l

List the names of files that match the pattern instead of printing the matching lines.

-q

Be quiet. Instead of writing lines to standard output, *grep* exits successfully if it matches the pattern unsuccessfully otherwise. (We haven't discussed success/nonsuccess yet; see Section 6.2 .)

-s

Suppress error messages. This is often used together with *-q* .

-v

Print lines that *don't* match the pattern.

Behavior

Read through each file named on the command line. When a line matches the pattern being searched for, print the line. When multiple files are named, *grep* precedes each line with the filename and a colon. The default is to use BREs.

Caveats

You can use multiple *-e* and *-f* options to build up a list of patterns to search for.

3.1.1. Simple grep

The simplest use of *grep* is with constant strings:

```
$ who Who is logged on:
tolstoy tty1 Feb 26 10:53
tolstoy pts/0 Feb 29 10:59
tolstoy pts/1 Feb 29 10:59
tolstoy pts/2 Feb 29 11:00
tolstoy pts/3 Feb 29 11:00
tolstoy pts/4 Feb 29 11:00
austen pts/5 Feb 29 15:39 (mansfield-park.example.com)
austen pts/6 Feb 29 15:39 (mansfield-park.example.com)
```

```
$ who | grep -F austen Where is austen
austen pts/5 Feb 29 15:39 (mansfield-park.example.com)
austen pts/6 Feb 29 15:39 (mansfield-park.example.com)
```

This example used the *-F* option, to search for the fixed string **austen** . And in fact, as long as your pattern contains any regular expression metacharacters, *grep* 's default behavior is effectively the same as if you'd used the *-E* option.

```
$ who | grep austen No -F, same results
austen pts/5 Feb 29 15:39 (mansfield-park.example.com)
austen pts/6 Feb 29 15:39 (mansfield-park.example.com)
```

< Day Day Up >

3.2. Regular Expressions

This section provides a brief review of regular expression construction and matching. In particular, it describes ERE constructs, which are intended to formalize the two basic "flavors" of regular expressions found among

We expect that you've had some exposure to regular expressions and text matching prior to this book. In this section, we summarize how you can expect to use regular expressions for portable shell scripting.

If you've had no exposure at all to regular expressions, the material here may be a little too condensed for you. You may want to consult a more introductory source, such as *Learning the Unix Operating System* (O'Reilly) or *sed & awk* (O'Reilly). Regular expressions are a fundamental part of the Unix tool-using and tool-building paradigms, and any investment you make in learning to use them, and use them well, will be amply rewarded, multifold, time after time.

If, on the other hand, you've been chopping, slicing, and dicing text with regular expressions for years, you may find this section cursory. If such is the case, we recommend that you review the first part, which summarizes POSIX BREs. If you are familiar with BREs, skip the rest of the section, and move on to a more in-depth source, such as *Mastering Regular Expressions*.

3.2.1. What Is a Regular Expression?

Regular expressions are a notation that lets you search for text that fits a particular criterion, such as "starts with a capital letter". Regular expression notation lets you write a single expression that can select, or *match*, multiple data strings.

Above and beyond traditional Unix regular expression notation, POSIX regular expressions let you:

- Write regular expressions that express locale-specific character sequence orderings and equivalences
- Write your regular expressions in a way that does not depend upon the underlying character set of the system

A large number of Unix utilities derive their power from regular expressions of one form or another. A partial list follows:

- The *grep* family of tools for finding matching lines of text: *grep* and *egrep*, which are always available, and the nonstandard but useful *agrep* utility^[1]

^[1] The original Unix version from 1992 is at <ftp://ftp.cs.arizona.edu/agrep/agrep-2.04.tar.Z>. A current version for Windows is at <http://www.tgries.de/agrep/337/agrep337.zip>. Unlike most downloadable software that we cite in this book, *agrep* is not for an arbitrary purpose; see the permissions files that come with the program.

- The *sed* stream editor, for making changes to an input stream, described later in the chapter

- String processing languages, such as *awk* , Icon, Perl, Python, Ruby, Tcl, and others
- File viewers (sometimes called pagers), such as *more* , *page* , and *pg* , which are common on commercial systems. The most popular *less* pager^[2]

^[2] So named as a pun on *more* . See <ftp://ftp.gnu.org/gnu/less/> .

- Text editors, such as the venerable *ed* line editor, the standard *vi* screen editor, and popular add-on editors like *jove* , *vile* , *vim* , and others

Because regular expressions are so central to Unix use, it pays to master them, and the earlier you do so, the better.

In terms of the nuts and bolts, regular expressions are built from two basic components: *ordinary characters* and *special characters*. An ordinary character is any character that isn't special, as defined in the following table. In some contexts, special characters are treated as ordinary characters. Special characters are often called *metacharacters* , a term that we use throughout this chapter. Table 3-1 lists the POSIX BRE and ERE metacharacters.

Table 3-1. POSIX BRE and ERE metacharacters

Character	BRE / ERE	Meaning in a pattern
\	Both	Usually, turn off the special meaning of the following character. Occasionally, enable the special meaning of the following character, such as for <code>\(... \)</code> and <code>\{ ... \}</code> .
.	Both	Match any <i>single</i> character except NUL. Individual programs may also disallow matching the null character.
*	Both	Match any number (or none) of the single character that immediately precedes it. For EREs, the character can instead be a regular expression. For example, since <code>.</code> (dot) means any character, <code>*.</code> means any number of any character." For BREs, <code>*</code> is not special if it's the first character of a regular expression.
^	Both	Match the following regular expression at the beginning of the line or string. BRE: special only at the beginning of a regular expression. ERE: special everywhere.
\$	Both	Match the preceding regular expression at the end of the line or string. BRE: special only at the end of a regular expression. ERE: special everywhere.
[...]	Both	Termed a <i>bracket expression</i> , this matches any <i>one</i> of the enclosed characters. A hyphen between two consecutive characters indicates a range of characters. (Caution: ranges are locale-sensitive, and thus not portable.) A backslash before a character in the brackets reverses the sense: it matches any one character <i>not</i> in the list. The closing bracket (<code>]</code>) as the first character is treated as a member of the list. All other metacharacters inside the brackets are treated as members of the list (i.e., literally). Bracket expressions may contain collating symbols, character classes (described shortly).

Character	BRE / ERE	Meaning in a pattern
$\{ n , m \}$	BRE	Termed an <i>interval expression</i> , this matches a range of occurrences of the single character that precedes it. $\{ n \}$ matches exactly n occurrences, $\{ n , \}$ matches at least n occurrences, and $\{ n , m \}$ matches any number of occurrences between n and m . n and m must be between 0 and 255, inclusive.
$(\)$	BRE	Save the pattern enclosed between $($ and $)$ in a special <i>holding space</i> . Up to nine such spaces are available. The text matched by the subpatterns can be reused later in the same pattern by the backreferences $\backslash 1$ to $\backslash 9$. For example, $(ab)\.*\backslash 1$ matches two occurrences of ab , with a in between.
$\backslash n$	BRE	Replay the n th subpattern enclosed in $($ and $)$ into the pattern at this point. n is a number between 1 and 9, starting on the left.
$\{ n , m \}$	ERE	Just like the BRE $\{ n , m \}$ earlier, but without the backslashes in front of the braces.
$+$	ERE	Match one or more instances of the preceding regular expression.
$?$	ERE	Match zero or one instances of the preceding regular expression.
$ $	ERE	Match the regular expression specified before or after.
$(\)$	ERE	Apply a match to the enclosed group of regular expressions.

Table 3-2 presents some simple examples.

Table 3-2. Simple regular expression matching examples

Expression	Matches
<code>tolstoy</code>	The seven letters <code>tolstoy</code> , anywhere on a line
<code>^tolstoy</code>	The seven letters <code>tolstoy</code> , at the beginning of a line
<code>tolstoy\$</code>	The seven letters <code>tolstoy</code> , at the end of a line
<code>^tolstoy\$</code>	A line containing exactly the seven letters <code>tolstoy</code> , and nothing else
<code>[Tt]olstoy</code>	Either the seven letters <code>Tolstoy</code> , or the seven letters <code>tolstoy</code> , anywhere on a line

Expression	Matches
<code>tol.toy</code>	The three letters <code>tol</code> , any character, and the three letters <code>toy</code> , anywhere on a line
<code>tol.*toy</code>	The three letters <code>tol</code> , any sequence of zero or more characters, and the three letters <code>toy</code> , and so on) <code>toltoy</code> , <code>tolstoy</code> , <code>tolWHOtoy</code> , and so on)

3.2.1.1 POSIX bracket expressions

In order to accommodate non-English environments, the POSIX standard enhanced the ability of character match characters not in the English alphabet. For example, the French `è` is an alphabetic character, but the `[z]` would not match it. Additionally, the standard provides for sequences of characters that should be treated as matching and collating (sorting) string data. (For example, there are locales where the two characters `ch` are treated as a single character and be matched and sorted that way.) The growing popularity of the Unicode character set standard adds further complexity to the use of simple ranges, making them even less appropriate for modern applications.

POSIX also changed what had been common terminology. What we saw earlier as a range expression is now called a "bracket expression" in the Unix literature. It is now called a bracket expression in the POSIX standard. Within "bracket expressions" characters such as `z` , `;` , and so on, you can have additional components. These are:

Character classes

A POSIX character class consists of keywords bracketed by `[: and :]` . The keywords describe different classes of characters such as alphabetic characters, control characters, and so on. See Table 3-3 .

Collating symbols

A collating symbol is a multicharacter sequence that should be treated as a unit. It consists of the characters `ch` and `.]` . Collating symbols are specific to the locale in which they are used.

Equivalence classes

An equivalence class lists a set of characters that should be considered equivalent, such as `e` and `è` . It consists of one or more elements from the locale, bracketed by `[= and =]` .

All three of these constructs *must* appear inside the square brackets of a bracket expression. For example, `[a]` matches a single alphabetic character or the exclamation mark, and `[[.ch.]]` matches the collating element `ch` , but

letter `c` or the letter `h`. In a French locale, `[[=e=]]` might match any of `e`, `è`, `ë`, `ê`, or `é`. We provide more classes, collating symbols, and equivalence classes shortly.

Table 3-3 describes the POSIX character classes.

Table 3-3. POSIX character classes

Class	Matching characters	Class	Matching characters
<code>[:alnum:]</code>	Alphanumeric characters	<code>[:lower:]</code>	Lowercase characters
<code>[:alpha:]</code>	Alphabetic characters	<code>[:print:]</code>	Printable characters
<code>[:blank:]</code>	Space and tab characters	<code>[:punct:]</code>	Punctuation characters
<code>[:cntrl:]</code>	Control characters	<code>[:space:]</code>	Whitespace characters
<code>[:digit:]</code>	Numeric characters	<code>[:upper:]</code>	Uppercase characters
<code>[:graph:]</code>	Nonspace characters	<code>[:xdigit:]</code>	Hexadecimal digits

BREs and EREs share some common characteristics, but also have some important differences. We'll start with BREs, and then we'll explain the additional metacharacters in EREs, as well as the cases where the same (or similar) metacharacters have different semantics (meaning).

3.2.2. Basic Regular Expressions

BREs are built up of multiple components, starting with several ways to match single characters, and then several additional metacharacters for matching multiple characters.

3.2.2.1 Matching single characters

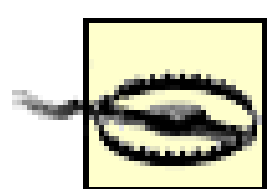
The first operation is to match a single character. This can be done in several ways: with ordinary characters; with the `.` (dot) metacharacter; or with a bracket expression:

- Ordinary characters are those not listed in Table 3-1. These include all alphanumeric characters, most punctuation characters. Thus, the regular expression `a` matches the character `a`. We say that ordinary characters stand for themselves, and this usage should be pretty straightforward and obvious. Thus, `shell` matches `shell` but not `word`, and so on.
- If metacharacters don't stand for themselves, how do you match one when you need to? The answer is done by preceding it with a backslash. Thus, `*` matches a literal `*`, `\` matches a single literal backslash, and `\[` matches a single literal left bracket. (If you put a backslash in front of an ordinary character, the POSIX standard leaves the behavior undefined.)

Typically, the backslash is ignored, but it's poor practice to do something like that.)

- The `.` (dot) character means "any single character." Thus, `a.c` matches all of `abc`, `aac`, `aqc`, and so on. It is only occasionally useful. It is much more often used together with other metacharacters that allow matching multiple characters, as described shortly.
- The last way to match a single character is with a *bracket expression*. The simplest form of a bracket expression is a list of characters between square brackets, such as `[aeiouy]`, which matches any lowercase English vowel. `c[aeiouy]t` matches `cat`, `cot`, and `cut` (as well as `cet`, `cit`, and `cyt`), but won't match `cbt`.
- Supplying a caret (`^`) as the first character in the bracket expression complements the set of characters. A complemented set matches any character *not* in the bracketed list. Thus, `[^aeiouy]` matches anything that is not a lowercase vowel, including the uppercase vowels, all consonants, digits, punctuation, and so on.

Matching lots of characters by listing them all gets tedious—for example, `[0123456789]` to match a digit or `[0123456789abcdefABCDEF]` to match a hexadecimal digit. For this reason, bracket expressions may include ranges. The previous two expressions can be shortened to `[0-9]` and `[0-9a-fA-F]`, respectively.



Originally, the range notation matched characters based on their numeric values in the machine's character set. Because of character set differences (ASCII versus EBCDIC), this notation was never 100% portable, although in practice it was "good enough," since almost all Unix systems used ASCII.

With POSIX locales, things have gotten worse. Ranges now work based on each character's position in the locale's collating sequence, which is unrelated to machine character-set numeric values. The range notation is portable only for programs running in the "POSIX" locale. The POSIX character class notation, mentioned earlier in the chapter, provides a way to portably express concepts such as "all digits," or "all alphabetic characters." Thus, ranges in bracket expressions are discouraged.

Earlier, in Section 3.2.1, we briefly mentioned POSIX collating symbols, equivalence classes, and character classes. These are final components that may appear inside the square brackets of a bracket expression. The following paragraphs describe some of these constructs.

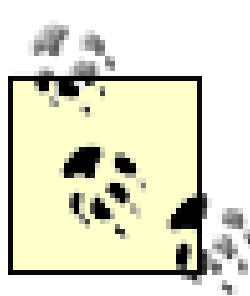
In several non-English languages, certain pairs of characters must be treated, for comparison purposes, as if they were a single character. Such pairs have a defined way of sorting when compared with single letters in the language. For Spanish, the two characters `ch` are kept together and are treated as a single unit for comparison purposes.

Collating is the act of giving an ordering to some group or set of items. A POSIX collating element consists of a character or a pair of characters, enclosed by `[. and .]`. For the `ch` just discussed, the locale might use `[.ch.]` because each locale defines its own collating elements.) Assuming the existence of `[.ch.]`, the regular expression `[.ch.]` matches any of the characters `a`, `b`, `d`, or `e`, or the pair `ch`. It does *not* match a standalone `c` or `h` character.

An equivalence class is used to represent different characters that should be treated the same when matching. The name of the class is enclosed between `[= and =]`. For example, in a French locale, there might be an `[=e=]`.

exists, then the regular expression `[a[=e=]iouy]` would match all the lowercase English vowels, as well as `o` and `n`.

As the last special component, character classes represent classes of characters, such as digits, lower- and uppercase letters, punctuation, whitespace, and so on. They are written by enclosing the name of the class in `[: and :]`. The names are listed in Table 3-3. The pre-POSIX range expressions for decimal and hexadecimal digits can (and should) be expressed as character classes: `[[:digit:]]` and `[[:xdigit:]]`.



Collating elements, equivalence classes, and character classes are only recognized *inside* of a bracket expression. Writing a standalone regular expression such as `[:alpha:]` matches `a`, `l`, `p`, `h`, and `:`. The correct way to write it is `[[:alpha:]]`.

Within bracket expressions, all other metacharacters lose their special meanings. Thus, `[*\.]` matches a literal backslash, or a literal period. To get a `]` into the set, place it first in the list: `[]*\.]` adds the `]` to the list. To get a `-` into the set, place it first in the list: `[-*\.]`. If you need both a right bracket and a minus, make the right bracket first and make the minus the last one in the list: `[]*\.-]`.

Finally, POSIX explicitly states that the NUL character (numeric value zero) need not be matchable. This is a problem for the language to indicate the end of a string, and the POSIX standard wanted to make it straightforward to implement in regular C strings. In addition, individual utilities may disallow matching of the newline character by the `.` in bracket expressions.

3.2.2.2 Backreferences

BREs provide a mechanism, known as *backreferences*, for saying "match whatever an earlier part of the regular expression matched." There are two steps to using backreferences. The first step is to enclose a subexpression in `\(` and `\)`. Then use `\n` to refer to the enclosed subexpressions within a single pattern, and they may be nested.

The next step is to use `\digit`, where *digit* is a number between 1 and 9, in a later part of the same pattern: "match whatever was matched by the *n*th earlier parenthesized subexpression." Here are some examples:

Pattern	Matches
<code>\(ab\) \(cd\) [def]* \2 \1</code>	<code>abcdcdab</code> , <code>abcdeeeecdab</code> , <code>abcddeeffcdab</code> , ...
<code>\(why\) .* \1</code>	A line with two occurrences of <code>why</code>
<code>\([[:alpha:]]_ [[:alnum:]]_*\) = \1;</code>	Simple C/C++ assignment statement

Backreferences are particularly useful for finding duplicated words and matching quotes:

`\(["']\).* \1` *Match single- or double-quoted words, 1*

This way, you don't have to worry about whether a single quote or double quote was found first.

3.2.2.3 Matching multiple characters with one expression

The simplest way to match multiple characters is to list them one after the other (concatenation). Thus, `ab` matches the characters `ab`, `..` (dot dot) matches any two characters, and `[[:upper:]][[:lower:]]` matches a character followed by any lowercase one. However, listing characters out this way is good only for short regular expressions.

Although the `.` (dot) metacharacter and bracket expressions provide a nice way to match one character at a time, regular expressions come into play when using the additional *modifier* metacharacters. These metacharacters modify the meaning of the regular expression, and they modify the meaning of the regular expression.

The most commonly used modifier is the asterisk or star (`*`), whose meaning is "match zero or more of the character." Thus, `ab*c` means "match an `a`, zero or more `b` characters, and a `c`." This regular expression matches `abbc`, `abbbc`, and so on.

It is important to understand that "match zero or more of one thing" does *not* mean "match anything." Thus, given the regular expression `ab*c`, the text `aQc` does not match, even though it contains the characters in `abc`. Instead, with the text `ac`, the `b*` in `ab*c` is said to match the *null string* (zero width) in between the `a` and the `c`. (The idea of a zero-width string takes some getting used to, but you've never seen it before. Nevertheless, it does come in handy, as will be shown later in the chapter.)

The `*` modifier is useful, but it is unlimited. You can't use `*` to say "match three characters but not four," and you can't type out a complicated bracket expression multiple times when you want an exact number of matches. Interval expressions solve this problem. Like `*`, they come after a single-character regular expression, and they let you control how many occurrences of the character will be matched. Interval expressions consist of one or two numbers enclosed between `\{` and `\}` as follows:

<code>\{ n \}</code>	Exactly n occurrences of the preceding regular expression
<code>\{ n , \}</code>	At least n occurrences of the preceding regular expression
<code>\{ n , m \}</code>	Between n and m occurrences of the preceding regular expression

Given interval expressions, it becomes easy to express things like "exactly five occurrences of `a`," or "between 10 and 42 occurrences of `q`." To wit: `a\{5\}` and `q\{10,42\}`.

The values for n and m must be between 0 and `RE_DUP_MAX`, inclusive. `RE_DUP_MAX` is a symbolic constant available via the `getconf` command. The minimum value for `RE_DUP_MAX` is 255; some systems allow larger values. On GNU/Linux systems, it's quite large:


```
$ getconf RE_DUP_MAX
```

```
32767
```

3.2.2.4 Anchoring text matches

Two additional metacharacters round out our discussion of BREs. These are the caret (^) and the dollar sign (\$) called *anchors* because they restrict the regular expression to matching at the beginning or end, respectively, of the text matched against. (This use of ^ is entirely separate from the use of ^ to complement the list of characters in a character class.) Assuming that the text to be matched is `abcABCdefDEF`, Table 3-4 provides some examples:

Table 3-4. Examples of anchors in regular expressions

Pattern	Matches?	Text matched (in bold) / Reason match fails
<code>ABC</code>	Yes	Characters 4, 5, and 6, in the middle: <code>abc ABC defDEF</code>
<code>^ABC</code>	No	Match is restricted to beginning of string
<code>def</code>	Yes	Characters 7, 8, and 9, in the middle: <code>abcABC def DEF</code>
<code>def\$</code>	No	Match is restricted to end of string
<code>[[:upper:]]\{3\}</code>	Yes	Characters 4, 5, and 6, in the middle: <code>abc ABC defDEF</code>
<code>[[:upper:]]\{3\}\$</code>	Yes	Characters 10, 11, and 12, at the end: <code>abcDEFdef DEF</code>
<code>^[[:alpha:]]\{3\}</code>	Yes	Characters 1, 2, and 3, at the beginning: <code>abc ABCdefDEF</code>

^ and \$ may be used together, in which case the enclosed regular expression must match the entire string (occasionally to use the simple regular expression `^$`, which matches empty strings or lines). Together with `grep -v`, which prints all lines that *don't* match a pattern, these can be used to filter out empty lines from a file.

For example, it's sometimes useful to look at C source code after it has been processed for `#include` files and you can see exactly what the C compiler sees. (This is low-level debugging, but sometimes it's what you have to do.) Source files often contain many more blank or empty lines than lines of source text: thus it's useful to exclude empty lines from the output of `cc -E`.

```
$ cc -E foo.c | grep -v '^$' > foo.out           Preprocess, remove empty lines
```

^ and \$ are special only at the beginning or end of a BRE, respectively. In a BRE such as `ab^cd`, the ^ stands for itself. In `ef$gh`, the \$ in this case stands for itself. And, as with any other metacharacter, `\^` and `\$` may be used, a

^[3] The corresponding `[^]` is not a valid regular expression. Make sure you understand why.

3.2.2.5 BRE operator precedence

As in mathematical expressions, the regular expression operators have a certain defined *precedence*. This means that some operators are applied before (have higher precedence than) other operators. Table 3-5 provides the precedence for the operators from highest to lowest.

Table 3-5. BRE operator precedence from highest to lowest

Operator	Meaning
<code>[. .] [= =] [: :]</code>	Bracket symbols for character collation
<code>\ <i>metacharacter</i></code>	Escaped metacharacters
<code>[]</code>	Bracket expressions
<code>\(\) \ <i>digit</i></code>	Subexpressions and backreferences
<code>* \{ \}</code>	Repetition of the preceding single-character regular expression
<i>no symbol</i>	Concatenation
<code>^ \$</code>	Anchors

3.2.3. Extended Regular Expressions

EREs, as the name implies, have more capabilities than do basic regular expressions. Many of the metacharacters are identical. However, some of the metacharacters that look similar to their BRE counterparts have different meanings.

3.2.3.1 Matching single characters

When it comes to matching single characters, EREs are essentially the same as BREs. In particular, normal characters, the backslash character for escaping metacharacters, and bracket expressions all behave as described earlier for BREs.

One notable exception is that in *awk*, `\` is special inside bracket expressions. Thus, to match a left bracket, you could use `[\[\- \] \]`. Again, this reflects historical practice.

3.2.3.2 Backreferences don't exist

Backreferences don't exist in EREs.^[4] Parentheses are special in EREs, but serve a different purpose than they do in BREs (as described shortly). In an ERE, `\(` and `\)` match literal left and right parentheses.

[4] This reflects differences in the historical behavior of the *grep* and *egrep* commands, not a technical incapability of regular life with Unix.

3.2.3.3 Matching multiple regular expressions with one expression

EREs have the most notable differences from BREs in the area of matching multiple characters. The `*` does BREs.^[5]

[5] An exception is that the meaning of a `*` as the first character of an ERE is "undefined," whereas in a BRE it means "match

Interval expressions are also available in EREs; however, they are written using plain braces, not braces preceded by `{`. Thus, our previous examples of "exactly five occurrences of `a`" and "between 10 and 42 instances of `q`" are `a{5}` and `q{10,42}`, respectively. Use `\{` and `\}` to match literal brace characters. POSIX purposely leaves the meaning of `{` in an ERE as "undefined."

EREs have two additional metacharacters for finer-grained matching control, as follows:

<code>?</code>	Match zero or one of the preceding regular expression
<code>+</code>	Match one or more of the preceding regular expression

You can think of the `?` character as meaning "optional." In other words, text matching the preceding regular expression is present or it's not. For example, `ab?c` matches both `ac` and `abc`, but nothing else. (Compare this to `ab*c`, which matches any number of intermediate `b` characters.)

The `+` character is conceptually similar to the `*` metacharacter, except that at least one occurrence of text matching the preceding regular expression must be present. Thus, `ab+c` matches `abc`, `abbc`, `abbbc`, and so on, but does *not* match `ac`. You can replace a regular expression of the form `ab+c` with `abb*c`; however, the `+` can save a lot of typing (and the preceding regular expression is complicated).

3.2.3.4 Alternation

Bracket expressions let you easily say "match this character, or that character, or" However, they don't let you say "match this sequence, or that sequence, or" You can do this using the *alternation* operator, which is the vertical bar `|`. Simply write the two sequences of characters, separated by a pipe. For example, `read|write` matches both `read` and `write`, `fast|slow` matches both `fast` and `slow`, and so on. You may use more than one: `sleep|doze|dream|nod` matches all five expressions.

The `|` character has the lowest precedence of all the ERE operators. Thus, the lefthand side extends all the way to the left of the operator, to either a preceding `|` character or the beginning of the regular expression. Similarly, the righthand side extends all the way to the right of the operator, to either a succeeding `|` character or the end of the whole regular expression. This is discussed in the next section.

3.2.3.5 Grouping

You may have noticed that for EREs, we've stated that the operators are applied to "the preceding regular expression" and that parentheses `(...)` provide grouping, to which the operators may then be applied. For example, `(why)` matches occurrences of the word `why`.

Grouping is particularly valuable (and necessary) when using alternation. It allows you to build complicated expressions. For example, `[Tt]he (CPU|computer) is` matches sentences using either `CPU` or `computer` and `is`. Note that here the parentheses are metacharacters, not input text to be matched.

Grouping is also often necessary when using a repetition operator together with alternation. `read|write+` matches one occurrence of the word `read` or an occurrence of the word `write`, followed by any number of `e` characters (on). A more useful pattern (and probably what would be meant) is `(read|write)+`, which matches one or either of the words `read` or `write`.

Of course, `(read|write)+` makes no allowance for intervening whitespace between words. `((read|write)+)` is a more complicated, but more realistic, regular expression. At first glance, this looks rather opaque. However, if you break it down into component parts, from the outside in, it's not too hard to follow. This is illustrated in Figure 3-1.

Figure 3-1. Reading a complicated regular expression

The upshot is that this single regular expression matches multiple successive occurrences of either `read` or `write`, separated by whitespace characters.

The use of a `*` after the `[[:space:]]` is something of a judgment call. By using a `*` and not a `+`, the match is optional (or string). However, this opens up the possibility of matching words with no intervening whitespace. In many cases, such expressions often require such judgment calls. How you build your regular expressions will depend on how you need to do with that data.

Finally, grouping is helpful when using alternation together with the `^` and `$` anchor characters. Because `|` is one of all the operators, the regular expression `^abcd|efgh$` means "match `abcd` at the beginning of the string, or `efgh` at the end of the string." This is different from `^(abcd|efgh)$`, which means "match a string containing exactly `abcd` or `efgh`."

3.2.3.6 Anchoring text matches

The `^` and `$` have the same meaning as in BREs: anchor the regular expression to the beginning or end of the string. There is one significant difference, though. In EREs, `^` and `$` are *always* metacharacters. Thus, regular expressions `ef$gh` are valid, but cannot match anything, since the text preceding the `^` and the text following the `$` prevent matching "the beginning of the string" and "the end of the string," respectively. As with the other metacharacters, the meaning inside bracket expressions.

3.2.3.7 ERE operator precedence

Operator precedence applies to EREs as it does to BREs. Table 3-6 provides the precedence for the ERE operators from highest to lowest.

Table 3-6. ERE operator precedence from highest to lowest

Operator	Meaning
[. .] [= =] [: :]	Bracket symbols for character collation
\ <i>metacharacter</i>	Escaped metacharacters
[]	Bracket expressions
()	Grouping
* + ? { }	Repetition of the preceding regular expression
<i>no symbol</i>	Concatenation
^ \$	Anchors
	Alternation

3.2.4. Regular Expression Extensions

Many programs provide extensions to regular expression syntax. Typically, such extensions take the form of adding an additional character, to create new operators. This is similar to the use of a backslash in `\(... \)` and `\{ ... \}`.

The most common extensions are the operators `\<` and `\>`, which match the beginning and end of a "word," made up of letters, digits, and underscores. We call such characters *word-constituent*.

The beginning of a word occurs at either the beginning of a line or the first word-constituent character following a nonword-constituent character. Similarly, the end of a word occurs at the end of a line, or after the last word-constituent character following a nonword-constituent one.

In practice, word matching is intuitive and straightforward. The regular expression `\<chop` matches `use chop`.

match `eat a lamb chop`. Similarly, the regular expression `chop\>` matches the second string, but does not. `\<chop\>` does not match either string.

Although standardized by POSIX only for the *ex* editor, word matching is universally supported by the *ed*, which comes standard with every commercial Unix system. Word matching is also supported on the "clone" versions that come with GNU/Linux and BSD systems, as well as in *emacs*, *vim*, and *vile*. Most GNU utilities support word matching; programs that support word matching often include *grep* and *sed*, but you should double-check the manpage for your system.

GNU versions of the standard utilities that deal with regular expressions typically support a number of additional operators are outlined in Table 3-7.

Table 3-7. Additional GNU regular expression operators

Operator	Meaning
<code>\w</code>	Matches any word-constituent character. Equivalent to <code>[[:alnum:]]</code> .
<code>\W</code>	Matches any nonword-constituent character. Equivalent to <code>[^[:alnum:]]</code> .
<code>\< \></code>	Matches the beginning and end of a word, as described previously.
<code>\b</code>	Matches the null string found at either the beginning or the end of a word. This is a generalization of the <code>\w</code> and <code>\W</code> operators. Note: Because <i>awk</i> uses <code>\b</code> to represent the backspace character, GNU <i>awk</i> (<i>gawk</i>) uses <code>\y</code> .
<code>\B</code>	Matches the null string between two word-constituent characters.
<code>\` \`</code>	Matches the beginning and end of an <i>emacs</i> buffer, respectively. GNU programs (besides <i>emacs</i>) use <code>\`</code> and <code>\`</code> being equivalent to <code>^</code> and <code>\$</code> .

Finally, although POSIX explicitly states that the NUL character need not be matchable, GNU programs handle the NUL character. If the NUL character occurs in input data, it can be matched by the `.` metacharacter or a bracket expression.

3.2.5. Which Programs Use Which Regular Expressions?

It is a historical artifact that there are two different regular expression flavors. While the existence of *egrep* and *grep* expressions was known during the early Unix development period, Ken Thompson didn't feel that it was necessary to have full-blown regular expressions for the *ed* editor. (Given the PDP-11's small address space, the complexity of regular expressions, and the fact that for most editing jobs basic regular expressions are enough, this decision made sense.)

The code for *ed* then served as the base for *grep*. (*grep* is an abbreviation for the *ed* command `g/re/p:ξ`.) *ed*'s code also served as an initial base for *sed*.

Somewhere in the pre-V7 timeframe, *egrep* was created by Al Aho, a Bell Labs researcher who did groundl expression matching and language parsing. The core matching code from *egrep* was later reused for regula

The `\<` and `\>` operators originated in a version of *ed* that was modified at the University of Waterloo by R Redelmeier, and David Tilbrook. (Rob Pike was the one who invented those operators.) Bill Joy at UCB ac editors, from whence it became widely used. Interval expressions originated in *Programmer's Workbench U* into the commercial Unix world via System III, and later, System V. Table 3-8 lists the various Unix program regular expression they use.

^[6] Programmer's Workbench (PWB) Unix was a variant used within AT&T to support telephone switch software developme commercial use.

Table 3-8. Unix programs and their regular expression type

Type	<i>grep</i>	<i>sed</i>	<i>ed</i>	<i>ex /vi</i>	<i>more</i>	<i>egrep</i>
BRE	
ERE						.
<code>\< \></code>	

lex is a specialized tool, generally used for the construction of lexical analyzers for language processors. E POSIX, we don't discuss it further, since it's not relevant for shell scripting. The *less* and *pg* pagers, while r support regular expressions. Some systems have a *page* program, which is essentially the same as *more* , b between each screenful of output.

As we mentioned at the beginning of the chapter, to (attempt to) mitigate the multiple *grep* problem, POSIX program. By default, POSIX *grep* uses BREs. With the `-E` option, it uses EREs, and with the `-F` option, it u matching algorithm. Thus, truly POSIX-conforming programs use `grep -E . . .` instead of `egrep . . .` . How systems do have it, and are likely to for many years to come, we continue to use it in our scripts.

A final note is that traditionally, *awk* did not support interval expressions within its flavor of extended regu 2005, support for interval expressions is not universal among different vendor versions of *awk* . For maximal match braces from an *awk* program, you should escape them with a backslash, or enclose them inside a bra

3.2.6. Making Substitutions in Text Files

Many shell scripting tasks start by extracting interesting text with *grep* or *egrep* . The initial results of a reg become the "raw data" for further processing. Often, at least one step consists of *text substitution* -that is, r with something else, or removing some part of the matched line.

Most of the time, the right program to use for text substitutions is *sed*, the Stream Editor. *sed* is designed to be used in a non-interactive fashion, rather than interactively. When you know that you have multiple changes to make, whether to one file or many, it is much easier to write down the changes in an editing script and apply the script to all the files that need to be edited for that purpose. (While it is possible to write editing scripts for use with the *ed* or *ex* line editors, doing so is more difficult and much harder to [remember to] save the original file.)

We have found that for shell scripting, *sed*'s primary use is making simple text substitutions, so we cover that use in detail, along with some additional background and explanation of *sed*'s capabilities, but we purposely don't go into a lot of detail about the more advanced features described in the book *sed & awk* (O'Reilly).

GNU *sed* is available at the location <ftp://ftp.gnu.org/gnu/sed/>. It has a number of interesting extensions that are described in the manual that comes with it. The GNU *sed* manual also contains some interesting examples, and the distribution includes several with some unusual programs. Perhaps the most amazing is an implementation of the Unix *dc* arbitrary-precision calculator using a *sed* script!

An excellent source for all things *sed* is <http://sed.sourceforge.net/>. It includes links to two FAQ documents. The first is available from <http://www.dreamwvr.com/sed-info/sed-faq.html>. The second, and older, FAQ is available from <ftp://rtfm.mit.edu/pub/faqs/editor-faq/sed>.

sed

Usage

```
sed [-n] 'editing command' [file ...]
sed [-n] -e 'editing command' ... [file ...]
sed [-n] -f script-file ... [file ...]
```

Purpose

To edit its input stream, producing results on standard output, instead of modifying files in place the way an interactive editor does. Although *sed* has many commands and can do complicated things, it is most commonly used for performing text substitutions on an input stream, usually as part of a pipeline.

Major options

`-e 'editing command '`

Use *editing command* on the input data. *-e* must be used when there are multiple commands.

`-f script-file`

Read editing commands from *script-file* . This is useful when there are many commands to execute.

`-n`

Suppress the normal printing of each final modified line. Instead, lines must be printed explicitly with the *p* command.

Behavior

This reads each line of each input file, or standard input if no files. For each line, *sed* executes every *command* that applies to the input line. The result is written on standard output (by default, or explicitly with the *p* command and the *-n* option). With no *-e* or *-f* options, *sed* treats the first argument as the *editing command* to use.

3.2.7. Basic Usage

Most of the time, you'll use *sed* in the middle of a pipeline to perform a substitution. This is done with the *s* command, a regular expression to look for, replacement text with which to replace matched text, and optional flags:

```
sed 's/:.*/' /etc/passwd | Remove everything after the first colon
sort -u Sort list and remove duplicates
```

Here, the */* character acts as a *delimiter* , separating the regular expression from the replacement text. In this example, the replacement text is empty (the infamous null string), which effectively deletes the matched text. Although the */* is the most common delimiter, any printable character may be used instead. When working with filenames, it is common to use a character like *:* as the delimiter (such as a semicolon, colon, or comma):

```
find /home/tolstoy -type d -print | Find all directories
sed 's;/home/tolstoy//;/home/lt/;' | Change name, note use of semi
sed 's/^/mkdir /' | Insert mkdir command
sh -x Execute, with shell tracing
```

This script creates a copy of the directory structure in `/home/tolstoy` in `/home/lt` (perhaps in preparation `find` command is described in Chapter 10. Its output in this case is a list of directory names, one per line, of underneath `/home/tolstoy`.) The script uses the interesting trick of *generating commands* and then feeding as input to the shell. This is a powerful and general technique that is not used as often as it should be.^[7]

^[7] This script does have a flaw: it can't handle directories whose names contain spaces. This can be solved using techniques in Chapter 10.

3.2.7.1 Substitution details

We've already mentioned that any delimiter may be used besides slash. It is also possible to escape the delimiter expression or the replacement text, but doing so can be much harder to read:

```
sed 's/\\/home\\/tolstoy\\/\\/\\/home\\/lt\\/\\/'
```

Earlier, in Section 3.2.2.2, when describing POSIX BREs, we mentioned the use of backreferences in regular expressions. Furthermore, they may be used *in the replacement text* to mean "substitute at this point by the *n*th parenthesized subexpression." This sounds worse than it is:

```
$ echo /home/tolstoy/ | sed 's;\/(\/home\/)\/tolstoy//;\/1\/lt//;'
```

```
/home/lt/
```

`sed` replaces the `\1` with the text that matched the `/home` part of the regular expression. In this case, all of the backslashes are escaped, but any regular expression can be enclosed between the `\(` and the `\)`. Up to nine backreferences are supported.

A few other characters are special in the replacement text as well. We've already mentioned the need to backslash the backslash character. This is also, not surprisingly, necessary for the backslash character itself. Finally, the `&` in the replacement text means "substitute at this point the entire text matched by the regular expression." For example, suppose that we work for the Chamber of Commerce, and we need to change our description of the city everywhere in our brochure:

```
mv atlga.xml atlga.xml.old
```

```
sed 's/Atlanta/&, the capital of the South/' < atlga.xml.old > atlga.xml
```


(Being a modern shop, we use XML for all the possibilities it gives us, instead of an expensive proprietary script saves the original brochure file, as a backup. Doing something like this is *always* a good idea, especially learning to work with regular expressions and substitutions. It then applies the change with *sed* .

To get a literal `&` character in the replacement text, backslash-escape it. For instance, the following small script converts literal backslashes in DocBook/XML files into the corresponding DocBook `\` entity:

```
sed 's/\\/\\&bsol;/g'
```

The `g` suffix on the previous `s` command stands for *global* . It means "replace *every* occurrence of the regular expression with the replacement text." Without it, *sed* replaces only the *first* occurrence. Compare the results from these two invocations without the `g` :

```
$ echo Tolstoy reads well. Tolstoy writes well. > example.txt           Sample
```

```
$ sed 's/Tolstoy/Camus/' < example.txt                                   No "g"
```

```
Camus reads well. Tolstoy writes well.
```

```
$ sed 's/Tolstoy/Camus/g' < example.txt                                  With "g"
```

```
Camus reads well. Camus writes well.
```

A little-known fact (amaze your friends!) is that you can specify a trailing number to indicate that the *n*th occurrence is replaced:

```
$ sed 's/Tolstoy/Camus/2' < example.txt                                  Second occurrence c
```

```
Tolstoy reads well. Camus writes well.
```

So far, we've done only one substitution at a time. While you can string multiple instances of *sed* together in a pipeline, you can also give *sed* multiple commands. On the command line, this is done with the `-e` option. Each command is provided as a separate editing command:

```
sed -e 's/foo/bar/g' -e 's/chicken/cow/g' myfile.xml > myfile2.xml
```

When you have more than a few edits, though, this form gets tedious. At some point, it's better to put all your editing commands in a file and then run *sed* using the `-f` option:

```
$ cat fixup.sed
```

```
s/foo/bar/g
```

```
s/chicken/cow/g
```

```
s/draft animal/horse/g
```

```
...
```

```
$ sed -f fixup.sed myfile.xml > myfile2.xml
```

You can build up a script by combining the `-e` and `-f` options; the script is the concatenation of all editing commands and the options, in the order given. Additionally, POSIX allows you to separate commands on the same line with semicolons.

```
sed 's/foo/bar/g ; s/chicken/cow/g' myfile.xml > myfile2.xml
```

However, many commercial versions of `sed` don't (yet) allow this, so it's best to avoid it for absolute portability.

Like its ancestor `ed` and its cousins `ex` and `vi`, `sed` remembers the last regular expression used at any point in a script. A regular expression may be reused by specifying an empty regular expression:

```
s/foo/bar/3           Change third foo
```

```
s//quux/            Now change first one
```

Consider a straightforward script named `html2xhtml.sed` for making a start at converting HTML to XHTML. It changes uppercase tags to lowercase, and changes the `
` tag into the self-closing form, `
`:

```
s/<H1>/<h1>/g           Slash delimiter
```

```
s/<H2>/<h2>/g
```

```
s/<H3>/<h3>/g
```

```
s/<H4>/<h4>/g
```

```
s/<H5>/<h5>/g
```

```
s/<H6>/<h6>/g
```

```
s:</H1>:</h1>;g         Colon delimiter, slash in data
```

```
s:</H2>:</h2>;g
```

```

s:</H3>:</h3>:g
s:</H4>:</h4>:g
s:</H5>:</h5>:g
s:</H6>:</h6>:g

s/<[Hh][Tt][Mm][Ll]>/<html>/g

s:</[Hh][Tt][Mm][Ll]>:</html>:g

s:<[Bb][Rr]>:<br/>:g

...

```

Such a script can automate a large part of the task of converting from HTML to XHTML, the standardized HTML.

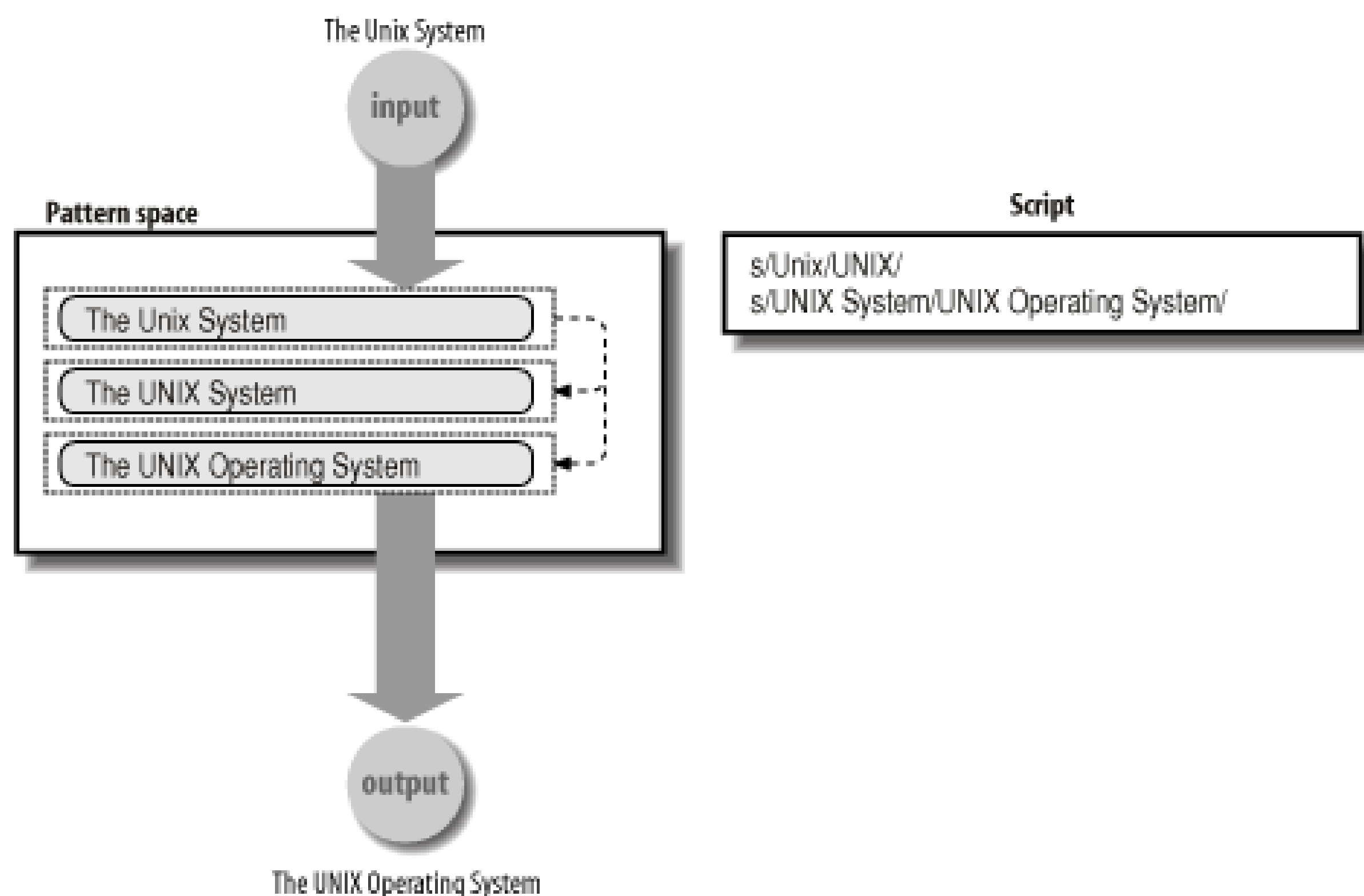
3.2.8. sed Operation

sed's operation is straightforward. Each file named on the command line is opened and read, in turn. If the input is used, and the filename "-" (a single dash) acts as a pseudonym for standard input.

sed reads through each file one line at a time. The line is placed in an area of memory termed the *pattern space* variable in a programming language: an area of memory that can be changed as desired under the direction of the script. All editing operations are applied to the contents of the pattern space. When all operations have been completed, the contents of the pattern space are written to standard output, and then goes back to the beginning, reading another line of input.

This operation is shown in Figure 3-2. The script uses two commands to change `The Unix System` into `The System`.

Figure 3-2. Commands in sed scripts changing the pattern space



3.2.8.1 To print or not to print

The `-n` option modifies `sed`'s default behavior. When supplied, `sed` does *not* print the final contents of the pattern space. Instead, `p` commands in the script explicitly print the line. For example, one might simulate `grep` in the following way:

```
sed -n '/<HTML>/p' *.html           Only print <HTML> lines
```

Although this example seems trivial, this feature is useful in more complicated scripts. If you use a script file, you can turn off automatic printing by using a special first line:

```
#n                                   Turn off automatic printing

/<HTML>/p                             Only print <HTML> lines
```

As in the shell and many other Unix scripting languages, the `#` is a comment. `sed` comments have to appear at the beginning of a line; they're syntactically commands; they're just commands that don't do anything. While POSIX indicates that comments can appear anywhere in a script, many older versions of `sed` allow them only on the first line. GNU `sed` does not have this restriction.

3.2.9. Matching Specific Lines

As mentioned, by default, `sed` applies every editing command to every input line. It is possible to restrict the command to apply only to specific lines by prefixing the command with an *address*. Thus, the full form of a `sed` command is:

```
address command
```

There are different kinds of addresses:

Regular expressions

Prefixing a command with a pattern limits the command to lines matching the pattern. This can be used

```
/oldfunc/ s/$/# XXX: migrate to newfunc/ Annotate some source code
```

An empty pattern in the `s` command means "use the previous regular expression":

```
/Tolstoy/ s//& and Camus/g Talk about both authors
```

The last line

The symbol `$` (as in *ed* and *ex*) means "the last line." For example, this script is a quick way to print the last line of each file:

```
sed -n '$p' "$1" Quoting as shown
```

For *sed*, the "last line" means the last line of the input. Even when processing multiple files, *sed* views them as one file, and `$` applies only to the last line of the last file. (GNU *sed* has an option to cause addresses to apply separately to each file; see the *sed* documentation.)

Line numbers

You can use an absolute line number as an address. An example is provided shortly.

Ranges

You can specify a range of lines by separating addresses with a comma:

```
sed -n '10,42p' foo.xml Print only lines 10-42
```

```
sed '/foo/,/bar/ s/baz/quux/g' Make substitution only on range
```

The second command says "starting with lines matching `foo` , and continuing through lines matching `bar` `baz` with `quux` ." (Readers familiar with `ed` , `ex` , or the colon command prompt in `vi` will recognize this use)

The use of two regular expressions separated by commas is termed a *range expression* . In `sed` , it *always* in

Negated regular expressions

Occasionally it's useful to apply a command to all lines that *don't* match a particular pattern. You specify a `!` character after a regular expression to look for:

```
/used/!s/new/used/g
```

Change new to used on lines

The POSIX standard indicates that the behavior when whitespace follows the `!` is "unspecified," and recon portable applications not place any space after it. This is apparently due to some historical versions of `sed` r

Example 3-1 demonstrates the use of absolute line numbers as addresses by presenting a simple version of

Example 3-1. A version of the head command using sed

```
# head --- print first n lines
```

```
#
```

```
# usage: head N file
```

```
count=$1
```

```
sed ${count}q "$2"
```

When invoked as `head 10 foo.xml` , `sed` ends up being invoked as `sed 10q foo.xml` . The `q` command c immediately; no further input is read or commands executed. Later, in Section 7.6.1 , we show how to make the real `head` command.

As we've seen so far, `sed` uses `/` characters to delimit patterns to search for. However, there is provision for `!` in patterns. This is done by preceding the character with a backslash:

```
$ grep tolstoy /etc/passwd
```

Show origina

```
tolstoy:x:2076:10:Leo Tolstoy:/home/tolstoy:/bin/bash
```



```
$ sed -n '\:tolstoy: s;;Tolstoy;p' /etc/passwd           Make a change
Tolstoy:x:2076:10:Leo   Tolstoy:/home/tolstoy:/bin/bash
```

In this example, the colon delimits the pattern to search for, and semicolons act as delimiters for the `s` command itself is trivial; our point here is to demonstrate the use of different delimiters, not to make the change.

3.2.10. How Much Text Gets Changed?

One issue we haven't discussed yet is the question "how much text matches?" Really, there are two questions: "where does the match start?" and "where does it end?" Indeed, when doing simple text searches, such as with `grep` or `egrep`, both questions you want to know is whether a line matched, and if so, to see the line. Where in the line the match starts, or how far it extends, doesn't matter.

However, knowing the answer to these questions becomes vitally important when doing text substitution with `awk`. (Understanding this is also important for day-to-day use when working inside a text editor, although that's not the focus of editing in this book.)

The answer to both questions is that a regular expression matches the *longest, leftmost substring* of the input that matches the entire expression. In addition, a match of the null string is considered to be longer than no match at all. (The POSIX standard states: "Consistent with the whole match being the longest of the leftmost matches, each subpattern, shall match the longest possible string." (Subpatterns are the parts enclosed in parentheses in an ERE program; programs often extend this feature to `\(... \)` in BREs too.)

If `sed` is going to be replacing the text matched by a regular expression, it's important to be sure that the regular expression matches just the right amount of text. Here's a simple example:

```
$ echo Tolstoy writes well | sed 's/Tolstoy/Camus/'     Use fixed string
Camus writes well
```

Of course, `sed` can use full regular expressions. This is where understanding the "longest leftmost" rule becomes important.

```
$ echo Tolstoy is worldly | sed 's/T.*y/Camus/'        Try a regular expression
Camus                                                  What happened?
```

The apparent intent was to match just `Tolstoy`. However, since the match extends over the longest possible substring, it matched `Tolstoy is worldly` all the way to the `y` in `worldly`! What's needed is a more refined regular expression:

```
$ echo Tolstoy is worldly | sed 's/T[[:alpha:]]*y/Camus/'
```

```
Camus is worldly
```

In general, and especially if you're still learning the subtleties of regular expressions, when developing scripts and slicing and dicing, you'll want to test things very carefully, and verify each step as you write it.

Finally, as we've seen, it's possible to match the null string when doing text searching. This is also true when allowing you to *insert* text:

```
$ echo abc | sed 's/b*/1/'           Replace first match
```

```
1abc
```

```
$ echo abc | sed 's/b*/1/g'        Replace all matches
```

```
1a1c1
```

Note how `b*` matches the null string at the front and at the end of `abc`.

3.2.11. Lines Versus Strings

It is important to make a distinction between lines and strings. Most simple programs work on lines of input and `grep`, and 99 percent of the time, `sed`. In such a case, by definition there won't be any embedded newlines being matched, and `^` and `$` represent the beginning and end of the line, respectively.

However, programming languages that work with regular expressions, such as `awk`, Perl, and Python, usually assume that each string represents a single input line, in which case `^` and `$` still represent the beginning and end of the line. These languages allow you to use different ways to specify how input records are delimited, opening up the possibility that the input "line" (i.e., record) may indeed have embedded newlines. In such a case, `^` and `$` do *not* match an embedded newline; they represent only the beginning and end of a *string*. This point is worth bearing in mind when you start using regular expression software tools.

3.3. Working with Fields

For many applications, it's helpful to view your data as consisting of records and fields. A *record* is a single piece of information, such as what a business might have for a customer, supplier, or employee, or what a school might have for a student. A *field* is a single component of a record, such as a last name, a first name, or a street address.

3.3.1. Text File Conventions

Because Unix encourages the use of textual data, it's common to store data in a text file, with each line representing a record. There are two conventions for separating fields within a line from each other. The first is to just use whitespaces.

```
$ cat myapp.data
```

```
# model      units sold   salesperson
xj11         23           jane
rj45         12           joe
cat6         65           chris
...
```

In this example, lines beginning with a # character represent comments, and are ignored. (This is a common convention. Having comment lines is helpful, but it requires that your software be able to ignore such lines.) Each field is separated by an arbitrary number of space or tab characters. The second convention is to use a particular delimiter character, such as a colon:

```
$ cat myapp.data
```

```
# model:units sold:salesperson
xj11:23:jane
rj45:12:joe
cat6:65:chris
...
```


Each convention has advantages and disadvantages. When whitespace is the separator, it's difficult to have fields' contents. (If you use a tab as the separator, you can use a space character within a field, but this is visible and can't easily tell the difference just by looking at the file.) On the flip side, if you use an explicit delimiter character, it's difficult to include that delimiter within your data. Often, though, it's possible to make a careful choice, so the chosen delimiter becomes minimal or nonexistent.



One important difference between the two approaches has to do with multiple occurrences of a character(s). When using whitespace, the convention is that multiple successive occurrences of a character act as a *single* delimiter. However, when using a special character, *each* occurrence separates fields. For example, two colon characters in the second version of `myapp.data` (a `": :"`) delimit a

The prime example of the delimiter-separated field approach is `/etc/passwd`. There is one line per user of the system, and the fields are colon-separated. We use `/etc/passwd` for many examples throughout the book, since a large number of tasks involve it. Here is a typical entry:

```
tolstoy:x:2076:10:Leo Tolstoy:/home/tolstoy:/bin/bash
```

The seven fields of a password file entry are:

1. The username.
2. The encrypted password. (This can be an asterisk if the account is disabled, or possibly a different character if passwords are stored separately in `/etc/shadow`.)
3. The user ID number.
4. The group ID number.
5. The user's personal name and possibly other relevant data (office number, telephone number, and so on).
6. The home directory.
7. The login shell.

Some Unix tools work better with whitespace-delimited fields, others with delimiter-separated fields, and some are adept at working with either kind of file, as we're about to see.

3.3.2. Selecting Fields with `cut`

The *cut* command was designed for cutting out data from text files. It can work on either a field basis or a character basis. It is useful for cutting out particular columns from a file. Beware, though: a tab character counts as a single character.

[8] This can be worked around with *expand* and *unexpand*: see the manual pages for *expand* (1).

cut

Usage

```
cut -c list [ file ... ]
```

```
cut -f list [ -d delim ] [ file ... ]
```

Purpose

To select one or more fields or groups of characters from an input file, presumably for further processing in a pipeline.

Major options

-c *list*

Cut based on characters. *list* is a comma-separated list of character numbers or ranges, such as 1,2,3.

-d *delim*

Use *delim* as the delimiter with the -f option. The default delimiter is the tab character.

-f *list*

Cut based on fields. *list* is a comma-separated list of field numbers or ranges.

Behavior

Cut out the named fields or ranges of input characters. When processing fields, each delimiter character is treated as a field. The output fields are separated by the given delimiter character. Read standard input if no file is specified on the command line. See the text for examples.

Caveats

On POSIX systems, *cut* understands multibyte characters. Thus, "character" is not synonymous with "byte". See the manual pages for *cut* (1) for the details.

Some systems have limits on the size of an input line, particularly when multibyte characters are involved.

For example, the following command prints the login name and full name of each user on the system:

```
$ cut -d : -f 1,5 /etc/passwd           Extract fields
root:root                               Administrative accounts
...
tolstoy:Leo Tolstoy                     Real users
austen:Jane Austen
camus:Albert Camus
...
```

By choosing a different field number, we can extract each user's home directory:

```
$ cut -d : -f 6 /etc/passwd           Extract home directory
/root                                   Administrative accounts
...
/home/tolstoy                           Real users
```



```
/home/austen
```

```
/home/camus
```

```
...
```

Cutting by character list can occasionally be useful. For example, to pull out just the permissions field from

```
$ ls -l | cut -c 1-10
```

```
total 2878
```

```
-rw-r--r--
```

```
drwxr-xr-x
```

```
-r--r--r--
```

```
-rw-r--r--
```

```
...
```

However, this is riskier than using fields, since you're not guaranteed that each field in a line will always have the same length. In general, we prefer field-based commands for extracting data.

3.3.3. Joining Fields with join

The *join* command lets you merge files, where the records in each file share a common *key* -that is, the field for the record. Keys are often things such as usernames, personal last names, employee ID numbers, and so on. For example, we have two files, one which lists how many items a salesperson sold and one which lists the salesperson's qu

join

Usage

```
join [ options ... ] file1 file2
```

Purpose

To merge records in sorted files based on a common key.

Major options

-1 field1

-2 field2

Specifies the fields on which to join. *-1 field1* specifies *field1* from *file1* , and *-2 field2* specifies *field2* from *file2* . Fields are numbered from one, not from zero.

-o file.field

Make the output consist of field *field* from file *file* . The common field is not printed unless requested explicitly. Use multiple *-o* options to print multiple output fields.

-t separator

Use *separator* as the input field separator instead of whitespace. This character becomes the output separator as well.

Behavior

Read *file1* and *file2* , merging records based on a common key. By default, runs of whitespace are treated as fields. The output consists of the common key, the rest of the record from *file1* , followed by the rest of the record from *file2* . If *file1* is *-* , *join* reads standard input. The first field of each file is the default key field; this can be changed with *-1* and *-2* . Lines without keys in both files are not printed by default. (Options exist to change this; see the manual pages for *join* (1).)

Caveats

The *-1* and *-2* options are relatively new. On older systems, you may need to use *-j1 field1* and *-*

```
$ cat sales                                Show sales file
# sales data                               Explanatory comments
# salesperson    amount
joe      100
jane     200
herman   150
chris    300
```

```
$ cat quotas                                Show quotas file
# quotas
# salesperson    quota
joe      50
jane     75
herman   80
chris    95
```

Each record has two fields: the salesperson's name and the corresponding amount. In this instance, there are two columns so that they line up nicely.

In order for *join* to work correctly, the input files must be *sorted*. The program in Example 3-2, *merge-sales.sh*, uses *join* to merge the two files.

Example 3-2. merge-sales.sh


```
#!/bin/sh

# merge-sales.sh

#

# Combine quota and sales data

# Remove comments and sort datafiles

sed '/^#/d' quotas | sort > quotas.sorted
sed '/^#/d' sales | sort > sales.sorted

# Combine on first key, results to standard output

join quotas.sorted sales.sorted

# Remove temporary files

rm quotas.sorted sales.sorted
```

The first step is to remove the comment lines with *sed*, and then to sort each file. The sorted temporary files are then joined using the *join* command, and finally the script removes the temporary files. Here is what happens when it's run:

```
$ ./merge-sales.sh
```

```
chris 95 300
```

```
herman 80 150
```

```
jane 75 200
```

```
joe 50 100
```

3.3.4. Rearranging Fields with *awk*

awk is a useful programming language in its own right. In fact, we devote Chapter 90 covering the most important language. Although you can do quite a lot with *awk*, it was purposely designed to be useful in shell script manipulation, such as field extraction and rearrangement. In this section, we examine the basics of *awk* so that you can recognize "one-liners" when you see them.

3.3.4.1 Patterns and actions

awk's basic paradigm is different from many programming languages. It is similar in many ways to *sed*:

```
awk 'program' [file ...]
```

awk reads records (lines) one at a time from each file named on the command line (or standard input if none is given). The commands as specified by the program to the line. The basic structure of an *awk* program is:

```
pattern { action }
```

```
pattern { action }
```

```
...
```

The *pattern* part can be almost any expression, but in one-liners, it's typically an ERE enclosed in slashes. In a multi-line *awk* statement, but in one-liners, it's typically a plain `print` statement. (Examples are coming up.)

Either the *pattern* or the *action* may be omitted (but, of course, not both). A missing *pattern* executes on every input record. A missing *action* is equivalent to `{ print }`, which (as we shall see shortly) prints the entire record. The general form is:

```
... | awk '{ print some-stuff }' | ...
```

For each record, *awk* tests each *pattern* in the program. If the pattern is true (e.g., the record matches the general expression evaluates to true), then *awk* executes the code in the *action*.

3.3.4.2 Fields

awk has fields and records as a central part of its design. *awk* reads input records (usually just lines) and divides each record into fields. It sets the built-in variable `NF` to the number of fields in each record.

By default, whitespace separates fields—i.e., runs of spaces and/or tab characters (like `join`). This is usually the case, but there are other options. By setting the variable `FS` to a different value, you can change how *awk* separates fields. For example, if `FS` is a character, then each occurrence of that character separates fields (like `cut -d`). Or, and here is where *awk* shines, if `FS` is a full ERE, in which case each occurrence of text that matches that ERE acts as a field separator.

Field values are designated as such with the `$` character. Usually `$` is followed by a numeric constant. How an expression; most typically the name of a variable. Here are some examples:

```
awk '{ print $1 }'           Print first field (no pattern)

awk '{ print $2, $5 }'      Print second and fifth fields (

awk '{ print $1, $NF }'     Print first and last fields (no

awk 'NF > 0 { print $0 }'   Print nonempty lines (pattern a

awk 'NF > 0'                Same (no action, default is to
```

A special case is field number zero, which represents the whole record.

3.3.4.3 Setting the field separators

For simple programs, you can change the field separator with the `-F` option. For example, to print the users in the `/etc/passwd` file:

```
$ awk -F: '{ print $1, $5 }' /etc/passwd      Process /etc/passwd

root root                                     Administrative accounts

...

tolstoy Leo Tolstoy                          Real users

austen Jane Austen

camus Albert Camus

...
```

The `-F` option sets the `FS` variable automatically. Note how the program does not have to reference `FS` direc

manage reading records and splitting them into fields; *awk* does it all automatically.

You may have noticed that each field in the output is separated with a space, even though the input field separator is almost all the other tools, *awk* treats the two separators as distinct from each other. You can change the output field separator with the `OFS` variable. You do this on the command line with the `-v` option, which sets *awk*'s variables. The value of `OFS` is `awk`'s default field separator. The following is an example:

```
$ awk -F: -v 'OFS=**' '{ print $1, $5 }' /etc/passwd          Process /
root**root                                                  Administrati
...
tolstoy**Leo Tolstoy                                       Real users
austen**Jane Austen
camus**Albert Camus
...
```

We will see shortly that there are other ways to set these variables. They may be more legible, depending on the context.

3.3.4.4 Printing lines

As we've shown so far, most of the time you just want to print selected fields, or arrange them in a different order. This is done with the `print` statement. You supply it a list of fields, variables, or strings to print:

```
$ awk -F: '{ print "User", $1, "is really", $5 }' /etc/passwd
User root is really root
...
User tolstoy is really Leo Tolstoy
User austen is really Jane Austen
User camus is really Albert Camus
...
```

A plain `print` statement, without any arguments, is equivalent to `print $0`, which prints the whole record.

For cases like the example just shown, when you want to mix text and values, it is usually clearer to use *awk* statement. It is similar enough to the shell (and C) version of *printf* described in Section 2.5.4 , that we won't repeat it here. Here is the previous example, using *printf* :

```
$ awk -F: '{ printf "User %s is really %s\n", $1, $5 }' /etc/passwd
```

```
User root is really root
```

```
...
```

```
User tolstoy is really Leo Tolstoy
```

```
User austen is really Jane Austen
```

```
User camus is really Albert Camus
```

```
...
```

As with the shell-level *echo* and *printf* , *awk* 's *print* statement automatically supplies a final newline, whereas with *printf* you must supply it yourself, using the `\n` escape sequence.

Be sure to separate arguments to *print* with a comma! Without the comma, *awk* concatenates a

```
$ awk -F: '{ print "User" $1 "is really" $5 }' /etc/passwd User
```

```
...
```

```
Usertolstoyis reallyLeo Tolstoy
```

```
Userausten is reallyJane Austen
```

```
Usercamus is reallyAlbert Camus
```

```
...
```

String concatenation of this form is unlikely to be what you want. Omitting the comma is a common mistake.

3.3.4.5 Startup and cleanup actions

Two special "patterns," `BEGIN` and `END` , let you provide startup and cleanup actions for your *awk* programs. In larger *awk* programs, usually written in separate files instead of on the command line:

```
BEGIN      { startup code }
```

```
pattern1  { action1  }
```

```
pattern2  { action2  }
```

```
END       { cleanup code }
```

`BEGIN` and `END` blocks are optional. If you have them, it is conventional, but not required, to place them at the beginning and end, respectively, of the `awk` program. You can also have multiple `BEGIN` and `END` blocks; `awk` executes them in the order encountered in the program: all the `BEGIN` blocks once at the beginning, and all the `END` blocks once at the end. `BEGIN` is used for setting variables:

```
$ awk 'BEGIN { FS = ":" ; OFS = "***" }           Use BEGIN to set variables
> { print $1, $5 }' /etc/passwd                 Quoted program continues o
root**root
...
tolstoy**Leo Tolstoy                           Output, as before
austen**Jane Austen
camus**Albert Camus
...
```

The POSIX standard describes the `awk` language and the options for the `awk` program. POSIX is on so-called "new `awk`," first released to the world with System V Release 3.1 in 1987, and somewhat later for System V Release 4 in 1989.

Alas, as late as 2005, the Solaris `/bin/awk` is *still* the original V7 version of `awk`, from 1977. On modern systems, you should use `/usr/xpg4/bin/awk`, or install one of the free versions of `awk` (see Chapter 9).

PREV

< Day Day Up >

3.4. Summary

The *grep* program is the primary tool for extracting interesting lines of text from input datafiles. POSIX mandates a single version with different options to provide the behavior traditionally obtained from the three *grep* variants: *grep*, *egrep*, and *fgrep*.

Although you can search for plain string constants, regular expressions provide a more powerful way to describe text to be matched. Most characters match themselves, whereas certain others act as metacharacters, specifying actions such as "match zero or more of," "match exactly 10 of," and so on.

POSIX regular expressions come in two flavors: Basic Regular Expressions (BREs) and Extended Regular Expressions (EREs). Which programs use which regular expression flavor is based upon historical practice, with the POSIX specification reducing the number of regular expression flavors to just two. For the most part, EREs are a superset of BREs, but not completely.

Regular expressions are sensitive to the locale in which the program runs; in particular, ranges within a bracket expression should be avoided in favor of character classes such as `[[:alnum:]]`. Many GNU programs have additional metacharacters.

sed is the primary tool for making simple string substitutions. Since, in our experience, most shell scripts use *sed* only for substitutions, we have purposely not covered everything *sed* can do. The *sed & awk* book listed in the [Chapter 16](#) provides more information.

The "longest leftmost" rule describes where text matches and for how long the match extends. This is important when doing text substitutions with *sed*, *awk*, or an interactive text editor. It is also important to understand when there is a distinction between a line and a string. In some programming languages, a single string may contain multiple lines, in which case `^` and `$` usually apply to the beginning and end of the string.

For many operations, it's useful to think of each line in a text file as an individual record, with data in the line consisting of fields. Fields are separated by either whitespace or a special delimiter character, and different Unix tools are available to work with both kinds of data. The *cut* command cuts out selected ranges of characters or fields, and *join* is handy for merging files where records share a common key field.

awk is often used for simple one-liners, where it's necessary to just print selected fields, or rearrange the order of fields within a line. Since it's a programming language, you have much more power, flexibility, and control, even in small programs.

 PREV

< Day Day Up >

Chapter 4. Text Processing Tools

Some operations on text files are so widely applicable that standard tools for those tasks were developed early in the Unix work at Bell Labs. In this chapter, we look at the most important ones.

4.1. Sorting Text

Text files that contain independent records of data are often candidates for sorting. A predictable record order is useful for users: book indexes, dictionaries, parts catalogs, and telephone directories have little value if they are unsorted. Sorting makes programming easier and more efficient, as we will illustrate with the construction of an office directory.

Like *awk*, *cut*, and *join*, *sort* views its input as a stream of records made up of fields of variable width, with fields separated by newline characters and fields delimited by whitespace or a user-specifiable single character.

sort

Usage

```
sort [ options ] [ file(s) ]
```

Purpose

Sort input lines into an order determined by the key field and datatype options, and the locale.

Major options

-b

Ignore leading whitespace.

-c

Check that input is correctly sorted. There is no output, but the exit code is nonzero if the input is not

-d

Dictionary order: only alphanumerics and whitespace are significant.

-g

General numeric value: compare fields as floating-point numbers. This works like *-n*, except that numbers have decimal points and exponents (e.g., `6.022e+23`). GNU version only.

-f

Fold letters implicitly to a common lettercase so that sorting is case-insensitive.

-i

Ignore nonprintable characters.

-k

Define the sort key field. See Section 4.1.2, for details.

-m

Merge already-sorted input files into a sorted output stream.

-n

Compare fields as integer numbers.

-O outfile

Write output to the specified file instead of to standard output. If the file is one of the input files, *sort* creates a temporary file before sorting and writing the output.

-r

Reverse the sort order to descending, rather than the default ascending.

-t char

Use the single character *char* as the default field separator, instead of the default of whitespace.

-u

Unique records only: discard all but the first record in a group with equal keys. Only the key fields and parts of the discarded records may differ.

Behavior

sort reads the specified files, or standard input if no files are given, and writes the sorted data on st

4.1.1. Sorting by Lines

In the simplest case, when no command-line options are supplied, complete records are sorted according to locale. In the traditional C locale, that means ASCII order, but you can set an alternate locale as we describe below.

A tiny bilingual dictionary in the ISO 8859-1 encoding translates four French words differing only in accents

```
$ cat french-english
```

Show the tiny dictionary

```
côte    coast
```

```
cote    dimension
```

```
coté    dimensioned
```

```
côté    side
```

To understand the sorting, use the octal dump tool, *od*, to display the French words in ASCII and octal:

```
$ cut -f1 french-english | od -a -b           Display French words in
0000000  c   t   t   e  nl  c   o   t   e  nl  c   o   t   i  nl  c
          143 364 164 145 012 143 157 164 145 012 143 157 164 351 012
0000020  t   t   i  nl
          364 164 351 012
0000024
```

Evidently, with the ASCII option *-a*, *od* strips the high-order bit of characters, so the accented letters have their octal values: *é* is 351₈ and *ô* is 364₈.

On GNU/Linux systems, you can confirm the character values like this:

```
$ man iso_8859_1           Check the ISO 8859-1 ma
...
      Oct   Dec   Hex   Char   Description
-----
...
      351   233   E9    é     LATIN SMALL LETTER E WITH ACUTE
...
      364   244   F4    ô     LATIN SMALL LETTER O WITH CIRCUMFLEX
...
```

First, sort the file in strict byte order:

```
$ LC_ALL=C sort french-english           Sort in traditional ASCII.
cote   dimension
coté   dimensioned
```

côte coast

côté side

Notice that e (145₈) sorted before é (351₈), and o (157₈) sorted before ô (364₈), as expected from their n

Now sort the text in Canadian-French order:

```
$ LC_ALL=fr_CA.iso88591 sort french-english Sort in Canadian-
```

côte coast

cote dimension

coté dimensioned

côté side

The output order clearly differs from the traditional ordering by raw byte values.

Sorting conventions are strongly dependent on language, country, and culture, and the rules are sometimes English, which mostly pretends that accents are irrelevant, can have complex sorting rules: examine your l how lettercase, digits, spaces, punctuation, and name variants like McKay and Mackay are handled.

4.1.2. Sorting by Fields

For more control over sorting, the *-k* option allows you to specify the field to sort on, and the *-t* option lets

If *-t* is not specified, then fields are separated by whitespace and leading and trailing whitespace in the recc option, the specified character delimits fields, and whitespace is significant. Thus, a three-character record has one field without *-t*, but three with *-t ' '* (the first and third fields are empty).

The *-k* option is followed by a field number, or number pair, optionally separated by whitespace after *-k*. E a dotted character position, and/or one of the modifier letters shown in Table 4-1 .

Table 4-1. Sort key field types

Letter	Description
b	Ignore leading whitespace.
d	Dictionary order.

Letter	Description
f	Fold letters implicitly to a common lettercase.
g	Compare as general floating-point numbers. GNU version only.
i	Ignore nonprintable characters.
n	Compare as (integer) numbers.
r	Reverse the sort order.

Fields and characters within fields are numbered starting from one.

If only one field number is specified, the sort key begins at the start of that field, and continues to the end of that field).

If a comma-separated pair of field numbers is given, the sort key starts at the beginning of the first field, and ends at the end of the second field.

With a dotted character position, comparison begins (first of a number pair) or ends (second of a number pair). For example, `k2.4,5.6` compares starting with the fourth character of the second field and ending with the sixth character of the second field.

If the start of a sort key falls beyond the end of the record, then the sort key is empty, and empty sort keys are sorted first.

When multiple `-k` options are given, sorting is by the first key field, and then, when records match in that key field, by the second key field, and so on.

While the `-k` option is available on all of the systems that we tested, `sort` also recognizes a deprecated specification, now considered obsolete, where fields and character positions are numbered. The key start for character `m` in field `n` is defined by `+n.m`, and the key end by `-n.m`. For example, `+5.4,4.3` is equivalent to `sort -k3.2,4.3`. If the character position is omitted, it defaults to zero. `+4nr` mean the same thing: a numeric key, beginning at the start of the fifth field, to be sorted in (descending) order.

Let's try out these options on a sample password file, sorting it by the username, which is found in the first field.

```
$ sort -t: -k1,1 /etc/passwd
```

Sort by username

```
bin:x:1:1:bin:/bin:/sbin/nologin
```

```
chico:x:12501:1000:Chico Marx:/home/chico:/bin/bash
```

```
daemon:x:2:2:daemon:/sbin:/sbin/nologin
```

```
groucho:x:12503:2000:Groucho    Marx:/home/groucho:/bin/sh
gummo:x:12504:3000:Gummo      Marx:/home/gummo:/usr/local/bin/ksh93
harpo:x:12502:1000:Harpo     Marx:/home/harpo:/bin/ksh
root:x:0:0:root:/root:/bin/bash
zeppo:x:12505:1000:Zeppo     Marx:/home/zeppo:/bin/zsh
```

For more control, add a modifier letter in the field selector to define the type of data in the field and the sort the password file by descending UID:

```
$ sort -t: -k3nr /etc/passwd           Sort by descending UID
```

```
zeppo:x:12505:1000:Zeppo     Marx:/home/zeppo:/bin/zsh
gummo:x:12504:3000:Gummo     Marx:/home/gummo:/usr/local/bin/ksh93
groucho:x:12503:2000:Groucho  Marx:/home/groucho:/bin/sh
harpo:x:12502:1000:Harpo     Marx:/home/harpo:/bin/ksh
chico:x:12501:1000:Chico     Marx:/home/chico:/bin/bash
daemon:x:2:2:daemon:/sbin:/sbin/nologin
bin:x:1:1:bin:/bin:/sbin/nologin
root:x:0:0:root:/root:/bin/bash
```

A more precise field specification would have been `-k3nr,3` (that is, from the start of field three, numerically to the end of field three), or `-k3,3nr`, or even `-k3,3 -n -r`, but `sort` stops collecting a number at the first nondigit, so `-k3,3nr` is the correct specification.

In our password file example, three users have a common GID in field 4, so we could sort first by GID, and then by UID:

```
$ sort -t: -k4n -k3n /etc/passwd       Sort by GID and UID
```

```
root:x:0:0:root:/root:/bin/bash
bin:x:1:1:bin:/bin:/sbin/nologin
daemon:x:2:2:daemon:/sbin:/sbin/nologin
```

```

chico:x:12501:1000:Chico    Marx:/home/chico:/bin/bash
harpo:x:12502:1000:Harpo   Marx:/home/harpo:/bin/ksh
zeppo:x:12505:1000:Zeppo   Marx:/home/zeppo:/bin/zsh
groucho:x:12503:2000:Groucho    Marx:/home/groucho:/bin/sh
gummo:x:12504:3000:Gummo    Marx:/home/gummo:/usr/local/bin/ksh93

```

The useful `-u` option asks `sort` to output only unique records, where *unique* means that their sort-key fields differ elsewhere. Reusing the password file one last time, we find:

```

$ sort -t: -k4n -u /etc/passwd           Sort by unique GID

root:x:0:0:root:/root:/bin/bash
bin:x:1:1:bin:/bin:/sbin/nologin
daemon:x:2:2:daemon:/sbin:/sbin/nologin
chico:x:12501:1000:Chico    Marx:/home/chico:/bin/bash
groucho:x:12503:2000:Groucho    Marx:/home/groucho:/bin/sh
gummo:x:12504:3000:Gummo    Marx:/home/gummo:/usr/local/bin/ksh93

```

Notice that the output is shorter: three users are in group 1000, but only one of them was output. We show records later in Section 4.2 .

4.1.3. Sorting Text Blocks

Sometimes you need to sort data composed of multiline records. A good example is an address list, which has one or more blank lines between addresses. For data like this, there is no constant sort-key position that could help out by supplying some extra markup. Here's a simple example:

```

$ cat my-friends           Show address file

# SORTKEY: Schloß, Hans Jürgen

Hans Jürgen Schloß

Unter den Linden 78

```


D-10117 Berlin

Germany

SORTKEY: Jones, Adrian

Adrian Jones

371 Montgomery Park Road

Henley-on-Thames RG9 4AJ

UK

SORTKEY: Brown, Kim

Kim Brown

1841 S Main Street

Westchester, NY 10502

USA

The sorting trick is to use the ability of *awk* to handle more-general record separators to recognize paragraphs. The line breaks inside each address with an otherwise unused character, such as an unprintable control character, break with a newline. *sort* then sees lines that look like this:

```
# SORTKEY: Schloß, Hans Jürgen^ZHans Jürgen Schloß^ZUnter den Linden
```

```
# SORTKEY: Jones, Adrian^ZAdrian Jones^Z371 Montgomery Park Road^Z..
```

```
# SORTKEY: Brown, Kim^ZKim Brown^Z1841 S Main Street^Z...
```

Here, `^z` is a Ctrl-Z character. A filter step downstream from *sort* restores the line breaks and paragraph breaks easily removed, if desired, with *grep*. The entire pipeline looks like this:

```
cat my-friends | Pipe in addresses
  awk -v RS="" { gsub("\n", "^Z"); print }' | Convert addresses
```

```

sort -f | Sort address b
awk -v ORS="\n\n" '{ gsub("^Z", "\n"); print }' | Restore line s
grep -v '# SORTKEY' Remove markup

```

The `gsub()` function performs "global substitutions." It is similar to the `s/x/y/g` construct in `sed`. The `RS` Separator. Normally, input records are separated by newlines, making each line a separate record. Using `RS` records are separated by blank lines; i.e., each block or "paragraph" of text forms a separate record. This is data. Finally, `ORS` is the Output Record Separator; each output record printed with `print` is terminated with normally a single newline; setting it here to `"\n\n"` preserves the input format with blank lines separating 1 constructs may be found in Chapter 9.)

The output of this pipeline on our address file is:

Kim Brown

1841 S Main Street

Westchester, NY 10502

USA

Adrian Jones

371 Montgomery Park Road

Henley-on-Thames RG9 4AJ

UK

Hans Jürgen Schloß

Unter den Linden 78

D-10117 Berlin

Germany

The beauty of this approach is that we can easily include additional keys in each address that can be used for example, an extra markup line of the form:

```
# COUNTRY: UK
```

in each address, and an additional pipeline stage of `grep '# COUNTRY: UK'` just before the `sort`, would let addresses for further processing.

You could, of course, go overboard and use XML markup to identify the parts of the address in excruciating

```
<address>
  <personalname>Hans Jürgen</personalname>
  <familyname>Schloß</familyname><br/>
  <streetname>Unter den Linden</streetname>
  <streetnumber>78</streetnumber><br/>
  <postalcode>D-10117</postalcode>
  <city>Berlin</city><br/>
  <country>Germany</country>
</address>
```

With fancier data-processing filters, you could then please your post office by presorting your mail by country. Minimal markup and simple pipeline are often good enough to get the job done.

4.1.4. Sort Efficiency

The obvious way to sort data requires comparing all pairs of items to see which comes first, and leads to algorithms like *insertion sort*. These quick-and-dirty algorithms are fine for small amounts of data, but they certainly aren't for large amounts, because their work to sort n records grows like n^2 . This is quite different from almost all of the algorithms in this book: they read a record, process it, and output it, so their execution time is directly proportional to the number of records.

Fortunately, the sorting problem has had lots of attention in the computing community, and good sorting algorithms have been developed. Their average complexity goes like $n^{3/2}$ (*shellsort*), $n \log n$ (*heapsort*, *mergesort*, and *quicksort*), and for restricted cases like *distribution sort*. The Unix `sort` command implementation has received extensive study and optimization, and will do the job efficiently, and almost certainly better than you can do yourself without learning a lot more.

4.1.5. Sort Stability

An important question about sorting algorithms is whether or not they are *stable*: that is, is the input order the output? A stable sort may be desirable when records are sorted by multiple keys, or more than once in a row. Some applications require that *sort* be stable, and most implementations are not, as this example shows:

```
$ sort -t_ -k1,1 -k2,2 << EOF          Sort four lines by first two
> one_two
> one_two_three
> one_two_four
> one_two_five
> EOF

one_two
one_two_five
one_two_four
one_two_three
```

The sort fields are identical in each record, but the output differs from the input, so *sort* is not stable. Fortunately, a new implementation in the *coreutils* package^[1] remedies that deficiency via the *-stable* option: its output for the input.

^[1] Available at <ftp://ftp.gnu.org/gnu/coreutils/>.

4.1.6. Sort Wrap-Up

sort certainly ranks in the top ten Unix commands: learn it well because you'll use it often. More details on *sort* are in the sidebar near the start of this chapter, but consult the manual pages for *sort* (1) for the complete story on *sort*, which is standardized by POSIX, so it should be available on every computer that you are likely to use.

4.2. Removing Duplicates

It is sometimes useful to remove consecutive duplicate records from a data stream. We showed in Section 4.1 that `sort -u` would do that job, but we also saw that the elimination is based on matching *keys* rather than matching *records*. The `uniq` command provides another way to filter data: it is frequently used in a pipeline to eliminate duplicate records downstream from a sort operation:

```
sort ... | uniq | ...
```

`uniq` has three useful options that find frequent application. The `-c` option prefixes each output line with a count of the number of times that it occurred, and we will use it in the word-frequency filter in Example 5 in Chapter 5. The `-d` option shows only lines that are duplicated, and the `-u` option shows just the nonduplicate lines. Here are some examples:

```
$ cat latin-numbers
```

Show the test file

```
tres
```

```
unus
```

```
duo
```

```
tres
```

```
duo
```

```
tres
```

```
$ sort latin-numbers | uniq
```

Show unique sorted records

```
duo
```

```
tres
```

```
unus
```

```
$ sort latin-numbers | uniq -c           Count unique sorted records
  2 duo
  3 tres
  1 unus
```

```
$ sort latin-numbers | uniq -d           Show only duplicate records
duo
tres
```

```
$ sort latin-numbers | uniq -u           Show only nonduplicate records
unus
```

uniq is sometimes a useful complement to the *diff* utility for figuring out the differences between two similar data streams: dictionary word lists, pathnames in mirrored directory trees, telephone books, and so on. Most implementations have other options that you can find described in the manual pages for *uniq* (1), but their use is rare. Like *sort*, *uniq* is standardized by POSIX, so you can use it everywhere.

< Day Day Up >

4.3. Reformatting Paragraphs

Most powerful text editors provide commands that make it easy to reformat paragraphs by changing line by line to a width that is comfortable for a human to read; we used such commands a lot in writing this book. Sometimes you can use `fmt` in a data stream in a shell script, or inside an editor that lacks a reformatting command but does have a shell escape like `ESC-o` you need. Although POSIX makes no mention of `fmt`, you can find it on every current flavor of Unix; if your system lacks `fmt`, simply install the GNU `coreutils` package.

Although some implementations of `fmt` have more options, only two find frequent use: `-s` means split long lines to make longer ones, and `-w n` sets the output line width to `n` characters (default: usually about 75 or so). Here's `fmt` reformatting chunks of a spelling dictionary that has just one word per line:

```
$ sed -n -e 9991,10010p /usr/dict/words | fmt -w 20          Reformat 20 dict
```

```
Graff graft graham grail grain grainy grammar grammarian grammatic
granary grand grandchild grandchildren granddaughter grandeur grandfath
grandiloquent grandiose grandma grandmother
```

```
$ sed -n -e 9995,10004p /usr/dict/words | fmt -w 30        Reformat 10 words
```

```
grain grainy grammar
grammarian grammatic
granary grand grandchild
grandchildren granddaughter
```

If your system does not have `/usr/dict/words`, then it probably has an equivalent file named `/usr/share/dict/words` or `/usr/share/lib/dict/words`.

The split-only option, `-s`, is helpful in wrapping long lines while leaving short lines intact, and thus minimizing the original version:

```
$ fmt -s -w 10 << END_OF_DATA          Reformat long lines
```

```
> one two three four five
> six
> seven
> eight
> END_OF_DATA
```

```
one two
```

```
three
```

```
four five
```

```
six
```

```
seven
```

```
eight
```

You might expect that you could split an input stream into one word per line with `fmt -w` breaks entirely with a large width. Unfortunately, `fmt` implementations vary in behavior:

- Older versions of `fmt` lack the `-w` option; they use `-n` to specify an `n`-character width.
- All reject a zero width, but accept `-w 1` or `-1`.
- All preserve leading space.
- Some preserve lines that look like mail headers.
- Some preserve lines beginning with a dot (*troff* typesetter commands).
- Most limit the width. We found peculiar upper bounds of 1021 (Solaris), 2048 (HP/IRIX), 8189 (OSF/1 4.0), 12285 (OSF/1 5.1), and 2147483647 (largest 32-bit signed integer) (GNU/Linux, and Mac OS).
- The NetBSD and OpenBSD versions of `fmt` have a different command-line syntax, and require a buffer to hold the output line, since they give an `out of memory` diagnostic for large widths.
- IRIX `fmt` is found in `/usr/sbin`, a directory that is unlikely to be in your search path.

- HP/UX before version 11.0 did not have *fmt* .

These variations make it difficult to use *fmt* in portable scripts, or for complex reformatti.



< Day Day Up >

4.4. Counting Lines, Words, and Characters

We have used the word-count utility, `wc`, a few times before. It is probably one of the oldest, and simplest, in the Unix toolbox, and POSIX standardizes it. By default, `wc` outputs a one-line report of the number of lines and bytes:

```
$ echo This is a test of the emergency broadcast system | wc          Report
      1          9         49
```

Request a subset of those results with the `-c` (bytes), `-l` (lines), and `-w` (words) options:

```
$ echo Testing one two three | wc -c          Count bytes
22
```

```
$ echo Testing one two three | wc -l          Count lines
1
```

```
$ echo Testing one two three | wc -w          Count words
4
```

The `-c` option originally stood for *character count*, but with multibyte character-set encodings, such as UTF-8, modern systems, bytes are no longer synonymous with characters, so POSIX introduced the `-m` option to count multibyte characters. For 8-bit character data, it is the same as `-c`.

Although `wc` is most commonly used with input from a pipeline, it also accepts command-line file arguments, producing a one-line report for each, followed by a summary report:

```
$ wc /etc/passwd /etc/group          Count data in two files
 26      68    1631 /etc/passwd
```

```
10376  10376 160082 /etc/group
```

```
10402  10444 161713 total
```

Modern versions of *wc* are locale-aware: set the environment variable `LC_CTYPE` to the desired locale to influence its interpretation of byte sequences as characters and word separators.

In Chapter 5, we will develop a related tool, *wf*, to report the frequency of occurrence of each word.



4.5. Printing

Compared to computers, printers are slow devices, and because they are commonly shared, it is generally unwise to send jobs directly to them. Instead, most operating systems provide commands to send requests to a print daemon, which handles printer and queue management. Print commands can be handled quickly because they run in the background when the needed resources are available.

^[2] A daemon (pronounced *dee-mon*) is a long-running process that provides a service, such as accounting, file access, login, or time of day.

Printing support in Unix evolved into two camps with differing commands but equivalent functionality, as summarized in Table 4-2. Commercial Unix systems and GNU/Linux usually support both camps, whereas BSD systems offer only the POSIX-compliant *lp* command.

Table 4-2. Printing commands

Berkeley	System V	POSIX
<i>lpr</i>	<i>lp</i>	Send files to print
<i>lprm</i>	<i>cancel</i>	Remove files from queue
<i>lpq</i>	<i>lpstat</i>	Report queue status

Here is an example of their use, first with the Berkeley style:

```
$ lpr -Plcb102 sample.ps           Send PostScript file to printer
```

```
$ lpq -Plcb102                     Ask for print queue status
```

```
lcb102 is ready and printing
```

```
Rank   Owner   Job     File(s)      Total Size
-----
active jones   81352   sample.ps    122888346 bytes
```



```
$ lprm -Plcb102 81352
```

Stop the presses! Kill that

and then with the System V style:

```
$ lp -d lcb102 sample.ps
```

Send PostScript file to pr

```
request id is lcb102-81355 (1 file(s))
```

```
$ lpstat -t lcb102
```

Ask for print queue status

```
printer lcb102 now printing lcb102-81355
```

```
$ cancel lcb102-81355
```

Whoops! Don't print that job

lp and *lpr* can, of course, read input from standard input instead of from command-line files, so they are commonly used as part of a pipeline.

System management can make a particular single queue the system default so that queue names need not be the system default. Individual users can set an environment variable, `PRINTER` (Berkeley) or `LPDEST` (System V) to set their personal default printer.

Print queue names are site-specific: a small site might just name the queue `printer`, and make it the default. Larger sites might pick names that reflect location, such as a building abbreviation and room number, or that identify particular printer capabilities, such as `bw` for a black-and-white printer and `color` for the expensive one.

Unfortunately, with modern networked intelligent printers, the *lprm*, *cancel*, *lpq*, and *lpstat* commands are not what they once were: print jobs arrive quickly at the printer and appear to the printer daemon to have been printed. Jobs are deleted from the print queue, even though the printer may still be holding them in memory or in a filesystem. Jobs are still being processed. At that point, the only recourse is to use the printer's control panel to cancel an unprinted job.

4.5.1. Evolution of Printing Technology

Printer technology has changed a lot since Unix was first developed. The industry has moved from large in electric typewriters that formed characters by hammering a ribbon and paper against a metal character shape matrix, inkjet, and laser printers that make characters from tiny dots.

Advances in microprocessors allowed the implementation inside the printer of simple command languages like the Printer Command Language (PCL) and HP Graphics Language (HPGL), and complete programming languages like PostScript.

PostScript. Adobe Portable Document Format (PDF) is a descendant of PostScript that is more compact, but PDF offers additional features like color transparency, digital signatures, document-access control, encrypted compression, and page independence. That last feature allows high-performance printers to rasterize pages and viewers to quickly display any requested page.

The newest generation of devices combines printing, copying, and scanning into a single system with a disk access, support for multiple page-description languages and graphics file formats, and, in at least one case, an embedded operating system.

Unfortunately, Unix printing software has not adapted rapidly enough to these improvements in printing technology. Level support for access to many features of newer printers remains poor. Two notable software projects address this situation: Common UNIX Printing System^[3] (*CUPS*), and *lpr* next generation^[4] (*LPRng*). Many large Unix systems use the other; both provide familiar Unix printing commands, but with a lot more options. Both fully support PostScript and PDF files: when necessary, they use the Aladdin or GNU *ghostscript* interpreter to convert such files to a format supported by less-capable printers. *CUPS* also supports printing of assorted graphics image file formats, and *n*-up printing of reduced page images on a single sheet.

^[3] Available at <http://www.cups.org/> and documented in a book listed in the Chapter 16.

^[4] Available at <http://www.lprng.org/>.

4.5.2. Other Printing Software

Despite its name, the venerable *pr* command does not print files, but rather, filters data in preparation for printing. In the case of a file, *pr* produces a page header timestamped with the file's modification time, or if input is from a pipe, with the filename (empty for piped input) and a page number, with a fixed number (66) of lines per page.

```
pr file(s) | lp
```

would print nice listings. However, that simplicity has not worked since the old mechanical printers of the 1950s, where font sizes and line spacing vary between printers, and multiple paper sizes are in common use.

pr

Usage

```
pr [ options ] [ file(s) ]
```

Purpose

Paginate text files for printing.

Major options

-c n

Produce *n* -column output. This option can be abbreviated to *-n* (e.g., *-4* instead of *-c4*).

-f

Prefix each page header after the first with an ASCII formfeed character. This option is called *-F* on NetBSD, and Mac OS X. OpenBSD recognizes both options. POSIX has both, but assigns them slightly different meanings.

-h althdr

Use the string *althdr* to replace the filename in the page header.

-l n

Produce *n* -line pages. Some implementations include page header and trailer lines in the count, while others do not.

-o n

Offset output lines with *n* spaces.

-t

Suppress page headers.

`-w n`

Produce lines of at most n characters. For single-column output, wrap longer lines onto additional lines as needed; otherwise, for multicolumn output, truncate long lines to fit.

Behavior

`pr` reads the specified files, or standard input if no files are given, and writes the paginated data on standard output.

Caveats

`pr` implementations vary considerably in supported options and output formatting; the GNU `coreutils` provides a way to get consistent behavior on all systems.

Instead, you generally have to experiment with setting the output page length with the `-l` option, and often the `-w` option and a text offset with the `-o` option. It is also essential to add the `-f` option (`-F` on some systems) to formfeed control character at the start of every page header after the first, to guarantee that each header starts on a new page. The reality is that you generally have to use something like this:

```
pr -f -l60 -o10 -w65 file(s) | lp
```

If you use a different printer later, you may need to change those numeric parameters. This makes it hard to write portable shell scripts.

There is one feature of `pr` that is often convenient: the `-c n` option requests n -column output. If you combine this with the `-t` option to omit the page headers, you can produce nice multicolumn listings, such as this example, which formats the words in the file `/usr/dict/words`:

```
$ sed -n -e 19000,19025p /usr/dict/words | pr -c5 -t
```

reproach	repugnant	request	reredos	resemblant
reptile	repulsion	require	rerouted	resemble
reptilian	repulsive	requisite	rerouting	resent
republic	reputation	requisition	rescind	resentful

```

republican    repute        required      rescue        reserpine
repudiate

```

If the column width is too small, *pr* silently truncates data to prevent column overlap. We can format the same (truncated) columns like this:

```
$ sed -n -e 19000,19025p /usr/dict/words | pr -c10 -t
```

```

reproa republ repugn reputa requir requit rerout rescue resemb resent
reptil republ repuls repute requis reredo rescin resemb resent reserp
reptil repudi repuls reques requis rerout

```

pr has a lot of options, and historically, there was considerable variation among Unix systems in those options, format and number of lines per page. We recommend using the version from the GNU *coreutils* package, since it is available everywhere, and more options than most other versions. Consult the manual pages for *pr* (1) for the details.

Although some PostScript printers accept plain text, many do not. Typesetting systems like TEX and *troff* convert plain text documents into PostScript and/or PDF page images. If you have just a plain text file, how do you print it? *pr* does not invoke suitable filters to do the conversion for you, but you then do not have any control over its appearance. On Linux, you can use to-PostScript filters like *a2ps*,^[5] *lptops*,^[6] or on Sun Solaris only, *mp*. Use them like this:

^[5] Available at <ftp://ftp.gnu.org/gnu/a2ps/>.

^[6] Available at <http://www.math.utah.edu/pub/lptops/>.

```

a2ps file > file.ps           Make a PostScript listing of file
a2ps file | lp                Print a PostScript listing of file

lptops file > file.ps         Make a PostScript listing of file
lptops file | lp              Print a PostScript listing of file

mp file > file.ps             Make a PostScript listing of file
mp file | lp                  Print a PostScript listing of file

```

All three have command-line options to choose the font, specify the typesize, supply or suppress page head, and multicolumn output.

BSD, IBM AIX, and Sun Solaris systems have *vgrind*,^[7] which filters files in a variety of programming languages into *troff* input, with comments in italics, keywords in bold, and the current function noted in the margin; *troff* then produces PostScript output. A derivative called *tgrind*^[8] does a similar job, but with more font choices, line numbering, and support for many more programming languages. *tgrind* produces TEX input that readily leads to PostScript output. Figure 4-1 shows a sample of its output. Both programs are easy to use for printing of typeset program listings:

^[7] Available at <http://www.math.utah.edu/pub/vgrind/> .

^[8] Available at <http://www.math.utah.edu/pub/tgrind/> .

```
$ tgrind -p hello.c                Typeset and print hello.c

$ tgrind -i 1 -fn Bookman -p hello.c  Print the listing shown in

$ vgrind hello.c | lp                Typeset and print hello.c
```

Figure 4-1. *tgrind* typesetting of a famous C program

(hello.c)

```

1 #include <stdio.h>
2 #include <stdlib.h>
3
4 const char *hello(void);
5 const char *world(void);
6
7 int
8 main(void)                                main
9 {
10     (void)printf("%s, %s\n", hello(), world());
11     return (EXIT_SUCCESS); /* use ISO Standard C exit code */
12 }
13
14 const char *
15 hello(void)                                hello
16 {
17     return ("hello");
18 }
19
20 const char *
21 world(void)                                world
22 {
23     return ("world");
24 }

```

Linenumber Index		
hello	15	main 8 world 21

4.6. Extracting the First and Last Lines

It is sometimes useful to extract just a few lines from a text file—most commonly, lines near the beginning. For example, the chapter titles for the XML files for this book are all visible in the first half-dozen lines of each end of job-log files provides a summary of recent activity.

Both of these operations are easy. You can display the first n records of standard input or each of a list of c with any of these:

```
head -n n      [ file(s) ]
```

```
head -n       [ file(s) ]
```

```
awk 'FNR <= n' [ file(s) ]
```

```
sed -e nq     [ file(s) ]
```

```
sed nq       [ file(s) ]
```

POSIX requires a *head* option of `-n 3` instead of `-3`, but every implementation that we tested accepts both.

When there is only a single edit command, *sed* allows the `-e` option to be omitted.

It is *not* an error if there are fewer than n lines to display.

The last n lines can be displayed like this:

```
tail -n n     [ file ]
```

```
tail -n      [ file ]
```

As with *head*, POSIX specifies only the first form, but both are accepted on all of our systems.

Curiously, although *head* handles multiple files on the command line, traditional and POSIX *tail* do not. Till all modern versions of *tail*.

In an interactive shell session, it is sometimes desirable to monitor output to a file, such as a log file, while the *-f* option asks *tail* to show the specified number of lines at the end of the file, and then to go into an endless loop, sleeping a second before waking up and checking for more output to display. With *-f*, *tail* terminates only when you type Ctrl-C:

```
$ tail -n 25 -f /var/log/messages           Watch the growth of the sys
...
^C                                           Ctrl-C stops tail
```

Since *tail* does not terminate on its own with the *-f* option, that option is unlikely to be of use in shell scripts.

There are no short and simple alternatives to *tail* with *awk* or *sed*, because the job requires maintaining a history of records.

Although we do not illustrate them in detail here, there are a few other commands that we use in small examples in this book, and that are worth adding to your toolbox:

- *dd* copies data in blocks of user-specified size and number. It also has some limited ability to convert uppercase and lowercase, and between ASCII and EBCDIC. For character-set conversions, however, the modern standard, *iconv* command for converting files from one code set to another has much more flexibility.
- *file* matches a few selected leading bytes of the contents of each of its argument files against a pattern database and produces a brief one-line report on standard output of its conclusions for each of them. Most vendor-provided implementations recognize 100 or so types of files, but are unable to classify binary executables and object files from other operating systems. There is a much better open-source version,^[9] however, that has many contributors: it can recognize more than 1200 file types, including many from non-Unix operating systems.

^[9] Available at <ftp://ftp.astron.com/pub/file/>.

- *od*, the octal dump command, prints byte streams in ASCII, octal, and hexadecimal. Command-line options specify the number of bytes read and can select the output format.
- *strings* searches its input for sequences of four or more printable characters ending with a newline or other non-printable character and prints them on standard output. It is often useful for peeking inside binary files, such as compiled programs and executables. Software, image, and sound files sometimes contain useful textual data near the beginning, and GNU

handy `-c` option to limit the output to a specified number of characters:

```
$ strings -a horne01.jpg | head -c 256 | fmt -w 65 Examine astronoi
```

```
JFIF Photoshop 3.0 8BIM Comet Hale-Bopp shows delicate  
filaments in it's blue ion tail in this exposure made Monday  
morning 3/17/97 using 12.5 inch F/4 Newtonian reflecting  
telescope. The 15 minute exposure was made on Fujicolor SG-800  
Plus film. 8BIM 8BI
```



< Day Day Up >

4.7. Summary

This chapter covered about 30 utilities for processing text files. Collectively, they are a powerful set of tools for writing shell scripts. The most important, and most complex, is *sort*. The *fmt*, *uniq*, and *wc* commands are often just the tools you need in a pipeline to simplify or summarize data. When you need to get a quick overview of a collection of unfamiliar files, *file*, *head*, *strings*, and *tail* are often a better choice than visiting each file in turn with a text editor. *a2ps*, *tgrind*, and *vgrind* can make listings of your programs, including shell scripts, easier to read.

Chapter 5. Pipelines Can Do Amazing Things

In this chapter, we solve several relatively simple text processing jobs. What's interesting about all the examples here is that they are scripts built from simple pipelines: chains of one command hooked into another. Yet each one accomplishes a significant task.

When you tackle a text processing problem in Unix, it is important to keep the Unix tool philosophy in mind: ask yourself how the problem can be broken down into simpler jobs, for each of which there is already an existing tool, or for which you can readily supply one with a few lines of a shell program or with a scripting language.

5.1. Extracting Data from Structured Text Files

Most administrative files in Unix are simple flat text files that you can edit, print, and read without any special tools. Many of them reside in the standard directory, `/etc`. Common examples are the password and group files (`passwd` and `group`), the filesystem mount table (`fstab` or `vfstab`), the hosts file (`hosts`), the default shell startup file (`/etc/passwd`), the system startup and shutdown shell scripts, stored in the subdirectory trees `rc0.d`, `rc1.d`, and so on, though there may be other directories as well.)

File formats are traditionally documented in Section 5 of the Unix manual, so the command `man 5 passwd` provides information about the structure of `/etc/passwd`.^[1]

^[1] On some systems, file formats are in Section 7; thus, you might need to use `man 7 passwd` instead.

Despite its name, the password file must always be publicly readable. Perhaps it should have been called `etc/passwd` because it contains basic information about every user account on the system, packed together in one line per account separated by colons. We described the file's format in Section 3.3.1. Here are some typical entries:

```
jones:*:32713:899:Adrian W. Jones/OSD211/555-0123:/home/jones:/bin/ksh
dorothy:*:123:30:Dorothy Gale/KNS321/555-0044:/home/dorothy:/bin/bash
toto:*:1027:18:Toto Gale/KNS322/555-0045:/home/toto:/bin/tcsh
ben:*:301:10:Ben Franklin/OSD212/555-0022:/home/ben:/bin/bash
jhancock:*:1457:57:John Hancock/SIG435/555-0099:/home/jhancock:/bin/ksh
betsy:*:110:20:Betsy Ross/BMD17/555-0033:/home/betsy:/bin/ksh
tj:*:60:33:Thomas Jefferson/BMD19/555-0095:/home/tj:/bin/bash
george:*:692:42:George Washington/BST999/555-0001:/home/george:/bin/ksh
```

To review, the seven fields of a password-file entry are:

1. The username
2. The encrypted password, or an indicator that the password is stored in a separate file

3. The numeric user ID
4. The numeric group ID
5. The user's personal name, and possibly other relevant data (office number, telephone number, and so
6. The home directory
7. The login shell

All but one of these fields have significance to various Unix programs. The one that does not is the fifth, which holds user information that is relevant only to local humans. Historically, it was called the *gecos* field, because of its use in the 1970s at Bell Labs when Unix systems needed to communicate with other computers running the GeneComprehensive Operating System, and some extra information about the Unix user was required for that system. Modern sites use it just to record the personal name, so we simply call it the name field.

For the purposes of this example, we assume that the local site records extra information in the name field: an office number identifier (OSD211 in the first sample entry), and a telephone number (555-0123), separated from the name by slashes.

One obvious useful thing that we can do with such a file is to write some software to create an office directory from it. The only file, `/etc/passwd`, needs to be kept up-to-date, and derived files can be created when the main file is updated, or more sensibly, by a *cron* job that runs at suitable intervals. (We will discuss *cron* in Section 13.6.4.)

For our first attempt, we make the office directory a simple text file, with entries like this:

```
Franklin, Ben           ·OSD212·555-0022
Gale, Dorothy          ·KNS321·555-0044
...
```

where `·` represents an ASCII tab character. We put the personal name in conventional directory order (family name first), padding the name field with spaces to a convenient fixed length. We prefix the office number and telephone number with a tab character to preserve some useful structure that other tools can exploit.

Scripting languages, such as *awk*, were designed to make such tasks easy because they provide automated concatenation and splitting of input records into fields, so we could write the conversion job entirely in such a language. In this section, we will show how to achieve the same thing with other Unix tools.

For each password file line, we need to extract field five, split it into three subfields, rearrange the names in the subfields, and then write an office directory line to a sorting process.

awk and *cut* are convenient tools for field extraction:


```
... | awk -F: '{ print $5 }' | ...
... | cut -d: -f5 | ...
```

There is a slight complication in that we have two field-processing tasks that we want to keep separate for ; need to combine their output to make a directory entry. The *join* command is just what we need: it expects each ordered by a common unique key value, and joins lines sharing a common key into a single output line over which fields are output.

Since our directory entries contain three fields, to use *join* we need to create three intermediate files containing separated pairs *key:person* , *key:office* , and *key:telephone* , one pair per line. These can all be temporary files derived automatically from the password file.

What key do we use? It just needs to be unique, so it could be the record number in the original password file; it can also be the username, since we know that usernames are unique in the password file and they make sense to humans than numbers do. Later, if we decide to augment our directory with additional information, such as job titles, we can create another nontemporary file with the pair *key:jobtitle* and add it to the processing stages.

Instead of hardcoding input and output filenames into our program, it is more flexible to write the program to read standard input and write standard output. For commands that are used infrequently, it is advisable to use descriptive, rather than short and cryptic, names, so we start our shell program like this:

```
#!/bin/sh

# Filter an input stream formatted like /etc/passwd,
# and output an office directory derived from that data.

#

# Usage:
#     passwd-to-directory < /etc/passwd > office-directory-file
#     ypcat passwd | passwd-to-directory > office-directory-file
#     niscat passwd.org_dir | passwd-to-directory > office-directory-
```

Since the password file is publicly readable, any data derived from it is public as well, so there is no real need to restrict access to our program's intermediate files. However, because all of us at times have to deal with sensitive data, it is a good programming habit of allowing file access only to those users or processes that need it. We therefore reset the permissions (see Section B.6.1.3 in Appendix B) as the first action in our program:


```
umask 077
```

Restrict temporary file access

For accountability and debugging, it is helpful to have some commonality in temporary filenames, and to associate them with the current directory: we name them with the prefix `/tmp/pd..` To guard against name collisions if multiple instances of our program are running at the same time, we also need the names to be unique: the process number, available in the shell variable `$$`, provides a distinguishing suffix. (This use of `$$` is described in more detail in Chapter 10.) We use these shell variables to represent our temporary files:

```
PERSON=/tmp/pd.key.person.$$
```

Unique temporary filenames

```
OFFICE=/tmp/pd.key.office.$$
```

```
TELEPHONE=/tmp/pd.key.telephone.$$
```

```
USER=/tmp/pd.key.user.$$
```

When the job terminates, either normally or abnormally, we want the temporary files to be deleted, so we use the `trap` command:

```
trap "exit 1" HUP INT PIPE QUIT TERM
```

```
trap "rm -f $PERSON $OFFICE $TELEPHONE $USER" EXIT
```

During development, we can just comment out the second *trap*, preserving temporary files for subsequent inspection. The *trap* command is described in Section 13.3.2. For now, it's enough to understand that when the script exits, it automatically runs *rm* with the given arguments.)

We need fields one and five repeatedly, and once we have them, we don't require the input stream from standard input, so we begin by extracting them into a temporary file:

```
awk -F: '{ print $1 ":" $5 }' > $USER
```

This reads standard input

We make the *key:person* pair file first, with a two-step *sed* program followed by a simple line sort; the *sort* command is discussed in detail in Section 4.1.

```
sed -e 's=/.*= = ' \
```

```
-e 's=^\[^\:]*\):\[^\:]*\)\ \([^\ ]*\)=\1:\3, \2=' <$USER | sort >$PERSON
```

The script uses `=` as the separator character for *sed*'s *s* command, since both slashes and colons appear in the input. The *sed* command edit strips everything from the first slash to the end of the line, reducing a line like this:

```
jones:Adrian W. Jones/OSD211/555-0123          Input line
```

to this:

```
jones:Adrian W. Jones                          Result of first edit
```

The second edit is more complex, matching three subpatterns in the record. The first part, `^\([^:]*\)`, matches the username field (e.g., `jones`). The second part, `\(.*\)` matches text up to a space (e.g., `Adrian W.` for a space character). The last part, `\([^]*\)`, matches the remaining nonspace text in the record (e.g., `OSD211/555-0123`). The replacement text reorders the matches, producing something like `Jones, Adrian W. OSD211/555-0123`. The result of this second edit is the desired reordering:

```
jones:Jones, Adrian W.                        Printed result of second edit
```

Next, we make the `key:office` pair file:

```
sed -e 's=^\([^:]*\):[^/]*/\([^/]*\)/.*$=\1:\2=' < $USER | sort > $OFFICE
```

The result is a list of users and offices:

```
jones:OSD211
```

The `key:telephone` pair file creation is similar: we just need to adjust the match pattern:

```
sed -e 's=^\([^:]*\):[^/]*/[^\s]*/\([^/]*\)=\1:\2=' < $USER | sort > $TELEPHONE
```

At this stage, we have three separate files, each of which is sorted. Each file consists of the key (the username) followed by the particular data (personal name, office, telephone number). The `$PERSON` file's contents look like this:

```
ben:Franklin, Ben
```

```
betsy:Ross, Betsy
```

```
...
```

The `$OFFICE` file has username and office data:

```
ben:OSD212
```

```
betsy:BMD17
```

```
...
```

The `$TELEPHONE` file records usernames and telephone numbers:

```
ben:555-0022
```

```
betsy:555-0033
```

```
...
```

By default, `join` outputs the common key, then the remaining fields of the line from the first file, followed by the remaining fields of the line from the second file. The common key defaults to the first field, but that can be changed with the `-t` option: we don't need that feature here. Normally, spaces separate fields for `join`, but we can change the separator with the `-t` option: we use it as `-t :`.

The join operations are done with a five-stage pipeline, as follows:

1. Combine the personal information and the office location:

```
join -t: $PERSON $OFFICE | ...
```

2. The results of this operation, which become the input to the next stage, look like this:

```
ben:Franklin, Ben:OSD212
```

```
betsy:Ross, Betsy:BMD17
```

```
...
```

3. Add the telephone number:

```
... | join -t: - $TELEPHONE | ...
```

4. The results of this operation, which become the input to the next stage, look like this:

```
ben:Franklin, Ben:OSD212:555-0022
```

```
betsy:Ross, Betsy:BMD17:555-0033
```


...

5. Remove the key (which is the first field), since it's no longer needed. This is most easily done with *cut* says "use fields two through the end," like so:

```
... | cut -d: -f 2- | ...
```

6. The results of this operation, which become the input to the next stage, look like this:

```
Franklin, Ben:OSD212:555-0022
```

```
Ross, Betsy:BMD17:555-0033
```

...

7. Re-sort the data. The data was previously sorted by login name, but now things need to be sorted by phone number. This is done with *sort* :

```
... | sort -t: -k1,1 -k2,2 -k3,3 | ...
```

8. This command uses a colon to separate fields, sorting on fields 1, 2, and 3, in order. The results of this become the input to the next stage, look like this:

```
Franklin, Ben:OSD212:555-0022
```

```
Gale, Dorothy:KNS321:555-0044
```

...

9. Finally, reformat the output, using *awk* 's *printf* statement to separate each field with tab characters. do this is:

```
... | awk -F: '{ printf("%-39s\t%s\t%s\n", $1, $2, $3) }'
```

10. For flexibility and ease of maintenance, formatting should always be left until the end. Up to that point, you have just text strings of arbitrary length.

Here's the complete pipeline:

```
join -t: $PERSON $OFFICE |
```

```

join -t: - $TELEPHONE |
    cut -d: -f 2- |
        sort -t: -k1,1 -k2,2 -k3,3 |
            awk -F: '{ printf("%-39s\t%s\t%s\n", $1, $2, $3) }'

```

The *awk* `printf` statement used here is similar enough to the shell *printf* command that its meaning should first colon-separated field left-adjusted in a 39-character field, followed by a tab, the second field, another tab field. Here are the full results:

```

Franklin, Ben                ·OSD212·555-0022
Gale, Dorothy                ·KNS321·555-0044
Gale, Toto                   ·KNS322·555-0045
Hancock, John                ·SIG435·555-0099
Jefferson, Thomas            ·BMD19·555-0095
Jones, Adrian W.            ·OSD211·555-0123
Ross, Betsy                  ·BMD17·555-0033
Washington, George           ·BST999·555-0001

```

That is all there is to it! Our entire script is slightly more than 20 lines long, excluding comments, with five m steps. We collect it together in one place in Example 5-1 .

Example 5-1. Creating an office directory

```

#!/bin/sh

# Filter an input stream formatted like /etc/passwd,
# and output an office directory derived from that data.
#
# Usage:
#     passwd-to-directory < /etc/passwd > office-directory-file

```

```
#      ypcat passwd | passwd-to-directory > office-directory-file
#      niscat passwd.org_dir | passwd-to-directory > office-directory-

umask 077

PERSON=/tmp/pd.key.person.$$
OFFICE=/tmp/pd.key.office.$$
TELEPHONE=/tmp/pd.key.telephone.$$
USER=/tmp/pd.key.user.$$

trap "exit 1"                                HUP INT PIPE QUIT TERM
trap "rm -f $PERSON $OFFICE $TELEPHONE $USER" EXIT

awk -F: '{ print $1 ":" $5 }' > $USER

sed -e 's=/.*= =' \
    -e 's=^\([^:]*\):(.*\) \([^ ]*\)=\1:\3, \2=' < $USER | sort > $

sed -e 's=^\([^:]*\):[^/]*/\([^/]*\)/*.*$=\1:\2=' < $USER | sort > $

sed -e 's=^\([^:]*\):[^/]*/[^^/]*/\([^/]*\)=\1:\2=' < $USER | sort >

join -t: $PERSON $OFFICE |
```



```

join -t: - $TELEPHONE |
    cut -d: -f 2- |
        sort -t: -k1,1 -k2,2 -k3,3 |
            awk -F: '{ printf("%-39s\t%s\t%s\n", $1, $2, $3) }'
```

The real power of shell scripting shows itself when we want to modify the script to do a slightly different job: the insertion of the job title from a separately maintained *key:jobtitle* file. All that we need to do is modify the script to look something like this:

```

join -t: $PERSON /etc/passwd.job-title |                               Extra join with job
    join -t: - $OFFICE |
        join -t: - $TELEPHONE |
            cut -d: -f 2- |
                sort -t: -k1,1 -k3,3 -k4,4 |                               Modify sort command
                    awk -F: '{ printf("%-39s\t%-23s\t%s\t%s\n",
                        $1, $2, $3, $4) }'                               And formatting command
```

The total cost for the extra directory field is one more *join*, a change in the *sort* fields, and a small tweak in the formatting command.

Because we were careful to preserve special field delimiters in our output, we can trivially prepare useful alternative directories like this:

```

passwd-to-directory < /etc/passwd | sort -t'·' -k2,2 > dir.by-office
passwd-to-directory < /etc/passwd | sort -t'·' -k3,3 > dir.by-telephone
```

As usual, `·` represents an ASCII tab character.

A critical assumption of our program is that there is a *unique key* for each data record. With that unique key, the key of the data can be maintained in files as *key:value* pairs. Here, the key was a Unix username, but in larger contexts it can be a book number (ISBN), credit card number, employee number, national retirement system number, part number, and so on. Now you know why we get so many numbers assigned to us! You can also see that the

be numbers: they just need to be unique text strings.

A Digression on Databases

Most commercial databases today are constructed as *relational databases* : data is accessible as *key:value* pairs, and join operations are used to construct multicolumn tables to provide views of selected subsets of data. Relational databases were first proposed in 1970 by E. F. Codd,^[2] who actively promoted them, despite initial database industry opposition that they could not be implemented efficiently. Fortunately, clever programmers soon figured out how to solve the efficiency problem. Codd's work is so important that, in 1981 he was given the prestigious ACM Turing Award, the closest thing in computer science to the Nobel Prize.

Today, there are several ISO standards for the *Structured Query Language (SQL)* , making vendor-independent database access possible, and one of the most important SQL operations is `join` . Hundreds of books have been published about SQL; to learn more, pick a general one like *SQL in a Nutshell* .^[3] Our simple office-directory task thus has an important lesson in it about the central concept of modern relational databases, and Unix software tools can be extremely valuable in preparing input for databases, and in processing their output.

^[2] E. F. Codd, *A Relational Model of Data for Large Shared Data Banks* , Communications of the ACM, 13(6) 377-387, June 1970. See also *Relational Database: A Practical Foundation for Productivity* , Communications of the ACM, 25(2) 109-117, February (1972 lecture).

^[3] By Kevin Kline and Daniel Kline, O'Reilly & Associates, 2000, ISBN 1-56592-744-3. See also <http://www.math.utah.edu/pub/tex/bib/sqlbooks.html> for an extensive list of SQL books.

5.2. Structured Data for the Web

The immense popularity of the World Wide Web makes it desirable to be able to present data like the official last section in a form that is a bit fancier than our simple text file.

Web files are mostly written in a markup language called *HyperText Markup Language (HTML)*. This is a specific instance of the *Standard Generalized Markup Language (SGML)*, which has been defined in several documents. The manuscript for this book was written in DocBook/XML, which is also a specific instance of SGML. You can find more information about HTML in *HTML & XHTML: The Definitive Guide* (O'Reilly).^[4]

^[4] In addition to this book (listed in the Bibliography), hundreds of books on SGML and derivatives are listed at <http://www.math.utah.edu/pub/tex/bib/sgml.html> and <http://www.math.utah.edu/pub/tex/bib/sgml2000.html>.

For the purposes of this section, we need only a tiny subset of HTML, which we present here in a small tutorial. If you are familiar with HTML, just skim the next page or two.

Here is a minimal standards-conformant HTML file produced by a useful tool written by one of us.^[5]

^[5] Available at <http://www.math.utah.edu/pub/sgml/>.

```
$ echo Hello, world. | html-pretty

<!-- -*-html-*- -->

<!-- Prettyprinted by html-pretty flex version 1.01 [25-Aug-2001] -->

<!-- on Wed Jan  8 12:12:42 2003 -->

<!-- for Adrian W. Jones (jones@example.com) -->

<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML//EN">

<HTML>

  <HEAD>

    <TITLE>

      <!-- Please supply a descriptive title here -->
```



```

</TITLE>

<!-- Please supply a correct e-mail address here -->

<LINK REV="made" HREF="mailto:jones@example.com">

</HEAD>

<BODY>

    Hello, world.

</BODY>

</HTML>

```

The points to note in this HTML output are:

- HTML comments are enclosed in `<!--` and `-->`.
- Special processor commands are enclosed in `<!>`: here, the `DOCTYPE` command tells an SGML parser and where to find its grammar file.
- Markup is supplied by angle-bracketed words, called *tags*. In HTML, lettercase is *not* significant in tags; normally uppercases tag names for better visibility.
- Markup environments consist of a begin tag, `< NAME >`, and an end tag, `</ NAME >`, and for many tags nested within each other according to rules defined in the HTML grammars.
- An HTML document is structured as an HTML object containing one `HEAD` and one `BODY` object.
- Inside the `HEAD`, a `TITLE` object defines the document title that web browsers display in the window title bar. Also inside the `HEAD`, the `LINK` object generally carries information about the web-page maintainer.
- The visible part of the document that browsers show is the contents of the `BODY`.
- Whitespace is not significant outside of quoted strings, so we can use horizontal and vertical spacing to format the document structure, as the HTML prettyprinter does.
- Everything else is just printable ASCII text, with three exceptions. Literal angle brackets must be replaced by *entities*, that consist of an ampersand, an identifier, and a semicolon: `<` and `>`. Since an ampersand has its own literal *entity* name: `&`. HTML supports a modest repertoire of entities for accented characters in the languages of Western Europe so that we can write, for example, `café` `du bon goû` `t t`

- Although not shown in our minimal example, font style changes are accomplished in HTML with `B` (bold), `I` (italic), `STRONG` (extra bold), and `TT` (typewriter (fixed-width characters)) environments: write `bold phrase .`

To convert our office directory to proper HTML, we need only one more bit of information: how to format a table. A table, which is how an office directory really is and we don't want to force the use of typewriter fonts to get everything to line up in the table.

In HTML 3.0 and later, a table consists of a `TABLE` environment, inside of which are rows, each of them a `TR` environment. Inside each row are cells, called table data, each a `TD` environment. Notice that columns of data receive no special treatment. A column is simply the set of cells taken from the same row position in all of the rows of the table. Happily, you don't need to know the number of rows and columns in advance. The job of the browser or formatter is to collect all of the cells, determine the width of each column, and then format the table with columns just wide enough to hold those widest cells.

For our office directory example, we need just three columns, so our sample entry could be marked up like

```
<TABLE>
```

```
...
```

```
<TR>
```

```
<TD>
```

```
    Jones, Adrian W.
```

```
</TD>
```

```
<TD>
```

```
    555-0123
```

```
</TD>
```

```
<TD>
```

```
    OSD211
```

```
</TD>
```

```
</TR>
```

```
...
```

```
</TABLE>
```

An equivalent, but compact and hard-to-read, encoding might look like this:

```
<TABLE>
    ...
    <TR><TD>Jones, Adrian W.</TD><TD>555-0123</TD><TD>OSD211</TD></TR>
    ...
</TABLE>
```

Because we chose to preserve special field separators in the text version of the office directory, we have to identify the cells in each row. Also, because whitespace is mostly not significant in HTML files (except to be particularly careful about getting tags nicely lined up: if that is needed later, *html-pretty* can do it perfectly. *html-pretty* has three steps:

1. Output the leading boilerplate down to the beginning of the document body.
2. Wrap each directory row in table markup.
3. Output the trailing boilerplate.

We have to make one small change from our minimal example: the `DOCTYPE` command has to be updated to look like this:

```
<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML//EN//3.0">
```

You don't have to memorize this: *html-pretty* has options to produce output in any of the standard HTML `DOCTYPE` commands; just copy a suitable `DOCTYPE` command from its output.

Clearly, most of the work is just writing boilerplate, but that is simple since we can just copy text from the original. The only programmatic step required is the middle one, which we could do with only a couple of lines in *sed*. We can achieve it with even less work using a *sed* stream-editor substitution with two edit commands: one to substitute the field delimiters with `</TD><TD>`, and a following one to wrap the entire line in `<TR><TD>...</TD></TR>`. We take care of accented characters are required in the directory, but we can easily allow for angle brackets and ampersand by adding three initial *sed* steps. We collect the complete program in Example 5-2.

Example 5-2. Converting an office directory to HTML

```
#!/bin/sh
```



```
# Convert a tab-separated value file to grammar-conformant HTML.
```

```
#
```

```
# Usage:
```

```
#   tsv-to-html < infile > outfile
```

```
cat << EOFILE Leading boilerplate
```

```
<!DOCTYPE HTML PUBLIC "-//IETF//DTD HTML//EN//3.0">
```

```
<HTML>
```

```
  <HEAD>
```

```
    <TITLE>
```

```
      Office directory
```

```
    </TITLE>
```

```
    <LINK REV="made" HREF="mailto:$USER@`hostname`">
```

```
  </HEAD>
```

```
  <BODY>
```

```
    <TABLE>
```

```
EOFILE
```

```
sed -e 's=&=\&amp;=g' \ Convert special characters to ent
```

```
-e 's=<=\&lt;=g' \
```

```
-e 's=>=\&gt;=g' \
```

```
-e 's=\t=</TD><TD>=g' \ And supply table markup
```

```
-e 's=^.*$= <TR><TD>&</TD></TR>='
```

```

cat << EOFILE                                Trailing boilerplate

        </TABLE>

    </BODY>

</HTML>

EOFILE

```

The `<<` notation is called a *here document*. It is explained in more detail in Section 7.3.1. Briefly, the shell delimiter following the `<<` (`EOFILE` in this case), does variable and command substitution on the contained standard input to the command.

There is an important point about the script in Example 5-2 it is independent of the number of columns in the input file. It can be used to convert *any* tab-separated value file to HTML. Spreadsheet programs can usually save data in a simple tool can produce correct HTML from spreadsheet data.

We were careful in *tsv-to-html* to maintain the spacing structure of the original office directory, because that is important for further filters downstream. Indeed, *html-pretty* was written precisely for that reason: standardization of HTML output simplifies other HTML tools.

How would we handle conversion of accented characters to HTML entities? We *could* augment the *sed* command like `-e 's=é=é=g'`, but there are about 100 or so entities to cater for, and we are likely to need similar conversions for other kinds of text files to HTML.

It therefore makes sense to delegate that task to a separate program that we can reuse, either as a pipeline stage or as a command in Example 5-2, or as a filter applied later. (This is the "detour to build specialized tools" principle.) This is just a tedious tabulation of substitution commands, and we need one for each of the local text encodings, such as the code pages mentioned in Section B.2 in Appendix B. We don't show such a filter completely here, but a fragment gives the general flavor. For readers who need it, we include the complete program for handling the common characters in the ISO 8859-1 encoding with this book's sample programs. HTML's entity repertoire isn't sufficient for these characters, but since the World Wide Web is moving in the direction of Unicode and XML in place of ASCII, this problem is being solved in a different way, by getting rid of character set limitations.

Example 5-3. Fragment of iso8859-1-to-html program

```

#! /bin/sh

# Convert an input stream containing characters in ISO 8859-1
# encoding from the range 128..255 to HTML equivalents in ASCII.

```

```
# Characters 0..127 are preserved as normal ASCII.
#
# Usage:
#       iso8859-1-to-html infile(s) >outfile
```

```
sed \
    -e 's= =\&nbsp;=g' \
    -e 's=¡=\&iexcl;=g' \
    -e 's=¢=\&cent;=g' \
    -e 's=£=\&pound;=g' \
    ...
    -e 's=ü=\&uuml;=g' \
    -e 's=☐=\&yacute;=g' \
    -e 's=☐=\&thorn;=g' \
    -e 's=ÿ=\&yuml;=g' \
    "$@"
```

Here is a sample of the use of this filter:

```
$ cat danish
```

Show sample Danish text in

```
Øen med åen lå i læ af én halv ,
og én stor , langs den græske kyst.
```

```
$ iso8859-1-to-html danish
```

Convert text to HTML entiti

Øen med åen lå i lå af én halv ,
og én stor Ø, langs den græske kyst.



< Day Day Up >

5.3. Cheating at Word Puzzles

Crossword puzzles give you clues about words, but most of us get stuck when we cannot think of, say, a ten-letter word that begins with a b and has either an x or a z in the seventh position.

Regular-expression pattern matching with *awk* or *grep* is clearly called for, but what files do we search? One good choice is the Unix spelling dictionary, available as `/usr/dict/words`, on many systems. (Other popular locations for this file are `/usr/share/dict/words` and `/usr/share/lib/dict/words`.) This is a simple text file, with one word per line, sorted in lexicographic order. We can easily create other similar-appearing files from any collection of text files, like this:

```
cat file(s) | TR A-Z a-z | tr -c a-z\ ' '\n' | sort -u
```

The second pipeline stage converts uppercase to lowercase, the third replaces nonletters by newlines, and the last sorts the result, keeping only unique lines. The third stage treats apostrophes as letters, since they are used in contractions. Every Unix system has collections of text that can be mined in this way—for example, the formatted manual pages in `/usr/man/cat*/*` and `/usr/local/man/cat*/*`. On one of our systems, they supplied more than 1 million lines of prose and produced a list of about 44,000 unique words. There are also word lists for dozens of languages in various Internet archives.^[6]

^[6] Available at <ftp://ftp.ox.ac.uk/pub/wordlists/>, <ftp://qiclab.scn.rain.com/pub/wordlists/>, ftp://ibiblio.org/pub/docs/books/gutenberg/etext96/pgw*, and <http://www.phreak.org/html/wordlists.shtml>. A search for "word list" in any Internet search engine turns up many more.

Let us assume that we have built up a collection of word lists in this way, and we stored them in a standard place that we can reference from a script. We can then write the program shown in [Example 5-4](#).

Example 5-4. Word puzzle solution helper

```
#!/bin/sh

# Match an egrep(1)-like pattern against a collection of
# word lists.

#
```

```
# Usage:
#      puzzle-help egrep-pattern [word-list-files]

FILES="
    /usr/dict/words
    /usr/share/dict/words
    /usr/share/lib/dict/words
    /usr/local/share/dict/words.biology
    /usr/local/share/dict/words.chemistry
    /usr/local/share/dict/words.general
    /usr/local/share/dict/words.knuth
    /usr/local/share/dict/words.latin
    /usr/local/share/dict/words.manpages
    /usr/local/share/dict/words.mathematics
    /usr/local/share/dict/words.physics
    /usr/local/share/dict/words.roget
    /usr/local/share/dict/words.sciences
    /usr/local/share/dict/words.unix
    /usr/local/share/dict/words.webster
"

pattern="$1"
```



```
egrep -h -i "$pattern" $FILES 2> /dev/null | sort -u -f
```

The `FILES` variable holds the built-in list of word-list files, customized to the local site. The `grep` option `-h` suppresses filenames from the report, the `-i` option ignores lettercase, and we discard the standard error output with `2> /dev/null`, in case any of the word-list files don't exist or they lack the necessary read permission. (This kind of redirection is described in [Section 7.3.2](#).) The final `sort` stage reduces the report to just a list of unique words, ignoring lettercase.

Now we can find the word that we were looking for:

```
$ puzzle-help '^b.....[xz]...$' | fmt
```

```
bamboozled Bamboozler bamboozles bdDenizens bdWheezing Belshazzar
botanizing Brontozoum Bucholzite bulldozing
```

Can you think of an English word with six consonants in a row? Here's some help:

```
$ puzzle-help '[^aeiouy]{6}' /usr/dict/words
```

```
Knightsbridge
```

```
mightn't
```

```
oughtn't
```

If you don't count `y` as a vowel, many more turn up: *encryption*, *klystron*, *porphyry*, *syzygy*, and so on.

We could readily exclude the contractions from the word lists by a final filter step- `egrep -i '^[a-z]+$'`-but there is little harm in leaving them in the word lists.

5.4. Word Lists

From 1983 to 1987, Bell Labs researcher Jon Bentley wrote an interesting column in *Communications of the ACM*. Some of the columns were later collected, with substantial changes, into two books listed in the Appendix. Bentley posed this challenge: write a program to process a text file, and output a list of the n most-frequent words, sorted by descending count. Noted computer scientists Donald Knuth and David Hanson, with interesting and clever literate programs,^[7] each of which took several hours to write. Bentley's original solution was so good that Hanson rephased it this way: Given a text file and an integer n , you are to print the words (and their frequencies of occurrence) that are among the n largest in order of decreasing frequency.

^[7] *Programming Pearls: A Literate Program: A WEB program for common words*, *Comm. ACM* **29** (6), 471-483, June (1986). *Programming: Printing Common Words*, **30** (7), 594-599, July (1987). Knuth's paper is also reprinted in his book *Literate Programming*, Center for the Study of Language and Information, 1992, ISBN 0-937073-80-6 (paper) and 0-937073-81-4 (cloth).

In the first of Bentley's articles, fellow Bell Labs researcher Doug McIlroy reviewed Knuth's program, and his solution that took only a couple of minutes to develop and worked correctly the first time. Moreover, unlike Knuth's, McIlroy's is devoid of explicit magic constants that limit the word lengths, the number of unique words, and the notion of what constitutes a word is defined entirely by simple patterns given in its first two executable statements. The word-recognition algorithm is easy.

McIlroy's program illustrates the power of the Unix tools approach: break a complex problem into simpler pieces, and show how to handle each. To solve the word-frequency problem, McIlroy converted the text file to a list of words, one word per line, mapped words to a single lowercase letter (using `tr` again), sorted the list (`sort`), reduced it to a list of unique words with their frequencies (`uniq -c`), sorted the list by descending counts (`sort`), and finally, printed the first several entries in the list (`sed`, though `head` would also work).

The resulting program is worth being given a name (`wf`, for word frequency) and wrapped in a shell script. We also extend McIlroy's original `sed` command to make the output list-length argument optional, and we modify the script to show the complete program in Example 5-5.

Example 5-5. Word-frequency filter

```
#!/bin/sh

# Read a text stream on standard input, and output a list of
# the n (default: 25) most frequently occurring words and
# their frequency counts, in order of descending counts, on
# standard output.
```

```

#
# Usage:
#     wf [n]

tr -cs A-Za-z\' '\n' |           Replace nonletters with newlines
tr A-Z a-z |                   Map uppercase to lowercase
sort |                          Sort the words in ascending order
uniq -c |                       Eliminate duplicates, showing their coun
sort -k1,1nr -k2 |             Sort by descending count, and then by a
sed ${1:-25}q                   Print only the first n (default: 25)

```

POSIX *tr* supports all of the escape sequences of ISO Standard C. The older X/Open Portability Guide specifies some additional escape sequences, and the original *tr* had none at all, forcing the newline to be written literally, which was McIlroy's original program. Fortunately, the *tr* command on every system that we tested now has the POSIX version.

A shell pipeline isn't the only way to solve this problem with Unix tools: Bentley gave a six-line *awk* implementation of an earlier column^[8] that is roughly equivalent to the first four stages of McIlroy's pipeline.

^[8] *Programming Pearls: Associative Arrays*, Comm. ACM **28** (6), 570-576, June, (1985). This is an excellent introduction to associative arrays (tables indexed by strings, rather than integers), a common feature of most scripting languages.

Knuth and Hanson discussed the computational complexity of their programs, and Hanson used runtime performance variants of his program to find the fastest one.

The complexity of McIlroy's is easy to identify. All but the *sort* stages run in a time that is linear in the size of the input, which is usually sharply reduced after the *uniq* stage. Thus, the rate-limiting step is the first *sort*. A good sorting algorithm like that in Unix *sort*, can sort n items in a time proportional to $n \log_2 n$. The logarithm-to-the-base-2 factor is about 20. Thus, in practice, we expect *wf* to be a few times slower than it would take to just copy its input.

Here is an example of applying this script to the text of Shakespeare's most popular play, *Hamlet*,^[9] reformatted for a four-column display:

^[9] Available in the wonderful Project Gutenberg archives at <http://www.gutenberg.net/>.

```
$ wf 12 < hamlet | pr -c4 -t -w80
```


1148	the	671	of	550	a	451	in
970	and	635	i	514	my	419	it
771	to	554	you	494	hamlet	407	tha

The results are about as expected for English prose. More interesting, perhaps, is to ask how many unique

```
$ wf 999999 < hamlet | wc -l
```

```
4548
```

and to look at some of the least-frequent words:

```
$ wf 999999 < hamlet | tail -n 12 | pr -c4 -t -w80
```

1	yaw	1	yesterday	1	yielding	1	you
1	yawn	1	yesternight	1	yon	1	you
1	yeoman	1	yesty	1	yond	1	zon

There is nothing magic about the argument `999999` : it just needs to be a number larger than any expected count. The keyboard repeat feature makes it easy to type.

We can also ask how many of the 4548 unique words were used just once:

```
$ wf 999999 < hamlet | grep -c '^ *1.'
```

```
2634
```

The `·` following the digit `1` in the `grep` pattern represents a tab. This result is surprising, and probably atypical for English prose: although the play's vocabulary is large, nearly 58 percent of the words occur only once. And yet, the number of unique words occurring more than once is rather small:

```
$ wf 999999 < hamlet | awk '$1 >= 5' | wc -l
```

```
740
```

This is about the number of words that a student might be expected to learn in a semester course on a foreign language before entering school.

Shakespeare didn't have computers to help analyze his writing,^[10] but we can speculate that part of his genius was what he wrote understandable to the broadest possible audience of his time.

[10] Indeed, the only word related to the root of "computer" that Shakespeare used is "computation," just once in each of two plays, *Richard III*. "Arithmetic" occurs six times in his plays, "calculate" twice, and "mathematics" thrice.

When we applied *wf* to the individual texts of Shakespeare's plays, we found that *Hamlet* has the largest vocabulary and *Comedy of Errors* has the smallest (2443). The total number of unique words in the Shakespeare corpus is 23,700, which shows that you need exposure to several plays to enjoy the richness of his work. About 36 percent of words occur only once, and only one word begins with x: Xanthippe, in *Taming of the Shrew*. Clearly, there is plenty of material for word-puzzle enthusiasts and vocabulary analysts!



5.5. Tag Lists

Use of the *tr* command to obtain lists of words, or more generally, to transform one set of characters to another set, as in Example 5-5 in the preceding section, is a handy Unix tool idiom to remember. It leads naturally to a solution of a problem that we had in writing this book: how do we ensure consistent markup through about 50K lines of manuscript files? For example, a command might be marked up with `<command>tr</command>` when we talk about it in the running text, but elsewhere, we might give an example of something that you type, indicated by the markup `<literal>tr</literal>`. A third possibility is a manual-page reference in the form `<emphasis>tr</emphasis>(1)`.

The *taglist* program in Example 5-6 provides a solution. It finds all begin/end tag pairs written on the same line and outputs a sorted list that associates tag use with input files. Additionally, it flags with an arrow cases where the same word is marked up in more than one way. Here is a fragment of its output from just the file for a version of this chapter:

```
$ taglist ch05.xml
...
    2 cut                command            ch05.xml
    1 cut                emphasis          ch05.xml <-----
...
    2 uniq              command            ch05.xml
    1 uniq              emphasis          ch05.xml <-----
    1 vfstab            filename           ch05.xml
...

```

The tag listing task is reasonably complex, and would be quite hard to do in most conventional programming languages, even ones with large class libraries, such as C++ and Java, and even if you started with the Knu or Hanson *literate* programs for the somewhat similar word-frequency problem. Yet, just nine steps in a Unix pipeline with by-now familiar tools suffice.

The word-frequency program did not deal with named files: it just assumed a single data stream. That is not

serious limitation because we can easily feed it multiple input files with *cat* . Here, however, we need a filename, since it does us no good to report a problem without telling where the problem is. The filename is *taglist* 's single argument, available in the script as `$1` .

1. We feed the input file into the pipeline with *cat* . We could, of course, eliminate this step by redirecting the input of the next stage from `$1` , but we find in complex pipelines that it is clearer to separate *data production* from *data processing* . It also makes it slightly easier to insert yet another stage into the pipeline if the program later evolves.

```
cat "$1" | ...
```

2. We apply *sed* to simplify the otherwise-complex markup needed for web URLs:

```
... | sed -e 's#systemitem *role="url"#URL#g' \
        -e 's#/systemitem#/URL#' | ...
```

3. This converts tags such as `<systemitem role="URL">` and `</systemitem>` into simpler `<URL>` and `</URL>` tags, respectively.

4. The next stage uses *tr* to replace spaces and paired delimiters by newlines:

```
... | tr ' ( ) { } [ ] ' '\n\n\n\n\n\n\n\n' | ...
```

5. At this point, the input consists of one "word" per line (or empty lines). Words are either actual text or SGML/XML tags. Using *egrep* , the next stage selects tag-enclosed words:

```
... | egrep '>[^<>]+</' | ...
```

6. This regular expression matches tag-enclosed words: a right angle bracket, followed by at least one nonangle bracket, followed by a left angle bracket, followed by a slash (for the closing tag).

7. At this point, the input consists of lines with tags. The first *awk* stage uses angle brackets as field separators, so the input `<literal>tr</literal>` is split into four fields: an empty field, followed by `literal` , `tr` , and `/literal` . The filename is passed to *awk* on the command line, where the `-v` option sets the *awk* variable `FILE` to the filename. That variable is then used in the *print* statement, which outputs the word, the tag, and the filename:

```
... | awk -F'[<>]' -v FILE="$1" \
```

```
'{ printf("%-31s\t%-15s\t%s\n", $3, $2, FILE) }' | ...
```

8. The *sort* stage sorts the lines into word order:

```
... | sort | ...
```

9. The *uniq* command supplies the initial count field. The output is a list of records, where the fields are *count*, *word*, *tag*, *file*:

```
... | uniq -c | ...
```

10. A second *sort* orders the output by word and tag (the second and third fields):

```
... | sort -k2,2 -k3,3 | ...
```

11. The final stage uses a small *awk* program to filter successive lines, adding a trailing arrow when it sees the same word as on the previous line. This arrow then clearly indicates instances where words have been marked up differently, and thus deserve closer inspection by the authors, the editors, or the book production staff:

```
... | awk '{
    print ($2 == Last) ? ($0 " <----") : $0
    Last = $2
}'
```

The full program is provided in Example 5-6.

Example 5-6. Making an SGML tag list

```
#!/bin/sh -
# Read an HTML/SGML/XML file given on the command
# line containing markup like <tag>word</tag> and output on
# standard output a tab-separated list of
#
```

```

#         count word tag filename

#

# sorted by ascending word and tag.

#

# Usage:

#         taglist xml-file

cat "$1" |

    sed -e 's#systemitem *role="url"#URL#g' -e 's#/systemitem#/URL#' |

    tr ' ( ){ }[ ]' '\n\n\n\n\n\n\n\n\n' |

    egrep '>[^<>]+</' |

    awk -F'[<>]' -v FILE="$1" \

        '{ printf("%-31s\t%-15s\t%s\n", $3, $2, FILE) }' |

    sort |

    uniq -c |

    sort -k2,2 -k3,3 |

    awk '{

        print ($2 == Last) ? ($0 " <----") : $0

        Last = $2

    }'

```

In Section 6.5, we will show how to apply the tag-list operation to multiple files.

5.6. Summary

This chapter has shown how to solve several text processing problems, none of which would be simple to do in most programming languages. The critical lessons of this chapter are:

- Data markup is extremely valuable, although it need not be complex. A unique single character, such as a tab, colon, or comma, often suffices.
- Pipelines of simple Unix tools and short, often inline, programs in a suitable text processing language, such as *awk*, can exploit data markup to pass multiple pieces of data through a series of processing stages, emerging with a useful report.
- By keeping the data markup simple, the output of our tools can readily become input to new tools, as shown by our little analysis of the output of the word-frequency filter, *wf*, applied to Shakespeare's texts.
- By preserving some minimal markup in the output, we can later come back and massage that data further, as we did to turn a simple ASCII office directory into a web page. Indeed, it is wise never to consider any form of electronic data as final: there is a growing demand in some quarters for page-description languages, such as PCL, PDF, and PostScript, to preserve the original markup that led to the page formatting. Word processor documents currently are almost devoid of useful logical markup, but that may change in the future. At the time of this writing, one prominent word processor vendor was reported to be considering an XML representation for document storage. The GNU Project's *gnnumeric* spreadsheet, the Linux Documentation Project,^[11] and the OpenOffice.org^[12] office suite already do that.

[11] See <http://www.tldp.org/>.

[12] See <http://www.openoffice.org/>.

- Lines with delimiter-separated fields are a convenient format for exchanging data with more complex software, such as spreadsheets and databases. Although such systems usually offer some sort of report-generation feature, it is often easier to extract the data as a stream of lines of fields, and then to apply filters written in suitable programming languages to manipulate the data further. For example, catalog and directory publishing are often best done this way.

Chapter 6. Variables, Making Decisions, and Repeating Actions

Variables are essential for nontrivial programs. They maintain values useful as data and for managing program state. Since the shell is mostly a string processing language, there are lots of things you can do with the string values of shell variables. However, because mathematical operations are essential too, the POSIX shell also provides a mechanism for doing arithmetic with shell variables.

Control-flow features make a programming language: it's almost impossible to get any real work done if all you have are imperative statements. This chapter covers the shell's facilities for testing results, and making decisions based on those results, as well as looping.

Finally, functions let you group task-related statements in one place, making it easier to perform that task from multiple points within your script.

6.1. Variables and Arithmetic

Shell variables are like variables in any conventional programming language. They hold values until you n shell variable names and values in Section 2.5.2. In addition, shell scripts and functions have *positional pa* for "command-line arguments."

Simple arithmetic operations are common in shell scripts; e.g., adding one to a variable each time around a notation for inline arithmetic called *arithmetic expansion*. The shell evaluates arithmetic expressions insid back into the text of the command.

6.1.1. Variable Assignment and the Environment

Shell variable assignment and usage were covered in Section 2.5.2. This section fills in the rest of the detail

Two similar commands provide variable management. The *readonly* command makes variables read-only; forbidden. This is a good way to create symbolic constants in a shell program:

```
hours_per_day=24 seconds_per_hour=3600 days_per_week=7      Assign value
readonly hours_per_day seconds_per_hour days_per_week      Make read-only
```

export, readonly

Usage

```
export name [= word ] ...
export -p
readonly name [= word ] ...
readonly -p
```

Purpose

export modifies or prints the environment. *readonly* makes variables unmodifiable.

Major options

-p

Print the name of the command and the names and values of all exported (read-only) variables in su allow the shell to reread the output to re-create the environment (read-only settings).

Behavior

With the *-p* option, both commands print their name and all variables and values that are exported c respectively. Otherwise, they apply the appropriate attribute to the named variables.

Caveats

The versions of `/bin/sh` on many commercial Unix systems are (sadly) still not POSIX-compliant. assignment form of *export* and *readonly* don't work. For strictest portability, use:

```
FOO=somevalue
```

```
export FOO
```

```
BAR=anothervalue
```

```
readonly BAR
```

Much more commonly used is the *export* command, which puts variables into the *environment* . The enviro value pairs that is available to every running program. New processes inherit the environment from their pa before creating new child processes of their own. The *export* command adds new variables to the environm

```
PATH=$PATH:/usr/local/bin
```

Update PATH

```
export PATH
```

Export it

The original Bourne shell required you to use a two-step process; i.e., the assignment and the *export* or *readonly* (we've just shown). The POSIX standard allows you to do the assignment and command together:

```
readonly hours_per_day=24 seconds_per_hour=3600 days_per_week=7
```

```
export PATH=$PATH:/usr/local/bin
```

The *export* command may also be used to print the current environment:

```
$ export -p Print current environment
```

```
export CDPATH=":/home/tolstoy"
```

```
export DISPLAY=":0.0"
```

```
export ENV="/home/tolstoy/.kshrc"
```

```
export EXINIT="set ai sm"
```

```
export FCEDIT="vi"
```

```
...
```

Variables may be added to a program's environment without permanently affecting the environment of the shell. This is done by prefixing the assignment to the command name and arguments:

```
PATH=/bin:/usr/bin awk '...' file1 file2
```

This changes the value of `PATH` only for execution of the single *awk* command. Any subsequent commands will have the original `PATH` in their environment.

The *export* command only adds variables to the environment. The *env* command may be used to remove variables from the environment, or to temporarily change environment variable values:

```
env -i PATH=$PATH HOME=$HOME LC_ALL=C awk '...' file1 file2
```

The *-i* option *initializes* the environment; i.e., throws away any inherited values, passing in to the program the default environment.

env

Usage

```
env [ -i ] [ var = value ... ] [ command_name [ arguments ... ] ]
```

Purpose

To provide fine-grained control over the environment inherited by *command_name* when it's run by *command_name*.

Major options

-i

Ignore the inherited environment, using only the variables and values given on the command line.

Behavior

With no *command_name*, print the names and values of all variables in the environment. Otherwise, assignments on the command line to modify the inherited environment, before invoking *command_name*. If the *-i* option, *env* ignores the inherited environment completely and uses only the supplied variables and values.

Caveats

When printing, *env* does not necessarily quote environment variable values correctly for re-inputting. Use `export -p` for that.

The *unset* command removes variables and functions from the running shell. By default it unsets variables, explicit with *-v*:


```
unset full_name           Remove the full_name variable
unset -v first middle last Remove the other variables
```

Use `unset -f` to remove functions:

```
who_is_on ( ) {           Define a function
    who | awk '{ print $1 }' | sort -u  Generate sorted list of users
}
...
unset -f who_is_on        Remove the function
```

Early versions of the shell didn't have functions or the *unset* command. POSIX added the *-f* option for removing functions and the *-v* option for symmetry with *-f*.

unset

Usage

```
unset [ -v ] variable ...
unset -f function ...
```

Purpose

To remove variables and functions from the current shell.

Major options

-f

Unset (remove) the named functions.

-v

Unset (remove) the named variables. This is the default action with no options.

Behavior

With no options, arguments are treated as variable names and said variables are removed. The same option. With the *-f* option, arguments are treated as function names and the functions are removed.



The assignment `myvar=` doesn't remove `myvar`, it merely sets it to the null string. In contrast, `unset myvar` removes it completely. This difference comes into play with the various "is the variable set but not null" expansions described in the next section.

6.1.2. Parameter Expansion

Parameter expansion is the process by which the shell provides the value of a variable for use in the program, variable, or as part or all of a command-line argument. The simplest form is undoubtedly familiar:

```
reminder="Time to go to the dentist!"           Save value in reminder
```

```
sleep 120                                       Wait two hours
```

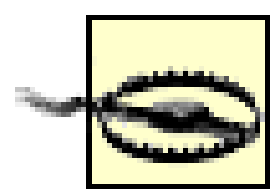
```
echo $reminder                                 Print message
```

The shell has more complicated forms that are useful in more specialized situations. All of these forms enclose the variable name in braces (`${variable}`), and then add additional syntax telling the shell what to do. Braces by themselves are also used to immediately follow a variable name with a character that might otherwise be interpreted as part of the name.

```
reminder="Time to go to the dentist!"           Save value in reminder
```

```
sleep 120                                       Wait two hours
```

```
echo _${reminder}_                             Print message with underscore.
```



By default, undefined variables expand to the null (empty) string. Sloppy programming c

```
rm -fr /$MYPROGRAM           If MYPROGRAM isn't set, disaster
```

It thus pays, as always, to program carefully!

6.1.2.1 Expansion operators

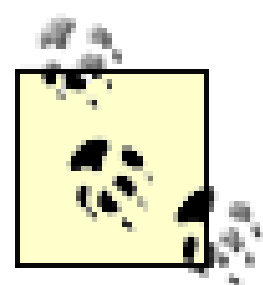
The first group of string-handling operators tests for the existence of variables and allows substitutions of c conditions. They are listed in Table 6-1.

Table 6-1. Substitution operators

Operator	Substitution
<code>\${ varname :- word }</code>	<p>If <i>varname</i> exists and isn't null, return its value; otherwise, return <i>word</i> .</p> <p>Purpose : To return a default value if the variable is undefined.</p> <p>Example : <code>\${count:-0}</code> evaluates to 0 if <code>count</code> is undefined.</p>
<code>\${ varname := word }</code>	<p>If <i>varname</i> exists and isn't null, return its value; otherwise, set it to <i>word</i> and then return</p> <p>Purpose : To set a variable to a default value if it is undefined.</p> <p>Example : <code>\${count:=0}</code> sets <code>count</code> to 0 if it is undefined.</p>
<code>\${ varname :? message }</code>	<p>If <i>varname</i> exists and isn't null, return its value; otherwise, print <i>varname</i> : <i>message</i> , at script. Omitting <i>message</i> produces the default message <code>parameter null or not set</code> . . shells do not have to abort. (Behavior varies across shells; caveat emptor!)</p> <p>Purpose : To catch errors that result from variables being undefined.</p> <p>Example : <code>\${count:? "undefined!"}</code> prints <code>count: undefined!</code> and exits if <code>count</code> is u</p>
<code>\${ varname :+ word }</code>	<p>If <i>varname</i> exists and isn't null, return <i>word</i> ; otherwise, return null.</p> <p>Purpose : To test for the existence of a variable.</p> <p>Example : <code>\${count:+1}</code> returns 1 (which could mean "true") if <code>count</code> is defined.</p>

The colon (:) in each of the operators in Table 6-1 is optional. If the colon is omitted, then change "exists and is defined"; i.e., the operator tests for existence only.

The operators in Table 6-1 have been part of the Bourne shell for more than 20 years. POSIX standardized pattern matching and text removal on variable values. The classic use for the new pattern-matching operators is to remove parts of pathnames, such as directory prefixes and filename suffixes. With that in mind, besides listing the shell's pattern-matching operators, this section also has examples showing how all of the operators work. For these examples, assume that the variable `path` has the value `/home/tolstoy/mem/long.file.name`.



The patterns used by the operators in Table 6-2 and in other places in the shell, such as the shell "wildcard" patterns. They're described in detail in Section 7.5. However we expect that you'll know the basics from your regular everyday use of the shell.

Table 6-2. Pattern-matching operators

Operator	Substitution
<code>\${ variable # pattern }</code>	If the pattern matches the beginning of the variable's value, delete the shortest part of the value that matches the pattern.
Example : <code>\${path#/*/}</code>	Result : <code>tolstoy/mem/long.file.name</code>
<code>\${ variable ## pattern }</code>	If the pattern matches the beginning of the variable's value, delete the longest part of the value that matches the pattern.
Example : <code>\${path##/*/}</code>	Result : <code>long.file.name</code>
<code>\${ variable % pattern }</code>	If the pattern matches the end of the variable's value, delete the shortest part of the value that matches the pattern.
Example : <code>\${path%.*}</code>	Result : <code>/home/tolstoy/mem/long.file</code>
<code>\${ variable %% pattern }</code>	If the pattern matches the end of the variable's value, delete the longest part of the value that matches the pattern.
Example : <code>\${path%%.*}</code>	Result : <code>/home/tolstoy/mem/long</code>

These can be hard to remember, so here's a handy mnemonic device: # matches the front because number s the rear because percent signs *follow* numbers. Another mnemonic comes from the typical placement (in th keys on the keyboard. Relative to each other, the # is on the left, and the % is on the right.

The two patterns used here are `/*/`, which matches anything between two slashes, and `.*`, which matches

Finally, POSIX standardized the string-length operator: `${# variable }` returns the length in characters of

```
$ x=supercalifragilisticexpialidocious      A famous word with amazing p.
```

```
$ echo There are ${#x} characters in $x
```

```
There are 34 characters in supercalifragilisticexpialidocious
```

6.1.2.2 Positional parameters

The so-called positional parameters represent a shell script's command-line arguments. They also represent shell functions. Individual arguments are named by integer numbers. For historical reasons, you have to enter numbers greater than nine:

```
echo first arg is $1
```

```
echo tenth arg is ${10}
```

You can apply all of the value-testing and pattern-matching operators from the previous section to the positional parameters.

```
filename=${1:-/dev/tty}      Use argument if given, /dev/tty otherwise
```

Special "variables" provide access to the total number of arguments that were passed, and to all the arguments.

`$#`

Provides the total number of arguments passed to the shell script or function. It is useful for creating loops to process options and arguments. For example:

```
while [ $# != 0 ]       $# decremented by shift, loop
```

```
do
```

```
    case $1 in
```

```
        ...
```

Process first argument

```
    esac
```

```
    shift
```

Shift first argument away (see

```
done
```

`$* , @$`

Represents all the command-line arguments at once. They can be used to pass the command-line arguments to a script or function.

`"$* "`

Represents all the command-line arguments as a single string. Equivalent to `"$1 $2 ..."`. The first character is a separator for the different values to create the string. For example:

```
printf "The arguments were %s\n" "$*"

```

`"$@ "`

Represents all the command-line arguments as separate, individual strings. Equivalent to `"$1" "$2" ...` the arguments on to another program, since it preserves any whitespace embedded within each argument.

```
lpr "$@" Print each file

```

The `set` command serves a number of purposes. (Full information is provided later in Section 7.9.1 .) When it changes the value of the positional parameters, throwing away any previously existing values:

```
set -- hi there how do you do The -- ends options; "h

```

The `shift` command "lops off" positional parameters from the list, starting at the left. Upon executing `shift` forever, replaced by the old value of `$2` . The value of `$2` , in turn, becomes the old value of `$3` , and so on. `shift` takes an optional argument, which is a count of how many arguments to shift off the list. Plain `shift` Here is an annotated example that ties all of these things together:

```
$ set -- hello "hi there" greetings Set new positional parameters

```

```
$ echo there are $# total arguments Print the count

```

```
there are 3 total arguments

```

```
$ for i in $* Loop over arguments individually

```



```
> do echo i is $i
```

```
> done
```

```
i is hello
```

```
i is hi
```

```
i is there
```

```
i is greetings
```

```
$ for i in $@
```

```
> do echo i is $i
```

```
> done
```

```
i is hello
```

```
i is hi
```

```
i is there
```

```
i is greetings
```

```
$ for i in "$@"
```

```
> do echo i is $i
```

```
> done
```

```
i is hello hi there greetings
```

```
$ for i in "$@"
```

```
> do echo i is $i
```

```
> done
```

```
i is hello
```

```
i is hi there
```

```
i is greetings
```

Note that embedded whitesp

Without quotes, \$ and \$@*

With quotes, \$ is one s*

With quotes, \$@ preserve

```

$ shift                                     Lop off the first argume

$ echo there are now $# arguments          Prove that it's now gone

there are now 2 arguments

$ for i in "$@"

> do   echo i is $i

> done

i is hi there

i is greetings

```

6.1.2.3 Special variables

Besides the special variables we've just seen, such as `$#` and `$*`, the shell has a number of additional built-single-character, nonalphabetic names. Others have names consisting of all uppercase letters.

Table 6-3 lists the variables that are built into the shell and that affect its behavior. All Bourne-style shells listed here that either affect interactive use or have other uses when doing shell programming. However, these are portable shell programming.

Table 6-3. POSIX built-in shell variables

Variable	Meaning
#	Number of arguments given to current process.
@	Command-line arguments to current process. Inside double quotes, expands to individual a
*	Command-line arguments to current process. Inside double quotes, expands to a single argu
- (hyphen)	Options given to shell on invocation.
?	Exit status of previous command.
\$	Process ID of shell process.
0 (zero)	The name of the shell program.
!	Process ID of last background command. Use this to save process ID numbers for later use

Variable	Meaning
ENV	Used only by interactive shells upon invocation; the <i>value</i> of <code>\$ENV</code> is parameter-expanded. It is a pathname for a file to be read and executed at startup. This is an XSI requirement.
HOME	Home (login) directory.
IFS	Internal field separator; i.e., the list of characters that act as word separators. Normally set to space and tab.
LANG	Default name of current locale; overridden by the other <code>LC_*</code> variables.
LC_ALL	Name of current locale; overrides <code>LANG</code> and the other <code>LC_*</code> variables.
LC_COLLATE	Name of current locale for character collation (sorting) purposes.
LC_CTYPE	Name of current locale for character class determination during pattern matching.
LC_MESSAGES	Name of current language for output messages.
LINENO	Line number in script or function of the line that just ran.
NLSPATH	The location of message catalogs for messages in the language given by <code>\$LC_MESSAGES</code> (XSI).
PATH	Search path for commands.
PPID	Process ID of parent process.
PS1	Primary command prompt string. Default is <code>"\$ "</code> .
PS2	Prompt string for line continuations. Default is <code>"> "</code> .
PS4	Prompt string for execution tracing with <code>set -x</code> . Default is <code>"+ "</code> .
PWD	Current working directory.

The special variable `$$` is useful in scripting for creating unique (usually temporary) filenames based on the process ID. However, systems that have the `mktemp` command should use that instead. Both of these are discussed in Chapter 7.

6.1.3. Arithmetic Expansion

The shell arithmetic operators are equivalent to their counterparts in the C language. Precedence and associativity are shown in Table 6-4. Table 6-4 shows the arithmetic operators that are supported, in order from highest precedence to lowest. Although some operators are special characters, there is no need to backslash-escape them, because they are within the `$((...))` syntax. The only special character is the double quote, which must be escaped with a backslash inside single quotes, except that an embedded double quote need not be escaped (see Section 7.7).

Table 6-4. Arithmetic operators

Operator	Meaning
++ --	Increment and decrement, prefix and postfix
+ - ! ~	Unary plus and minus; logical and bitwise negation
* / %	Multiplication, division, and remainder
+ -	Addition and subtraction
<< >>	Bit-shift left and right
< <= > >=	Comparisons
= !=	Equal and not equal
&	Bitwise AND
^	Bitwise Exclusive OR
	Bitwise OR
&&	Logical AND (short-circuit)
	Logical OR (short-circuit)
? :	Conditional expression
= += -= *= /= %= &= ^= <<= >>= =	Assignment operators

Parentheses can be used to group subexpressions. As in C, the relational operators (< , <= , > , >= , = , != , and !) that acts as a truth value: 1 for true and 0 for false.

For example, `$((3 > 2))` has the value 1; `$(((3 > 2) || (4 <= 1)))` also has the value 1, since at least one is true.

For the logical AND and OR operators, *any* nonzero value functions as true:

```
$ echo $( ( 3 && 4 ) )           Both 3 and 4 are "true"
```

```
1
```

This use of nonzero as "true" applies in just about all languages derived from C, such as C++, Java, and *awk*.

If you're familiar with C, C++, or Java, the operators listed in Table 6-4 will be familiar. If you're not, some explanation.

The assignment forms of the regular operators are a convenient shorthand for the more conventional way of

example, in many languages you might write $x = x + 2$ to add 2 to x . The `+=` operator lets you do that more concisely: `x += 2`. This adds 2 to x and stores the result back in x .

Since adding and subtracting one are such frequent operations, the `++` and `--` operators provide an even more concise way to do this. As you might guess, `++` adds one, and `--` subtracts one. These are unary operators. Let's take a quick look at them.

```
$ i=5
```

```
$ echo $((i++)) $i
```

```
5 6
```

```
$ echo $((++i)) $i
```

```
7 7
```

What's going on here? In both cases, the value of `i` is increased by one. However, the value returned by the shell is different. In the first case, the value of `i` is incremented first, and then the value of `i` is returned. This is a *postfix* operator (one that occurs after the variable being operated upon). In the second case, the value of `i` is returned first, and then `i` is incremented. This is a *prefix* operator, which comes before the variable being operated upon. The `--` operator works the same as `++`, but it decrements the variable instead of incrementing it.

The `++` and `--` operators are optional: conforming implementations do not have to support them, but most shells do support them.

The standard allows an implementation to support additional operators. All versions of `ksh` support the `^` operator, and recent versions support exponentiation with `**`. `bash` also supports both of these operators.

The standard only describes arithmetic using constant values. When parameter evaluation occurs first, the arithmetic evaluator only sees constant values. In practice, all shells that support arithmetic expansion provide a variable name without prefixing it with `$`.

According to POSIX, arithmetic is done using C signed `long` integers. `ksh93` supports floating-point arithmetic, but that's not portable. For portable programs, use integer arithmetic.

6.2. Exit Statuses

Every command—be it built-in, shell function, or external—when it exits, returns a small integer value to the programming with the shell.

6.2.1. Exit Status Values

By convention, an exit status of 0 indicates "success"; i.e., that the program ran and didn't encounter any problem. The shell contains the exit value of the last program that the shell ran.

^[1] C and C++ programmers take note! This is backward from what you're used to, and takes a while to get comfortable with.

For example, when you type `ls`, the shell finds and runs the `ls` program. When `ls` finishes, the shell recovers

```
$ ls -l /dev/null ls on an exist
crw-rw-rw- 1 root root 1, 3 Aug 30 2001 /dev/null ls's output
$ echo $? Show exit stat
0 Exit status w
$ ls foo Now ls a nonex.
ls: foo: No such file or directory ls's error mess
$ echo $? Show exit stat
1 Exit status i
```

The POSIX standard defines the exit statuses and their meanings, as shown in Table 6-5

Ta

Value	
0	Command exited successfully.

Value	
> 0	Failure during redirection or word expansion (tilde, variable, command, and arithmetic expansions)
1-125	Command exited unsuccessfully. The meanings of particular exit values are defined by each individual shell.
126	Command found, but file was not executable.
127	Command not found.
> 128	Command died due to receiving a signal.

Curiously, POSIX leaves exit status 128 unspecified, apart from requiring that it represent some sort of failure value divided by 256.

Your shell script can pass an exit value back to its caller, using the *exit* command. Simply pass a number to

```
exit 42      Return the answer to the ultimate question
```

€

Usage

```
exit [ exit-value ]
```

Purpose

To return an exit status from a shell script to the script's caller.

Major options

None.

Behavior

The default exit status used if none is supplied is the exit status of the last command executed. If the

```
exit $?
```

6.2.2. if-elif-else-fi

The most obvious way to use a program's exit status is with the `if` statement. The general syntax is:

```
if pipeline
    [ pipeline ... ]
then
    statements-if-true-1
[ elif pipeline
    [ pipeline ... ]
then
    statements-if-true-2
... ]
[ else
    statements-if-all-else-fails ]
fi
```

(The square brackets indicate optional parts; they are not typed literally.) The shell's syntax is based loosely on opening and closing keywords to bracket statement groups, instead of the `begin` and `end` delimiters of Algol.

In the case at hand, you can probably guess how this works: the shell runs the first group of statements between `if` and `then`. If that fails, it tries the next group of statements. If the last one exits successfully, it runs `statements-if-true-1`.

If none of the `if` or `elif` statements is true, and an `else` clause is present, it executes `statements-if-all-else-fails`. If none was executed, the exit status is 0. For example:

```
if grep pattern myfile > /dev/null
```

```

then
    ...    Pattern is there
else
    ...    Pattern is not there
fi

```

`grep` exits with a 0 status if `myfile` contains `pattern` . It exits with a value of 1 if no line matched the pattern.

6.2.3. Logical NOT, AND, and OR

Sometimes it's easier to phrase your tests in the negative: "if John is *not* at home, then ..." The way to do this is:

```

if ! grep pattern myfile > /dev/null
then
    ...    Pattern is not there
fi

```

POSIX introduced this notation in the 1992 standard. You will likely see older shell scripts that use the colon notation:

```

if grep pattern myfile > /dev/null
then
    :      # do nothing
else
    ...    Pattern is not there
fi

```

Besides just testing the inverse of things with `!` , you will often want to test multiple subconditions, with `A` executes the first one. If it exits successfully, the shell executes the second one. If that exits successfully to


```

if grep pattern1 myfile && grep pattern2 myfile
then
    ...      myfile contains both patterns
fi

```

In contrast, the `||` operator is used when you want to test if one condition or the other is true:

```

if grep pattern1 myfile || grep pattern2 myfile
then
    ...      One or the other is present
fi

```

Both of these are *short-circuit* operators, meaning that the shell stops evaluating commands as soon as it can determine the whole thing could be true, so *command2* never executes. Similarly for *command1 || command2* : if *command1*

Don't try to be overly "terse" and use `&&` and `||` to replace the `if` statement. We have little objection to something like

```

$ who | grep tolstoy > /dev/null && echo tolstoy is logged on

```

tolstoy is logged on

This runs `who | grep ...`, and if that succeeds it prints the message. However, we have seen vendor shell scripts use

```

some_command && {
    one command
    a second command
    and a third command
}

```

The braces serve to group all the commands together, which are executed only if *some_command* succeeds.

```

if some_command

```

then

one command

a second command

and a third command

fi

6.2.4. The test Command

The aptly named *test* command exists to perform a variety of useful tasks in shell scripts. It produces no output; it performs.

test

Usage

```
test [ expression ]  
[ [ expression ] ]
```

Purpose

To test conditions in shell scripts, returning results via the exit status. Note that in the second form of *test*, there is a space between the two *[* characters.

Major options and expressions

See Table 6-6 and text.

Behavior

test tests file attributes, compares strings, and compares numbers.

Caveats

The expressions mandated by POSIX are a subset of what is often available on real systems. Care is taken to ensure that the expressions are portable. Except on absolutely ancient Unix systems, *test* is built into the shell. Since built-in commands are found in the shell, they are named *test*. Such programs must be invoked as `./test` (assuming they're in the current directory).

The *test* command has a variant form: `[...]`. It works identically to the *test* command. Thus, these two statements are equivalent:

```
if test "$str1" = "$str2"
then
    ...
fi

if [ "$str1" = "$str2" ]
then
    ...
fi
```

POSIX describes the arguments to *test* as "expressions." There are unary and binary expressions. The unary expressions are `-s file`, `-e file`, and `-f file`, where *file* is always a filename. The binary expressions have two operands with an embedded operator that performs some comparison. The operators are provided in Table 6-6.

T

Operator
<i>string</i>
<code>-b file</code>
<code>-c file</code>
<code>-d file</code>
<code>-e file</code>
<code>-f file</code>
<code>-g file</code>
<code>-h file</code>
<code>-L file</code>
<code>-n string</code>

Operator
<code>-p file</code>
<code>-r file</code>
<code>-S file</code>
<code>-s file</code>
<code>-t n</code>
<code>-u file</code>
<code>-w file</code>
<code>-x file</code>
<code>-z string</code>
<code>s1 = s2</code>
<code>s1 != s2</code>
<code>n1 -eq n2</code>
<code>n1 -ne n2</code>
<code>n1 -lt n2</code>
<code>n1 -gt n2</code>
<code>n1 -le n2</code>
<code>n1 -ge n2</code>


Tests may be negated by preceding them with `!`. Here are some sample tests in action:

```
if [ -f "$file" ]
then
    echo $file is a regular file
elif [ -d "$file" ]
then
    echo $file is a directory
```

```
fi

if [ ! -x "$file" ]
then
    echo $file is NOT executable
fi
```

XSI-conformant systems have a more complicated version of *test*. Expressions can be combined with *-a* (logical AND) and *-o* (logical OR) binary operators. Parentheses may be used for grouping and to change evaluation order.



There is a difference between using *-a* and *-o*, which are *test* operators, and *&&* and *||*, which are shell operators.

```
if [ -n "$str" -a -f "$file" ]      Two conditions, one test comma
if [ -n "$str" ] && [ -f "$file" ]  Two commands, short-circuit
if [ -n "$str" && -f "$file" ]      Syntax error, see text
```

In the first case, *test* evaluates both conditions. In the second one, the shell runs the first *test* command. This command will complain that there is no terminating *]* character, and exits with a non-zero status. The third command named *-f*.

Both *ksh93* and *bash* support a number of additional tests. More information is available in Section 14.3.2.

The POSIX algorithm for *test* is summarized in Table 6-7.

Table 6-7

Arguments	Argument values
0	
1	If \$1 is non-null
If \$1 is null	Exit false (1).

Arguments	Argument values
2	If \$1 is !
If \$1 is a unary operator	Result of the operator's test.
Anything else	Unspecified.
3	If \$2 is a binary operator
If \$1 is !	Negate result of double-argument test, \$2 \$3 .
If \$1 is (and \$3 is)	Result of single-argument test, \$2 (XSI).
Anything else	Unspecified.
4	If \$1 is !
If \$1 is (and \$4 is)	Result of two-argument test, \$2 \$3 (XSI).
Anything else	Unspecified.
> 4	

For portability, the POSIX standard recommends the use of shell-level tests for multiple conditions, instead

```
if [ -f "$file" ] && ! [ -w "$file" ]
```

then

```
    # $file exists and is a regular file, but is not writable
```

```
    echo $0: $file is not writable, giving up. >&2
```

```
    exit 1
```

fi

There are some Section 14.1 associated with *test* as well:

Arguments are required

For this reason, all shell variable expansions should be quoted so that *test* receives an argument, even

```
if [ -f "$file" ] ... Correct
```



```
if [ -f $file ] ...
```

Incorrect

In the second case, should `$file` happen to be empty, `test` receives one less argument than it needs, leading

String comparisons are tricky

In particular, if a string value is empty, or starts with a minus, `test` could become confused. This lead

```
if [ "X$answer" = "Xyes" ] ...
```

You will see this used in many shell scripts, and it is in fact used in examples throughout the POSIX stand:

The algorithm just given for `test`, along with always quoting all arguments, should be enough for a modern. However, if maximal portability is more important than readability, you may wish to use it (and we do so,

`test` can be fooled

When checking the access of files mounted over a network, it is possible for unusual combinations o access the file. Thus, although:

```
test -r a_file && cat a_file
```

should always work in principle, it can fail in practice.^[2] About all you can do is add another layer of defer

^[2] Mike Haertel points out that this has never been completely reliable: `a_file` could be changed in the interval between run

```
if test -r a_file && cat a_file
```

```
then
```

```
    # cat worked, proceed on
```

```
else
```

```
    # attempt to recover, issue an error message, etc.
```

```
fi
```

Numeric tests are integer-only

You cannot do any kind of floating-point arithmetic with *test* . All numeric tests work only with integers. Example 6-1 presents an improved version of the *finduser* script presented in Section 2.6 . This version tests

Example 6-1. Findusers script, requires a username argument

```
#!/bin/sh

# finduser --- see if user named by first argument is logged in

if [ $# != 1 ]
then
    echo Usage: finduser username >&2
    exit 1
fi

who | grep $1
```

< Day Day Up >

6.3. The case Statement

If you need to check a variable for one of many values, you could use a cascading series of `if` and `elif` tests together with `test`:

```
if [ "X$1" = "X-f" ]
then
    ...      Code for -f option
elif [ "X$1" = "X-d" ] || [ "X$1" = "X--directory" ] # long option
then
    ...      Code for -d option
else
    echo $1: unknown option >&2
    exit 1
fi
```

However, this is awkward to write and difficult to read. (The `>&2` in the `echo` command sends the output to error. This is described in Section 7.3.2.) Instead, the shell's `case` construct should be used for pattern matching.

```
case $1 in
-f)
    ...      Code for -f option
;;
-d | --directory) # long option allowed
    ...      Code for -d option
```



```
;;  
*)  
  
    echo $1: unknown option >&2  
  
    exit 1  
  
# ;; is good form before `esac', but not required  
  
esac
```

As can be seen, the value to be tested appears between `case` and `in`. Double-quoting the value, while not required, doesn't hurt either. The value is tested against each list of shell patterns in turn. When one matches, the corresponding body of code, up to the `;;`, is executed. Multiple patterns may be used, separated by the `|` character, which in this context means "or." The patterns may contain any shell wildcard characters, and variable, command, and arithmetic substitutions are performed on the value before it is used for pattern matching.

The unbalanced right parenthesis after each pattern list is perhaps surprising; this is the only instance in the language of unbalanced delimiters. (In Section 14.3.7, we will see that *bash* and *ksh* actually allow a leading `|` in front of the pattern list.)

It is typical, but not required, to use a final pattern of `*`, which acts as a default case. This is usually where one would print a diagnostic message and exit. As shown previously, the final case does not require the trailing `;;` although it's definitely good form to include it.

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6.4. Looping

Besides the `if` and `case` statements, the shell's looping constructs are the workhorse facilities for getting th

6.4.1. for Loops

The `for` loop iterates over a list of objects, executing the loop body for each individual object in turn. The command-line arguments, filenames, or anything else that can be created in list format. In Section 3.2.7.1 , w two-line script to update an XML brochure file:

```
mv atlga.xml atlga.xml.old
```

```
sed 's/Atlanta/&, the capital of the South/' < atlga.xml.old > atlga.xml
```

Now suppose, as is much more likely, that we have a number of XML files that make up our brochure. In t want to make the change in *all* the XML files. The `for` loop is perfect for this:

```
for i in atlbrochure*.xml
```

```
do
```

```
    echo $i
```

```
    mv $i $i.old
```

```
    sed 's/Atlanta/&, the capital of the South/' < $i.old > $i
```

```
done
```

This loop moves each original file to a backup copy by appending a `.old` suffix, and then processing the fil create the new file. It also prints the filename as a sort of running progress indicator, which is helpful wher files to process.

The `in list` part of the `for` loop is optional. When omitted, the shell loops over the command-line argum Specifically, it's as if you had typed `for i in "$@"`:

```
for i          # loop over command-line args
```

```

do
    case $i in
        -f) ...
            ;;
        ...
    esac
done

```

6.4.2. while and until Loops

The shell's `while` and `until` loops are similar to loops in conventional programming languages. The syntax

<code>while</code>	<i>condition</i>	<code>until</code>	<i>condition</i>
<code>do</code>		<code>do</code>	
	<i>statements</i>		<i>statements</i>
<code>done</code>		<code>done</code>	

As for the `if` statement, *condition* may be a simple list of commands, or commands involving `&&` and `||`

The only difference between `while` and `until` is how the exit status of *condition* is treated. `while` continues as long as *condition* exits successfully. `until` loops as long as *condition* exits unsuccessfully. For exam

<code>pattern=...</code>	<i>pattern controls shortening of</i>
<code>while [-n "\$string"]</code>	<i>While string is not empty</i>
<code>do</code>	
	<i>process current value of \$string</i>
	<i>string=\${string%\$pattern}</i>
	<i>Lop off part of string</i>
<code>done</code>	

In practice, the `until` loop is used much less than the `while` loop, but it can be useful when you need to wait for something to happen. This is shown in Example 6-2.

Example 6-2. Wait for a user to log in, using `until`

```
# wait for specified user to log in, check every 30 seconds

printf "Enter username: "

read user

until who | grep "$user" > /dev/null

do

    sleep 30

done
```

It is possible to pipe *into* a `while` loop, for iterating over each line of input, as shown here:

```
generate data |

    while read name rank serial_no

    do

        ...

    done
```

In such cases, the command used for the `while` loop's condition is usually the `read` command. We present an example later in Section 7.3.1, when discussing here-documents. In Section 7.6, we show that you can also pipe the body of a loop into another command.

6.4.3. `break` and `continue`

Not everything in the shell came straight from Algol 68. The shell borrowed the `break` and `continue` commands from other languages. They are used to leave a loop, or to skip the rest of the loop body, respectively. The `until ...do` wait-for-a-user script in Example 6-2 can be rewritten more conventionally, as shown here in Example 6-3

Example 6-3. Wait for a user to log in, using while and break

```
# wait for specified user to log in, check every 30 seconds

printf "Enter username: "

read user

while true

do

    if who | grep "$user" > /dev/null

    then

        break

    fi

    sleep 30

done
```

The *true* command does nothing but exit successfully. It's used for writing infinite loops—loops that run forever. When you write an infinite loop, you have to place an exit condition in the body of the loop, just as was done here. Analogous, but considerably less-used command, *false*, which does nothing, but it does so unsuccessfully. You can use *false* in an infinite `until false ...` loop.

The *continue* command is used to start the next iteration of a loop early, before reaching the bottom of a loop.

Both the *break* and the *continue* commands take an optional numeric argument. This indicates how many iterations should be broken out of or continued. (Use `$((...))` if the loop count needs to be an expression calculated at runtime.) Here's an example:

```
while condition1                                Outer loop
do ...
    while condition2                            Inner loop
```

```

do ...
    break 2                Break out of outer loop
done
done
...                       Execution continues here after break

```

It is interesting to note that *break* and *continue*, particularly with the ability to break or continue multiple times, compensate in a clean fashion for the absence of a `goto` keyword in the shell language.

6.4.4. shift and Option Processing

We briefly mentioned the *shift* command earlier, in Section 6.1.2.2. *shift* is used when working with command arguments. Its job is to move them left by one (or more). After executing *shift*, the original `$1` is lost; it is the old value of `$2`. The new value of `$2` is the old value of `$3`, and so on. The value of `$#` decreases each time *shift* accepts an optional argument, which is the number of places to shift by: the default is 1.

Simple option processing is often done by combining *while*, *case*, *break*, and *shift*, like so:

```

# set flag vars to empty
file=  verbose=  quiet=  long=

while [ $# -gt 0 ]           Loop until no args left
do
    case $1 in               Check first arg
        -f)  file=$2
              shift          Shift off "-f" so that shift at end gets 1
              ;;
        -v)  verbose=true
              quiet=
    esac
done

```



```

        ;;
    -q)  quiet=true
        verbose=
        ;;
    -l)  long=true
        ;;
    --)  shift          By convention, - - ends options
        break
        ;;
    -*)  echo $0: $1: unrecognized option >&2
        ;;
    *)  break          Nonoption argument, break while loop
        ;;
esac

shift          Set up for next iteration

done

```

After this loop has finished, the various flag variables are set, and may be tested using *test* or *case* . Any nonoption arguments are still available for further processing in "\$@" .

The *getopts* command simplifies option processing. It understands the POSIX option conventions that allow multiple option letters together, and can be used to loop through command-line arguments one at a time.

getopts

Usage

```
getopts option_spec variable [ arguments ... ]
```

Purpose

To simplify argument processing, and make it possible for shell scripts to easily adhere to POSIX argument processing conventions.

Major options

None.

Behavior

When called repeatedly (such as in a `while` loop), step through the provided command-line arguments or "\$@" if none, exiting nonzero at `--` or the first nonoption argument, or upon error. The *option_spec* describes options and their arguments; see the text for details.

For each valid option, set *variable* to the option letter. If the option has an argument, the argument value is placed in `OPTARG`. At the end of processing, `OPTIND` is set to the number of the first nonoption argument. See text for further details.

Caveats

The *ksh93* version of *getopts* conforms to POSIX, but has many additional features. See the *ksh93* documentation and *Learning the Korn Shell* (O'Reilly).

The first argument to *getopts* is a string listing valid option letters. If an option letter is followed by a colon, the option requires an argument, which must be supplied. Upon encountering such an option, *getopts* places the

value into the variable `OPTARG`. The variable `OPTIND` contains the index of the next argument to be processed and initializes this variable to 1.

The second argument is a variable name. This variable is updated each time `getopts` is called; its value is the option letter. When `getopts` finds an invalid option, it sets the variable to a question mark character. Here is the program using `getopts`:

```
# set flag vars to empty

file=    verbose=    quiet=    long=

while getopts f:vql opt
do
    case $opt in
        f)      file=$OPTARG
                ;;
        v)      verbose=true
                quiet=
                ;;
        q)      quiet=true
                verbose=
                ;;
        l)      long=true
                ;;
    esac
done

shift $((OPTIND - 1))    Remove options, leave arguments
```


Three things are immediately noticeable. First, the test in the case is only on the option letter. The leading `1` removed. Second, the case for `--` is gone: *getopts* handles that automatically. Third, also gone is the default invalid option: *getopts* automatically prints an error message.

Often, though, it's easier to handle errors in the script than to use *getopts*'s default handling. Placing a colon option string as the *first* character makes *getopts* change its behavior in two ways. First, it won't print any error message. Second, besides setting the variable to a question mark, `OPTARG` contains the invalid option letter that was processed. Here's the final version of the option processing loop:

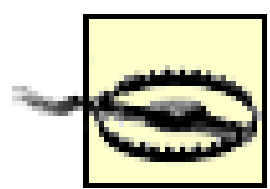
```
# set flag vars to empty
file=    verbose=    quiet=    long=

# leading colon is so we do error handling
while getopts :f:vql opt
do
    case $opt in
        Check option letter
        f)    file=$OPTARG
              ;;
        v)    verbose=true
              quiet=
              ;;
        q)    quiet=true
              verbose=
              ;;
        l)    long=true
              ;;
        '?' )    echo "$0: invalid option -$OPTARG" >&2
```

```
    echo "Usage: $0 [-f file] [-vql] [files ...]" >&2
    exit 1
    ;;
esac

done

shift $((OPTIND - 1))      Remove options, leave arguments
```



The `OPTIND` variable is shared between a parent script and any functions it invokes. A function wishes to use `getopts` to parse its own arguments should reset `OPTIND` to 1. Calling such a function from within the parent script's option processing loop is not advisable. (For this reason, `ks` gives each function its own private copy of `OPTIND`. Once again, caveat emptor.)

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6.5. Functions

As in other languages, a *function* is a separate piece of code that performs some well-defined single task. The function can then be used (called) from multiple places within the larger program.

Functions must be defined before they can be used. This is done either at the beginning of a script, or by having them in a separate file and sourcing them with the "dot" (.) command. (The . command is discussed later on in Section 7.9.) They are defined as shown in Example 6-4.

Example 6-4. Wait for a user to log in, function version

```
# wait_for_user --- wait for a user to log in
#
# usage: wait_for_user user [ sleeptime ]

wait_for_user ( ) {
    until who | grep "$1" > /dev/null
    do
        sleep ${2:-30}
    done
}
```

Functions are invoked (executed) the same way a command is: by providing its name and any corresponding arguments. The `wait_for_user` function can be invoked in one of two ways:

```
wait_for_user tolstoy          Wait for tolstoy, check every 30 seconds
```

```
wait_for_user tolstoy 60      Wait for tolstoy, check every 60 seconds
```


Within a function body, the positional parameters (`$1` , `$2` , etc., `$#` , `$*` , and `$@`) refer to the *function's* arguments. The parent script's arguments are temporarily *shadowed* , or hidden, by the function's arguments. `$0` remains the name of the parent script. When the function finishes, the original command-line arguments are restored.

Within a shell function, the *return* command serves the same function as *exit* and works the same way:

```
answer_the_question ( ) {  
  
    ...  
  
    return 42  
  
}
```

Note that using *exit* in the body of a shell function terminates the entire shell script!

return

Usage

```
return [ exit-value ]
```

Purpose

To return an exit value from a shell function to the calling script.

Major options

None.

Behavior

The default exit status used if none is supplied is the exit status of the last command executed. If that is what you want, it is best to do this explicitly in the shell function:

```
return $?
```

Caveats

Some shells allow the use of *return* within a script but outside of a function body to mean the same as *exit*. This usage isn't recommended, for portability reasons.

Since the *return* statement returns an exit value to the caller, you can use functions in *if* and *while* statements. For example, instead of using *test* to compare two strings, you could use the shell's constructs to do so:

```
# equal --- compare two strings
```

```
equal ( ) {
    case "$1" in
        "$2")    return 0 ;; # they match
    esac

    return 1          # they don't match
}
```

```
if equal "$a" "$b" ...
```

```
if ! equal "$c" "$d" ...
```

One item to note here is the use of double quotes in the *case* pattern list. This forces the value to be

treated as a literal string, rather than as a shell pattern. The quotes around `$1` don't hurt, but aren't necessary here.

Functions return integer exit status values, just like commands. For functions also, zero means success, nonzero means failure. To return some other value, a function should either set a global shell variable, or print the value, with the parent script capturing it using command substitution (see Section 7.6):

```
myfunc ( ) {
    ...
}

...

x=$(myfunc "$@")           Call myfunc, save output
```

Example 5-6 in Section 5.5, showed a nine-stage pipeline to produce a sorted list of SGML/XML tags from an input file. It worked only on the one file named on the command line. We can use a `for` loop for argument processing, and a shell function to encapsulate the pipeline, in order to easily process multiple files. The modified script is shown in Example 6-5.

Example 6-5. Making an SGML tag list from multiple files

```
#!/bin/sh -

# Read one or more HTML/SGML/XML files given on the command
# line containing markup like <tag>word</tag> and output on
# standard output a tab-separated list of
#
#           count word tag filename
#
# sorted by ascending word and tag.
#
# Usage:
```



```

#         taglist xml-files

process( ) {
    cat "$1" |
        sed -e 's#systemitem *role="url"#URL#g' -e 's#/systemitem#/URL#' |
        tr ' ( ){ }[ ]' '\n\n\n\n\n\n\n\n' |
        egrep '>[^<>]+</' |
        awk -F'[<>]' -v FILE="$1" \
            '{ printf("%-31s\t%-15s\t%s\n", $3, $2, FILE) }' |
        sort |
        uniq -c |
        sort -k2 -k3 |
        awk '{
            print ($2 == Last) ? ($0 " <----") : $0
            Last = $2
        }'
}

for f in "$@"
do
    process "$f"
done

```

Functions (at least in the POSIX shell) have no provision for local variables.^[3] Thus, all functions *share*

variables with the parent script; this means you have to be careful not to change something that the parent script doesn't expect to be changed, such as `PATH` . It also means that other state is shared, such as the current directory and traps for signals. (Signals and traps are discussed in Section 13.3.2 .)

^[3] All of `bash` , `ksh88` , `ksh93` , and `zsh` do provide for local variables, but not necessarily using the same syntax.



6.6. Summary

Variables are necessary for any serious programming. Shell variables hold string values, and a large array of operators for use in `${var...}` lets you control the results of variable substitution.

The shell provides a number of special variables (those with nonalphanumeric names, such as `$?` and `$!`), that give you access to special information, such as command exit status. The shell also has a number of special variables with predefined meanings, such as `PS1`, the primary prompt string. The positional parameters and special variables `$*` and `$@` give you access to the arguments used when a script (or function) was invoked. `env`, `export`, and `readonly` give you control over the environment.

Arithmetic expansion with `$(...)` provides full arithmetic capabilities, using the same operators and precedence as in C.

A program's exit status is a small integer number that is made available to the invoker when the program is done. Shell scripts use the `exit` command for this, and shell functions use the `return` command. A shell script can get the exit status of the last command executed in the special variable `$?`.

The exit status is used for control-flow with the `if`, `while`, and `until` statements, and the `!`, `&&` and `||` operators.

The `test` command, and its alias `[...]`, test file attributes and string and numeric values, and are useful in `if`, `while`, and `until` statements.

The `for` loop provides a mechanism for looping over a supplied set of values, be they strings, filenames, or whatever else. `while` and `until` provide more conventional looping, with `break` and `continue` providing additional loop control. The `case` statement provides a multiway comparison facility, similar to the `switch` statement in C and C++.

`getopts`, `shift`, and `$#` provide the tools for processing the command line.

Finally, shell functions let you group related commands together and invoke them as a single unit. They act like a shell script, but the commands are stored in memory, making them more efficient, and they can affect the invoking script's variables and state (such as the current directory).

Chapter 7. Input and Output, Files, and Command Evaluation

This chapter completes the presentation of the shell language. We first look at files, both for I/O and for generating filenames in different ways. Next is command substitution, which lets you use the output of a command as arguments on a command line, and then we continue to focus on the command line by discussing the various kinds of quoting that the shell provides. Finally, we examine evaluation order and discuss those commands that are built into the shell.

7.1. Standard Input, Output, and Error

Standard I/O is perhaps the most fundamental concept in the Software Tools philosophy. The idea is that programs should have a data source, a data sink (where data goes), and a place to report problems. These are referred to by the names *standard input*, *standard output*, and *standard error*, respectively. A program should neither know, nor care, what kind of device lies behind its input and outputs: disk files, terminals, tape drives, network connections, or even another running program! A program can expect these standard places to be already open and ready to use when it starts up.

Many, if not most, Unix programs follow this design. By default, they read standard input, write standard output, and send error messages to standard error. As we saw in [Chapter 5](#), such programs are called *filters* because they "filter" streams of data, each one performing some operation on the data stream and passing it down the pipeline to the next one.

7.2. Reading Lines with read

The *read* command is one of the most important ways to get information *into* a shell program:

```
$ x=abc ; printf "x is now '%s'. Enter new value: " $x ; read x
```

```
x is now 'abc'. Enter new value: PDQ
```

```
$ echo $x
```

```
PDQ
```

read

Usage

```
read [-r] variable ...
```

Purpose

To read information into one or more shell variables.

Major options

-r

Raw read. Don't interpret backslash at end-of-line as meaning line continuation.

Behavior

Lines are read from standard input and split as via shell field splitting (using `$IFS`). The first word is assigned to the first variable, the second to the second, and so on. If there are more words than variables, the trailing words are assigned to the last variable. `read` exits with a failure value upon encountering a non-readable file.

If an input line ends with a backslash, `read` discards the backslash and newline, and continues reading from the next line. The `-r` option forces `read` to treat a final backslash literally.

Caveats

When `read` is used in a pipeline, many shells execute it in a separate process. In this case, any variables set by `read` do not retain their values in the parent shell. This is also true for loops in the middle of pipes.

`read` can read values into multiple variables at one time. In this case, characters in `$IFS` separate the input into words. For example:

```
printf "Enter name, rank, serial number: "
read name rank serno
```

A typical use is processing the `/etc/passwd` file. The standard format is seven colon-separated fields: username, password, numeric user ID, numeric group ID, full name, home directory, and login shell. For example:

```
jones:*:32713:899:Adrian W. Jones/OSD211/555-0123:/home/jones:/bin/ksh
```

You can use a simple loop to process `/etc/passwd` line by line:

```
while IFS=: read user pass uid gid fullname homedir shell
do
    ...      Process each user's line
done < /etc/passwd
```

This loop does *not* say "while `IFS` is equal to colon, read . . ." Rather, the assignment to `IFS` causes `read` to

field separator, without affecting the value of `IFS` for use in the loop body. It changes the value of `IFS` *only* inherited by `read`. This was described in Section 6.1.1. The `while` loop was described in Section 6.4.

`read` exits with a nonzero exit status when it encounters the end of the input file. This terminates the `while`

Placing the redirection from `/etc/passwd` at the end of the loop body looks odd at first. However, it's necessary for subsequent lines each time around the loop. Had the loop been written this way:

```
# Incorrect use of redirection:

while IFS=: read user pass uid gid fullname homedir shell < /etc/passwd
do

    ...      Process each user's line

done
```

it would never terminate! Each time around the loop, the shell would open `/etc/passwd` anew, and `read` would read a new line of the file!

An alternative to the `while read ... do ... done < file` syntax is to use `cat` in a pipeline with the loop:

```
# Easier to read, with tiny efficiency loss in using cat:

cat /etc/passwd |

    while IFS=: read user pass uid gid fullname homedir shell
    do

        ...      Process each user's line

    done
```

This is a general technique: *any* command can be used to pipe input into `read`. This is particularly useful with the `while` loop. In Section 3.2.7, we presented this simple script for copying a directory tree:

```
find /home/tolstoy -type d -print      |      Find all directories

    sed 's;/home/tolstoy;/home/lt/;'   |      Change name, note use of semi-
    sed 's/^/mkdir /'                  |      Insert mkdir command
```

```
sh -x
```

Execute, with shell tracing

However, it can be done easily, and more naturally from a shell programmer's point of view, with a loop:

```
find /home/tolstoy -type d -print    |    Find all directories
sed 's;/home/tolstoy/;/home/lt/;' |    Change name, note use of semi
while read newdir                    Read new directory name
do
    mkdir $newdir                     Make new directory
done
```

(We note in passing that this script isn't perfect. In particular, it doesn't retain the ownership or permissions of the directories.)

If there are more input words than variables, the trailing words are assigned to the last variable. Desirable to avoid this rule: using *read* with a single variable reads an entire input line into that variable.

Since time immemorial, the default behavior of *read* has been to treat a trailing backslash on an input line as a *continuation*. Such a line causes *read* to discard the backslash-newline combination and continue reading the next line:

```
$ printf "Enter name, rank, serial number: " ; read name rank serno
Enter name, rank, serial number: Jones \
> Major \
> 123-45-6789
$ printf "Name: %s, Rank: %s, Serial number: %s\n" $name $rank $serno
Name: Jones, Rank: Major, Serial number: 123-45-6789
```

Occasionally, however, you want to read exactly one line, no matter what it contains. The *-r* option accomplishes this (the *-r* option is a POSIX-ism; many Bourne shells don't have it.) When given *-r*, *read* does not treat a trailing backslash as a continuation:

```
$ read -r name rank serno
```



```
tolstoy \
```

Only two fields provided

```
$ echo $name $rank $serno
```

```
tolstoy \
```

\$serno is empty



< Day Day Up >

7.3. More About Redirections

We have already introduced and used the basic I/O redirection operators: `<`, `>`, `>>`, and `|`. In this section, rest of the available operators and examine the fundamentally important issue of file-descriptor manipulat

7.3.1. Additional Redirection Operators

Here are the additional operators that the shell provides:

Use `>|` with `set -C`

The POSIX shell has an option that prevents accidental file truncation. Executing the command `set` shell's so-called *noclobber* option. When it's enabled, redirections with plain `>` to preexisting files fai operator overrides the *noclobber* option.

Provide inline input with `<<` and `<<-`

Use `program << delimiter` to provide input data within the body of a shell script.

Such data is termed a *here document*. By default, the shell does variable, command, and arithmetic substit body of the here document:

```
cd /home           Move to top of home directories
du -s *           | Generate raw disk usage
sort -nr          | Sort numerically, highest numbers first
sed 10q          | Stop after first 10 lines
while read amount name
do
    mail -s "disk usage warning" $name << EOF
```

Greetings. You are one of the top 10 consumers of disk space on the system. Your home directory uses \$amount disk blocks.

Please clean up unneeded files, as soon as possible.

Thanks,

Your friendly neighborhood system administrator.

EOF

done

This example sends email to the top ten "disk hogs" on the system, asking them to clean up their home directory. (In real life, such messages are seldom effective, but they do make the system administrator feel better.)

If the delimiter is quoted in any fashion, the shell does no processing on the body of the input:

```
$ i=5                                     Set a variab
$ cat << 'E'OF                             Delimiter is
> This is the value of i: $i               Try a variab
> Here is a command substitution: $(echo hello, world)  Try command
> EOF
```

This is the value of i: \$i *Text comes ou*

Here is a command substitution: \$(echo hello, world)

The second form of the here document redirector has a trailing minus sign. In this case, all leading tab characters from the here document and the closing delimiter before being passed to the program as input. (Note that only leading characters are removed, not leading spaces!) This makes shell scripts much easier to read. The revised form is shown in Example 7-1.

Example 7-1. A form letter for disk hogs

```

cd /home           Move to top of home directories

du -s *           | Generate raw disk usage
  sort -nr        | Sort numerically, highest numbers first
    sed 10q       | Stop after first 10 lines

while read amount name
do
    mail -s "disk usage warning" $name <<- EOF

        Greetings. You are one of the top 10 consumers
of disk space on the system.  Your home directory
uses $amount disk blocks.

        Please clean up unneeded files, as soon as possible.

        Thanks ,

        Your friendly neighborhood system administrator.

        EOF
done

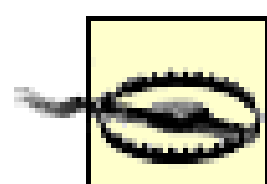
```

Open a file for input and output with <>

Use *program* <> *file* to open *file* for both reading and writing. The default is to open *file* on *st*

Normally, < opens a file read-only, and > opens a file write-only. The <> operator opens the given *fi*

reading and writing. It is up to *program* to be aware of this and take advantage of it; in practice, there is no need for this operator.



The `<>` operator was in the original V7 Bourne shell, but it wasn't documented, and there were problems getting it to work correctly in many environments. For this reason it is not known or used. Although it was standardized in the 1992 POSIX standard, on many systems `/bin/sh` doesn't support it. Thus, you should probably avoid it if absolute portability is a requirement.

Similar caveats apply to `>|`. A feature borrowed from the Korn shell, it has been standard since 1992, although some systems may not support it.

7.3.2. File Descriptor Manipulation

Internally, Unix represents each process's open files with small integer numbers called *file descriptors*. They start at zero, and go up to some system-defined limit on the number of open files. Historically, the shell allowed you to manipulate up to 10 open files: file descriptors 0 through 9. (The POSIX standard leaves it up to the implementer whether it is possible to manipulate file descriptors greater than 9. *bash* lets you, *ksh* does not.)

File descriptors 0, 1, and 2 correspond to standard input, standard output, and standard error, respectively. As mentioned, each program starts out with these file descriptors attached to the terminal (be it a real terminal or a pseudoterminal, such as an X window). By far the most common activity is to change the location of one or more file descriptors, although it is possible to manipulate others as well. As a first example, consider sending a program's standard output to one file and its error messages to another:

```
make 1> results 2> ERRS
```

This sends *make*'s^[1] standard output (file descriptor 1) to *results* and its standard error (file descriptor 2) to *ERRS*. The program never knows the difference: it neither knows nor cares that it isn't sending output or errors to the terminal. Redirecting error messages in a separate file is often useful; this way you can review them with a pager or editor while you work on other problems. Otherwise, a large number of errors would just scroll off the top of your screen. A different take on this is to be cavalier and throw error messages away:

^[1]The *make* program is used for controlling recompilation of source files into object files. However, it has many uses. For more information, see *Managing Projects with GNU make* (O'Reilly).

```
make 1> results 2> /dev/null
```

The explicit `1` in `1> results` isn't necessary: the default file descriptor for output redirections is standard output, file descriptor 1. This next example sends both output and error messages to the same file:

```
make > results 2>&1
```

The redirection `> results` makes file descriptor 1 (standard output) be the file `results`. The subsequent `re` has two parts. `2>` redirects file descriptor 2; i.e., standard error. The `&1` is the shell's notation for "wherever file descriptor 1 is". In this case, file descriptor 1 is the file `results`, so that's where file descriptor 2 is also attached. Note that `2>&1` must be kept together on the command line.

Ordering here is significant: the shell processes redirections left to right. Had the example been:

```
make 2>&1 > results
```

the shell would first send standard error to wherever file descriptor 1 is—which is still the terminal—and *then* file descriptor 1 (standard output) to `results`. Furthermore, the shell processes pipelines before file descriptors, making it possible to send both standard output and standard error down the same pipeline:

```
make 2>&1 | ...
```

Finally, the `exec` command may be used to change the shell's own I/O settings. When used with just I/O redirection arguments, `exec` changes the shell's file descriptors:

```
exec 2> /tmp/$0.log           Redirect shell's own standard error
```

```
exec 3< /some/file           Open new file descriptor 3
```

```
...
```

```
read name rank serno <&3     Read from that file
```




The first example line that redirects the shell's standard error should be used only in a script shells print their prompts on standard error; if you run this command interactively, you won't get a prompt! If you wish to be able to undo a redirection of standard error, save the file descriptor by copying it to a new one. For example:

```
exec 5>&2           Save original standard error on
exec 2> /tmp/$0.log Redirect standard error
...              Stuff here
exec 2>&5          Copy original back to fd 2
exec 5>&-         Close fd 5, no longer needed
```

exec

Usage

```
exec [ program [ arguments ... ] ]
```

Purpose

To replace the shell with a new program, or to change the shell's own I/O settings.

Major options

None.

Behavior

With arguments, replace the shell with the named program, passing the arguments on to it. With jus

I/O redirections, change the shell's own file descriptors.

When used with arguments, *exec* serves a different purpose, which is to run the named program in place of the shell. In other words, the shell starts the new program running in its current process. For example, suppose that you are using the shell for option processing, but that most of your task is accomplished by some other program. You could write a script like this:

```
while [ $# -gt 1 ] Loop over arguments
do
    case $1 in Process options
        -f)    # code for -f here
                ;;
        -q)    # code for -q here
                ;;
        ...
        *)    break ;; Nonoption, break loop
    esac

    shift Move next argument down
done

exec real-app -q "$qargs" -f "$fargs" "$@" Run the program

echo real-app failed, get help! 1>&2 Emergency message
```

When used this way, *exec* is a one-way operation. In other words, control never returns to the script. The only way to return to the shell is if the new program can't be invoked. In that case, you may wish to have "emergency" code that at least prints an error message and then does any other possible clean-up tasks.

 PREV

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7.4. The Full Story on printf

We introduced the *printf* command in Section 2.5.4 . This section completes the description of that command.

printf

Usage

```
printf format [ string ... ]
```

Purpose

To produce output from shell scripts. Since *printf*'s behavior is defined by the POSIX standard, scripts that use it can be more portable than those that use *echo* .

Major options

None.

Behavior

printf uses the *format* string to control the output. Plain characters in the string are printed. Escape sequences as described for *echo* are interpreted. Format specifiers consisting of % and a letter direct formatting of corresponding argument strings. See text for details.

As we saw earlier, the full syntax of the *printf* command has two parts:

```
printf format-string [ arguments ... ]
```

The first part is a string that describes the format specifications; this is best supplied as a string constant in quotes. The second part is an argument list, such as a list of strings or variable values, that correspond to the format specifications. The format string combines text to be output literally with specifications describing the format of subsequent arguments on the *printf* command line. Regular characters are printed verbatim. Escape sequences, similar to those of *echo*, are interpreted and then output as the corresponding character. *Format specifiers*, which begin with the character `%` and end with one of a defined set of letters, control the output following corresponding arguments. *printf*'s escape sequences are described in Table 7-1.

Table 7-1. printf escape sequences

Sequence	Description
<code>\a</code>	Alert character, usually the ASCII BEL character.
<code>\b</code>	Backspace.
<code>\c</code>	Suppress any final newline in the output. ^[2] Furthermore, any characters left in the argument, all following arguments, and any characters left in the format string are ignored (not printed).
<code>\f</code>	Formfeed.
<code>\n</code>	Newline.
<code>\r</code>	Carriage return.
<code>\t</code>	Horizontal tab.
<code>\v</code>	Vertical tab.
<code>\</code>	A literal backslash character.
<code>\ddd</code>	Character represented as a 1- to 3-digit octal value. Valid only in the format string.
<code>\0ddd</code>	Character represented as a 1- to 3-digit octal value.

^[2] Valid only in argument strings under control of the `%b` format specifier.

printf's handling of escape sequences can be a bit confusing. By default, escape sequences are treated spec only in the format string. Escape sequences appearing in argument strings are not interpreted:

```
$ printf "a string, no processing: <%s>\n" "A\nB"
```

```
a string, no processing: <A\nB>
```

When the `%b` format specifier is used, *printf* does interpret escape sequences in argument strings:

```
$ printf "a string, with processing: <%b>\n" "A\nB"
```

```
a string, with processing: <A
```

```
B>
```

As can be seen in Table 7-1, most of the escape sequences are treated identically, whether in the format string or in argument strings printed with `%b`. However, `\c` and `\0 ddd` are only valid for use with `%b`, and `\ ddd` is interpreted in the format string. (We have to admit that the occasional wine cooler is a handy accessory to have when first learning some of the Unix utility idiosyncracies.)

As may be surmised, it is the format specifiers that give *printf* its power and flexibility. The format specifier letters are given in Table 7-2.

Table 7-2. printf format specifiers

Item	Description
<code>%b</code>	The corresponding argument is treated as a string containing escape sequences to be processed. See Table 7-1, earlier in this section.
<code>%c</code>	ASCII character. Print the first character of the corresponding argument.
<code>%d</code> , <code>%i</code>	Decimal integer.
<code>%e</code>	Floating-point format (<code>([-]d .precision e [+]-dd)</code>).
<code>%E</code>	Floating-point format (<code>([-]d .precision E [+]-dd)</code>).
<code>%f</code>	Floating-point format (<code>([-]ddd .precision)</code>).
<code>%g</code>	<code>%e</code> or <code>%f</code> conversion, whichever is shorter, with trailing zeros removed.
<code>%G</code>	<code>%E</code> or <code>%f</code> conversion, whichever is shorter, with trailing zeros removed.
<code>%o</code>	Unsigned octal value.
<code>%s</code>	String.
<code>%u</code>	Unsigned decimal value.
<code>%x</code>	Unsigned hexadecimal number. Use <code>a -f</code> for 10 to 15.
<code>%X</code>	Unsigned hexadecimal number. Use <code>A -F</code> for 10 to 15.
<code>%%</code>	Literal <code>%</code> .

The floating-point formats, `%e`, `%E`, `%f`, `%g`, and `%G`, "need not be supported," according to the POSIX standard. This is because *awk* supports floating-point arithmetic and has its own `printf` statement. Thus, a shell program needing to do formatted printing of floating-point values can use a small *awk* program to do so. However, the `printf` commands built into *bash*, *ksh93*, and *zsh* do support the floating-point formats.

The `printf` command can be used to specify the width and alignment of output fields. To accomplish this, a format expression can take three optional modifiers following the `%` and preceding the format specifier:

```
%flags width.precision format-specifier
```

The *width* of the output field is a numeric value. When you specify a field width, the contents of the field are right-justified by default. You must specify a flag of `-` to get left justification. (The rest of the *flags* are discussed shortly.) Thus, `"%-20s"` outputs a left-justified string in a field 20 characters wide. If the string is longer than 20 characters, the field is padded with spaces to fill. In the following examples, `|` is output to indicate the actual width of the field. The first example right-justifies the text:

```
$ printf "|%10s|\n" hello
```

```
|      hello|
```

The next example left-justifies the text:

```
$ printf "|%-10s|\n" hello
```

```
|hello      |
```

The *precision* modifier is optional. For decimal or floating-point values, it controls the number of digits that appear in the result. For string values, it controls the maximum number of characters from the string that will be printed. The precise meaning varies by format specifier, as shown in Table 7-3.

Table 7-3. Meaning of precision

Conversion	Precision means
<code>%d</code> , <code>%i</code> , <code>%o</code> , <code>%u</code> , <code>%x</code> , <code>%X</code>	The minimum number of digits to print. When the value has fewer digits, it is padded with leading zeros. The default precision is 1.

Conversion	Precision means
<code>%e , %E</code>	The minimum number of digits to print. When the value has fewer digits, it is padded with zeros after the decimal point. The default precision is 6. A precision of 0 inhibits printing decimal point.
<code>%f</code>	The number of digits to the right of the decimal point.
<code>%g , %G</code>	The maximum number of significant digits.
<code>%s</code>	The maximum number of characters to print.

Here are some quick examples of the precision in action:

```
$ printf "%.5d\n" 15
```

```
00015
```

```
$ printf "%.10s\n" "a very long string"
```

```
a very lon
```

```
$ printf "%.2f\n" 123.4567
```

```
123.46
```

The C library `printf()` function allows you to specify the width and precision dynamically, via additional values in the argument list. The POSIX standard doesn't supply this, instead recommending the use of shell variable values in the format string.^[3] Here is an example:

^[3] Some versions of `printf`, such as those built into `ksh93` and `bash`, do support dynamic width and precision specifications.

```
$ width=5  prec=6  myvar=42.123456
```

```
$ printf "|%${width}.${prec}G|\n" $myvar          POSIX
```

```
|42.1235|
```

```
$ printf "|%*.*G|\n" 5 6 $myvar                  ksh93 and bash
```

```
|42.1235|
```

Finally, one or more *flags* may precede the field width and the precision. We've already seen the `-` flag for justification. The complete set of flags is shown in Table 7-4 .

Table 7-4. Flags for printf

Character	Description
-	Left-justify the formatted value within the field.
<i>space</i>	Prefix positive values with a space and negative values with a minus.
+	Always prefix numeric values with a sign, even if the value is positive.
#	Use an alternate form: %o has a preceding 0 ; %x and %X are prefixed with 0x and 0X , respectively ; %e , %E , and %f always have a decimal point in the result; and %g and %G do not have trailing zeros removed.
0	Pad output with zeros, not spaces. This happens only when the field width is wider than the converted result. In the C language, this flag applies to all output formats, even nonnumeric ones. For the <i>printf</i> command, it applies only to the numeric formats.

And again, here are some quick examples:

```
$ printf "|%-10s| |%10s|\n" hello world      Left-, right-justified strings
```

```
|hello      | |      world|
```

```
$ printf "|% d| |% d|\n" 15 -15           Space flag
```

```
| 15| | -15|
```

```
$ printf "%+d %+d\n" 15 -15             + flag
```

```
+15 -15
```

```
$ printf "%x %#x\n" 15 15              # flag
```

```
f 0xf
```

```
$ printf "%05d\n" 15                   0 flag
```

```
00015
```

For the %b , %c , and %s conversion specifiers, the corresponding arguments are treated as strings. Otherwise they're interpreted as C-language numeric constants (leading 0 for octal, and leading 0x or 0X for hexadecimal).

Furthermore, if an argument's first character is a single or double quote, the corresponding numeric value is the ASCII value of the string's second character:

```
$ printf "%s is %d\n" a "'a"
```

```
a is 97
```

When there are more arguments than format specifiers, the format specifiers are reused as needed. This is convenient when the argument list is of unknown length, such as from a wildcard expression. If there are more specifiers left in the *format* string than arguments, the missing values are treated as zero for numeric conversions and as the empty string for string conversions. (This seems to be only marginally useful. It's much better to be sure that you supply the same number of arguments as the format string expects.) If *printf* cannot perform a format conversion, it returns a nonzero exit status.



7.5. Tilde Expansion and Wildcards

The shell does two different expansions related to filenames. The first is *tilde expansion*, and the second is variously termed *wildcard expansion*, *globbing*, or *pathname expansion*.

7.5.1. Tilde Expansion

The shell performs tilde expansion if the first character of a command-line string is a tilde (~), or if the first character after any unquoted colon in the value of a variable assignment (such as for the `PATH` or `CDPATH` variable) is a tilde.

The purpose of tilde expansion is to replace a symbolic representation for a user's home directory with the path to that directory. The user may be named either explicitly, or implicitly, in which case it is the current user running the program:

```
$ vi ~/.profile           Same as vi $HOME/.profile
$ vi ~tolstoy/.profile   Edit user tolstoy's .profile file
```

In the first case, the shell replaces the ~ with `$HOME`, the current user's home directory. In the second case, it looks up user `tolstoy` in the system's password database, and replaces `~tolstoy` with `tolstoy`'s home directory, whatever that may be.

Tilde expansion first appeared in the Berkeley C shell, *cs*. It was intended primarily as an interactive feature. It proved to be very popular, and was adopted by the Korn shell, *bash*, and just about every other modern Bourne-style shell. It thus also found its way into the POSIX standard.

However (and there's always a "however"), many commercial Unix Bourne shell's don't support it. Thus, you should not use tilde expansion inside a shell script that has to be portable.

Tilde expansion has two advantages. First, it is a concise conceptual notation, making it clear to the reader of a shell script what's going on. Second, it avoids hardcoding pathnames into a program. Consider the following fragment:

```
printf "Enter username: "           Print prompt
```

```

read user          Read user

vi /home/$user/.profile  Edit user's .profile file

...

```

The preceding program assumes that all user home directories live in `/home`. If this ever changes (for example, division of users into subdirectories based on department), then the script will have to be rewritten. By using tilde expansion, this can be avoided:

```

printf "Enter username: "  Print prompt

read user          Read user

vi ~$user/.profile      Edit user's .profile file

...

```

Now the program works correctly, no matter where the user's home directory is.

Many shells, such as `ksh88`, `ksh93`, `bash`, and `zsh`, provide additional tilde expansions: see Section 14.3.7, for more information.

7.5.2. Wildcarding

One of the shell's services is to look for special characters in filenames. When it finds these characters, it treats them as patterns to be matched: i.e., a specification of a set of files whose names all match the given pattern. The shell then replaces the pattern on the command line with the sorted set of filenames that match the pattern.^[4]

^[4] Since files are kept within directories in an unspecified order, the shell sorts the results of each wildcard expansion. On some systems, the sorting is subject to an ordering that is appropriate to the system's location, but that is different from the underlying machine collating order. Unix traditionalists can use `export LC_ALL=C` to get the behavior they're used to. This was discussed in Section 2.8.

If you've had any exposure to even the simple command-line environment available under MS-DOS, you're probably familiar with the `*.*` wildcard that matches all filenames in the current directory. Unix shell wildcards are similar, but much more powerful. The basic wildcards are listed in Table 7-5.

Table 7-5. Basic wildcards

Wildcard	Matches
?	Any single character
*	Any string of characters
[<i>set</i>]	Any character in <i>set</i>
[! <i>set</i>]	Any character <i>not</i> in <i>set</i>

The ? wildcard matches any single character, so if your directory contains the files `whizprog.c`, `whizprog` and `whizprog.o`, then the expression `whizprog.?` matches `whizprog.c` and `whizprog.o`, but not `whizprog`.

The asterisk (*) is more powerful and far more widely used; it matches any string of characters. The expression `whizprog.*` matches all three files in the previous paragraph; web designers can use the expression `*.htm` to match their input files.



MS-DOS, MS-Windows, and OpenVMS users should note that there is *nothing special* about the dot (.) in Unix filenames (aside from the leading dot, which "hides" the file); it's just another character. For example, `ls *` lists all files in the current directory; you don't need `*.*` as you do on other systems.

The remaining wildcard is the *set* construct. A set is a list of characters (e.g., `abc`), an inclusive range (e.g., `a-c`), or some combination of the two. If you want the dash character to be part of a list, just list it first or last. This section (which assumes an ASCII environment) should explain things more clearly.

Table 7-6. Using the set construct wildcards

Expression	Single character matched
[<code>abc</code>]	<code>a</code> , <code>b</code> , or <code>c</code>
[<code>,,;</code>]	Period, comma, or semicolon
[<code>-_</code>]	Dash or underscore
[<code>a-c</code>]	<code>a</code> , <code>b</code> , or <code>c</code>
[<code>a-z</code>]	Any lowercase letter
[<code>!0-9</code>]	Any nondigit
[<code>0-9!</code>]	Any digit, or an exclamation mark

Expression	Single character matched
<code>[a-zA-Z]</code>	Any lower- or uppercase letter
<code>[a-zA-Z0-9_-]</code>	Any letter, any digit, underscore, or dash

In the original wildcard example, `whizprog.[co]` and `whizprog.[a-z]` both match `whizprog.c` and `whizprog.o`, but not `whizprog.log`.

An exclamation mark after the left bracket lets you "negate" a set. For example, `[!.;]` matches any character except period and semicolon; `[!a-zA-Z]` matches any character that isn't a letter.

The range notation is handy, but you shouldn't make too many assumptions about what characters are included in a range. It's generally safe to use a range for uppercase letters, lowercase letters, digits, or any subranges thereof (e.g., `[f-q]`, `[2-6]`). Don't use ranges on punctuation characters or mixed-case letters: e.g., `[a-z]` and `[A-z]` are not trusted to include all of the letters and nothing more. The problem is that such ranges are not entirely portable between different types of computers.

Another problem is that modern systems support different *locales*, which are ways of describing how the local character set works. In most countries, the default locale's character set is different from that of plain ASCII. To solve these problems, the POSIX standard introduced *bracket expressions* to denote letters, digits, punctuation, and other kinds of characters in a portable fashion. We discussed bracket expressions in Section 3.2.1.1. The same elements that may appear in regular expression bracket expressions may also be used in shell wildcard patterns. POSIX-conformant shells, but should be avoided in portable shell scripts.

7.5.2.1 Hidden files

By convention, when doing wildcard expansion, Unix shells ignore files whose names begin with a dot. Such files are typically used as program configuration or startup files. Examples include `$HOME/.profile` for the user's profile, `$HOME/.exrc` for the *ex* / *vi* editor, and `$HOME/.inputrc` for the GNU *readline* library used by *bash* and *glibc* (among others).

To see such files, provide an explicit period in front of the pattern. For example:

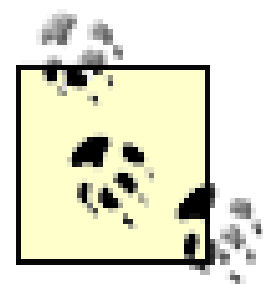
```
echo .* Show hidden files
```

You may use the `-a` (show all) option to `ls` to make it include hidden files in its output:

```
$ ls -la
total 4525
drwxr-xr-x  39 tolstoy  wheel           4096 Nov 19 14:44 .
```



```
drwxr-xr-x  17 root      root          1024 Aug 26 15:56 ..
-rw-----   1 tolstoy  wheel          32 Sep  9 17:14 .MCOP-rando
-rw-----   1 tolstoy  wheel          306 Nov 18 22:52 .Xauthority
-rw-r--r--   1 tolstoy  wheel          142 Sep 19 1995 .Xdefaults
-rw-r--r--   1 tolstoy  wheel          767 Nov 18 16:20 .article
-rw-r--r--   1 tolstoy  wheel          158 Feb 14 2002 .aumixrc
-rw-----   1 tolstoy  wheel        18828 Nov 19 11:35 .bash_histo:
...
```



We cannot emphasize enough that hiding dot files is only a *convention* . It is enforced entirely in user-level software: the kernel doesn't treat dot files any differently from any other files.

7.6. Command Substitution

Command substitution is the process by which the shell runs a command and replaces the command substitution with the output of the executed command. That sounds like a mouthful, but it's pretty straightforward in practice.

There are two forms for command substitution. The first form uses so-called backquotes, or grave accents (` `) to enclose the command to be run:

```
for i in `cd /old/code/dir ; echo *.c`    Generate list of files in /old
do                                         Loop over them
    diff -c /old/code/dir/$i $i | more    Compare old version to new in .
done
```

The shell first executes `cd /old/code/dir ; echo *.c`. The resulting output (a list of files) then becomes the `for` loop.

The backquoted form is the historical method for command substitution, and is supported by POSIX because many scripts exist that use it. However, all but the most simplest uses become complicated quickly. In particular, command substitutions and/or the use of double quotes require careful escaping with the backslash character.

```
$ echo outer `echo inner1 \ `echo inner2\ ` inner1` outer
outer inner1 inner2 inner1 outer
```

This example is contrived, but it illustrates how backquotes must be used. The commands are executed in the following order:

1. `echo inner2` is executed. Its output (the word `inner2`) is placed into the next command to be executed.
2. `echo inner1 inner2 inner1` is executed. Its output (the words `inner1 inner2 inner1`) is placed into the next command to be executed.
3. Finally, `echo outer inner1 inner2 inner1 outer` is executed.

Things get worse with double-quoted strings:

```
$ echo "outer +`echo inner -\`echo \"nested quote\" here\`- inner`+ outer"
outer +inner -nested quote here- inner+ outer
```

For added clarity, the minus signs enclose the inner command substitution, and plus signs enclose the outer command substitution. This style can get pretty messy.

Because nested command substitutions, with or without quoting, quickly become difficult to read, the POSIX shell introduced a new feature from the Korn shell. Instead of using backquotes, enclose the command in `$(...)`. Because this uses only one opening and closing delimiters, it is *much* easier to follow. Compare the earlier examples, redone with the new syntax:

```
$ echo outer $(echo inner1 $(echo inner2) inner1) outer
```

```
outer inner1 inner2 inner1 outer
```

```
$ echo "outer +$(echo inner -$(echo "nested quote" here)- inner)+ outer"
```

```
outer +inner -nested quote here- inner+ outer
```

This is much easier to read. Note also how the embedded double quotes no longer need escaping. This style is recommended for all new development, and it is what we use in many of the examples in this book.

Here is the `for` loop we presented earlier that compared different versions of files from two different directories, using the new syntax:

```
for i in $(cd /old/code/dir ; echo *.c)  Generate list of files in /old/code/dir
do                                       Loop over them
    diff -c /old/code/dir/$i $i        Compare old version to new
done | more                             Run all results through pager
```

The differences here are that the example uses `$(...)` command substitution, and that the output of the `diff` command is piped into the `more` screen-pager program.

7.6.1. Using `sed` for the `head` Command

Earlier, Example 3-1 in Chapter 3 showed a simple version of the `head` command that used `sed` to print the first `n` lines of a file. The real `head` command allows you to specify with an option how many lines to show; e.g., `head -n 10 file`. Traditional pre-POSIX versions of `head` allowed you to specify the number of lines as an option (e.g., `head 10 file`), and many longtime Unix users are used to running `head` that way.

Using command substitution and *sed*, we can provide a slightly modified shell script that works the same version of *head*. It is shown in Example 7-2.

Example 7-2. The head command as a script using sed, revised version

```
# head --- print first n lines
#
# usage:   head -N file

count=$(echo $1 | sed 's/^-//')      # strip leading minus
shift                                # move $1 out of the way
sed ${count}q "$@"
```

When this script is invoked as `head -10 foo.xml`, *sed* ends up being invoked as `sed 10q foo.xml`.

7.6.2. Creating a Mailing List

Consider the following problem. New versions of the various Unix shells appear from time to time, and at are permitted to choose their login shell from among the authorized ones listed in `/etc/shells`. Thus, it w system management to notify users by email when a new version of a particular shell has been installed.

To do this, we need to identify users by login shell and create a mailing list that the installer can use when announcing the new shell version. Since the text of that message is likely to differ at each announcement, v script to send mail directly, but instead, we just want to make a list that we can mail to. Mailing-list format clients, so we make the reasonable assumption that ours only expects a comma-separated list of email addr per line, and does not mind if the last address is followed by a comma.

In this case, a reasonable approach is to make one pass through the password file, creating one output file f with one comma-terminated username per line. Here is the password file that we used in Chapter 5

```
jones:*:32713:899:Adrian W. Jones/OSD211/555-0123:/home/jones:/bin/k:
dorothy:*:123:30:Dorothy Gale/KNS321/555-0044:/home/dorothy:/bin/basl
toto:*:1027:18:Toto Gale/KNS322/555-0045:/home/toto:/bin/tcsh
ben:*:301:10:Ben Franklin/OSD212/555-0022:/home/ben:/bin/bash
```

```

jhancock:*:1457:57:John      Hancock/SIG435/555-0099:/home/jhancock:/bin/
betsy:*:110:20:Betsy       Ross/BMD17/555-0033:/home/betsy:/bin/ksh
tj:*:60:33:Thomas        Jefferson/BMD19/555-0095:/home/tj:/bin/bash
george:*:692:42:George     Washington/BST999/555-0001:/home/george:/bin/

```

The script itself combines variable and command substitution, the *read* command, and a *while* loop to get less than ten lines of executable code! See Example 7-3

Example 7-3. Convert password file to shell mailing list

```

#!/bin/sh

# passwd-to-mailing-list

#

# Generate a mailing list of all users of a particular shell.

#

# Usage:

#  passwd-to-mailing-list < /etc/passwd

#  ypcat passwd | passwd-to-mailing-list

#  niscat passwd.org_dir | passwd-to-mailing-list

# Possibly a bit of overkill:

rm -f /tmp/*.mailing-list

# Read from standard input

while IFS=: read user passwd uid gid name home shell

```

```

do
    shell=${shell:-/bin/sh} # Empty shell field means /bin/sh
    file="/tmp/$(echo $shell | sed -e 's;^/;;' -e 's;/;-ig').mailing-li
    echo $user, >> $file
done

```

As each password file entry is read, the program generates the filename on the fly, based on the shell's filename. The `sed` command removes the leading `/` character, and changes each subsequent `/` to a hyphen. This creates filename `/tmp/bin-bash.mailing-list`. Each user's name and a trailing comma are then appended to the particular file. After running our script, we have the following results:

```
$ cat /tmp/bin-bash.mailing-list
```

```
dorothy,
```

```
ben,
```

```
jhancock,
```

```
tj,
```

```
$ cat /tmp/bin-tcsh.mailing-list
```

```
toto,
```

```
george,
```

```
$ cat /tmp/bin-ksh.mailing-list
```

```
jones,
```

```
betsy,
```

Being able to create mailing lists can be generally useful. For example, if process accounting is enabled, it is possible to create a mailing list for every program on the system by extracting program names and the names of the users who used the program from the process accounting records. Note that `root` privileges are required to access the accounting files. The software varies from vendor to vendor, but the same sort of data is accumulated by all of them, so only minor modifications may be necessary to accommodate their differences. The GNU accounting summary utility, `sa` (see the manual page for `sa`), can produce a report with output lines that look like this:


```
# sa -u

...

jones      0.01 cpu      377k mem      0 io gcc

...
```

That is, we have whitespace-separated fields in which the first entry is a username and the last is a program name. We suggest that we simply filter that output to make it look like password-file data, and then pipe it into our `passwd-to-mailing` program:

```
sa -u | awk '{ print $1 ":::::" $8 }' | sort -u | passwd-to-mailing
```

(The `sort` command sorts the data; the `-u` option removes duplicate lines.) The beauty of Unix filters and pipe data markup, is readily apparent. We don't have to write a new mailing-list creation program to handle accounts; we just need one simple `awk` step and a `sort` step to make the data look like something that we already can handle.

7.6.3. Simple Math: `expr`

The `expr` command is one of the few Unix commands that is poorly designed and hard to use. Although standardized in POSIX, its use in new programs is strongly discouraged, since there are other programs and facilities that can do shell scripting, the major use of `expr` is for shell arithmetic, so that is what we focus on here. Read the `expr` manual page if you're curious about the rest of what it can do.

`expr`'s syntax is picky: operands and operators must each be separate command-line arguments; thus liberal quoting is highly recommended. Many of `expr`'s operators are also shell metacharacters, so careful quoting is also recommended.

`expr` is designed to be used inside of command substitution. Thus, it "returns" values by printing them to standard output, and by using its exit code (`$?` in the shell).

Table 7-7 lists `expr`'s operators, in order of increasing precedence. Operators with the same precedence are listed together.

Table 7-7. `expr` operators

Expression	Meaning
<code>e1 e2</code>	If <code>e1</code> is nonzero or non-null, its value is used. Otherwise, if <code>e2</code> is nonzero or non-null, its value is used. Otherwise, the final value is zero.
<code>e1 & e2</code>	If <code>e1</code> and <code>e2</code> are non-zero or non-null, the return value is that of <code>e1</code> . Otherwise, the final value is zero.

Expression	Meaning
$e1 = e2$	Equal.
$e1 \neq e2$	Not equal.
$e1 < e2$	Less than.
$e1 \leq e2$	Less than or equal to.
$e1 > e2$	Greater than.
$e1 \geq e2$	Greater than or equal to.
	These operators cause <i>expr</i> to print 1 if the indicated comparison is true, 0 otherwise. If <i>b</i> integers, the comparison is numeric; otherwise, it's a string comparison.
$e1 + e2$	The sum of <i>e1</i> and <i>e2</i> .
$e1 - e2$	The difference of <i>e1</i> and <i>e2</i> .
$e1 * e2$	The product of <i>e1</i> and <i>e2</i> .
$e1 / e2$	The integer division of <i>e1</i> by <i>e2</i> (TRuncates).
$e1 \% e2$	The remainder of the integer division of <i>e1</i> by <i>e2</i> (TRuncates).
$e1 : e2$	Match of <i>e1</i> to BRE <i>e2</i> ; see the <i>expr</i> (1) manpage for details.
(<i>expression</i>)	The value of <i>expression</i> ; used for grouping, as in most programming languages.
<i>integer</i>	A number consisting only of digits, although an optional leading minus sign is allowed. S not supported.
<i>string</i>	A string value that cannot be mistaken for a number or an operator.

In new code, you can do almost all of these operations using either *test* or $\$((\dots))$. Regular-expression ma extraction can be done with *sed* or the shell's *case* statement.

Here is an example of simple arithmetic. In a real script, the loop body would do something worthwhile, in printing the loop variable's value:

```

$ i=1                                     Initialize counter
$ while [ "$i" -le 5 ]                   Loop test
> do

```

```

> echo i is $i
i is 1
> i=`expr $i + 1`
i is 2
> done
i is 3
i is 4
i is 5
$ echo $i
6

```

Loop body: real code goes here

Increment loop counter

Show final value

This kind of arithmetic represents 99% of the use of *expr* that you are likely to encounter. We've purposely used *test* (in its alias as `[...]`) and backquotes for command substitution, since that is how *expr* is typically used. You should use the shell's built-in arithmetic substitution:

```

$ i=1
$ while [ "$i" -le 5 ]
> do
> echo i is $i
> i=$((i + 1))
> done
i is 1
i is 2
i is 3
i is 4
i is 5

```

Initialize counter

Loop test

Loop body: real code goes here

Increment loop counter


```
$ echo $i
```

Show final value

```
6
```

For whatever it's worth, *expr* supports 32-bit arithmetic, and on many systems, 64-bit arithmetic. Thus, there counter overflow.



7.7. Quoting

Quoting is how you prevent the shell from interpreting things differently from what you want it to. For example, if you want a command to receive an argument containing metacharacters, such as `*` or `?`, you have to quote the metacharacters. Or, quite typically, when you want to keep something as a single argument that the shell would otherwise treat as separate arguments, you have to quote the arguments. There are three ways to quote things:

Backslash escaping

Preceding a character with a backslash (`\`) tells the shell to treat that character literally. This is the easiest way to quote a single character:

```
$ echo here is a real star: \* and a real question mark: \?
```

```
here is a real star: * and a real question mark: ?
```

Single quotes

Single quotes (`'...'`) force the shell to treat everything between the pair of quotes literally. The shell strips the two quotes, and otherwise leaves the enclosed text completely alone:

```
$ echo 'here are some metacharacters: * ? [abc] ` $ \'
```

```
here are some metacharacters: * ? [abc] ` $ \
```

There is no way to embed a single quote within a single-quoted string. Even backslash is not special within single quotes. (On some systems, a command like `echo 'A\tB'` makes it look like the shell treats backslash specially. However, it is the `echo` command doing the special treatment: see [Table 2-2](#) for more information.)

If you need to mix single and double quotes, you can do so by careful use of backslash escaping and concatenation of differently quoted strings:

```
$ echo 'He said, "How\'\'s tricks?'''
```

```
He said, "How's tricks?"
```

```
$ echo "She replied, \"Movin' along\""
```

```
She replied, "Movin' along"
```

Note that no matter how you do it, though, such combinations are almost always hard to read.

Double quotes

Like single quotes, double quotes ("...") group the enclosed text as a single string. However, the shell does process the enclosed text for escaped characters and for variable, arithmetic, and command substitutions:

```
$ x="I am x"
```

```
$ echo "\$x is \"$x\". Here is some output: '$(echo Hello World)'"
```

```
$x is "I am x". Here is some output: 'Hello World'
```

Within double quotes, the characters `$`, `"`, ```, and `\` must be preceded by a `\` if they are to be included literally. A backslash in front of any other character is not special. The sequence `\-newline` is removed completely, just as when used in the body of a script.

Note that, as shown in the example, single quotes are not special inside double quotes. They don't have to be in matching pairs, nor do they have to be escaped.

In general, use single quotes when you want no processing done at all. Otherwise, use double quotes when you want multiple words to be treated as a single string, but you need the shell to do some work for you. For example, to concatenate the value of one variable onto another, you would use something like this:

```
oldvar="$oldvar $newvar"
```

Append newvar's value to oldvar

7.8. Evaluation Order and eval

The various expansions and substitutions that we've covered are done in a defined order. The POSIX standard details. Here, we describe things at the level a shell programmer needs to understand things. This explanation covers the most petty details: e.g., middles and ends of compound commands, special characters, etc.

Each line that the shell reads from the standard input or a script is called a *pipeline* ; it contains one or more zero or more pipe characters (|). (Actually, several special symbols separate individual commands: semicolon, ampersand, &, logical AND, &&, and logical OR, ||.) For each pipeline it reads, the shell breaks it up into I/O for the pipeline, and then does the following for each command, in the order shown:

1. Splits the command into *tokens* that are separated by the fixed set of *metacharacters* : space, tab, new line, and &. Types of tokens include *words*, *keywords*, I/O redirectors, and semicolons.

It's a subtle point, but variable, command, and arithmetic substitution can be performed while the shell does keyword recognition. This is why the `vi ~$user/.profile` example presented earlier in Section 7.5.1, actually

2. Checks the first token of each command to see if it is a *keyword* with no quotes or backslashes. If it's a keyword and other control-structure openers, {, or (, then the command is actually a *compound command*. The shell internally for the compound command, reads the next command, and starts the process again. If the keyword is a control-structure middle like `then`, `else`, or `do`, an end like `fi` or `done`, the shell signals a syntax error.
3. Checks the first word of each command against the list of *aliases*. If a match is found, it substitutes the alias and goes back to step 1; otherwise it goes on to step 4. (Aliases are intended for interactive shells. As such, they can be used here.) The return to step 1 allows aliases for keywords to be defined: e.g., `alias aslongas=while` or `alias procedure=function`. Note that the shell does not do *recursive* alias expansion: instead, it recognizes the same command, and stops the potential recursion. Alias expansion can be inhibited by quoting the command. protected.
4. Substitutes the user's home directory (`$HOME`) for the tilde character (~) if it is at the beginning of a word or the home directory for ~ *user*.

Tilde substitution (in shells that support it) occurs at the following places:

- o As the first unquoted character of a word on the command line
- o After the = in a variable assignment and after any : in the value of a variable assignment

- o For the *word* part of variable substitutions of the form `${ variable op word }`
5. Performs *parameter (variable) substitution* for any expression that starts with a dollar sign (`$`).
 6. Does *command substitution* for any expression of the form `$(string)` or ``string``.
 7. Evaluates *arithmetic expressions* of the form `$((string))`.
 8. Takes the parts of the line that resulted from parameter, command, and arithmetic substitution and splits them again. This time it uses the characters in `$IFS` as delimiters instead of the set of metacharacters in step 4.

Normally, successive multiple input occurrences of characters in `IFS` act as a single delimiter, which is true only for whitespace characters, such as space and tab. For nonwhitespace characters, this is not true. For example, when reading the colon-separated fields of `/etc/passwd`, two successive colons delimit an empty field:

```
while IFS=: read name passwd uid gid fullname homedir shell
do
    ...
done < /etc/passwd
```

9. Performs *filename generation*, a.k.a. *wildcard expansion*, for any occurrences of `*`, `?`, and `[...]` pairs.
10. Uses the first word as a command following the search order described later in Section 7.9 (i.e., as a special builtin, then as a function, then as a regular built-in command, and finally as the first file found in a search of `PATH`).
11. Runs the command after setting up I/O redirection and other such things.

As shown in Figure 7-1, quoting lets you bypass different parts of the evaluation process. On the flip side, `eval` lets you go through the process again. Performing command-line processing twice may seem strange, but it's a powerful feature: it lets you write scripts that create command strings on the fly and then pass them to the shell for execution. This is particularly useful when you can give scripts intelligence to modify their own behavior as they are running. (This is discussed further in Section 7.10.)

Figure 7-1. Steps in command-line processing



The total sequence of steps shown in Figure 7-1 is pretty complicated. Each step happens inside the shell's internal processing; it's not really possible to get the shell to show you each step as it happens. However, we can

shell's memory and see how the command line is transformed at each phase. We start with the following:

```
$ mkdir /tmp/x                                Create temp
$ cd /tmp/x                                    Change the
$ touch f1 f2                                  Create file
$ f=f y="a b"                                  Assign two
$ echo ~+/${f}[12] $y $(echo cmd subst) $((3 + 2)) > out    A busy co
```

Evaluation proceeds in the steps outlined previously:

1. The command is first split into tokens based on the shell's syntax. Most importantly, the I/O redirection is saved for later. Processing continues with this line, where the extent of each token is as shown on the command:

```
echo ~+/${f}[12] $y $(echo cmd subst) $((3 + 2))
| 1| |--- 2 ---| 3 |----- 4 -----| |-- 5 ---|
```

2. The first word (`echo`) is checked to see if it's a keyword, such as `if` or `for`. In this case it's not, so processing continues with the line unchanged.
3. The first word (still `echo`) is checked to see if it's an alias. It isn't, so processing continues with the line unchanged.
4. All words are scanned for tilde expansion. In this case, `~+` is a `ksh93` and `bash` extension which is equivalent to the current directory. (This is described in Section 14.3.7.) Token 2 is modified, and processing continues with the line:

```
echo /tmp/x/${f}[12] $y $(echo cmd subst) $((3 + 2))
| 1| |----- 2 -----| 3 |----- 4 -----| |-- 5 ---|
```

5. The next step is variable expansion: tokens 2 and 3 are modified. This produces:

```
echo /tmp/x/f[12] a b $(echo cmd subst) $((3 + 2))
| 1| |---- 2 ---| |3| |----- 4 -----| |-- 5 ---|
```

6. Command substitutions are processed next. Note that this can recursively invoke all the steps in the list.

trying to keep things easy to follow, command substitution modifies token 4, producing:

```
echo /tmp/x/f[12] a b cmd subst $((3 + 2))
| 1| |----- 2 ---| |3| |-- 4 --| |-- 5 ---|
```

7. Arithmetic substitution is now performed. Token 5 is modified, and the result is:

```
echo /tmp/x/f[12] a b cmd subst 5
| 1| |----- 2 ---| |3| |-- 4 --| 5
```

8. The results of all the previous expansions are rescanned for the characters in `$IFS`. If found, they act as additional words. For example, the two characters `$Y` made up one word originally, but the expansion stage into two words, `a` and `b`. The same applies for the results of the command substitution, `$(echo ...)` previous token 3 becomes tokens 3 and 4, and the previous token 4 becomes tokens 5 and 6. The result is:

```
echo /tmp/x/f[12] a b cmd subst 5
| 1| |----- 2 ---| 3 4 |5| | 6 | 7
```

9. The last substitution stage is wildcard expansion. Token 2 becomes tokens 2 and 3. The result is:

```
echo /tmp/x/f1 /tmp/x/f2 a b cmd subst 5
| 1| |-- 2 --| |-- 3 --| 4 5 6 | 7 | 8
```

10. The shell is now ready to run the final command. It looks up `echo`. It happens that in both `ksh93` and `dash`, `echo` is built into the shell.

11. The shell actually runs the command. It first performs the `> out` I/O redirection, and then calls `int` to print out the final arguments.

Here is the final result:

```
$ cat out
/tmp/x/f1 /tmp/x/f2 a b cmd subst 5
```

7.8.1. The eval Statement

The *eval* statement tells the shell to take *eval*'s arguments and run them through the command-line process. Here is an example to help you understand the implications of *eval*.

`eval ls` passes the string `ls` to the shell to execute, so the shell prints a list of files in the current directory. This is a bit simplistic: nothing about the string `ls` needs to be sent through the command-processing steps twice. How?

```
listpage="ls | more"
```

```
$listpage
```

Instead of producing a paginated file listing, the shell treats `|` and `more` as arguments to `ls`, and `ls` complains that `|` and `more` don't exist. Why? Because the pipe character appears in step 5 when the shell evaluates the variable *after* it has already processed the pipe characters (in step 1). The variable's expansion isn't even parsed until step 8. As a result, the shell treats `ls` as if it were `ls | more` so that `ls` tries to find files called `|` and `more` in the current directory!

Now consider `eval $listpage` instead of just `$listpage`. When the shell gets to the last step, it runs the command `eval $listpage` with arguments `ls`, `|`, and `more`. This causes the shell to go back to step 1 with a line that consists of these arguments and splits the line into two commands, `ls` and `more`. Each command is processed in the normal way, and the final result is a paginated list of the files in your current directory.

7.8.2. Subshells and Code Blocks

Two other constructs are occasionally useful: *subshells* and *code blocks*.

A subshell is a group of commands enclosed in parentheses. The commands are run in a separate process.^[5] This is useful if you need a small group of commands to run in a different directory, without changing the current directory. For example, the following pipeline, for copying a directory tree from one place to another, was in the original

^[5] The POSIX standard terms it a "subshell environment." This means that the commands need not actually run in a separate process, but they are forbidden to change the environment (variables, current directory, and so on) of the main script. *ksh93* will avoid starting a new process for subshells if it can. Most other shells do create a separate process.

```
tar -cf - . | (cd /newdir; tar -xpf -)
```

The lefthand `tar` command creates a `tar` archive of the current directory, sending it to standard output. This output goes through the pipe to the commands in the subshell on the right. The leading `cd` command first changes to the new directory, then the righthand `tar` command extracts the files from the archive. Note that the shell (or script) has not changed its directory.

A code block is conceptually similar to a subshell, but it does not create a new process. Commands in a code block are enclosed in curly braces, and do affect the main script's state (such as its current directory). For historical reasons, the brace keywords are only recognized as the first symbol in a command. Practically speaking, you should place the closing brace after a newline or after a semicolon. For example:

```

cd /some/directory || {                                     Start code block
    echo could not change to /some/directory! >&2         What went wron
    echo you lose! >&2                                       Snide remark
    exit 1                                                  Terminate whol
}                                                         End of code bloc.

```

I/O redirection may be applied to subshells (as shown in the *two-tar* example) and code blocks. In that case their input or send their output from the redirected source. Table 7-8 summarizes the differences between subshells and code blocks.

Table 7-8. Subshell and code block summary

Construct	Delimiters	Recognized where	
Subshell	()	Anywhere on the line	Ye
Code block	{ }	After newline, semicolon, or keyword	Nc

When to use a subshell versus when to use a code block is mostly a matter of taste and judgment. The primary difference is that a code block shares state with the main script. Thus, a *cd* command affects the main script, as do variable assignments. An *exit* in a code block terminates the entire script. Thus, you should use a subshell when you want the enclosed code to execute *without* affecting the main script. Otherwise, use a code block.

7.9. Built-in Commands

The shell has a number of commands that are *built-in*. This means that the shell itself executes the command, instead of running an external program in a separate process. Furthermore, POSIX distinguishes between "special" built-ins and "regular" built-ins. The built-in commands are listed in Table 7-9. Special built-ins are marked with a `.`. Most of the regular built-ins listed here have to be built-in for the shell to function correctly (e.g., `read`). Others are typically built into the shell only for efficiency (e.g., `true` and `false`). The standard allows other commands to be built-in for efficiency as well, but all regular built-ins must be accessible as separate programs that can be executed directly by other binary programs. `test` is a primary example of a command that often is built into the shell for efficiency reasons.

Table 7-9. POSIX shell built-in commands

Command	Summary
<code>:</code> (colon) ^[6]	Do nothing (just do expansions of arguments).
<code>.</code> (dot)	Read file and execute its contents in current shell.
<i>alias</i>	Set up shorthand for command or command line (interactive use).
<i>bg</i>	Put job in background (interactive use).
<i>break a</i>	Exit from surrounding <code>for</code> , <code>while</code> , or <code>until</code> loop.
<i>cd</i>	Change working directory.
<i>command</i>	Locate built-in and external commands; find a built-in command instead of an identically named function.
<i>continue a</i>	Skip to next iteration of <code>for</code> , <code>while</code> , or <code>until</code> loop.
<i>eval a</i>	Process arguments as a command line.
<i>exec a</i>	Replace shell with given program or change I/O for shell.
<i>exit a</i>	Exit from shell.
<i>export a</i>	Create environment variables.
<i>false</i>	Do nothing, unsuccessfully.
<i>fc</i>	Work with command history (interactive use).

Command	Summary
<i>fg</i>	Put background job in foreground (interactive use).
<i>getopts</i>	Process command-line options.
<i>jobs</i>	List background jobs (interactive use).
<i>kill</i>	Send signals.
<i>newgrp</i>	Start new shell with new group ID (obsolete).
<i>pwd</i>	Print working directory.
<i>read</i>	Read a line from standard input.
<i>readonly a</i>	Make variables read-only (unassignable).
<i>return a</i>	Return from surrounding function.
<i>set a</i>	Set options or positional parameters.
<i>shift a</i>	Shift command-line arguments.
<i>times a</i>	Print accumulated user and system CPU times for the shell and its children.
<i>trap a</i>	Set up signal-catching routine.
<i>true</i>	Do nothing, successfully.
<i>umask</i>	Set/show file permission mask.
<i>unalias</i>	Remove alias definitions (interactive use).
<i>unset a</i>	Remove definitions of variables or functions.
<i>wait</i>	Wait for background job(s) to finish.

^[6] The *source* command in *bash* (borrowed from the BSD C shell) is equivalent to the *dot* command.

The distinction between special and regular built-in commands comes into play when the shell searches for commands to execute. The command-search order is special built-ins first, then shell functions, then regular built-ins, and finally external commands found by searching the directories listed in `$PATH`. This search order makes it possible to define shell functions that extend or override regular shell built-ins.

This feature is used most often in interactive shells. For example, suppose that you would like the shell's prompt to contain the last component of the current directory's pathname. The easiest way to make this happen is to have the shell change `PS1` each time you change directories. You could just write your own function:

```
# chdir --- private function to update PS1 when changing directories

chdir ( ) {
    cd "$@"          Actually change directory
    x=$(pwd)        Get current directory name into variable x
    PS1="$${x##*/}\$ " Lop off leading components, assign to PS1
}

```

The problem is that you have to remember to type `chdir` at the shell instead of `cd`, and if you accidentally forget and type `cd`, you'll be in the new directory, but the prompt won't be changed. For this reason, you can write a function named `cd`, and the shell will find your function *first*, since `cd` is a regular built-in:

```
# cd --- private version to update PS1 when changing directories
#
#      (won't actually work, see text)

```

```
cd ( ) {
    cd "$@"          Actually change directory?!?
    x=$(pwd)        Get current directory name into variable x
    PS1="$${x##*/}\$ " Lop off leading components, assign to PS1
}

```

There is one small fly in the ointment here. How does the shell function access the functionality of the "real" `cd` command? The `cd "$@"` shown here just calls the function again, leading to infinite recursion. What's needed is an "escape hatch" that tells the shell to bypass the search for functions and access the real command. This is the job of the `command` built-in command, whose use is shown in Example 7-4.

Example 7-4. Updating PS1 when changing directories

```
# cd --- private version to update PS1 when changing directories

```



```
cd ( ) {  
    command cd "$@"      Actually change directory  
    x=$(pwd)             Get current directory name into variable x  
    PS1="$${x##*/}\$ "   Lop off leading components, assign to PS1  
}
```

command

Usage

```
command [ -p ] program [ arguments ... ]
```

Purpose

To bypass the shell's inclusion of functions in the search for commands to run. This allows access to built-in versions of commands from functions with the same name as the built-in command.

Major options

-p

When searching for commands, use a default value of `$PATH` that is guaranteed to find the system's utilities.

Behavior

command finds the named *program* by looking for special and regular built-ins, and then searching along `$PATH`. With the `-p` option, it uses a default value for `$PATH`, instead of the current setting.

When *program* is a special built-in command, any syntax errors do not abort the shell, and any preceding variable assignments do not remain in effect after the command has finished.

Caveats

The *command* built-in command is *not* a special built-in command. Woe be to the shell programmer who defines a function named *command* !

The POSIX standard provides the following two additional special qualities for the special built-in commands:

- A syntax error in a special built-in utility may cause a shell executing that utility to abort, while a syntax error in a regular built-in utility shall not cause a shell executing that utility to abort. [...] If a special built-in utility encountering a syntax error does not abort the shell, its exit value shall be nonzero.
- Variable assignments specified with special built-in utilities remain in effect after the built-in completes; this shall not be the case with a regular built-in or other utility.

The second item needs some explanation. As mentioned earlier in Section 6.1.1, you can specify a variable assignment at the front of a command, and the variable will have that value in the environment of the executed command only, without affecting the variable in the current shell or subsequent commands:

```
PATH=/bin:/usr/bin:/usr/ucb awk '...'
```

However, when such an assignment is used with a special built-in command, the assignment stays in effect from then on, even after the special built-in completes.

Table 7-9 lists several commands not otherwise described in this chapter. Most of them are either specialized, or irrelevant for shell scripting, but to be complete here's a brief description of what they do and when to use them:

alias, *unalias*

These are used to define and remove aliases, respectively. The shell expands alias definitions when commands are read. Aliases are primarily useful for interactive shells; e.g., `alias 'rm=rm -i'` to force `rm` to ask for confirmation. The shell does not do recursive alias expansion, thus this definition is valid.

bg , fg , jobs , kill

These commands are used for *job control* , an operating system facility by which jobs may be moved in and out of the background.

fc

Short for "fix command," this command is also intended for interactive use. It manages the shell's saved history of previously executed commands, allowing the interactive user to recall a previous command, edit it, and then re-execute it.

This command was originally developed in *ksh* to provide a feature comparable to the "`! -history`" mechanism in the BSD C shell, *cs**h* . *fc* is now largely superseded by the interactive command-line editing features of *ksh* , *bash* , and *zsh* .

times

This command prints the CPU time accumulated by the shell and all child processes that it has run so far. It is not particularly useful for day-to-day scripting.

umask

This sets the file permission creation mask, and is discussed in Section B.6.1.3 in Appendix B .

Two remaining commands are useful in scripts. The first is *wait* , which waits for background programs to finish. With no arguments, *wait* waits for *all* background jobs to finish. Otherwise, each argument is either the process ID (see Section 13.2) of a background job, or a job-control job specification.

Finally, the `.` (dot) command is important. It is used to read and execute commands contained in a separate file. For example, if you have a number of shell functions that you would like to use in multiple scripts, the right way to do this is to place them in a separate "library" file, and then read them with the dot command:


```
. my_funcs          # read in functions
```

If the named file does not contain a slash, then the shell searches the directories in `$PATH` in order to find the file. The file does not need to be executable, just readable.



Everything in the read-in file is executed *in the current shell*. Thus, variable assignments, function definitions, and directory changes with `cd` all take effect. This is very different from simply running a separate shell script, which runs in a separate process and does not affect the current shell.

7.9.1. The set Command

The `set` command serves several conceptually distinct purposes.^[7] It also uses an unusual option syntax, which the POSIX standard retains for historical compatibility. As a result, it is somewhat hard to learn.

^[7] It thus violates the "do one thing well" Software Tools principle. The reason for this is that Steven Bourne wished to avoid having lots of reserved commands built into the shell.

set

Usage

```
set
set -- [ arguments ... ]
set [ - short-options ] [ -o long-option ] [ arguments ... ]
set [ + short-options ] [ +o long-option ] [ arguments ... ]
set -o
set +o
```

Purpose

To print the names and values of all current shell variables; to set or unset the value of shell *options* (which change the way that the shell behaves); and to change the values of the positional parameters.

Major options

See text.

Behavior

- With no options or arguments, print the names and values of all shell variables in a form that can later be reread by the shell.
- With `--` and arguments, replace the positional parameters with the supplied arguments.
- With short-form options that begin with a `-`, or long-form options that begin with `-o`, enable particular shell options. Additional nonoption arguments set the positional parameters. See text for details.
- With short-form options that begin with a `+`, or long-form options that begin with `+o`, disable particular shell options. See text for details.
- A single `-o` prints the current settings of the shell options "in an unspecified format." *ksh93* and *bash* both print a sorted list, where each line is an option name and the word `on` or `off`:

```
$ set -o                               From bash
allexport                               off
...
```

- A single `+o` prints the current settings of the shell options in a way that they may be later reread by the shell to achieve the same set of option settings.

Caveats

Real shells have additional short and long options, above and beyond the ones described in Table 7-10. Details are given in Chapter 14. Don't use them if portability is a major concern.

Some versions of `/bin/sh` don't recognize `set -o` at all.

The simplest job of the `set` command is to print the names and values of all shell variables in sorted order. This is what it does when invoked with no options or arguments. The output is in a form that may later be reread by the shell, including quoting as appropriate. The idea is that it should be possible for a shell script to save its state, and then restore it later via the `.` (dot) command.

The next job for `set` is to change the positional parameters (`$1` , `$2` , etc.). By using a first argument of `--` to end options to `set` itself, all following arguments replace the positional parameters, even if they start with a minus or plus sign.

Finally, `set` is used to enable or disable *shell options* , which are internal settings that change the way the shell behaves. Here's where the complexity comes in: historically, shell options were described with single letters, enabled with a minus sign and disabled with a plus sign. POSIX added long-name options, enabled or disabled with `-o` or `+o` . Each single-letter option has a corresponding long-name option. Table 7-10 lists the options, along with a brief description of what they do.

Table 7-10. POSIX shell options

Short option	-o form	Description
<code>-a</code>	<code>allexport</code>	Export all subsequently defined variables.
<code>-b</code>	<code>notify</code>	Print job-completion messages right away, instead of waiting for next prompt. Intended for interactive use.
<code>-C</code>	<code>noclobber</code>	Don't allow <code>></code> redirection to existing files. The <code>> </code> operator overrides the setting of this option. Intended for interactive use.
<code>-e</code>	<code>errexit</code>	Exit the shell when a command exits with nonzero status.
<code>-f</code>	<code>noglob</code>	Disable wildcard expansion.
<code>-h</code>		Locate and remember the location of commands called from function bodies when the function is defined, instead of when the function is executed (XSI).
<code>-m</code>	<code>monitor</code>	Enable job control (on by default). Intended for interactive use.
<code>-n</code>	<code>noexec</code>	Read commands and check for syntax errors, but don't execute them. Interactive shells are allowed to ignore this option.
<code>-u</code>	<code>nounset</code>	Treat undefined variables as errors, not as null.
<code>-v</code>	<code>verbose</code>	Print commands (verbatim) before running them.

Short option	-o form	Description
<code>-x</code>	<code>xtrace</code>	Print commands (after expansions) before running them.
	<code>ignoreeof</code>	Disallow Ctrl-D to exit the shell.
	<code>nolog</code>	Disable command history for function definitions.
	<code>vi</code>	Use <i>vi</i> -style command-line editing. Intended for interactive use.

Perhaps surprisingly, *set* does *not* set shell variables (unlike the same command in the BSD C shell). That task is accomplished with simple `variable = value` assignments.



Although not part of POSIX, the command `set -o emacs` is widely implemented (*ksh88*, *ksh93*, *bash*, *zsh*). If you're already comfortable with *emacs*, using this command gives you a one-line mini-screen editor that accepts *emacs* commands for working with your shell history.

The special variable `$-` is a string representing the currently enabled shell options. Each option's short option letter appears in the string if that option is enabled. This can be used to test option settings, like so:

```
case $- in
*C*)      ...           The noclobber option is enabled
        ;;
esac
```

Interestingly enough, while the POSIX standard goes to some lengths to make it possible to save and restore the state of shell variables and traps, there is no defined way to save a list of function definitions for later reuse. This appears to be a simple oversight in the standard. We will show how to do this in Section 14.1

7.10. Summary

The *read* command reads lines and splits the data into fields, for assigning to named shell variables. The *-r* option provides some control over how data is read.

I/O redirection allows you to change the source or destination of one program, or multiple programs running together in a subshell or code block. Besides redirecting to or from files, pipelines let you hook multiple programs together. Here documents provide inline input.

File descriptor manipulation, particularly of file descriptors 1 and 2, is a fundamental operation, used repeatedly in everyday scripting.

printf is a flexible, albeit somewhat complicated, command for generating output. Most of the time, it can be used in a simple manner, but its power is occasionally needed and valuable.

The shell performs a number of expansions (or substitutions) on the text of each command line: tilde expansion (if supported) and wildcards; variable expansion; arithmetic expansion; and command substitution. Wildcarding now includes POSIX character classes for locale-dependent matching of characters in filenames. By convention, "dot files" are not included in wildcard expansions. Variable and arithmetic expansion were described in [Chapter 6](#). Command substitution has two forms: ``...`` is the original form, and `$(...)` is the newer, easier-to-write form.

Quoting protects different source-code elements from special treatment by the shell. Individual characters may be quoted by preceding them with a backslash. Single quotes protect all enclosed characters; no processing is done on the quoted text, and it's impossible to embed a single quote into single-quoted text. Double quotes group the enclosed items into a single word or argument, but variable, arithmetic, and command substitutions are still applied to the contents.

The *eval* command exists to supersede the normal command-line substitution and evaluation order, making it possible for a shell script to build up commands dynamically. This is a powerful facility, but it must be used carefully. Because the shell does so many different kinds of substitutions, it pays to understand the order in which the shell evaluates input lines.

Subshells and code blocks give you two choices for grouping commands. They have different semantics, so you should use them appropriately.

Built-in commands exist either because they change the shell's internal state and must be built-in (such as *cd*), or for efficiency (such as *test*). The command search order that allows functions to be found before regular built-ins, combined with the *command* command, make it possible to write shell

functions that override built-in commands. This has its uses. Of the built-in commands, the *set* command is the most complicated.



< Day Day Up >

Chapter 8. Production Scripts

In this chapter, we move on to some more-complex processing tasks. The examples that we consider are each of general utility, yet they are completely different from one another, and are absent from most Unix toolboxes.

The programs in this chapter include examples of command-line argument parsing, computing on remote hosts, environment variables, job logging, parallel processing, runtime statement evaluation with *eval*, scratch files, shell functions, user-defined initialization files, and consideration of security issues. The programs exercise most of the important statements in the shell language, and give a flavor of how typical Unix shell scripts are written. We developed them for this book, and they have proved to be solid production tools that we use, and rely on, in our daily work.

8.1. Path Searching

Some programs support searching for input files on directory paths, much like the Unix shell searches the current directory list in `PATH` for executable programs. This makes it easier for users, who can refer to files by short names, not be aware of exactly where in the filesystem they are found. Unix doesn't provide any special command for finding a file in a search path, even though there is historical precedent in other operating systems for such a command. It isn't hard to implement a path search, given the right tools.

Rather than implement a path search for one particular program, let's write a new tool that takes as arguments a variable name whose expansion is the desired search path, followed by zero or more file patterns, and have it find all matching files. Our program will then be of general utility in all other software that needs path-search support. (This is an application of the "Detour to build specialized tools" principle that we mentioned in Chapter 1.)

It is sometimes useful to know whether a file is found more than once in the path because you might want to control which version is found, when differing versions exist in the path. Our program should offer the user the option to choose between reporting just the first one found, and reporting all of them. Also, it is becoming standard for software to provide an identifying version number on request, and to offer brief help so that the user often refers to the program's manual pages to get a reminder about an option name. Our program provides those features too.

The complete program is shown later in Example 8-1, but because of its length, we present it here first as a sequence of fragments of descriptive prose and shell code.

We begin with the usual introductory comment block. It starts with the magic line that identifies the program used to execute the script. The comment block then continues with a brief statement of what the program does:

```
#!/bin/sh -

#

# Search for one or more ordinary files or file patterns on a search
# path defined by a specified environment variable.

#

# The output on standard output is normally either the full path
# to the first instance of each file found on the search path,
```

```

# or "filename: not found" on standard error.
#
# The exit code is 0 if all files are found, and otherwise a
# nonzero value equal to the number of files not found (subject
# to the shell exit code limit of 125).
#
# Usage:
#
#     pathfind [--all] [--?] [--help] [--version] envvar pattern(s)
#
# With the --all option, every directory in the path is
# searched, instead of stopping with the first one found.

```

In a networked environment, security has to be given serious consideration. One of the insidious ways that attacked is by manipulating the input field separator, `IFS`, which influences how the shell subsequently interpret this kind of attack, some shells simply reset `IFS` to a standard value before executing any script; others prevent this kind of attack, some shells simply reset `IFS` to a standard value before executing any script; others external setting of that variable. We prevent that by doing the job ourselves as the first action in our script:

```
IFS= '

```

It is hard to see on a screen or a printed page what appears inside the quotes: it is the three-character string newline, a space, and a tab. The default value of `IFS` is space, tab, newline, but if we write it that way, a word editor might eliminate trailing spaces, reducing the string's value to just a newline. It would be better to be explicit escape characters, such as `IFS="\040\t\n"`, but regrettably, the Bourne shell does not support the

There is one subtle point that we need to be aware of when redefining `IFS`. When `"$*"` is expanded to record line, the first character of the value of `IFS` is used as the field separator. We don't use `$*` in this script, so our characters in `IFS` does not matter.

Another common way to break security is to trick software into executing unintended commands. To discover programs that we invoke to be trusted versions, rather than imposters that might be lurking in a user-provided therefore reset `PATH` to a minimal value, saving the original value for later use:


```
OLDPATH= "$PATH"
```

```
PATH=/bin:/usr/bin
```

```
export PATH
```

The *export* statement is crucial: it ensures that our secure search path is inherited by all subprocesses.

The program code continues with five short functions, ordered alphabetically for reader convenience.

The first function, `error()`, prints its arguments on standard error, and then calls a function, to be described later, that does not return:

```
error( )
{
    echo "$@" 1>&2
    usage_and_exit 1
}
```

The second function, `usage()`, writes a brief message showing the expected way to use the program, and then returns. Notice that the function needs the program name, but doesn't hardcode it: it gets it from the variable `PROGRAM`. This variable should be set to the name by which the program was invoked. This permits an installer to rename the program with a different name, in the event that there is a collision with an already-installed program with an identical name and purpose. The function itself is simple:

```
usage( )
{
    echo "Usage: $PROGRAM [--all] [--?] [--help] [--version] envvar path"
}
```

The third function, `usage_and_exit()`, produces the usage message, and then exits with a status code given as an argument:

```
usage_and_exit( )
```

```

{
    usage
    exit $1
}

```

The fourth function, `version()`, displays the program version number on standard output, and returns to `)`, it uses `PROGRAM` to obtain the program name:

```

version( )
{
    echo "$PROGRAM version $VERSION"
}

```

The fifth and last function, `warning()`, prints its arguments on standard error, increments the variable `EXITCODE` the number of warnings issued, and returns to its caller:

```

warning( )
{
    echo "$@" 1>&2
    EXITCODE=`expr $EXITCODE + 1`
}

```

We discussed `expr` in more detail in Section 7.6.3. Its usage here is a common shell idiom for incrementing shells permit the simpler form `EXITCODE=$((EXITCODE + 1))`, but there are still plenty of systems where not yet recognized.

Even though this program is short enough that we don't really need functions, except for avoiding code duplication programming practice to hide irrelevant details: tell what we're doing, but not how we do it.

We have now reached the point where the first statement is executed at runtime. We initialize five variable choice, the user-provided environment variable name, the exit code, the program name, and the program version

```
all=no
```

```
envvar=
```

```
EXITCODE=0
```

```
PROGRAM=`basename $0`
```

```
VERSION=1.0
```

In our program, we follow the convention that lowercase variables are local to functions or to the main code and uppercase ones are shared globally by the entire program. We use a string value, instead of a number, for `EXITCODE` because it makes the program clearer, with negligible runtime cost.



The *basename* command is the traditional tool for extracting the filename part of a complete pathname. It removes the leading characters of its first argument up to and including the final slash, and reports the remainder as output:

```
$ basename resolv.conf           Report the bare filename
```

```
$ basename /etc/resolv.conf       Report the bare filename
```

Descendants of the Bourne shell offer the pattern-matching operators shown in Table 6-2 in Chapter 6, but *basename* is an ordinary command, and thus works with all shells.

With a second argument representing a filename suffix, *basename* strips any matching suffix from the first argument:

```
$ basename /etc/resolv.conf .conf  Report the suffixless filename
```

```
resolv
```

```
$ basename /etc/resolv.conf .pid   Report the bare filename
```

```
resolv.conf
```

Although *basename*'s first argument is normally a pathname, *basename* simply treats it as a text string. It does not require, or check, that it corresponds to a real file.

If the argument is omitted, or is an empty string, *basename*'s behavior is implementation-defined.

The big block of code that follows is typical of command-line argument parsing in all Unix programs: while there are arguments (determined by the argument count, `$#`, being greater than zero), process that argument in a *case* statement.

a code block according to the string value of the argument:

```
while test $# -gt 0
do
    case $1 in
```

The `case` selectors bear some explanation. GNU programming style encourages long, descriptive option names instead of old cryptic, single-character options historically used in Unix. Such brevity is acceptable when the option name in a program is used frequently. Otherwise, descriptive names are better, provided that we permit the user to shorten them to guarantee uniqueness. However, such abbreviations should be avoided when these options are supplied to programs, since that makes the code clearer to a human, and guards against surprises when new options are added in later versions of the program.

There isn't any simple way in the shell language to specify that a long name can be matched by a leading uppercase letter of that name, so we just have to supply all of the alternatives.

Long option names retrofitted into older programs are sometimes distinguished from the original options by a leading hyphen. For new code, we therefore allow either one or two hyphens, which is easily accommodated by distinguishing abbreviations in the case selectors and adding an extra hyphen.

We *could* write the case selectors with wildcard matching: `--a* | -a*)`. However, we view that as unacceptably poor practice, since it allows matches against completely different names than those documented.

For the `-all` option, we simply record the fact that the option was found by resetting the variable `all` to `yes`:

```
--all | --al | --a | -all | -al | -a )
    all=yes
;;
```

The doubled semicolons are mandatory after each case block, except for the last. We could have written this more compactly:

```
--all | --al | --a | -all | -al | -a ) all=yes ;;
```

However, it is easier to verify that all cases are properly terminated when the semicolons appear on their own line. This also facilitates adding extra statements to the block. Careful use of indentation helps to clarify and emphasize local scope in almost any programming language.

The GNU convention is to respond to a `-help` request with a brief summary on standard output of how to

then to exit immediately with a success status code (0 in POSIX and Unix). For larger programs, that sum up a short description of each of the options, but ours is simple enough that extra explanation is not necessary. Since the mark, `?`, is a shell wildcard character, we must quote its use in the case selector:

```
--help | --hel | --he | --h | '--?' | -help | -hel | -he | -h | '-?'
    usage_and_exit 0
;;
```

Similarly, the GNU convention is that a `-version` option should produce a (usually) one-line report on standard error and then immediate successful exit. The same applies to other kinds of status-request options that might be offered like `-author`, `-bug-reports`, `-copyright`, `-license`, `-where-from`, and so on:

```
--version | --versio | --versi | --vers | --ver | --ve | --v | \
-version | -versio | -versi | -vers | -ver | -ve | -v )
    version
    exit 0
;;
```

The case selector `-*)` matches any other option: we report the illegal option on standard error, call the `usage` function to remind the user what was expected, and exit immediately with a failure status code (1):

```
-* )
    error "Unrecognized option: $1"
;;
```

The distinction between standard error and standard output is not always obeyed by software, and when used interactively, the user won't see a difference, since both streams go to the same display device. If the program reports errors and status reports, like the output from the `-help` and `-version` options, should go to standard error to avoid contaminating a pipeline; otherwise, status reports can go to standard output. Since status reports are a relatively new contribution from the GNU world, programming practice is still evolving, and standards have yet to be issued. Neither traditional Unix documentation seems to address this issue.

The final case selector `*)` matches everything else. It is analogous to the `default` selector in the `switch` statement in C and Java languages, and it is always a good idea to include it, even if its body is empty, to demonstrate to the user that the program has no other options.

alternatives have been considered. Here, a match indicates that we have processed all of the options, so we
 Since we have now handled all of the possible cases, we end the *case* statement with the terminating keywo

```
* )
    break
;;
esac
```

We are now at the end of the option loop. Just before its final statement, we use *shift* to discard the first arg
 now been processed, and to move the remaining ones down in the argument list. This guarantees eventual l
 the argument count, \$# , reaches zero:

```
    shift
done
```

On exit from the loop, all options have been handled, and what remain in the argument list are the environ
 and the files to find. We save the variable name in *envvar* and if at least one argument remains, we discard

```
envvar="$1"
test $# -gt 0 && shift
```

The remaining arguments are available as "\$@" . We avoid storing them in a variable, such as with *files="*
 filenames with spaces would be handled incorrectly: the embedded spaces would become argument separa

Since it is possible that the user-supplied environment variable is *PATH* , which we reset on entry for securit
 for this, and update *envvar* accordingly:

```
test "x$envvar" = "xPATH" && envvar=OLDPATH
```

The leading *x* is commonly seen: here, it prevents the expansion of the variable from being confused with a
 expansion starts with a hyphen.

All arguments have now been handled, and we come to the tricky part: the use of the shell *eval* statement. V
 the environment variable in *envvar* , available as "\$envvar " , but we want its expansion. We also want to t
 separators into normal whitespace separators. We therefore construct the argument string '{ "\$envvar" }'
 expands to the equivalent of '{MYPATH}' , if *MYPATH* were the name supplied by the user. The surrounding :
 from further expansion. That string is then given to *eval* , which sees two arguments: *echo* and \${MYPATH}

MYPATH in the environment, finding, say, /bin:/usr/bin:/home/jones/bin , and then evaluates the expansion /bin:/usr/bin:/home/jones/bin , which in turn sends /bin:/usr/bin:/home/jones/bin down the pipe which converts colons to spaces, producing /bin /usr/bin /home/jones/bin . The surrounding backquotes (modern shells) turn that into the value assigned to dirpath . We silence any errors from eval by the usual trick of sending them to /dev/null :

```
dirpath=`eval echo '${"$envvar"}' 2>/dev/null | tr : ' ' `
```

It took a long paragraph to explain the single short statement that sets dirpath , so you can see that it is true that the shell has significant power to the language.

After eval , understanding the rest of the program is pretty easy. First there are some sanity checks to handle error conditions that would cause problems later on: every good program should make such checks, to avoid the garbage-out syndrome. Notice that the last sanity check, for an empty file list, does not cause an error report. Any program that processes a list should always handle an empty list gracefully: if there is nothing to do, then report but success:

```
# sanity checks for error conditions

if test -z "$envvar"

then

    error Environment variable missing or empty

elif test "x$dirpath" = "x$envvar"

then

    error "Broken sh on this platform: cannot expand $envvar"

elif test -z "$dirpath"

then

    error Empty directory search path

elif test $# -eq 0

then

    exit 0

fi
```

We then have three nested loops: the outer one over the argument files or patterns, the middle one over the search path, and the inner one over matching files in a single directory. We want the loops in that order so that reports would be mixed up. Before starting the middle loop, we set `result` to the empty string, since we use it to determine whether anything was found:

```
for pattern in "$@"
do
    result=
    for dir in $dirpath
    do
        for file in $dir/$pattern
        do
```

In the body of the innermost loop, `test -f` tells us whether `$file` exists and is a regular file. (It is also true for a symbolic link that ultimately points to a regular file.) If it does, we record it in `result`, report it on standard output via `echo` command, and if the default of reporting only the first one applies, we break out of the innermost and middle loops. If the loop continues over the remaining matching files, possibly producing more reports:

```
        if test -f "$file"
        then
            result="$file"
            echo $result
            test "$all" = "no" && break 2
        fi
    done
done
```

In this program, there is no need in the middle loop to test whether `$dir` itself exists as a valid directory be

subsumed by the existence check in the innermost loop for `$file` . However, with a more complex loop be desirable, and can be easily done with a single statement: `test -d $dir || continue` .

At the completion of the middle loop, we have searched all of the directories in the search path for `$pattern` holds the name of the last match found or is still empty, if no matches were found.

We test whether the expansion `$result` is empty, and if so, we report the missing file on standard error, increment in `EXITCODE` (inside the `warning` function), and then continue the outer loop with the next file:

```
test -z "$result" && warning "$pattern: not found"
```

```
done
```

At the completion of the outer loop, we have looked for every requested match in every directory in the search path, and are ready to return to the invoking program. There is only one small problem left to deal with: user exit-code values range 0 through 125, as shown in Table 6-5 in Chapter 6 , so we cap the `EXITCODE` value at 125:

```
test $EXITCODE -gt 125 && EXITCODE=125
```

Our program is almost complete: its last statement returns to the parent process with an explicit exit status, which Unix programs should. That way, the parent can test the exit status to determine whether the child process

```
exit $EXITCODE
```

In Example 8-1 , we present the complete text of `pathfind` , without our commentary, so that you can see its total length is about 90 lines, ignoring comments and empty lines.

Example 8-1. Searching a path for input files

```
#!/bin/sh -
#
# Search for one or more ordinary files or file patterns on a search
# path defined by a specified environment variable.
#
# The output on standard output is normally either the full path
# to the first instance of each file found on the search path,
```



```
# or "filename: not found" on standard error.
#
# The exit code is 0 if all files are found, and otherwise a
# nonzero value equal to the number of files not found (subject
# to the shell exit code limit of 125).
#
# Usage:
#     pathfind [--all] [--?] [--help] [--version] envvar pattern(s)
#
# With the --all option, every directory in the path is
# searched, instead of stopping with the first one found.

IFS='
'

OLDPATH="$PATH"

PATH=/bin:/usr/bin

export PATH

error( )
{
    echo "$@" 1>&2
}
```

```
        usage_and_exit 1
    }

usage( )
{
    echo "Usage: $PROGRAM [--all] [--?] [--help] [--version] envvar pat
}

usage_and_exit( )
{
    usage
    exit $1
}

version( )
{
    echo "$PROGRAM version $VERSION"
}

warning( )
{
    echo "$@" 1>&2

    EXITCODE=`expr $EXITCODE + 1`
}
```

```
}

all=no

envvar=

EXITCODE=0

PROGRAM=`basename $0`

VERSION=1.0

while test $# -gt 0
do

    case $1 in

        --all | --al | --a | -all | -al | -a )
            all=yes
            ;;

        --help | --hel | --he | --h | '--?' | -help | -hel | -he | -h | '-?'
            usage_and_exit 0
            ;;

        --version | --versio | --versi | --vers | --ver | --ve | --v | \
        -version | -versio | -versi | -vers | -ver | -ve | -v )
            version
            exit 0
            ;;

        -* )
```



```
        error "Unrecognized option: $1"
    ;;
*)
    break
    ;;
esac

shift

done

envvar="$1"

test $# -gt 0 && shift

test "x$envvar" = "xPATH" && envvar=OLDPATH

dirpath=`eval echo '${"$envvar"}' 2>/dev/null | tr : ' '`

# sanity checks for error conditions

if test -z "$envvar"

then

    error Environment variable missing or empty

elif test "x$dirpath" = "x$envvar"

then

    error "Broken sh on this platform: cannot expand $envvar"
```

```
elif test -z "$dirpath"
then
    error Empty directory search path
elif test $# -eq 0
then
    exit 0
fi

for pattern in "$@"
do
    result=
    for dir in $dirpath
    do
        for file in $dir/$pattern
        do
            if test -f "$file"
            then
                result="$file"
                echo $result
                test "$all" = "no" && break 2
            fi
        done
    done
done
```

```

    test -z "$result" && warning "$pattern: not found"

done

# Limit exit status to common Unix practice

test $EXITCODE -gt 125 && EXITCODE=125

exit $EXITCODE

```

Let's wrap up this section with some simple tests of our program, using a search path, `PATH`, that Unix systems use. Each test includes a display of the exit code, `$?`, so that we can verify the error handling. First, we check the help options:

```
$ pathfind -h
```

```
Usage: pathfind [--all] [--?] [--help] [--version] envvar pattern(s)
```

```
$ echo $?
```

```
0
```

```
$ pathfind --version
```

```
pathfind version 1.0
```

```
$ echo $?
```

Next, we provoke some error reports with bad options, and missing arguments:

```
$ pathfind --help-me-out
```

```
Unrecognized option: --help-me-out
```

```
Usage: pathfind [--all] [--?] [--help] [--version] envvar pattern(s)
```

```
$ echo $?
```


1

```
$ pathfind
```

Environment variable missing or empty

Usage: pathfind [--all] [--?] [--help] [--version] envvar pattern(s)

```
$ echo $?
```

1

```
$ pathfind NOSUCHPATH ls
```

Empty directory search path

Usage: pathfind [--all] [--?] [--help] [--version] envvar pattern(s)

```
$ echo $?
```

1

Then we supply some nonsense filenames:

```
$ pathfind -a PATH foobar
```

foobar: not found

```
$ echo $?
```

1

```
$ pathfind -a PATH "name with spaces"
```

name with spaces: not found

```
$ echo $?
```

1

The empty filename list test is next:

```
$ pathfind PATH
```

```
$ echo $?
```

```
0
```

Here's what happens when a quickly typed Ctrl-C interrupts the running program:

```
$ pathfind PATH foo
```

```
^C
```

```
$ echo $?
```

```
130
```

The exit code is $128 + 2$, indicating that signal number 2 was caught and terminated the program. On this platform, INT signal, corresponding to interactive input of the keyboard interrupt character.

So far, error reporting is exactly as we intended. Now let's search for files that we know exist, and exercise

```
$ pathfind PATH ls
```

```
/usr/local/bin/ls
```

```
$ echo $?
```

```
0
```

```
$ pathfind -a PATH ls
```

```
/usr/local/bin/ls
```

```
/bin/ls
```

```
$ echo $?
```

Next, we check the handling of a quoted wildcard pattern that must match files that we know exist:

```
$ pathfind -a PATH '?sh'
```

```
/usr/local/bin/ksh
```

```
/usr/local/bin/zsh
```

```
/bin/csh
```

```
/usr/bin/rsh
```

```
/usr/bin/ssh
```

Then we do the same for a pattern that should not match anything:

```
$ pathfind -a PATH '*junk*'
```

```
*junk*: not found
```

Now for a big test: find some C and C++ compilers on this system:

```
$ pathfind -a PATH c89 c99 cc c++ CC gcc g++ icc lcc pgcc pgCC
```

```
c89: not found
```

```
c99: not found
```

```
/usr/bin/cc
```

```
/usr/local/bin/c++
```

```
/usr/bin/c++
```

```
CC: not found
```

```
/usr/local/bin/gcc
```

```
/usr/bin/gcc
```

```
/usr/local/gnat/bin/gcc
```

```
/usr/local/bin/g++
```

```
/usr/bin/g++
```



```
/opt/intel_cc_80/bin/icc
/usr/local/sys/intel/compiler70/ia32/bin/icc
/usr/local/bin/lcc
/usr/local/sys/pgi/pgi/linux86/bin/pgcc
/usr/local/sys/pgi/pgi/linux86/bin/pgCC
$ echo $?
3
```

An *awk* one-liner lets us verify that the exit-code counter logic works as intended. We try 150 nonexistent files and it correctly caps at 125:

```
$ pathfind PATH $(awk 'BEGIN { while (n < 150) printf("x.%d ", ++n) }'
x.1: not found
...
x.150: not found

$ echo $?
125
```

Our final test verifies that standard error and standard output are handled as promised, by capturing the two files, and then showing their contents:

```
$ pathfind -a PATH c89 gcc g++ >foo.out 2>foo.err
$ echo $?
1

$ cat foo.out
```

```
/usr/local/bin/gcc
```

```
/usr/bin/gcc
```

```
/usr/local/gnat/bin/gcc
```

```
/usr/local/bin/g++
```

```
/usr/bin/g++
```

```
$ cat foo.err
```

```
c89: not found
```

At this point, we can probably declare our *pathfind* command a success, although some shell wizard might hole^[1] in it, and there is no substitute for extensive testing, particularly with unexpected input, such as from footnote in Section B.3 in Appendix B . Ideally, testing should exercise every combination of legal, and at least one illegal, argument. Since we have three main option choices, each with several abbreviations, there are $(6 + 1) \times 10 = 70$ option combinations, and each of these needs to be tested with zero, one, two, and at least three remaining arguments. However, when we put on our testing hat, we must first view the program as a black box whose contents are not known and whose behavior is documented to behave a certain way. Later, we should put on a different testing hat, sneak inside the program knowing how it works, try hard to figure out how to break it. Also, test data needs to be devised that can be applied to every single line of the program. Exhaustive testing is tedious!

^[1] Notable security holes include altering the input field separator (`IFS`); substituting rogue commands for trusted ones by always sneaking backquoted commands, shell metacharacters, and control characters (including NUL and newline) into arguments; passing arguments that are too long for various internal shell resource limits; and runtime interrupts; and passing arguments that are too long for various internal shell resource limits.

Because undocumented software is likely to be unusable software, and because few books describe how to develop a manual page for *pathfind* in Appendix A .

pathfind has proved a valuable exercise. Besides being a handy new tool that isn't available in the standard Unix toolboxes, it has all the major elements of most Unix programs: argument parsing, option handling, and data processing. We have also shown three steps that can be taken to eliminate some notorious security holes: the initial shell command line with the `-` option, and immediately setting `IFS` and `PATH` . Serendipitously, a good idea can be reused, with minor modifications, for the next shell script that you write: the leading comment banner, the `IFS` and `PATH` , the five helper functions, the *while* and *case* statements for argument processing, and at least the files collected from the command line.

As an exercise, you might consider what needs to be changed for these extensions to *pathfind* :

- To save redirections of standard output and standard error to `/dev/null`, add a `-quiet` option to suppress the only indication of whether a match was found is the exit code. There is precedence for this program in `cmp`'s `-s` option and `grep`'s `-q` option.
- Add a `-trace` option to echo on standard error the full path for every file tested.
- Add a `-test x` option to allow the `test` option `-f` to be replaced by some other one, such as `-h` (file is a directory), `-r` (file is readable), `-x` (file is executable), and so on.
- Make `pathfind` act like a filter: when no files are named on the command line, it should read a list of files from standard input. How does this affect the program's structure and organization?
- Patch any security holes that you can find, such as those listed in the most recent footnote.

8.2. Automating Software Builds

Because Unix runs on so many different platforms, it is common practice to build software packages from installing binary distributions. Large Unix sites often have multiple platforms, so their managers have the packages on several systems. This is clearly a case for automation.

Many software developers now adopt software-packaging conventions developed within the GNU Project.

- Packages that are distributed in compressed archive files named `package-x.y.z.tar.gz` (or `package-x.y.z.tar.bz2`) are unbundled into a directory named `package-x.y.z`.
- A top-level `configure` script, usually generated automatically by the GNU `autoconf` command from a `configure.in` or `configure.ac` file. Executing that script, sometimes with command-line options, produces a header file, usually called `config.h`, a customized `Makefile`, derived from the template file `Makefile.in`, and other files.
- A standard set of `Makefile` targets that is documented in *The GNU Coding Standards*, among them `check` (run validation tests), `clean` (remove unneeded intermediate files), `distclean` (restore the directory to its original state) and `install` (install all needed files on the local system).
- Installed files that reside in directories under a default tree defined by the variable `prefix` in the `Makefile` at configure time with the `-prefix=dir` command-line option, or supplied via a local system-wide custom `prefix` is `/usr/local`, but an unprivileged user could use something like `$HOME/local`, or better, `$HOME/arch` is a command that prints a short phrase that defines the platform uniquely. GNU/Linux and Sun Solaris use `arch`. On other platforms, we install our own implementations, usually just a simple shell-script wrapper around the `install` command.

The task is then to make a script that, given a list of packages, finds their source distributions in one of several locations on the current system, copies them to each of a list of remote hosts, unbundles them there, and builds and validates them. It is unwise to automate the installation step: the build logs first need to be examined carefully.

This script must be usable by any user at any Unix site, so we cannot embed information about particular hosts. Instead, that the user has provided two customization files: `directories` to list places to look for the package distributions, and `hosts` to list usernames, remote hostnames, remote build directories, and special environment variables. We place these files in a hidden directory, `$HOME/.build`, to reduce clutter. However, since the list of source directories is likely to change from site to site, we include a reasonable default list so that the `directories` file may not be needed.

A build should sometimes be done on only a subset of the normal build hosts, or with archive files in unusual locations. The script should make it possible to set those values on the command line.

The script that we develop here can be invoked like this:

```
$ build-all coreutils-5.2.1 gawk-3.1.4           Build two packages on
```

```
$ build-all --on loaner.example.com gnupg-1.2.4   Build one package on
```

```
$ build-all --source $HOME/work butter-0.3.7     Build package from 1
```

These commands do a *lot* of work. Here is an outline of the steps that they carry out for each specified software package, on the default, or selected, build hosts:

1. Find the package distribution in the local filesystem.
2. Copy the distribution to the remote build host.
3. Initiate login connections on the remote host.
4. Change to the remote build directory and unbundle the distribution file.
5. Change to the package build directory and configure, build, and test the package.
6. Record all of the output on the initiating host in separate log files for each package and build environment.

The builds on the remote hosts proceed in parallel, so the total wall-clock time required is that for the slowest build plus the sum of the individual times. Thanks to *build-all*, builds in up to 100 environments are routine for us, and for package developers.

The *build-all* script is long, so we present it in parts, with surrounding commentary, and then for reader convenience the complete program later in this chapter, in Example 8-2 .

We begin with the usual introductory comment header:

```
#!/bin/sh -

# Build one or more packages in parallel on one or more build hosts.

#

# Usage:
```

```

#      build-all [ --? ]
#
#      [ --all "." ]
#
#      [ --cd "." ]
#
#      [ --check "." ]
#
#      [ --configure "." ]
#
#      [ --environment "." ]
#
#      [ --help ]
#
#      [ --logdirectory dir ]
#
#      [ --on "[user@]host[:dir][,envfile] ..." ]
#
#      [ --source "dir ..." ]
#
#      [ --userhosts "file(s)" ]
#
#      [ --version ]
#
#      package(s)
#
# Optional initialization files:
#
#      $HOME/.build/directories      list of source directories
#
#      $HOME/.build/userhosts        list of [user@]host[:dir][,envf

```

We initialize the input field separator, `IFS`, to newline-space-tab:

```
IFS='

```

```

'
```

Next, we set the search path to a limited list and make it global with `export`, so that all subprocesses on the

```
PATH=/usr/local/bin:/bin:/usr/bin
```



```
export PATH
```

We set the permission mask (see Section B.6.1.3 in Appendix B) to allow full access for user and group, and a group is given full access because, on some of our systems, more than one system manager handles software managers all belong to a common trusted group. The same mask is needed later on the remote systems, so we use the convention by giving it an uppercase name:

```
UMASK=002
```

```
umask $UMASK
```

It proves convenient to delegate part of the work to separate functions, so that we can limit code blocks to small functions that are defined at this point in the program. However, for tutorial purposes, we delay their presentation until the main body of the program.

We need a few variables, most initially empty, to collect command-line settings:

ALLTARGETS=	<i>Programs or make targets to build</i>
altlogdir=	<i>Alternative location for log files</i>
altsrkdirs=	<i>Alternative location for source files</i>
ALTUSERHOSTS=	<i>File with list of additional hosts</i>
CHECKTARGETS=check	<i>Make target name to run package check</i>
CONFIGUREDIR=.	<i>Subdirectory with configure scripts</i>
CONFIGUREFLAGS=	<i>Special flags for configure program</i>
LOGDIR=	<i>Local directory to hold log files</i>
userhosts=	<i>Additional build hosts named on command line</i>

We also need to refer a few times to the directory where *build-all*'s initialization files are found, so we give

```
BUILDHOME=$HOME/.build
```

Two scripts, executed on the remote host in the context of the login shell at the beginning and end of the build, handle customization and log-file reports. They overcome a secure-shell (*ssh*) problem with login shells of *ksh* or *zsh* where `$HOME/.profile` unless they are started as login shells, and the secure shell doesn't arrange for that to happen.

command arguments, as *build-all* does:

```
BUILDBEGIN= ./ .build/begin
```

```
BUILDEND= ./ .build/end
```

As in *pathfind* in Example 8-1 , warnings contribute to a final exit code:

```
EXITCODE=0
```

There are no default extra environment variables:

```
EXTRAENVIRONMENT= Any extra environment variable
```

The program name is needed later, so we save its value and its version number:

```
PROGRAM=`basename $0` Remember program name
```

```
VERSION=1.0 Record program version number
```

We include timestamps in the build-log filenames, using the odometer style requested by the date format in filenames that sort in time order. Apart from punctuation, this is the format recommended in ISO 8601:2000.^[2] way later on the remote hosts, so we want the complex date format to be defined in just one place:

^[2] *Data elements and interchange formats-Information interchange-Representation of dates and times* , available at <http://www.iso.org>. That standard writes dates in the form YYYY-MM-DDThh:mm:ss or YYYYMMDDThhmmss. The colons in the first form are for portability reasons, and the second form is hard for humans to read.

```
DATEFLAGS=" +%Y.%m.%d.%H.%M.%S "
```

At our sites, we communicate with remote hosts using the secure shell, and we need both *scp* and *ssh* . Site: insecure *remote shell* could change them to *rcp* and *rsh* . During development, we set these variables to "ec that the logs record what would have been done, without actually doing it:

```
SCP=scp
```

```
SSH=ssh
```

Depending on user and system configuration file settings, *ssh* may create a separate encrypted channel for . almost never require that feature in software builds, so we reduce startup overhead by turning it off with th the `SSHFLAGS` environment variable supplies a different set of options:

```
SSHFLAGS=${SSHFLAGS--x}
```

It proves useful to permit shell-style comments in initialization files. `STRIPCOMMENTS` provides a simple way that the comment character does not otherwise appear in the files:

```
STRIPCOMMENTS='sed -e s/#.*$//'
```

We also need a filter to indent a data stream (for better-looking output), and another to replace newlines by

```
INDENT="awk '{ print "\t\t\t" \$0 }'"
```

```
JOINLINES="tr '\n' '\040'"
```

Definitions of the two optional initialization files come next:

```
defaultdirectories=$BUILDHOME/directories
```

```
defaultuserhosts=$BUILDHOME/userhosts
```

The final initialization sets the list of source directories:

```
SRCDIRS="`$STRIPCOMMENTS $defaultdirectories 2> /dev/null`"
```

Since command substitution replaces newlines by spaces and collapses runs of whitespace, directories in the file are written one or more per line.

If the user customization file does not exist, `STRIPCOMMENTS` produces an empty string in `SRCDIRS`, so we test and reset `SRCDIRS` to a reasonable default list honed by years of experience:

```
test -z "$SRCDIRS" && \
    SRCDIRS="
        .
        /usr/local/src
        /usr/local/gnu/src
        $HOME/src
        $HOME/gnu/src"
```

```

/tmp
/usr/tmp
/var/tmp
"

```

A backslash following the `||` and `&&` operators at end-of-line is required for the C-shell family, and is harmful for the Bourne shell family. The current directory (`.`) is a member of this list because we might have just downloaded to an arbitrary location and we want to try to build.

Now that initializations have been taken care of, we are ready to process the command-line options. This is done in all shell scripts: *while* an argument remains, select a suitable branch of a *case* statement to process the argument, shift the argument list down, and continue the loop. Any branch that needs to consume another argument first does so. Before, we permit both single- and double-hyphen forms of options, and we allow them to be abbreviated to the minimum.

```

while test $# -gt 0
do

```

```

    case $1 in

```

The *-all*, *-cd*, *-check*, and *-configure* cases save the following argument, discarding any previously saved arguments.

```

        --all | --al | --a | -all | -al | -a )

```

```

            shift

```

```

            ALLTARGETS="$1"

```

```

        ;;

```

```

        --cd | -cd )

```

```

            shift

```

```

            CONFIGUREDIR="$1"

```

```

        ;;

```



```

--check | --chec | --che | --ch | -check | -chec | -che | -ch )
    shift
    CHECKTARGETS="$1"
    ;;

--configure | --configur | --configu | --config | --confi | \
--conf | --con | --co | \
-configure | -configur | -configu | -config | -confi | \
-conf | -con | -co )
    shift
    CONFIGUREFLAGS="$1"
    ;;

```

The *-environment* option provides a way to supply one-time settings of configure-time environment variables without having to change build configuration files:

```

--environment | --environmen | --environme | --environm | --environ
--enviro | --envir | --envi | --env | --en | --e | \
-environment | -environmen | -environme | -environm | -environ | \
-enviro | -envir | -envi | -env | -en | -e )
    shift
    EXTRAENVIRONMENT="$1"
    ;;

```

The *-help* case calls one of our yet-to-be-shown functions, and terminates the program:

```

--help | --hel | --he | --h | '--?' | -help | -hel | -he | -h | '-?'
    usage_and_exit 0
;;

```

The *-logdirectory* case also saves the following argument, discarding any saved value:

```

--logdirectory | --logdirector | --logdirecto | --logdirect | \
--logdirec | --logdire | --logdir | --logdi | --logd | --log | \
--lo | --l | \
-logdirectory | -logdirector | -logdirecto | -logdirect | \
-logdirec | -logdire | -logdir | -logdi | -logd | -log | -lo | -l )
    shift
    altlogdir="$1"
;;

```

The `altlogdir` variable names the directory where all of the build log files are written, if the default locati

The *-on* and *-source* cases merely accumulate arguments, so the user can write `-s "/this/dir /that/c`
`/that/dir :`

```

--on | --o | -on | -o )
    shift
    userhosts="$userhosts $1"
;;

--source | --sourc | --sour | --sou | --so | --s | \
-source | -sourc | -sour | -sou | -so | -s )
    shift

```

```

    altsrkdirs="$altsrkdirs $1"
;;

```

Because `altsrkdirs` separates list elements with a space, directories with spaces in their names will not be such names.

The `-userhosts` case also accumulates arguments, but with the additional convenience of checking an alternate, we can relegate the work to a function:

```

--userhosts | --userhost | --userhos | --userho | --userh | \
--user | --use | --us | --u | \
-userhosts | -userhost | -userhos | -userho | -userh | \
-user | -use | -us | -u )
    shift
    set_userhosts $1
;;

```

The `-version` case displays a version number and exits with a success status code:

```

--version | --versio | --versi | --vers | --ver | --ve | --v | \
-version | -versio | -versi | -vers | -ver | -ve | -v )
    version
    exit 0
;;

```

The next-to-last case catches any unrecognized options and terminates with an error:

```

-*)
    error "Unrecognized option: $1"
;;

```


The last case matches anything but an option name, so it must be a package name, and we leave the option

```
* )
    break
;;

esac
```

A *shift* discards the just-processed argument, and we continue with the next loop iteration:

```
    shift
done
```

We need a mail-client program to report log-file locations. Unfortunately, some systems have a low-level *n* accept a subject line, but have a *mailx* command that does. Other systems lack *mailx*, but have subject-line have both, with one of them a link to the other. Because *build-all* must run on any flavor of Unix without *c* the preferred mail-client name. Instead, we have to search for it dynamically using a list that we found by *ε* flavors of Unix:

```
for MAIL in /bin/mailx /usr/bin/mailx /usr/sbin/mailx /usr/ucb/mailx \
            /bin/mail /usr/bin/mail
do
    test -x $MAIL && break
done

test -x $MAIL || error "Cannot find mail client"
```

If the user supplied additional source directories, we put them at the front of the default list. The possibility does not appear to have any value, so we don't provide a way to do so:

```
SRCDIRS="$altsrkdirs $SRCDIRS"
```

Correct setting of the final `userhosts` list is complex, and requires explanation. We have three potential sources:

- Command-line `-o n` options added their arguments to the `userhosts` variable.
- Command-line `-userhosts` options added files, each containing zero or more build-host specification variable.
- The `defaultuserhosts` variable contains the name of a file that supplies default build-host specifications. Command-line options provide them. For most invocations of `build-all`, this file supplies the complete list.

If the `userhosts` variable contains data, then the contents of any files recorded in `ALTUSERHOSTS` must be a list:

```
if test -n "$userhosts"
then
    test -n "$ALTUSERHOSTS" &&
        userhosts="$userhosts ` $STRIPCOMMENTS $ALTUSERHOSTS 2> /dev/null `"
```

Otherwise, the `userhosts` variable is empty, and there are still two possibilities. If `ALTUSERHOSTS` was set, and was not set, we set it to the default file. Then we assign the contents of the files in `ALTUSERHOSTS` to the `userhosts` list:

```
else
    test -z "$ALTUSERHOSTS" && ALTUSERHOSTS="$defaultuserhosts"
    userhosts="` $STRIPCOMMENTS $ALTUSERHOSTS 2> /dev/null `"
```

```
fi
```

Before we begin the real work, a sanity check is essential to ensure that we have at least one host. Although the program is executed in such a case, we want to avoid unnecessary directory and log-file creation. If `userhosts` is empty, so a reminder of how to use the program is called for:

```
test -z "$userhosts" && usage_and_exit 1
```

Here at last is the outer loop of the program, a loop over packages. The shell does not execute the loop body if the list is empty, which is exactly what we want. The loop is large enough that we present only a few lines at a time:

```
for p in "$@"
```

```
do
```

The work of locating the package archive in the source directory list is delegated to the *find_package* function in global variables-among them, `PARFILE` (package archive file):

```
find_package "$p"
```

If `PARFILE` is empty, we issue a complaint on standard error and continue with the next package:

```
if test -z "$PARFILE"
```

```
then
```

```
    warning "Cannot find package file $p"
```

```
    continue
```

```
fi
```

Otherwise, if a log directory was not supplied, or was but is not a directory or is not writable, we attempt to put the logs underneath the directory where the package archive was found. If that directory cannot be found, or is not writable, we put the logs under the user's `$HOME/.build/logs` directory, or else in a temporary directory. We prefer the latter directories over `/tmp`, which is usually lost at a reboot, so we use it only as a last resort:

```
LOGDIR="$altlogdir"
```

```
if test -z "$LOGDIR" -o ! -d "$LOGDIR" -o ! -w "$LOGDIR"
```

```
then
```

```
    for LOGDIR in "`dirname $PARFILE`/logs/$p" $BUILDHOME/logs/$p \
        /usr/tmp /var/tmp /tmp
```

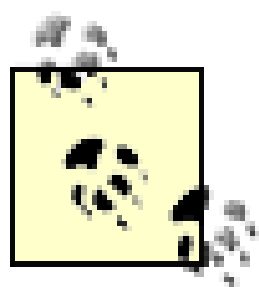
```
do
```

```
    test -d "$LOGDIR" || mkdir -p "$LOGDIR" 2> /dev/null
```

```
    test -d "$LOGDIR" -a -w "$LOGDIR" && break
```

```
done
```

fi



The *dirname* command is the companion to the *basename* command that we introduced in Section 1.1. It removes the last character in its argument from the final slash onward, recovering a directory path from a full path. The result is printed on standard output:

```
$ dirname /usr/local/bin/nawk           Report the directory
```

If the argument does not contain a slash, *dirname* produces a dot representing the current directory.

```
$ dirname whimsical-name           Report the directory
```

Like *basename*, *dirname* treats its argument as a simple text string, without checking for its existence.

If the argument is omitted, *dirname*'s behavior is implementation-defined.

We tell the user where the logs are created, and record that location in email as well, because the user might want to check the logs before the build of a large package completes:

```
msg="Check build logs for $p in `hostname`:$LOGDIR"
echo "$msg"
echo "$msg" | $MAIL -s "$msg" $USER 2> /dev/null
```

The final step in the main loop is a nested loop over the remote hosts to start building the current package. Once again, most of the work is relegated to a function. This also ends the outer loop:

```
for u in $userhosts
do
    build_one $u
done
done
```

The *build_one* invocations are done sequentially so we can more easily identify communications problems. The *build_one* invocation on each remote build host runs in the background on those systems, so *build_one* actually completes its work on all hosts before returning.

At this point, the program has done its work. The last statements cap the cumulative status code at the limit code to the caller:

```
test $EXITCODE -gt 125 && EXITCODE=125

exit $EXITCODE
```

We have left several build processes running in the background, with their output accumulating in associated files anyway so that *build-all* runs quickly.

Some people might prefer an alternate design that does not return until all of the background processes have finished. A simple way to do this: immediately before the final *exit* statement, insert this statement:

```
wait
```

We don't find that approach useful because it either ties up a terminal window until all builds are complete or, if run in the background, its completion notice is likely to be mixed in with other output, and thus missed, when it appears.

Now that we have a general picture of how the program works, it is time to examine the details that are hidden in the source code. We present them in order of use.

usage is a simple function: it prints a short help message on standard output, using a here document instead of multiple statements:

```
usage( )

{

    cat <<EOF
```

Usage:

```
    $PROGRAM [ --? ]

    [ --all "..." ]

    [ --cd "..." ]

    [ --check "..." ]

    [ --configure "..." ]

    [ --environment "..." ]
```

```

[ --help ]

[ --logdirectory dir ]

[ --on "[user@]host[:dir][,envfile] ..." ]

[ --source "dir ..." ]

[ --userhosts "file(s)" ]

[ --version ]

package(s)

```

EOF

```
}

```

usage_and_exit calls *usage*, and then exits with the status code supplied as its argument:

```
usage_and_exit( )
```

```
{
```

```
    usage
```

```
    exit $1
```

```
}
```

version displays the version number on standard output:

```
version( )
```

```
{
```

```
    echo "$PROGRAM version $VERSION"
```

```
}
```

error displays its arguments on standard error, follows them with the usage message, and then terminates with the status code:

```
error( )
```

```
{
    echo "$@" 1>&2
    usage_and_exit 1
}
```

warning displays its arguments on standard error, increments the warning count in `EXITCODE`, and returns:

```
warning( )
```

```
{
    echo "$@" 1>&2
    EXITCODE=`expr $EXITCODE + 1`
}
```

The outer loop in the main body began with a call to *find_package*. That function loops over the source directories, and handles details that we haven't discussed yet:

```
find_package( )
```

```
{
    # Usage: find_package package-x.y.z
    base=`echo "$1" | sed -e 's/[-_][.]*[0-9].*$//`
    PAR=
    PARFILE=
    for srcdir in $SRCDIRS
    do
        test "$srcdir" = "." && srcdir=`pwd`
```

```

    for subdir in "$base" ""
    do

        # NB: update package setting in build_one( ) if this list c

        find_file $srcdir/$subdir/$1.tar.gz "tar xzf"    && ret

        find_file $srcdir/$subdir/$1.tar.Z "tar xzf"    && ret

        find_file $srcdir/$subdir/$1.tar "tar xf"      && ret

        find_file $srcdir/$subdir/$1.tar.bz2 "tar xfj"  && ret

        find_file $srcdir/$subdir/$1.tgz "tar xzf"    && ret

        find_file $srcdir/$subdir/$1.zip "unzip -q"    && ret

        find_file $srcdir/$subdir/$1.jar "jar xf"      && ret

    done

done

}

```

It is evident from the inner loop body that *find_package* recognizes multiple archive formats, and that another function is called upon to do the real work: when it succeeds, we can immediately return. In the second iteration of the loop, the pathnames have two consecutive slashes—but that is harmless, as discussed in Section B.4.1 in Appendix B. The superficial similarity to the *pathfind* command in Example 8-1, here we need to look for several files in each directory, one thing for each one.

We noted at the beginning of this section that the `.tar.gz` archive format is common. However, other common formats are also found. *tar* is primarily a Unix command, and although implementations for other operating systems exist, it is not a standard distribution. The InfoZip format^[3] was developed collaboratively with the goal of supporting cross-platform use on any operating system, and Java *jar*^[4] files also use the InfoZip format. The loop body in *find_package*

^[3] See <http://www.info-zip.org/>.

^[4] *jar* files can contain checksums and digital signatures that can be used to detect file corruption and tampering, so they may be useful for software distribution.

At a small site, it may be reasonable to store package archives in a single directory, such as `/usr/local/src`. As the collection grows, that organization soon becomes unwieldy. At our sites, each package is given its own source directory. The archive for Version 3.1.4 of *gawk* is stored in `/usr/local/gnu/src/gawk/gawk-3.1.4.tar.gz`, and the

are stored in `/usr/local/gnu/src/gawk/logs/gawk-3.1.4`. A `WHERE-FROM` file in each package directory points to the Internet master archive location, making it easy to check for newer releases. We generally keep the last few around, because they might be necessary someday to rebuild a package when the network is not available or the archive site is not reachable. Thus, the loop body in `find_package` strips the version number from the package name and it first tries to find packages in `$srcdir/$base` before falling back to looking in `$srcdir`.

We have found it quite useful to retain build logs, since investigation of a bug that shows up long after installation which compiler and options were used. Also, with less-portable packages, it is often necessary to make minor adjustments to the process, or even to source files, to get a build to complete. If that information is recorded in log files, it can be used when newer versions of those packages need to be built and installed.

The `find_file` function is essentially just a readability and existence test for the package archive file, the recursive search, and the return of a status result. It simplifies the code in `find_package` considerably:

```
find_file( )
{
    # Usage:
    #       find_file file program-and-args
    # Return 0 (success) if found, 1 (failure) if not found

    if test -r "$1"
    then
        PAR="$2"           Program and arguments to use
        PARFILE="$1"      Actual file to extract source
        return 0
    else
        return 1
    fi
}
```

The `set_userhosts` function provides the convenience of allowing userhosts files to be specified with explicit the current directory, or found in the `$BUILDHOME` initialization directory. This makes it convenient to create by compiler, platform, or package, in order to accommodate packages that are known to build only in certain number of userhosts files can be provided, so we simply accumulate their names in `ALTUSERHOSTS` :

```
set_userhosts( )
{
    # Usage: set_userhosts file(s)
    for u in "$@"
    do
        if test -r "$u"
        then
            ALTUSERHOSTS="$ALTUSERHOSTS $u"
        elif test -r "$BUILDHOME/$u"
        then
            ALTUSERHOSTS="$ALTUSERHOSTS $BUILDHOME/$u"
        else
            error "File not found: $u"
        fi
    done
}
```

The last function, `build_one` , is where the work for one package on one remote host is handled. It is long e parts:

```
build_one( )
{
    # Usage:
```

```
#      build_one [user@]host[:build-directory][,envfile]
```

Until now, apart from a brief mention in the comment banner, we have not precisely specified what is in the initialization file. We require up to four pieces of information: the username on the remote host (if different host), the hostname itself, the name of the *existing* directory on the remote host where the build should take additional environment variable settings specific to this build. It isn't convenient in a shell script to maintain lists, so we simply borrow syntax from the remote and secure shells and jam them together with separator (

```
jones@freebsd.example.com:/local/build,$HOME/.build/c99
```

Only the hostname component is mandatory.

We need the parts as well, so we use *echo* and *sed* to split the argument apart. Passing the argument through environment variables in the name (like *HOME* in `$HOME/.build/c99`), avoiding the need to hardcode system paths in the `userhosts` files. For convenience, we provide a default build directory of `/tmp` if one was not :

```
arg="`eval echo $1`" Expand e
```

```
userhost="`echo $arg | sed -e 's/:.*$//`" Remove col  
everything
```

```
user="`echo $userhost | sed -e s'/@.*$//`" Extract us
```

```
test "$user" = "$userhost" && user=$USER Use $USER
```

```
host="`echo $userhost | sed -e s'/^[^@]*@//`" Extract ho
```

```
envfile="`echo $arg | sed -e 's/^[^,]*,//`" Name of en
```

```
test "$envfile" = "$arg" && envfile=/dev/null
```

```
builddir="`echo $arg | sed -e s'/^.*:/' -e 's/,.*//`" Build dire
```

```
test "$builddir" = "$arg" && builddir=/tmp
```

We would prefer one of the nonvolatile temporary directories for `builddir`, but Unix vendors disagree on extra lines of code could make a suitable test, but we assume that most users will specify a sensible build directory. `/tmp` is usually cleared upon a reboot, there are other reasons why `/tmp` is *not* a good choice for `builddir`:

- On many systems, `/tmp` is a separate filesystem that is too small to hold the build tree for a large package.
- On some systems, `/tmp` is mounted without permission to execute programs in it: that may cause `configure` checks to fail.
- Under several releases of Sun Solaris, for unknown reasons native compilers could not compile code.

The `envfile` facility is essential: it allows us to override defaults chosen by `configure`. Software developers use as many compilers as possible to verify portability and ferret out bugs. By choosing different build directories, one can do multiple simultaneous builds on the same host with different compilers. The `envfile` files are quite simple, like this:

```
$ cat $HOME/.build/c99
```

```
CC=c99
```

```
CXX=CC
```

The next step in our program is to save the bare filename (e.g., `gawk-3.1.4.tar.gz`) in the variable `parbase`:

```
parbase=`basename $PARFILE`
```

The package name (e.g., `gawk-3.1.4`) is saved in the variable `package`:

```
package="`echo $parbase | \
    sed -e 's/[.]jar$//' \
        -e 's/[.]tar[.]bz2$//' \
        -e 's/[.]tar[.]gz$//' \
        -e 's/[.]tar[.]Z$//' \
        -e 's/[.]tar$//'`"
```



```

-e 's/[.]tgz$//' \
-e 's/[.]zip$//'`"

```

We use explicit *sed* patterns to strip the suffixes: there are too many dots in the name to make a simpler pattern. Since they work with older *sed* implementations, we specify them in separate substitution commands, instead of a single complex expression. Should support for new archive formats ever be added to *find_package*, these editor patterns need to be updated.

The next step is to copy the archive file to the build directory on the remote host, unless it can already be seen via filesystem mounting or mirroring. That is common at our sites, so the check saves time and disk space.

Although we usually avoid writing chatty programs, the *echo* command before each communication with a remote host gives the user essential feedback. The remote copy can be time-consuming and can fail or hang: without a simple way to tell why the script is taking unexpectedly long, or what host is responsible for the failure. The *test* command serves to distinguish between a temporary copy of the archive file and a preexisting one:

```

echo $SSH $SSHFLAGS $userhost "test -f $PARFILE"

if $SSH $SSHFLAGS $userhost "test -f $PARFILE"
then
    parbaselocal=$PARFILE
else
    parbaselocal=$parbase

    echo $SCP $PARFILE $userhost:$builddir
    $SCP $PARFILE $userhost:$builddir
fi

```

Ideally, we should use a pipeline to do the unbundling, since that halves the amount of input/output, and all other things being equal, reduces the number of remote requirements. Alas, only *jar* and *tar* can read their archives that way: *unzip* requires an actual file. In principle, we could use a pipeline to read the archive file, allowing us to replace *unzip* with *jar* and use the pipeline. Unfortunately, at the time of this writing, *jar* has not yet found at least one implementation that chokes on a *.zip* file.

Observe that the remote copies are done sequentially, rather than in parallel. The latter would be possible, but at the cost of added complexity in the main body, which would have to first find and distribute packages, wait for their distribution, and then build them. However, the build time is usually much longer than the remote copy time, so sequential copying is the total runtime.

and the *source* command, we must do this in a single complex command that relies on the equal precedence

```
test -f $BUILDBEGIN && . $BUILDBEGIN || \
test -f $BUILDBEGIN && source $BUILDBEGIN || \
true ;
```

We are not happy with the complexity of this statement, but the severe design requirement that *build-all* must force it upon us, and we could find no acceptable simpler solution.

We assume that the startup script has been debugged before *build-all* is used. Otherwise, if execution of the script terminates with an error, there may be two attempts to execute it.

Based on long experience, we find it useful to record extra information in the build logs, so there are a score of variables, carefully formatted for better log-file readability:

```
echo 'Package:           $package' ;
echo 'Archive:          $PARFILE' ;
echo 'Date:              $now' ;
echo 'Local user:        $USER' ;
echo 'Local host:         `hostname`' ;
echo 'Local log directory: $LOGDIR' ;
echo 'Local log file:     $logfile' ;
echo 'Remote user:        $user' ;
echo 'Remote host:        $host' ;
echo 'Remote directory:   $builddir' ;
```

It is also sometimes useful to know how long a build takes (on one of our older systems, the GNU C compiler was slow, so the script reports before and after dates. These are obtained on the remote host, which might be in a different time zone, from clock skew, and it may be important later to match timestamps of installed files with entries in the build log. The way to use *echo* to generate a partial line, so we use *printf* :

```
printf 'Remote date:      %s' ;
```

```
date $DATEFLAGS ;
```

Similarly, we record system and GNU compiler version information, since that may be needed in bug reports.

```
printf 'Remote uname:           ' ;
uname -a || true ;
printf 'Remote gcc version:      ' ;
gcc --version | head -n 1 || echo ;
printf 'Remote g++ version:      ' ;
g++ --version | head -n 1 || echo ;
```

There is no common way with other compilers to get version information, so we cannot handle that task in the script. Our script continues, producing any desired reports from suitable commands in the `$BUILDBEGIN` script.

```
echo 'Configure environment:  ` $STRIPCOMMENTS $envfile | $JOINL
echo 'Extra environment:      $EXTRAENVIRONMENT' ;
echo 'Configure directory:    $CONFIGUREDIR' ;
echo 'Configure flags:         $CONFIGUREFLAGS' ;
echo 'Make all targets:        $ALLTARGETS' ;
echo 'Make check targets:     $CHECKTARGETS' ;
```

Running out of disk space has proven to be a common cause of failures, so we use `df` to report on the available disk space in the build directory:

```
echo 'Disk free report for $builddir/$package:' ;
df $builddir | $INDENT ;
```

`configure` and `make` can be influenced by environment variables, so we finish off the log-file header with a summary of the environment:

```
echo 'Environment:' ;
env | env LC_ALL=C sort | $INDENT ;
```




You should generally ignore package installation instructions that tell you to build and in the `root` account: there are *extremely few* packages that require such privileges, and even installation step should need `root` access.

Next, we unpack the archive:

```
$PAR $parbaselocal ;
```

It is important to realize that `$PAR` is expanded on the initiating host, but run on the remote host. In particular is the GNU version that supports the `-j` and `-z` options, and that `unzip` and `jar` are available. Each user of this shell startup files appropriately set on each remote host to ensure that these programs can be found. We can find these programs because the paths may be different on each remote host.

If the archive was copied to the remote host, then `parbaselocal` and `parbase` have identical values, and since `parbase` is no longer needed on the remote host, we remove it:

```
test "$parbase" = "$parbaselocal" && /bin/rm -f $parbase ;
```

We are ready to change to the package directory and start the build. For software packages that follow the standard conventions, that directory is the top-level package directory. Unfortunately, some packages bury the build tree, among them, the widely used Tcl and Tk tools for scripting and fast window-system interface construction (the `configure` option supplies a relative path to the build directory that is saved in `CONFIGUREDIR`, overriding its default value). We therefore need both the `package` variable and the `CONFIGUREDIR` variable to change to the build directory; otherwise we exit with an error:

```
cd $package/$CONFIGUREDIR || exit 1 ;
```

Many packages now come with `configure` scripts, so we test for one, and if it is found, we execute it with a set of variables supplied by `envfile`. We also pass on any additional flags supplied by a `-configure` option. Most packages do not use such flags, but some of the more complex ones often do:

```
test -f configure && \
  chmod a+x configure && \
  env ` $STRIPCOMMENTS $envfile | $JOINLINES ` \
  $EXTRAENVIRONMENT \
  nice time ./configure $CONFIGUREFLAGS ;
```



```

        test -f $BUILDEND && source $BUILDEND || \

        true ;

    echo '=
= = = = = = = = = = = = = = = = = = = = = = = = = = = =
= = = = = = = = = = = = = = = = = = = = = = = = = = = =

```

The last two lines of the *build_one* function close off the list of remote commands and the function body, redirecting standard output and standard error to the log file, and importantly, run the remote commands in the background so that execution continues in the inner loop of the main body. The remote shell's input is redirected to the null device so it does not receive any input:

```

        " < /dev/null > "$LOGDIR/$logfile" 2>&1 &

    }

```

A program of this size and power certainly requires online documentation. Space does not permit us to present *build-all* here, but both the script and its manual-page file are available at this book's web site.

The complete script, with a few comments that we omitted in our piecewise presentation, and reordering to alphabetical order near the beginning, is collected in Example 8-2 . Although it is about 320 lines long (ignoring blank lines), the payoff for our programming investment is substantial. Once a new distribution of a package has been installed on a system, a one-line command starts the build and validation on all of the build hosts in parallel. After a suitable amount of time, then check the build logs for their success or failure and decide on which machines it is safe to run *make install* on the system, after which the build directory can be removed from the remote system.

Build failures that are not attributable to local errors can, and should, be reported to the package maintainers. Few developers have access to a wide range of platforms, so it is only from installer feedback that we can make their packages more portable and more robust. Before doing so, however, it is always a good idea to check the release notes for the package (typically in files named *BUGS* , *FAQ* , *INSTALL* , *README* , etc.) to find out whether the problem that you discovered has already been reported, but is just a common issue. A software model where developers get rapid installer feedback has proven to be extremely effective. Raymond has written about it in an interesting extended essay in book form.^[6]

^[6] *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*

Example 8-2. The build-all program

```

#!/bin/sh -

```



```
# Build one or more packages in parallel on one or more build hosts.
#
# Usage:
#
#     build-all [ --? ]
#
#         [ --all "..." ]
#
#         [ --check "..." ]
#
#         [ --configure "..." ]
#
#         [ --environment "..." ]
#
#         [ --help ]
#
#         [ --logdirectory dir ]
#
#         [ --on "[user@]host[:dir][,envfile] ..." ]
#
#         [ --source "dir ..." ]
#
#         [ --userhosts "file(s)" ]
#
#         [ --version ]
#
#         package(s)
#
# Optional initialization files:
#
#     $HOME/.build/directories      list of source directories
#
#     $HOME/.build/userhosts        list of [user@]host[:dir][,envf
#
#
IFS='
'
```

```
PATH=/usr/local/bin:/bin:/usr/bin
```

```
export PATH
```

```
UMASK=002
```

```
umask $UMASK
```

```
build_one( )
```

```
{
```

```
    # Usage:
```

```
    #      build_one [user@]host[:build-directory][,envfile]
```

```
    arg="`eval echo $1`"
```

```
    userhost="`echo $arg | sed -e 's/:.*$//'`"
```

```
    user="`echo $userhost | sed -e s'/@.*$//'`"
```

```
    test "$user" = "$userhost" && user=$USER
```

```
    host="`echo $userhost | sed -e s'/^[^@]*@//'`"
```

```
    envfile="`echo $arg | sed -e 's/^[^,]*, //'`"
```

```
    test "$envfile" = "$arg" && envfile=/dev/null
```

```
builddir="`echo $arg | sed -e s'/^.*:/' -e 's/,.*/'`"
test "$builddir" = "$arg" && builddir=/tmp

parbase=`basename $PARFILE`

# NB: update find_package( ) if these patterns are changed
package="`echo $parbase | \
    sed      -e 's/[.]jar$/' \
            -e 's/[.]tar[.]bz2$/' \
            -e 's/[.]tar[.]gz$/' \
            -e 's/[.]tar[.]Z$/' \
            -e 's/[.]tar$/' \
            -e 's/[.]tgz$/' \
            -e 's/[.]zip$/'`"

# Copy the package file if we cannot see it on the remote host
echo $SSH $SSHFLAGS $userhost "test -f $PARFILE"
if $SSH $SSHFLAGS $userhost "test -f $PARFILE"
then
    parbaselocal=$PARFILE
else
    parbaselocal=$parbase
    echo $SCP $PARFILE $userhost:$builddir
```



```

echo 'Remote host:                $host' ;

echo 'Remote directory:          $builddir' ;

printf 'Remote date:             ' ;

date $DATEFLAGS ;

printf 'Remote uname:           ' ;

uname -a || true ;

printf 'Remote gcc version:      ' ;

gcc --version | head -n 1 || echo ;

printf 'Remote g++ version:      ' ;

g++ --version | head -n 1 || echo ;

echo 'Configure environment:     ` $STRIPCOMMENTS $envfile | $JOINL

echo 'Extra environment:         $EXTRAENVIRONMENT' ;

echo 'Configure directory:       $CONFIGUREDIRE' ;

echo 'Configure flags:           $CONFIGUREFLAGS' ;

echo 'Make all targets:          $ALLTARGETS' ;

echo 'Make check targets:        $CHECKTARGETS' ;

echo 'Disk free report for $builddir/$package:' ;

df $builddir | $INDENT ;

echo 'Environment:' ;

env | env LC_ALL=C sort | $INDENT ;

echo '=' = = = = = = = = = = = = = = = = = = = = =
= = = = = = = = = = = = = = = = = = = = =
umask $UMASK ;

```



```
    " < /dev/null > "$LOGDIR/$logfile" 2>&1 &  
}
```

```
error( )
```

```
{  
    echo "$@" 1>&2  
    usage_and_exit 1  
}
```

```
find_file( )
```

```
{  
    # Usage:  
    #     find_file file program-and-args  
    # Return 0 (success) if found, 1 (failure) if not found  
  
    if test -r "$1"  
    then  
        PAR="$2"  
        PARFILE="$1"  
        return 0  
    else  
        return 1  
    fi
```

```
}
```

```
find_package( )
```

```
{
```

```
  # Usage: find_package package-x.y.z
```

```
  base=`echo "$1" | sed -e 's/[-_][.]*[0-9].*$//`
```

```
  PAR=
```

```
  PARFILE=
```

```
  for srcdir in $SRCDIRS
```

```
  do
```

```
    test "$srcdir" = "." && srcdir=`pwd`
```

```
    for subdir in "$base" ""
```

```
    do
```

```
      # NB: update package setting in build_one( ) if this list c
```

```
      find_file $srcdir/$subdir/$1.tar.gz "tar xfz" && ret
```

```
      find_file $srcdir/$subdir/$1.tar.Z "tar xfz" && ret
```

```
      find_file $srcdir/$subdir/$1.tar "tar xf" && ret
```

```
      find_file $srcdir/$subdir/$1.tar.bz2 "tar xfj" && ret
```

```
      find_file $srcdir/$subdir/$1.tgz "tar xfz" && ret
```

```
      find_file $srcdir/$subdir/$1.zip "unzip -q" && ret
```

```
      find_file $srcdir/$subdir/$1.jar "jar xf" && ret
```

```
    done
```



```
done
}

set_userhosts( )
{
    # Usage: set_userhosts file(s)
    for u in "$@"
    do
        if test -r "$u"
        then
            ALTUSERHOSTS="$ALTUSERHOSTS $u"
        elif test -r "$BUILDHOME/$u"
        then
            ALTUSERHOSTS="$ALTUSERHOSTS $BUILDHOME/$u"
        else
            error "File not found: $u"
        fi
    done
}

usage( )
{
    cat <<EOF
```

Usage:

```
$PROGRAM [ --? ]

[ --all "..." ]
[ --check "..." ]
[ --configure "..." ]
[ --environment "..." ]
[ --help ]
[ --logdirectory dir ]
[ --on "[user@]host[:dir][,envfile] ..." ]
[ --source "dir ..." ]
[ --userhosts "file(s)" ]
[ --version ]

package(s)
```

EOF

}

usage_and_exit()

{

usage

exit \$1

}

version()

```
{  
    echo "$PROGRAM version $VERSION"  
}
```

warning()

```
{  
    echo "$@" 1>&2  
    EXITCODE=`expr $EXITCODE + 1`  
}
```

ALLTARGETS=

altlogdir=

altsrkdirs=

ALTUSERHOSTS=

BUILDBEGIN=./.build/begin

BUILDEND=./.build/end

BUILDHOME=\$HOME/.build

CHECKTARGETS=check

CONFIGUREDIR=.

CONFIGUREFLAGS=

DATEFLAGS="+%Y.%m.%d.%H.%M.%S"

EXITCODE=0

EXTRAENVIRONMENT=

```
INDENT="awk '{ print "\t\t\t" \$0 }'"
JOINLINES="tr '\n' '\040'"
LOGDIR=
PROGRAM=`basename $0`
SCP=scp
SSH=ssh
SSHFLAGS=${SSHFLAGS--x}
STRIPCOMMENTS='sed -e s/#.*$// '
userhosts=
VERSION=1.0

# Default initialization files
defaultdirectories=$BUILDHOME/directories
defaultuserhosts=$BUILDHOME/userhosts

# List of places to find package distributions, with a default
# list if the user has no personalized list:
SRCDIRS="`$STRIPCOMMENTS $defaultdirectories 2> /dev/null`"
test -z "$SRCDIRS" && \
    SRCDIRS="
        .
        /usr/local/src
        /usr/local/gnu/src"
```



```
        $HOME/src
        $HOME/gnu/src
        /tmp
        /usr/tmp
        /var/tmp
    "

while test $# -gt 0
do
    case $1 in

        --all | --al | --a | -all | -al | -a )
            shift
            ALLTARGETS="$1"
            ;;

        --cd | -cd )
            shift
            CONFIGUREDIR="$1"
            ;;

        --check | --chec | --che | --ch | -check | -chec | -che | -ch )
            shift
```

```
    CHECKTARGETS="$1"

    ;;

--configure | --configur | --configu | --config | --confi | \
--conf | --con | --co | \
-configure | -configur | -configu | -config | -confi | \
-conf | -con | -co )

    shift

    CONFIGUREFLAGS="$1"

    ;;

--environment | --environmen | --environme | --environm | --environ
--enviro | --envir | --envi | --env | --en | --e | \
-environment | -environmen | -environme | -environm | -environ | \
-enviro | -envir | -envi | -env | -en | -e )

    shift

    EXTRAENVIRONMENT="$1"

    ;;

--help | --hel | --he | --h | '--?' | -help | -hel | -he | -h | '-?'

    usage_and_exit 0

    ;;
```

```

--logdirectory | --logdirector | --logdirecto | --logdirect | \
--logdirec | --logdire | --logdir | --logdi | --logd | --log | \
--lo | --l | \
-logdirectory | -logdirector | -logdirecto | -logdirect | \
-logdirec | -logdire | -logdir | -logdi | -logd | -log | -lo | -l )

    shift

    altlogdir="$1"

    ;;

--on | --o | -on | -o )

    shift

    userhosts="$userhosts $1"

    ;;

--source | --sourc | --sour | --sou | --so | --s | \
-source | -sourc | -sour | -sou | -so | -s )

    shift

    altsrkdirs="$altsrkdirs $1"

    ;;

--userhosts | --userhost | --userhos | --userho | --userh | \
--user | --use | --us | --u | \
-userhosts | -userhost | -userhos | -userho | -userh | \

```

```
-user | -use | -us | -u )
    shift
    set_userhosts $1
    ;;

--version | --versio | --versi | --vers | --ver | --ve | --v | \
-version | -versio | -versi | -vers | -ver | -ve | -v )
    version
    exit 0
    ;;

-*)
    error "Unrecognized option: $1"
    ;;

*)
    break
    ;;

esac
shift
done
```



```
# Find a suitable mail client
for MAIL in /bin/mailx /usr/bin/mailx /usr/sbin/mailx /usr/ucb/mailx \
           /bin/mail /usr/bin/mail
do
    test -x $MAIL && break
done

test -x $MAIL || error "Cannot find mail client"

# Command-line source directories precede defaults
SRCDIRS="$altsrkdirs $SRCDIRS"

if      test -n "$userhosts"
then
    test -n "$ALTUSERHOSTS" &&
        userhosts="$userhosts ` $STRIPCOMMENTS $ALTUSERHOSTS 2> /dev/:"
else
    test -z "$ALTUSERHOSTS" && ALTUSERHOSTS="$defaultuserhosts"
    userhosts="` $STRIPCOMMENTS $ALTUSERHOSTS 2> /dev/null`"
fi

# Check for something to do
test -z "$userhosts" && usage_and_exit 1
```

```
for p in "$@"
do

    find_package "$p"

    if test -z "$PARFILE"
    then

        warning "Cannot find package file $p"

        continue
    fi

    LOGDIR="$altlogdir"

    if test -z "$LOGDIR" -o ! -d "$LOGDIR" -o ! -w "$LOGDIR"
    then

        for LOGDIR in "`dirname $PARFILE`/logs/$p" $BUILDDIR/logs/$p \
            /usr/tmp /var/tmp /tmp
        do

            test -d "$LOGDIR" || mkdir -p "$LOGDIR" 2> /dev/null

            test -d "$LOGDIR" -a -w "$LOGDIR" && break
        done
    fi

    msg="Check build logs for $p in `hostname`:$LOGDIR"

    echo "$msg"
```

```
echo "$msg" | $MAIL -s "$msg" $USER 2> /dev/null

for u in $userhosts
do
    build_one $u
done

done

# Limit exit status to common Unix practice
test $EXITCODE -gt 125 && EXITCODE=125

exit $EXITCODE
```

< Day Day Up >

8.3. Summary

In this chapter, we have written two useful tools that do not already exist on Unix systems, using shell statements and existing standard tools to carry out the task. Neither of them is particularly time-consuming to run, so there is little temptation to rewrite them in a programming language like C or C++. As shell scripts, they can be run without change on almost any modern Unix platform.

Both programs support command-line options, cleanly processed by *while* and *case* statements. Both use shell functions to simplify processing and prevent unnecessary code duplication. Both pay attention to security issues and perform sanity checks on their arguments and variables.

Chapter 9. Enough *awk* to Be Dangerous

The *awk* programming language was designed to simplify many common text processing tasks. In this chapter, we present a subset that suffices for most of the shell scripts that we use in this book.

For an extended treatment of the *awk* language, consult any of the books on *awk* listed in the [Chapter 16](#). If GNU *gawk* is installed on your system, then its manual should be available in the online *info* system.^[1]

^[1] The GNU documentation reader, *info*, is part of the *texinfo* package available at <ftp://ftp.gnu.org/gnu/texinfo/>. The *emacs* text editor also can be used to access the same documentation: type `Ctrl-H i` in an *emacs* session to get started.

All Unix systems have at least one *awk* implementation. When the language was significantly extended in the mid-1980s, some vendors kept the old implementation *asawk*, and sometimes also as *oawk*, and then named the new one *nawk*. IBM AIX and Sun Solaris both continue that practice, but most others now provide only the new one. Solaris has a POSIX-compliant version in `/usr/xpg4/bin/awk`. In this book, we consider only the extended language and refer to it as *awk*, even though you might have to use *nawk*, *gawk*, or *mawk* on your system.

We must confess here to a strong bias about *awk*. We like it. A lot. We have implemented, maintained, ported, written about, and used the language for many years. Even though many *awk* programs are short, some of our larger *awk* programs are thousands of lines long. The simplicity and power of *awk* often make it just the right tool for the job, and we seldom encounter a text processing task in which we need a feature that is not already in the language, or cannot be readily implemented. When we have on occasion rewritten an *awk* program in a conventional programming language like C or C++, the result was usually much longer, and much harder to debug, even if it did run somewhat faster.

Unlike most other scripting languages, *awk* enjoys multiple implementations, a healthy situation that encourages adherence to a common language base and that permits users to switch freely from one to another. Also, unlike other scripting languages, *awk* is part of POSIX, and there are implementations for non-Unix operating systems.

If your local version of *awk* is substandard, get one of the free implementations listed in [Table 9-1](#). All of these programs are very portable and easy to install. *gawk* has served as a testbed for several interesting new built-in functions and language features, including network I/O, and also for profiling, internationalization, and portability checking.

Table 9-1. Freely available awk versions

Program	Location
Bell Labs <i>awk</i>	http://cm.bell-labs.com/who/bwk/awk.tar.gz
<i>gawk</i>	ftp://ftp.gnu.org/gnu/gawk/
<i>mawk</i>	ftp://ftp.whidbey.net/pub/brennan/mawk-1.3.3.tar.gz
<i>awka</i>	http://awka.sourceforge.net/ (<i>awk</i> -to-C translator)

< Day Day Up >

9.1. The awk Command Line

An *awk* invocation can define variables, supply the program, and name the input files:

```
awk [ -F fs ] [ -v var=value ... ] 'program' [ -- ] \  
    [ var=value ... ] [ file(s) ]
```

```
awk [ -F fs ] [ -v var=value ... ] -f programfile [ -- ] \  
    [ var=value ... ] [ file(s) ]
```

Short programs are usually provided directly on the command line, whereas longer ones are relegated to files selected by the *-f* option. That option may be repeated, in which case the complete program is the concatenation of the specified program files. This is a convenient way to include libraries of shared *awk* code. Another approach to library inclusion is to use the *igawk* program, which is part of the *gawk* distribution. Options must precede filenames and ordinary *var=value* assignments.

If no filenames are specified on the command line, *awk* reads from standard input.

The *-* option is special: it indicates that there are no further command-line options for *awk* itself. Any following options are then available to your program.

The *-F* option redefines the default field separator, and it is conventional to make it the first command-line option. Its *fs* argument is a regular expression that immediately follows the *-F*, or is supplied as the next argument. The field separator can also be set with an assignment to the built-in variable *FS* (see [Table 9-2](#) in [Section 9.3.4](#), later in this chapter):

```
awk -F '\t' '{ ... }' files FS="[\f\v]" files
```

Here, the value set with the *-F* option applies to the first group of files, and the value assigned to *FS* applies to the second group.

Initializations with *-v* options must precede any program given directly on the command line; they take effect before the program is started, and before any files are processed. A *-v* option after a command-line program is interpreted as a (probably nonexistent) filename.

Initializations elsewhere on the command line are done as the arguments are processed, and may be interspersed with filenames. For example:

```
awk '{...}' Pass=1 *.tex Pass=2 *.tex
```

processes the list of files twice, once with `Pass` set to one and a second time with it set to two.

Initializations with string values need not be quoted unless the shell requires such quoting to protect special characters or whitespace.

The special filename `-` (hyphen) represents standard input. Most modern *awk* implementations, but not POSIX, also recognize the special name `/dev/stdin` for standard input, even when the host operating system does not support that filename. Similarly, `/dev/stderr` and `/dev/stdout` are available for use within *awk* programs to refer to standard error and standard output.



9.2. The awk Programming Model

awk views an input stream as a collection of *records*, each of which can be further subdivided into *fields*. Normally, a record is a line, and a field is a word of one or more nonwhitespace characters. However, what constitutes a record and a field is entirely under the control of the programmer, and their definitions can even be changed during processing.

An *awk* program consists of pairs of patterns and braced actions, possibly supplemented by functions that implement the details of the actions. For each pattern that matches the input, the action is executed, and all patterns are examined for every input record.

Either part of a pattern/action pair may be omitted. If the pattern is omitted, the action is applied to every input record. If the action is omitted, the default action is to print the matching record on standard output. Here is the typical layout of an *awk* program:

```

pattern { action }           Run action if pattern matches
pattern                       Print record if pattern matches
                                { action }           Run action for every record

```

Input is switched automatically from one input file to the next, and *awk* itself normally handles the opening, reading, and closing of each input file, allowing the user program to concentrate on record processing. The code details are presented later in Section 9.5.

Although the patterns are often numeric or string expressions, *awk* also provides two special patterns with the reserved words `BEGIN` and `END`.

The action associated with `BEGIN` is performed just once, *before* any command-line files or ordinary command-line assignments are processed, but *after* any leading `-v` option assignments have been done. It is normally used to handle any special initialization tasks required by the program.

The `END` action is performed just once, *after* all of the input data has been processed. It is normally used to produce summary reports or to perform cleanup actions.

`BEGIN` and `END` patterns may occur in any order, anywhere in the *awk* program. However, it is conventional to make the `BEGIN` pattern the first one in the program, and to make the `END` pattern the last one.

When multiple `BEGIN` or `END` patterns are specified, they are processed in their order in the *awk* program.

This allows library code included with extra *-f* options to have startup and cleanup actions.



9.3. Program Elements

Like most scripting languages, *awk* deals with numbers and strings. It provides *scalar* and *array* variables to hold data, numeric and string expressions, and a handful of statement types to process data: assignments, comments, conditionals, functions, input, loops, and output. Many features of *awk* expressions and statements are purposely similar to ones in the C programming language.

9.3.1. Comments and Whitespace

Comments in *awk* run from sharp (#) to end-of-line, just like comments in the shell. Blank lines are equivalent to empty comments.

Wherever whitespace is permitted in the language, any number of whitespace characters may be used, so blank lines and indentation can be used for improved readability. However, single statements usually cannot be split across multiple lines, unless the line breaks are immediately preceded with a backslash.

9.3.2. Strings and String Expressions

String constants in *awk* are delimited by quotation marks: "This is a string constant". Character strings contain any 8-bit character *except* the control character NUL (character value 0), which serves as a string terminator in the underlying implementation language, C. The GNU implementation, *gawk*, removes that restriction, so *gawk* can safely process arbitrary binary files.

awk strings contain zero or more characters, and there is no limit, other than available memory, on the length of a string. Assignment of a string expression to a variable automatically creates a string, and the memory occupied by any previous string value of the variable is automatically reclaimed.

Backslash escape sequences allow representation of unprintable characters, just like those for the *echo* command shown in Section 2.5.3. "A\tZ" contains the characters A, tab, and Z, and "\001" and "\x01" each contain the character Ctrl-A.

Hexadecimal escape sequences are not supported by *echo*, but were added to *awk* implementations after they were introduced in the 1989 ISO C Standard. Unlike octal escape sequences, which use at most three digits, a hexadecimal escape consumes all following hexadecimal digits. *gawk* and *nawk* follow the C Standard, but *mawk* does not: it collects at most two hexadecimal digits, reducing "\x404142" to "@4142" instead of to the 1-bit value $0x42 = 66$, which is the position of 'B' in the ASCII character set. POSIX *awk* does not support hexadecimal escapes at all.

awk provides several convenient built-in functions for operating on strings; we treat them in detail in Section 9.9.7. For now, we mention only the string-length function: `length(string)` returns the number of characters in `string`.

Strings are compared with the conventional relational operators: `=` (equality), `!=` (inequality), `<` (less than), `<=` (less than or equal to), `>` (greater than), and `>=` (greater than or equal to). Comparison returns 0 for false and non-zero for true. When strings of different lengths are compared and one string is an initial substring of the other, the shorter is defined to be less than the longer: thus, `"A" < "AA"` evaluates to true.

Unlike most programming languages with string datatypes, *awk* has no special string concatenation operator. Instead, two strings in succession are automatically concatenated. Each of these assignments sets the scalar variable `s` to the same four-character string:

```
s = "ABCD"
```

```
s = "AB" "CD"
```

```
s = "A" "BC" "D"
```

```
s = "A" "B" "C" "D"
```

The strings need not be constants: if we follow the last assignment with:

```
t = s s s
```

then `t` has the value `"ABCDABCDABCD"`.

Conversion of a number to a string is done implicitly by concatenating the number to an empty string: `n = 123` followed by `s = "" n`, assigns the value `"123"` to `s`. Some caution is called for when the number is not exactly representable: we address that later when we show how to do formatted number-to-string conversions in Section 9.9.8.

Much of the power of *awk* comes from its support of regular expressions. Two operators, `~` (matches) and `!~` (does not match), make it easy to use regular expressions: `"ABC" ~ /^[A-Z]+$/` is true, because the left string contains only uppercase letters, and the right regular expression matches any string of (ASCII) uppercase letters. *awk* supports Extended Regular Expressions (EREs), as described in Section 3.2.3.

Regular expression constants can be delimited by either quotes or slashes: `"ABC" ~ /^[A-Z]+$/` is equivalent to `"ABC" ~ /^[A-Z]+$/` in the last example. Which of them to use is largely a matter of programmer taste, although the slashed form is usually preferred, since it emphasizes that the enclosed material is a regular expression, rather than an arbitrary string. However, in the rare cases where a slash delimiter might be confused with a division operator, use the quoted form.

Just as a literal quote in a quoted string must be protected by a backslash ("`...\"`"), so must a literal slash in a slash-delimited regular expression (`/...\/`). When a literal backslash is needed in a regular expression, it too must be protected, but the quoted form requires an extra level of protection: "`\\TeX`" and `/\\TeX/` are regular expressions that each match a string containing `\TeX`.

9.3.3. Numbers and Numeric Expressions

All numbers in *awk* are represented as double-precision floating-point values, and we provide some of the details in the nearby sidebar. Although you do not have to become an expert in floating-point arithmetic, it is important to be aware of the limitations of computer arithmetic so that you do not expect more than the computer can deliver, and so that you can avoid some of the pitfalls.

More on Floating-Point Arithmetic

Virtually all platforms today conform to the 1985 *IEEE 754 Standard for Binary Floating-Point Arithmetic*. That standard defines a 32-bit single-precision format, a 64-bit double-precision format, and an optional extended-precision format, which is usually implemented in 80 or 128 bits. *awk* implementations use the 64-bit format (corresponding to the C datatype `double`), although in the interests of portability, the *awk* language specification is intentionally vague about the details. The POSIX *awk* specification says only that the arithmetic shall follow the ISO C Standard, which does not require any particular floating-point architecture.

IEEE 754 64-bit double-precision values have a sign bit, an 11-bit biased exponent, and a 53-bit significand whose leading bit is not stored. This permits representing numbers with up to about 16 decimal digits. The largest finite magnitude is about 10^{+308} , and the smallest normalized nonzero magnitude is about 10^{-308} . Most IEEE 754 implementations also support subnormal numbers, which extend the range down to about 10^{-324} , but with a loss of precision: this *gradual underflow* to zero has several desirable numerical properties, but is usually irrelevant to nonnumerical software.

Because the sign bit is explicitly represented, IEEE 754 arithmetic supports both positive and negative zero. Many programming languages get this wrong, however, and *awk* is no exception: some implementations print a negative zero without its minus sign.

IEEE 754 arithmetic also includes two special values, Infinity and not-a-number (NaN). Both can be signed, but the sign of NaN is not significant. They are intended to allow nonstop computation on high-performance computers while still being able to record the occurrence of exceptional conditions. When a value is too big to represent, it is said to *overflow*, and the result is Infinity. When a value is not well-defined, such as Infinity - Infinity, or 0/0, the result is a NaN.

Infinity and NaN propagate in computations: Infinity + Infinity and Infinity * Infinity produce

Infinity, and NaN combined with anything produces NaN.

Infinities of the same sign compare equal. NaN compares unequal to itself: the test $(x \neq x)$ is true only if x is a NaN.

awk was developed before IEEE 754 arithmetic became widely available, so the language does not fully support Infinity and NaN. In particular, current *awk* implementations trap attempts to divide by zero, even though that operation is perfectly well-defined in IEEE 754 arithmetic.

Floating-point numbers may include a trailing power-of-10 exponent represented by the letter *e* (or *E*) and an optionally signed integer. For example, `0.03125`, `3.125e-2`, `3125e-5`, and `0.003125E1` are equivalent representations of the value $1/32$. Because all arithmetic in *awk* is floating-point arithmetic, the expression `1` can be written that way without fear that it will evaluate to zero, as happens in programming languages with integer datatypes.

There is no function for explicit conversion of a string to a number, but the *awk* idiom is simple: just add zero to the string. For example, `s = "123"`, followed by `n = 0 + s`, assigns the number 123 to `n`.

Non-numeric strings are coerced to numbers by converting as much of the string that looks like a number: `"+123ABC"` converts to 123, and `"ABC"`, `"ABC123"`, and `""` all convert to 0.

The limited precision of floating-point numbers means that some values cannot be represented exactly: the order of evaluation is significant (floating-point arithmetic is not associative), and computed results are normally rounded to the nearest representable number.

The limited range of floating-point numbers means that very small or very large numbers are not representable. On modern systems, such values are converted to zero and infinity.

Even though all numeric computations in *awk* are done in floating-point arithmetic, integer values can be represented exactly, provided that they are not too large. With IEEE 754 arithmetic, the 53-bit significand limits integers to at most $2^{53} = 9,007,199,254,740,992$. That number is large enough that few text processing applications that involve counting things are likely to reach it.

Numeric operators in *awk* are similar to those in several other programming languages. We collect them in Table 9-1.

Table 9-2. Numeric operators in *awk* (in decreasing precedence)

Operator	Description
<code>++</code> <code>--</code>	Increment and decrement (either prefix or postfix)

Operator	Description
<code>^ **</code>	Exponentiate (right-associative)
<code>! + -</code>	Not, unary plus, unary minus
<code>* / %</code>	Multiply, divide, remainder
<code>+ -</code>	Add, subtract
<code>< <= = = <= != > >=</code>	Compare
<code>&&</code>	Logical AND (short-circuit)
<code> </code>	Logical OR (short-circuit)
<code>? :</code>	Ternary conditional
<code>= += -= *= /= %= ^= **=</code>	Assign (right -associative)

Like most programming languages, *awk* allows parentheses to control evaluation order. Few people can remember operator precedence, especially if they work with multiple languages: when in doubt, parentheses

The increment and decrement operators work like those in the shell, described in Section 6.1.3. In isolation, `++n` and `n++` are equivalent. However, because they have the *side effect* of updating the variable as well as returning a value, ambiguities in evaluation order can arise when they are used more than once in the same statement. For example, the result of an expression like `n++ + ++n` is implementation defined. Despite such ambiguities, the increment and decrement operators receive wide use in programming languages that have them.

Exponentiation raises the left operand to the power given by the right operand. Thus, `n^3` and `n**3` both mean the cube of `n`. The two operator names are equivalent, but come from different ancestor languages. C programmers should note that *awk*'s `^` operator is different from C's, despite the similarity of major parts of the two languages.

Exponentiation and assignment are the only operators in *awk* that are *right-associative*: thus, `a^b^c^d` means `a^(b^(c^d))`, whereas `a/b/c/d` means `((a/b)/c)/d`. These associativity rules are common to most other programming languages, and are conventional in mathematics.

In the original *awk* specification, the result of the remainder operator is implementation-defined when either operand is negative. POSIX *awk* requires that it behave like the ISO Standard C function `fmod()`. This in turn requires that if `x % y` is representable, then the expression has the sign of `x`, and magnitude less than `y`. All *awk* implementations that we tested follow the POSIX mandate.

Just as in the shell, the logical operators `&&` and `||` are short-circuiting forms of AND and OR: they evaluate their righthand operand only if needed.

The operator in the next-to-last row in the table is the ternary short-circuiting conditional operator. If the first operand is nonzero (true), the result is the second operand; otherwise, it is the third operand. Only one of the second and third operands is evaluated. Thus, in *awk*, you can write a compact assignment `a = (u > w) ? x^3 : y^7` that in other programming languages might require something like this:

```
if (u > w) then
    a = x^3
else
    a = y^7
endif
```

The assignment operators are perhaps unusual for two reasons. First, the compound ones, like `/=`, use the left operand as the first operand on the right: `n /= 3` is simply shorthand for `n = n / 3`. Second, the result of an assignment is an expression that may be used as part of another expression: `a = b = c = 123` first assigns to `c` (because the assignment operator is right-associative), then assigns the value of `c` to `b`, and finally, assigns the value of `b` to `a`. The result, as expected, is that `a`, `b`, and `c` all receive the value 123. Similarly, `x = (y + 123) + (z = 321)` sets `x`, `y`, and `z` to 444, 123, and 321, respectively.

The `**` and `**=` operators are not part of POSIX *awk* and are not recognized by *mawk*. They should therefore be avoided in new code: use `^` and `^=` instead.

Be sure to note the difference between assignment with `=`, and equality test with `= =`. Because assignments are valid expressions, the expression `(r = s) ? t : u` is syntactically correct, but is probably not what you intended. It assigns `s` to `r`, and then if that value is nonzero, it returns `t`, and otherwise returns `u`. This warning also applies to C, C++, Java, and other languages with `=` and `= =` operators.

The built-in function `int()` returns the integer part of its argument: `int(-3.14159)` evaluates to -3.

awk provides some of the common elementary mathematical functions that may be familiar to you from calculators and from other programming languages: `sqrt()`, `sin()`, `cos()`, `log()`, `exp()`, and so on. They are summarized in Section 9.10.

9.3.4. Scalar Variables

Variables that hold a single value are called scalar variables. In *awk*, as in most scripting languages, variables are not explicitly declared. Instead, they are created automatically at their first use in the program, usually by

assignment of a value, which can be either a number or a string. When a variable is used, the context makes clear whether a number or a string is expected, and the value is automatically converted from one to the other as needed.

All *awk* variables are created with an initial empty string value that is treated as zero when a numeric value is required.

awk variable names begin with an ASCII letter or underscore, and optionally continue with letters, underscores, and digits. Thus, variable names match the regular expression `[A-Za-z_][A-Za-z_0-9]*`. There is no practical limit on the length of a variable name.

awk variable names are case-sensitive: `foo`, `Foo`, and `FOO` are distinct names. A common, and recommended convention is to name local variables in lowercase, global variables with an initial uppercase letter, and built-in variables in uppercase.

awk provides several built-in variables, all spelled in uppercase. The important ones that we often need for programs are shown in Table 9-2.

Table 9-3. Commonly used built-in scalar variables in *awk*

Variable	Description
<code>FILENAME</code>	Name of the current input file
<code>FNR</code>	Record number in the current input file
<code>FS</code>	Field separator (regular expression) (default: " ")
<code>NF</code>	Number of fields in current record
<code>NR</code>	Record number in the job
<code>OFS</code>	Output field separator (default: " ")
<code>ORS</code>	Output record separator (default: "\n ")
<code>RS</code>	Input record separator (regular expression in <i>gawk</i> and <i>mawk</i> only) (default: "\n ")

9.3.5. Array Variables

Array variables in *awk* follow the same naming conventions as scalar variables, but contain zero or more data items, selected by an array index following the name.

Most programming languages require arrays to be indexed by simple integer expressions, but *awk* allows array indices to be arbitrary numeric or string expressions, enclosed in square brackets after the array name. If you

have not encountered such arrays before, they may seem rather curious, but *awk* code like this fragment of office-directory program makes their utility obvious:

```
telephone["Alice"] = "555-0134"
telephone["Bob"]   = "555-0135"
telephone["Carol"] = "555-0136"
telephone["Don"]   = "555-0141"
```

Arrays with arbitrary indices are called *associative arrays* because they associate names with values, much humans do. Importantly, the technique that *awk* uses to implement these arrays allows *find*, *insert*, and *remove* operations to be done in essentially constant time, independent of the number of items stored.

Arrays in *awk* require neither declaration nor allocation: array storage grows automatically as new element referenced. Array storage is *sparse*: only those elements that are explicitly referenced are allocated. This means that you can follow `x[1] = 3.14159` with `x[10000000] = "ten million"`, without filling in elements 2 through 9999999. Most programming languages with arrays require all elements to be of the same type, but not the case with *awk* arrays.

Storage can be reclaimed when elements are no longer needed. `delete array[index]` removes an element from an array, and recent *awk* implementations allow `delete array` to delete all elements. We describe another way to delete array elements at the end of Section 9.9.6.

A variable cannot be used as both a scalar and an array at the same time. Applying the `delete` statement removes *elements* of an array, but not its *name*: therefore, code like this:

```
x[1] = 123
delete x
x = 789
```

causes *awk* to complain that you cannot assign a value to an array name.

Sometimes, multiple indices are needed to uniquely locate tabular data. For example, the post office uses house number, street, and postal code to identify mail-delivery locations. A row/column pair suffices to identify a position in a two-dimensional grid, such as a chessboard. Bibliographies usually record author, title, edition, publisher, and year to identify a particular book. A clerk needs a manufacturer, style, color, and size to retrieve the correct pair of shoes from a stockroom.

awk simulates arrays with multiple indices by treating a *comma-separated list of indices* as a single string.

However, because commas might well occur in the index values themselves, *awk* replaces the index-separator commas by an unprintable string stored in the built-in variable `SUBSEP`. POSIX says that its value is implementation-defined; generally, its default value is `"\034"` (the ASCII field-separator control character but you can change it if you need that string in the index values. Thus, when you write `maildrop[53, "Oak Lane", "T4Q 7XV"]`, *awk* converts the index list to the string expression `"53" SUBSEP "Oak Lane" SUBSEP "T4Q 7XV"`, and uses its string value as the index. This scheme can be subverted, although we do not recommend that you do so—these statements all print the same item:

```
print maildrop[53, "Oak Lane", "T4Q 7XV"]

print maildrop["53" SUBSEP "Oak Lane" SUBSEP "T4Q 7XV"]

print maildrop["53\034Oak Lane", "T4Q 7XV"]

print maildrop["53\034Oak Lane\034T4Q 7XV"]
```

Clearly, if you later change the value of `SUBSEP`, you will invalidate the indices of already-stored data, so `SUBSEP` really should be set just once per program, in the `BEGIN` action.

You can solve an astonishingly large number of data processing problems with associative arrays, once you rearrange your thinking appropriately. For a simple programming language like *awk*, they have shown themselves to be a superb design choice.

9.3.6. Command-Line Arguments

awk's automated handling of the command line means that few *awk* programs need concern themselves with it. This is quite different from the C, C++, Java, and shell worlds, where programmers are used to handling command-line arguments explicitly.

awk makes the command-line arguments available via the built-in variables `ARGC` (argument count) and `ARGV` (argument vector, or argument values). Here is a short program to illustrate their use:

```
$ cat showargs.awk
```

```
BEGIN {

    print "ARGC =", ARGC

    for (k = 0; k < ARGC; k++)

        print "ARGV[" k "] = [" ARGV[k] "]"

}
```

Here is what it produces for the general *awk* command line:

```
$ awk -v One=1 -v Two=2 -f showargs.awk Three=3 file1 Four=4 file2 file3

ARGC = 6

ARGV[0] = [awk]

ARGV[1] = [Three=3]

ARGV[2] = [file1]

ARGV[3] = [Four=4]

ARGV[4] = [file2]

ARGV[5] = [file3]
```

As in C and C++, the arguments are stored in array entries 0, 1, ..., *ARGC* - 1, and the zeroth entry is the name of the *awk* program itself. However, arguments associated with the *-f* and *-v* options are not available. Similar to any other command-line program is not available:

```
$ awk 'BEGIN { for (k = 0; k < ARGC; k++)
>     print "ARGV[" k "]" = [" ARGV[k] "]" }' a b c

ARGV[0] = [awk]

ARGV[1] = [a]

ARGV[2] = [b]

ARGV[3] = [c]
```

Whether a directory path in the program name is visible or not is implementation-dependent:

```
$ /usr/local/bin/gawk 'BEGIN { print ARGV[0] }'

gawk
```

```
$ /usr/local/bin/mawk 'BEGIN { print ARGV[0] }'
```


mawk

```
$ /usr/local/bin/nawk 'BEGIN { print ARGV[0] }'
```

```
/usr/local/bin/nawk
```

The *awk* program can modify *ARGC* and *ARGV*, although it is rarely necessary to do so. If an element of *ARGV* (re)set to an empty string, or deleted, *awk* ignores it, instead of treating it as a filename. If you eliminate trailing entries of *ARGV*, be sure to decrement *ARGC* accordingly.

awk stops interpreting arguments as options as soon as it has seen either an argument containing the program text, or the special *-* option. Any following arguments that look like options must be handled by your program and then deleted from *ARGV*, or set to an empty string.

It is often convenient to wrap the *awk* invocation in a shell script. To keep the script more readable, store a lengthy program in a shell variable. You can also generalize the script to allow the *awk* implementation to be chosen at runtime by an environment variable with a default of *nawk*:

```
#!/bin/sh -

AWK=${AWK:-nawk}

AWKPROG='
    ... long program here ...
'

$AWK "$AWKPROG" "$@"
```

Single quotes protect the program text from shell interpretation, but more care is needed if the program itself contains single quotes. A useful alternative to storing the program in a shell variable is to put it in a separate file in a shared library directory that is found relative to the directory where the script is stored:

```
#!/bin/sh -

AWK=${AWK:-nawk}

$AWK -f `dirname $0`/../share/lib/myprog.awk -- "$@"
```

The *dirname* command was described in Section 8.2. For example, if the script is in */usr/local/bin*, the

program is in `/usr/local/share/lib`. The use of *dirname* here ensures that the script will work as long as the relative location of the two files is preserved.

9.3.7. Environment Variables

awk provides access to all of the environment variables as entries in the built-in array `ENVIRON`:

```
$ awk 'BEGIN { print ENVIRON["HOME"]; print ENVIRON["USER"] }'
```

```
/home/jones
```

```
jones
```

There is nothing special about the `ENVIRON` array: you can add, delete, and modify entries as needed. However, POSIX requires that subprocesses inherit the environment in effect when *awk* was started, and we found no current implementations that propagate changes to the `ENVIRON` array to either subprocesses or built-in functions. In particular, this means that you cannot control the possibly locale-dependent behavior of string functions, like `tolower()`, with changes to `ENVIRON["LC_ALL"]`. You should therefore consider `ENVIRON` to be a read-only array.

If you need to control the locale of a subprocess, you can do so by setting a suitable environment variable in the command string. For example, you can sort a file in a Spanish locale like this:

```
system("env LC_ALL=es_ES sort infile > outfile")
```

The `system()` function is described later, in Section 9.7.8.

9.4. Records and Fields

Each iteration of the implicit loop over the input files in *awk*'s programming model processes a single *record*, typically a line of text. Records are further divided into smaller strings, called *fields*.

9.4.1. Record Separators

Although records are normally text lines separated by newline characters, *awk* allows more generality through the record-separator built-in variable, `RS`.

In traditional and POSIX *awk*, `RS` must be either a single literal character, such as newline (its default value), or an empty string. The latter is treated specially: records are then paragraphs separated by one or more blank lines, and empty lines at the start or end of a file are ignored. Fields are then separated by newlines or whatever `FS` is set to.

gawk and *mawk* provide an important extension: `RS` may be a regular expression, provided that it is longer than a single character. Thus, `RS = "+"` matches a literal plus, whereas `RS = ":+"` matches one or more colons. This provides much more powerful record specification, which we exploit in some of the examples in [Section 9.6](#).

With a regular expression record separator, the text that matches the separator can no longer be determined from the value of `RS`. *gawk* provides it as a language extension in the built-in variable `RT`, but *mawk* does not.

Without the extension of `RS` to regular expressions, it can be hard to simulate regular expressions as record separators, if they can match across line boundaries, because most Unix text processing tools deal with a line at a time. Sometimes, you can use *tr* to convert newline into an otherwise unused character, making the data stream one giant line. However, that often runs afoul of buffer-size limits in other tools. *gawk*, *mawk*, and *emacs* are unusual in freeing you from the limiting view of line-oriented data.

9.4.2. Field Separators

Fields are separated from each other by strings that match the current value of the field-separator regular expression, available in the built-in variable `FS`.

The default value of `FS`, a single space, receives special interpretation: it means one or more whitespace

characters (space or tab), and leading and trailing whitespace on the line is ignored. Thus, the input lines:

```
alpha beta gamma
```

```
alpha    beta    gamma
```

both look the same to an *awk* program with the default setting of `FS`: three fields with values "alpha", "beta", and "gamma". This is particularly convenient for input prepared by humans.

For those rare occasions when a single space separates fields, simply set `FS = "[]"` to match exactly one space. With that setting, leading and trailing whitespace is no longer ignored. These two examples report different numbers of fields (two spaces begin and end the input record):

```
$ echo ' un deux trois ' | awk -F' ' '{ print NF ":" $0 }'
```

```
3: un deux trois
```

```
$ echo ' un deux trois ' | awk -F'[ ]' '{ print NF ":" $0 }'
```

```
7: un deux trois
```

The second example sees seven fields: "", "", "un", "deux", "trois", "", and "".

`FS` is treated as a regular expression only when it contains more than one character. `FS = "."` uses a period as the field separator; it is *not* a regular expression that matches any single character.

Modern *awk* implementations also permit `FS` to be an empty string. Each *character* is then a separate field, but in older implementations, each record then has only one field. POSIX says only that the behavior for an empty field separator is unspecified.

9.4.3. Fields

Fields are available to the *awk* program as the special names `$1`, `$2`, `$3`, ..., `$NF`. Field references need not be constant, and they are converted (by truncation) to integer values if necessary: assuming that `k` is 3, the values `$k`, `$(1+2)`, `$(27/9)`, `$3.14159`, `"3.14159"`, and `$3` all refer to the third field.

The special field name `$0` refers to the current record, initially exactly as read from the input stream, and the record separator is not part of the record. References to field numbers above the range `0` to `NF` are *not* erroneous: they return empty strings and do not create new fields, unless you assign them a value.

References to fractional, or non-numeric, field numbers are implementation-defined. References to negative field numbers are fatal errors in all implementations that we tested. POSIX says only that references to anything other than non-negative integer field numbers are unspecified.

Fields can be assigned too, just like normal variables. For example, `$1 = "alef"` is legal, but has an important side effect: if the complete record is subsequently referenced, it is reassembled from the current values of the fields, but separated by the string given by the output-field-separator built-in variable, `OFS`, which defaults to a single space.



9.5. Patterns and Actions

Patterns and actions form the heart of *awk* programming. It is *awk*'s unconventional *data-driven* programming contributes to the brevity of many *awk* programs.

9.5.1. Patterns

Patterns are constructed from string and/or numeric expressions: when they evaluate to nonzero (true) for the action is carried out. If a pattern is a bare regular expression, then it means to match the entire input record against `/regexp/` instead of just `/regexp/`. Here are some examples to give the general flavor of selection patterns:

<code>NF == 0</code>	<i>Select empty records</i>
<code>NF > 3</code>	<i>Select records with more than 3 fields</i>
<code>NR < 5</code>	<i>Select records 1 through 4</i>
<code>(FNR == 3) && (FILENAME ~ /[.][ch]\$/)</code>	<i>Select record 3 in C source files</i>
<code>\$1 ~ /jones/</code>	<i>Select records with "jones" as first field</i>
<code>/[Xx][Mm][Ll]/</code>	<i>Select records containing "XML" or "xml"</i>
<code>\$0 ~ /[Xx][Mm][Ll]/</code>	<i>Same as preceding selection</i>

awk adds even more power to the matching by permitting *range expressions*. Two expressions separated by a comma select the records from the left expression up to, and including, the record that matches the right expression. If both range expressions match the same record, only that single record is selected. This behavior is different from that of *sed*, which looks for the range end only in record selection. Here are some examples:

<code>(FNR == 3), (FNR == 10)</code>	<i>Select records 3 through 10</i>
<code>/<[Hh][Tt][Mm][Ll]>/, /<\ [Hh][Tt][Mm][Ll]>/</code>	<i>Select body of an HTML document</i>
<code>/[aeiouy][aeiouy]/, /^[^aeiouy][^aeiouy]/</code>	<i>Select from two vowels to the next non-vowel</i>

In the `BEGIN` action, `FILENAME`, `FNR`, `NF`, and `NR` are initially undefined; references to them return a null string.

If a program consists only of actions with `BEGIN` patterns, `awk` exits after completing the last action, without

On entry to the first `END` action, `FILENAME` is the name of the last input file processed, and `FNR`, `NF`, and `NR` record. The value of `$0` in the `END` action is unreliable: `gawk` and `mawk` retain it, `nawk` does not, and POSIX

9.5.2. Actions

We have now covered most of the `awk` language elements needed to select records. The action section that the action is: it specifies how to process the record.

`awk` has several statement types that allow construction of arbitrary programs. However, we delay presentation now, apart from the assignment statement, we consider only the simple `print` statement.

In its simplest form, a bare `print` means to print the current input record (`$0`) on standard output, followed by `ORS`, which is by default a single newline character. These programs are therefore equivalent:

<code>1</code>		<i>Pattern is true, default action is true</i>
<code>NR > 0</code>	<code>{ print }</code>	<i>Print when have records, is always true</i>
<code>1</code>	<code>{ print }</code>	<i>Pattern is true, explicit print, default</i>
	<code>{ print }</code>	<i>No pattern is treated as true, explicit</i>
	<code>{ print \$0 }</code>	<i>Same, but with explicit value to print</i>

A one-line `awk` program that contained any of those lines would simply copy the input stream to standard output.

More generally, a `print` statement can contain zero or more comma-separated expressions. Each is evaluated and its output on standard output, separated by the value of the output field separator, `OFS`. The last item is followed by the output separator, `ORS`.

The argument lists for `print` and its companions `printf` and `sprintf` (see Section 9.9.8) may optionally be enclosed in quotes to avoid parsing ambiguity when the argument list contains a relational operator, since `<` and `>` are also used in I/O redirection. See Section 9.7.7.

Here are some complete `awk` program examples. In each, we print just the first three input fields, and by one record. Semicolons separate `awk` program statements, and we vary the action code slightly to change the output.

```
$ echo 'one two three four' | awk '{ print $1, $2, $3 }'
```

```
one two three
```

```
$ echo 'one two three four' | awk '{ OFS = "..."; print $1, $2, $3 }'
```

one...two...three

```
$ echo 'one two three four' | awk '{ OFS = "\n"; print $1, $2, $3 }'
```

one

two

three

Changing the output field separator without assigning any field does *not* alter \$0 :

```
$ echo 'one two three four' | awk '{ OFS = "\n"; print $0 }'
```

one two three four

However, if we change the output field separator, and we assign at least one of the fields (even if we do not of the record with the new field separator:

```
$ echo 'one two three four' | awk '{ OFS = "\n"; $1 = $1; print $0 }'
```

one

two

three

four

< Day Day Up >

9.6. One-Line Programs in *awk*

We have now covered enough *awk* to do useful things with as little as one line of code; few other programs can do so much with so little. In this section, we present some examples of these one-liners, although page-limitations sometimes force us to wrap them onto more than one line. In some of the examples, we show in one program a solution in *awk*, or with other Unix tools:

- We start with a simple implementation in *awk* of the Unix word-count utility, *wc* :

```
awk '{ C += length($0) + 1; W += NF } END { print NR, W, C }'
```

- Notice that pattern/action groups need not be separated by newlines, even though we usually do that for readability. Although we could have included an initialization block of the form `BEGIN { C = W = 0 }`, *awk*'s default initializations make it unnecessary. The character count in `C` is updated at each record to count the length, plus the newline that is the default record separator. The word count in `W` accumulates the number of words in each record. We do not need to keep a line-count variable because the built-in record count, `NR`, automatically tracks the number of records for us. The `END` action handles the printing of the one-line report that *wc* produces.
- *awk* exits immediately without reading any input if its program is empty, so it can match *cat* as an efficient sink:

```
$ time cat *.xml > /dev/null
```

```
0.035u 0.121s 0:00.21 71.4%      0+0k 0+0io 99pf+0w
```

```
$ time awk '' *.xml
```

```
0.136u 0.051s 0:00.21 85.7%      0+0k 0+0io 140pf+0w
```

- Apart from issues with NUL characters, *awk* can easily emulate *cat* -these two examples produce identical output:

```
cat *.xml
```

```
awk 1 *.xml
```

- To print original data values and their logarithms for one-column datafiles, use this:

```
awk '{ print $1, log($1) }' file(s)
```

- To print a random sample of about 5 percent of the lines from text files, use the pseudorandom-number function (see Section 9.10), which produces a result uniformly distributed between zero and one:

```
awk 'rand( ) < 0.05' file(s)
```

- Reporting the sum of the n -th column in tables with whitespace-separated columns is easy:

```
awk -v COLUMN=n '{ sum += $COLUMN } END { print sum }' file(s)
```

- A minor tweak instead reports the average of column n :

```
awk -v COLUMN=n '{ sum += $COLUMN } END { print sum / NR }' file(s)
```

- To print the running total for expense files whose records contain a description and an amount in the built-in variable `NF` in the computation of the total:

```
awk '{ sum += $NF; print $0, sum }' file(s)
```

- Here are three ways to search for text in files:

```
egrep 'pattern|pattern' file(s)
```

```
awk '/pattern|pattern/' file(s)
```

```
awk '/pattern|pattern/ { print FILENAME ":" FNR ":" $0 }' file(s)
```

- If you want to restrict the search to just lines 100-150, you can use two tools and a pipeline, albeit with information:

```
sed -n -e 100,150p -s file(s) | egrep 'pattern'
```

- We need GNU *sed* here for its *-s* option, which restarts line numbering for each file. Alternatively, you can use *yc* with a fancier pattern:

```
awk '(100 <= FNR) && (FNR <= 150) && /pattern/ \
    { print FILENAME ":" FNR ":" $0 }' file(s)
```

- To swap the second and third columns in a four-column table, assuming tab separators, use any of the

```
awk -F'\t' -v OFS='\t' '{ print $1, $3, $2, $4 }' old > new
```

```
awk 'BEGIN { FS = OFS = "\t" } { print $1, $3, $2, $4 }' old > new
```

```
awk -F'\t' '{ print $1 "\t" $3 "\t" $2 "\t" $4 }' old > new
```

- To convert column separators from tab (shown here as `.`) to ampersand, use either of these:

```
sed -e 's/./\&/g' file(s)
```

```
awk 'BEGIN { FS = "\t"; OFS = "&" } { $1 = $1; print }' file(s)
```

- Both of these pipelines eliminate duplicate lines from a sorted stream:

```
sort file(s) | uniq
```

```
sort file(s) | awk 'Last != $0 { print } { Last = $0 }'
```

- To convert carriage-return/newline line terminators to newline terminators, use one of these:

```
sed -e 's/\r$//' file(s)
```

```
sed -e 's/^M$//' file(s)
```

```
mawk 'BEGIN { RS = "\r\n" } { print }' file(s)
```

- The first *sed* example needs a modern version that recognizes escape sequences. In the second example, `^M` represents a literal Ctrl-M (carriage return) character. For the third example, we need either *gawk* or *n*

nawk and POSIX *awk* do not support more than a single character in `RS` .

- To convert single-spaced text lines to double-spaced lines, use any of these:

```
sed -e 's/$/\n/' file(s)
```

```
awk 'BEGIN { ORS = "\n\n" } { print }' file(s)
```

```
awk 'BEGIN { ORS = "\n\n" } 1' file(s)
```

```
awk '{ print $0 "\n" }' file(s)
```

```
awk '{ print; print "" }' file(s)
```

- As before, we need a modern *sed* version. Notice how a simple change to the output record separator, first *awk* example solves the problem: the rest of the program just prints each record. The two other *a* require more processing for each record, and usually are slower than the first one.
- Conversion of double-spaced lines to single spacing is equally easy:

```
gawk 'BEGIN { RS="\n *\n" } { print }' file(s)
```

- To locate lines in Fortran 77 programs that exceed the 72-character line-length limit,^[2] either of these d

^[2] The Fortran line-length limit was not a problem in the old days of punched cards, but once screen-based editing became it became a source of nasty bugs caused by the compiler's silently ignoring statement text beyond column 72.

```
egrep -n '^.{73,}' *.f
```

```
awk 'length($0) > 72 { print FILENAME ":" FNR ":" $0 }' *.f
```

- We need a POSIX-compliant *egrep* for the extended regular expression that matches 73 or more of any
- To extract properly hyphenated International Standard Book Number (ISBN) values from documents lengthy, but straightforward, regular expression, with the record separator set to match all characters 1 part of an ISBN:

```
gawk 'BEGIN { RS = "[^-0-9Xx]" }'
```

```
/[0-9][0-9][0-9][0-9][0-9][0-9][0-9][0-9][0-9][0-9][0-9][0-9]-[0-9]
```


file(s)

- With a POSIX-conformant *awk*, that long regular expression can be shortened to `/[0-9][-0-9]{10}`. Our tests found that `gawk --posix`, HP/Compaq/DEC OSF/1 *awk*, Hewlett-Packard HP-UX *awk*, and Sun Solaris `/usr/xpg4/bin/awk` are the only ones that support the POSIX extension of braced in expressions in regular expressions.
- To strip angle-bracketed markup tags from HTML documents, treat the tags as record separators, like

```
mawk 'BEGIN { ORS = " "; RS = "<[^<>]*>" } { print }' *.html
```

- By setting `ORS` to a space, HTML markup gets converted to a space, and all input line breaks are preserved.
- Here is how we can extract all of the titles from a collection of XML documents, such as the files for `print` them, one title per line, with surrounding markup. This program works correctly even when the titles span multiple lines, and handles the uncommon, but legal, case of spaces between the tag word and the closing bracket:

```
$ mawk -v ORS=' ' -v RS='[\n]' '/<title *>/, /<\s*/title *>/' *.xml |
```

```
> sed -e 's@</title *> *@&\n@g'
```

...

```
<title>Enough awk to Be Dangerous</title>
```

```
<title>Freely available awk versions</title>
```

```
<title>The awk Command Line</title>
```

...

- The *awk* program produces a single line of output, so the modern *sed* filter supplies the needed line breaks. *sed* could eliminate *sed* here, but to do so, we need some *awk* statements discussed in the next section.

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9.7. Statements

Programming languages need to support sequential, conditional, and iterative execution. *awk* provides these with statements borrowed largely from the C programming language. This section also covers the different types that are specific to *awk*.

9.7.1. Sequential Execution

Sequential execution is provided by lists of statements, written one per line, or separated by semicolons. The following lines:

```
n = 123
```

```
s = "ABC"
```

```
t = s n
```

can also be written like this:

```
n = 123; s = "ABC"; t = s n
```

In one-liners, we often need the semicolon form, but in *awk* programs supplied from files, we usually put each statement on its own line, and we rarely need a semicolon.

Wherever a single statement is expected, a *compound statement* consisting of a braced group of statements is used instead. Thus, the actions associated with *awk* patterns are just compound statements.

9.7.2. Conditional Execution

awk provides for conditional execution with the `if` statement:

```
if (expression)
```

```
    statement1
```

```
if (expression)
```

```

    statement1
else
    statement2

```

If the *expression* is nonzero (true), then execute *statement*₁. Otherwise, if there is an *else* part, execute *statement*₂. Each of these statements may themselves be *if* statements, so the general form of a multibranch conditional statement is usually written like this:

```

if (expression1)
    statement1
else if (expression2)
    statement2
else if (expression3)
    statement3
...
else if (expressionk)
    statementk
else
    statementk+1

```

The optional final *else* is always associated with the closest preceding *if* at the same level.

In a multibranch *if* statement, the conditional expressions are tested in order: the first one that matches selects the associated statement for execution, after which control continues with the statement following the complete *if* statement, without evaluating conditional expressions in the remainder of the statement. If no expressions match, then the final *else* branch, if present, is selected.

9.7.3. Iterative Execution

awk provides four kinds of iterative statements (loops):

- Loop with a termination test at the beginning:

```
while (expression)
    statement
```

- Loop with a termination test at the end:

```
do
    statement
while (expression)
```

- Loop a countable number of times:

```
for (expr1; expr2; expr3)
    statement
```

- Loop over elements of an associative array:

```
for (key in array)
    statement
```

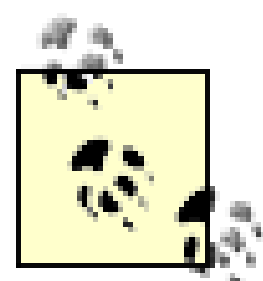
The `while` loop satisfies many iteration needs, typified by *while we have data, process it*. The `do` loop is not common: it appears, for example, in optimization problems that reduce to *compute an error estimate, and while the error is too big*. Both loop while the expression is nonzero (true). If the expression is initially zero, the `while` loop body is not executed at all, whereas the `do` loop body is executed just once.

The first form of the `for` loop contains three semicolon-separated expressions, any or all of which may be used. The first expression is evaluated before the loop begins. The second is evaluated at the start of each iteration, and if nonzero (true), the loop continues. The third is evaluated at the end of each iteration. The traditional loop form is written like this:

```
for (k = 1; k <= n; k++)
    statement
```


However, the index need not increase by one each iteration. The loop can be run backward like this:

```
for (k = n; k >= 1; k--)
    statement
```



Because floating-point arithmetic is usually inexact, avoid `for`-statement expressions that evaluate to nonintegral values. For example, the loop:

```
$ awk 'BEGIN { for (x = 0; x <= 1; x += 0.05) print x }' ..
0.85
0.9
0.95
```

does not print 1 in its last iteration because the additions of the inexactly represented value 0 produce a final `x` value that is slightly larger than 1.0.

C programmers should note that `awk` lacks a comma operator, so the three `for` loop expressions cannot be separated lists of expressions.

The second form of the `for` loop is used for iterating over the elements of an array when the number of elements is not known, or do not form a computable integer sequence. The elements are selected in arbitrary order, so of:

```
for (name in telephone)
    print name "\t" telephone[name]
```

is unlikely to be in the order that you want. We show how to solve that problem in Section 9.7.7. The `split` function, described in Section 9.9.6, handles the case of multiply-indexed arrays.

As in the shell, the `break` statement exits the innermost loop prematurely:

```
for (name in telephone)
    if (telephone[name] == "555-0136")
```

```
break
```

```
print name, "has telephone number 555-0136"
```

However, the shell-style multilevel `break n` statement is not supported.

Just like in the shell, the `continue` statement jumps to the end of the loop body, ready for the next iteration. The shell does not recognize the shell's multilevel `continue n` statement. To illustrate the `continue` statement, the program in Example 9-1 determines by brute-force testing of divisors whether a number is composite or prime (recall that a prime number is any whole number larger than one that has no integral divisors other than one and itself), and prints any factorization that it can find.

Example 9-1. Integer factorization

```
# Compute integer factorizations of integers supplied one per line.

# Usage:

#      awk -f factorize.awk

{

    n = int($1)

    m = n = (n >= 2) ? n : 2

    factors = ""

    for (k = 2; (m > 1) && (k^2 <= n); k++)
    {
        if (int(m % k) != 0)
        {
            k++

            continue
        }

        m /= k
    }
}
```

```

        factors = (factors = = "") ? (" " k) : (factors " * " k)
    }

    if ((1 < m) && (m < n))

        factors = factors " * " m

    print n, (factors = = "") ? "is prime" : ("= " factors)
}

```

Notice that the loop variable `k` is incremented, and the `continue` statement executed, only when we find a divisor of `m`, so the third expression in the `for` statement is empty.

If we run it with suitable test input, we get this output:

```

$ awk -f factorize.awk test.dat

2147483540 = 2 * 2 * 5 * 107374177
2147483541 = 3 * 7 * 102261121
2147483542 = 2 * 3137 * 342283
2147483543 is prime
2147483544 = 2 * 2 * 2 * 3 * 79 * 1132639
2147483545 = 5 * 429496709
2147483546 = 2 * 13 * 8969 * 9209
2147483547 = 3 * 3 * 11 * 21691753
2147483548 = 2 * 2 * 7 * 76695841
2147483549 is prime
2147483550 = 2 * 3 * 5 * 5 * 19 * 23 * 181 * 181

```

9.7.4. Array Membership Testing

The membership test `key in array` is an expression that evaluates to 1 (true) if `key` is an index element of

The test can be inverted with the *not* operator: `!(key in array)` is 1 if *key* is not an index element of *array*. parentheses are mandatory.

For arrays with multiple subscripts, use a parenthesized comma-separated list of subscripts in the test: `(i , n) in array` .

A membership test never creates an array element, whereas referencing an element always creates it, if it does not already exist. Thus, you should write:

```
if ("Sally" in telephone)
    print "Sally is in the directory"
```

rather than:

```
if (telephone["Sally"] != "")
    print "Sally is in the directory"
```

because the second form installs her in the directory with an empty telephone number, if she is not already there.

It is important to distinguish finding an *index* from finding a particular *value* . The index membership test runs in constant time, whereas a search for a value takes time proportional to the number of elements in the array, as shown by the `for` loop in the `break` statement example in the previous section. If you need to do both of these operations frequently, it is worthwhile to construct an inverted-index array:

```
for (name in telephone)
    name_by_telephone[telephone[name]] = name
```

You can then use `name_by_telephone["555-0136"]` to find "Carol" in constant time. Of course, this assumes all values are unique: if two people share a telephone, the `name_by_telephone` array records only the last one stored. You can solve that problem with just a bit more code:

```
for (name in telephone)
{
    if (telephone[name] in name_by_telephone)
        name_by_telephone[telephone[name]] = \
            name_by_telephone[telephone[name]] "\t" name
    else
        name_by_telephone[telephone[name]] = name
}
```



```

else
    name_by_telephone[telephone[name]] = name
}

```

Now `name_by_telephone` contains tab-separated lists of people with the same telephone number.

9.7.5. Other Control Flow Statements

We have already discussed the `break` and `continue` statements for interrupting the control flow in iterative statements. Sometimes, you need to alter the control flow in *awk*'s matching of input records against the pattern list of pattern/action pairs. There are three cases to handle:

Skip further pattern checking for this record only

Use the `next` statement. Some implementations do not permit `next` in user-defined functions (described in Section 9.8).

Skip further pattern checking for the current input file

gawk and recent releases of *nawk* provide the `nextfile` statement. It causes the current input file to be closed immediately, and pattern matching restarts with records from the next file on the command line.

You can easily simulate the `nextfile` statement in older *awk* implementation, with some loss of efficiency, by using the `nextfile` statement with `SKIPFILE = FILENAME; next`, and then add these new pattern/action pairs at the beginning of the program:

```

FNR = 1 { SKIPFILE = "" }
FILENAME = FILENAME SKIPFILE { next }

```

The first pattern/action pair resets `SKIPFILE` to an empty string at the start of each file so that the program works properly if the same filename appears as two successive arguments. Even though records continue to be read from the current file, they are immediately ignored by the `next` statement. When end-of-file is reached and the next file is opened, the second pattern no longer matches, so the `next` statement in its action is not executed.

Skip further execution of the entire job, and return a status code to the shell

Use the `exit n` statement.

9.7.6. User-Controlled Input

`awk`'s transparent handling of input files specified on the command line means that most `awk` programs need not open and process files themselves. It is quite possible to do so, however, through `awk`'s `getline` statement. For example, a spellchecker usually needs to load in one or more dictionaries before it can do its work.

`getline` returns a value and can be used like a function, even though it is actually a statement, and one with unconventional syntax. The return value is +1 when input has been successfully read, 0 at end-of-file, and -1 on error. It can be used in several different ways that are summarized in Table 9-3.

Table 9-4. `getline` variations

Syntax	Description
<code>getline</code>	Read the next record from the current input file into <code>\$0</code> , and update <code>NF</code> , <code>NR</code> , and <code>FNR</code> .
<code>getline var</code>	Read the next record from the current input file into <code>var</code> , and update <code>NR</code> and <code>FNR</code> .
<code>getline < file</code>	Read the next record from <code>file</code> into <code>\$0</code> , and update <code>NF</code> .
<code>getline var < file</code>	Read the next record from <code>file</code> into <code>var</code> .
<code>cmd getline</code>	Read the next record from the external command, <code>cmd</code> , into <code>\$0</code> , and update <code>NF</code> .
<code>cmd getline var</code>	Read the next record from the external command, <code>cmd</code> , into <code>var</code> .

Let's look at some of these uses of `getline`. First, we pose a question, and then read and check the answer:

```
print "What is the square root of 625?"
```

```
getline answer
```

```
print "Your reply, ", answer ", is", (answer == 25) ? "right." : "
```

If we wanted to ensure that input came from the controlling terminal, rather than standard input, we instead have used:

```
getline answer < "/dev/tty"
```

Next, we load a list of words from a dictionary:

```
nwords = 1

while ((getline words[nwords] < "/usr/dict/words") > 0)

    nwords++
```

Command pipelines are a powerful feature in *awk*. The pipeline is specified in a character string, and can contain arbitrary shell commands. It is used with `getline` like this:

```
"date" | getline now

close("date")

print "The current time is", now
```

Most systems limit the number of open files, so when we are through with the pipeline, we use the `close()` function to close the pipeline file. In older *awk* implementations, `close` was a statement, so there is no portability to use it like a function and get a reliable return code back.

Here is how you can use a command pipeline in a loop:

```
command = "head -n 15 /etc/hosts"

while ((command | getline s) > 0)

    print s

close(command)
```

We used a variable to hold the pipeline to avoid repetition of a possibly complicated string, and to ensure that uses of the command match exactly. In command strings, every character is significant, and even an inadvertent difference of a single space would refer to a different command.

9.7.7. Output Redirection

The `print` and `printf` statements (see Section 9.9.8) normally send their output to standard output. However, output can be sent to a file instead:

```
print "Hello, world" > file

printf("The tenth power of %d is %d\n", 2, 2^10) > "/dev/tty"
```


To append to an existing file (or create a new one if it does not yet exist), use `>>` output redirection:

```
print "Hello, world" >> file
```

You can use output redirection to the same file on any number of output statements. When you are finished output, use `close(file)` to close the file and free its resources.

Avoid mixing `>` and `>>` for the same file without an intervening `close()`. In *awk*, these operators tell how output file should be opened. Once open, the file remains open until it is explicitly closed, or until the program terminates. Contrast that behavior with the shell, where redirection requires the file to be opened and closed in a separate command.

Alternatively, you can send output to a pipeline:

```
for (name in telephone)
    print name "\t" telephone[name] | "sort"
close("sort")
```

As with input from a pipeline, close an output pipeline as soon as you are through with it. This is particularly important if you need to read the output in the same program. For example, you can direct the output to a temporary file, and then read it after it is complete:

```
tmpfile = "/tmp/telephone.tmp"
command = "sort > " tmpfile
for (name in telephone)
    print name "\t" telephone[name] | command
close(command)
while ((getline < tmpfile) > 0)
    print
close(tmpfile)
```

Pipelines in *awk* put the entire Unix toolbox at our disposal, eliminating the need for much of the library su

offered in other programming languages, and helping to keep the language small. For example, *awk* does not have a built-in function for sorting because it would just duplicate functionality already available in the powerful `sort` command described in Section 4.1 .

Recent *awk* implementations, but not POSIX, provide a function to flush buffered data to the output stream `flush(file)` . Notice the doubled initial `ff` (for *file flush*). It returns 0 on success and -1 on failure. The behavior of `fflush()` (omitted argument) and `fflush("")` (empty string argument) is implementation-dependent: `fflush()` is used in portable programs.

9.7.8. Running External Programs

We showed earlier how the `getline` statement and output redirection in *awk* pipelines can communicate with external programs. The `system(command)` function provides a third way: its return value is the exit status of the command. It first flushes any buffered output, then starts an instance of `/bin/sh` , and sends it the command. The shell's standard error and standard output are the same as that of the *awk* program, so unless the command's output is redirected, output from both the *awk* program and the shell command appears in the expected order.

Here is a shorter solution to the telephone-directory sorting problem, using a temporary file and `system()` instead of an *awk* pipeline:

```
tmpfile = "/tmp/telephone.tmp"

for (name in telephone)
    print name "\t" telephone[name] > tmpfile

close(tmpfile)

system("sort < " tmpfile)
```

The temporary file must be closed before the call to `system()` to ensure that any buffered output is properly written in the file.

There is no need to call `close()` for commands run by `system()` , because `close()` is only for files or pipes opened with the I/O redirection operators and `getline` , `print` , or `printf` .

The `system()` function provides an easy way to remove the script's temporary file:

```
system("rm -f " tmpfile)
```

The command passed to `system()` can contain multiple lines:

```
system("cat <<EOF\nuno\ndos\ntres\nEOF")
```

It produces the output expected when copying the here document to standard output:

```
uno
```

```
dos
```

```
tres
```

Because each call to `system()` starts a fresh shell, there is no simple way to pass data between commands separate calls to `system()`, other than via intermediate files. There is an easy solution to this problem-use an output pipeline to the shell to send multiple commands:

```
shell = "/usr/local/bin/ksh"
```

```
print "export INPUTFILE=/var/tmp/myfile.in" | shell
```

```
print "export OUTPUTFILE=/var/tmp/myfile.out" | shell
```

```
print "env | grep PUTFILE" | shell
```

```
close(shell)
```

This approach has the added virtue that you get to choose the shell, but has the drawback that you cannot retrieve the exit-status value.

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9.8. User-Defined Functions

The *awk* statements that we have covered so far are sufficient to write almost any data processing program. Because human programmers are poor at understanding large blocks of code, we need a way to split such blocks into manageable chunks that each perform an identifiable job. Most programming languages provide this ability, through features variously called functions, methods, modules, packages, and subroutines. For simplicity, *awk* provides only functions. As in C, *awk* functions can optionally return a scalar value. Only a function's documentation, or its code, if quite short, can make clear whether the caller should expect a return value.

Functions can be defined anywhere in the program at top level: before, between, or after pattern/action groups. In single-file programs, it is conventional to place all functions after the pattern/action code, and it is usually most convenient to keep them in alphabetical order. *awk* does not care about these conventions, but people

A function definition looks like this:

```
function name(arg1, arg2, ..., argn)
{
    statement(s)
}
```

The named arguments are used as local variables within the function body, and they hide any global variables of the same name. The function may be used elsewhere in the program by calls of the form:

```
name(expr1, expr2, ..., exprn)           Ignore any return value
```

```
result = name(expr1, expr2, ..., exprn)   Save return value in result
```

The expressions at the point of each call provide initial values for the function-argument variables. The parenthesized argument list must immediately follow the function name, without any intervening whitespace.

Changes made to scalar arguments are not visible to the caller, but changes made to arrays *are* visible. In other words, scalars are passed *by value*, whereas arrays are passed *by reference*: the same is true of the C language.

A *return expression* statement in the function body terminates execution of the body, and returns control to the point of the call, with the value of *expression*. If *expression* is omitted, then the returned value is implementation-defined. All of the systems that we tested returned either a numeric zero, or an empty string. POSIX does not address the issue of a missing *return* statement or value.

All variables used in the function body that do not occur in the argument list are *global*. *awk* permits a function to be called with fewer arguments than declared in the function definition; the extra arguments then serve as *local* variables. Such variables are commonly needed, so it is conventional to list them in the function argument list, prefixed by some extra whitespace, as shown in Example 9-2. Like all other variables in *awk*, the extra arguments are initialized to an empty string at function entry.

Example 9-2. Searching an array for a value

```
function find_key(array, value,          key)
{
    # Search array[ ] for value, and return key such that
    # array[key] == value, or return "" if value is not found

    for (key in array)
        if (array[key] == value)
            return key

    return ""
}
```

Failure to list local variables as extra function arguments leads to hard-to-find bugs when they clash with variables used in calling code. *gawk* provides the *-dump-variables* option to help you check for this.

As in most programming languages, *awk* functions can call themselves: this is known as *recursion*. Obviously, the programmer must make some provision for eventual termination: this is usually done by making the job smaller for each successive invocation so that at some point, no further recursion is needed. Example 9-3 shows a famous example from elementary number theory that uses a method credited to the Greek mathematician Euclid (ca. 300 BCE), but probably known at least 200 years earlier, to find the greatest common denominator of two integers.

Example 9-3. Euclid's greatest common denominator algorithm

```
function gcd(x, y, r)
{
    # return the greatest common denominator of integer x, y

    x = int(x)
    y = int(y)
    # print x, y

    r = x % y

    return (r == 0) ? y : gcd(y, r)
}
```

If we add this action

```
{ g = gcd($1, $2); print "gcd(" $1 " , " $2 ") =", g }
```

to the code in Example 9-3 and then we uncomment the `print` statement and run it from a file, we can see how the recursion works:

```
$ echo 25770 30972 | awk -f gcd.awk
```

```
25770 30972
```

```
30972 25770
```

```
25770 5202
```

```
5202 4962
```

```
4962 240
```

```
240 162
```

```
162 78
```

78 6

```
gcd(25770, 30972) = 6
```

Euclid's algorithm always takes relatively few steps, so there is no danger of overflowing the *call stack* inside *awk* that keeps track of the nested function-call history. However, that is not always the case. There is a particularly nasty function discovered by the German mathematician Wilhelm Ackermann^[3] in 1926 whose value, and recursion depth, grow much faster than exponentially. It can be defined in *awk* with the code in Example 9-4.

^[3] See <http://mathworld.wolfram.com/AckermannFunction.html> for background and history of the Ackermann function.

Example 9-4. Ackermann's worse-than-exponential function

```
function ack(a, b)
{
    N++                # count recursion depth
    if (a == 0)
        return (b + 1)
    else if (b == 0)
        return (ack(a - 1, 1))
    else
        return (ack(a - 1, ack(a, b - 1)))
}
```

If we augment it with a test action:

```
{ N = 0; print "ack(" $1 ", " $2 ") = ", ack($1, $2), "[" N " calls]"
```

and run it from a test file, we find:

```
$ echo 2 2 | awk -f ackermann.awk
```

```
ack(2, 2) = 7 [27 calls]
```

```
$ echo 3 3 | awk -f ackermann.awk
```

```
ack(3, 3) = 61 [2432 calls]
```

```
$ echo 3 4 | awk -f ackermann.awk
```

```
ack(3, 4) = 125 [10307 calls]
```

```
$ echo 3 8 | awk -f ackermann.awk
```

```
ack(3, 8) = 2045 [2785999 calls]
```

ack(4, 4) is completely uncomputable.

< Day Day Up >

9.9. String Functions

In Section 9.3.2 we introduced the `length(string)` function, which returns the length of a string `string`. String operations include concatenation, data formatting, lettercase conversion, matching, searching, splitting, and substring extraction.

9.9.1. Substring Extraction

The substring function, `substr(string , start , len)`, returns a copy of the substring of `len` characters starting from character `start`. Character positions are numbered starting from one: `substr("abcde", 2, 3)` returns "bcde". The `len` argument can be omitted, in which case, it defaults to `length(string) - start + 1`, selecting the rest of the string.

It is *not* an error for the arguments of `substr()` to be out of bounds, but the result may be implementation dependent. For example, `nawk` and `gawk` evaluate `substr("ABC", -3, 2)` as "AB", whereas `mawk` produces the empty string. `gawk` produces an empty string for `substr("ABC", 4, 2)` and for `substr("ABC", 1, 0)`. `gawk`'s `-lint` option enforces bounds arguments in `substr()` calls.

9.9.2. Lettercase Conversion

Some alphabets have uppercase and lowercase forms of each letter, and in string searching and matching, it is often desirable to ignore case differences. `awk` provides two functions for this purpose: `tolower(string)` returns a copy of `string` with all characters replaced by their lowercase equivalents, and `toupper(string)` returns a copy with all characters replaced by their uppercase equivalents. `tolower("aBcDeF123")` returns "abcdef123", and `toupper("aBcDeF123")` returns "ABCDEF123". These functions work on ASCII letters, but they do not correctly case-convert accented letters. Nor do they handle unusual situations like the lowercase letter ß (eszett, sharp s), whose uppercase form is two letters, SS.

9.9.3. String Searching

`index(string , find)` searches the text in `string` for the string `find`. It returns the starting position of `find` in `string`, or 0 if `find` is not found in `string`. For example, `index("abcdef", "de")` returns 4.

Subject to the caveats noted in Section 9.9.2, you can make string searches ignore lettercase like this: `index(string , tolower(find))`. Because case insensitivity is sometimes needed in an entire program, `gawk` provides the built-in variable `IGNORECASE` to nonzero to ignore lettercase in string matches, searches, and comparisons.

`index()` finds the first occurrence of a substring, but sometimes, you want to find the last occurrence. There is no built-in function to do that, but we can easily write one, shown in Example 9-5.

Example 9-5. Reverse string search

```
function rindex(string, find, k, ns, nf)
{
    # Return index of last occurrence of find in string,
    # or 0 if not found

    ns = length(string)
    nf = length(find)

    for (k = ns + 1 - nf; k >= 1; k--)
        if (substr(string, k, nf) == find)
            return k

    return 0
}
```

The loop starts at a `k` value that lines up the ends of the strings `string` and `find`, extracts a substring from same length as `find`, and compares that substring with `find`. If they match, then `k` is the desired index of `find` and the function returns that value. Otherwise, we back up one character, terminating the loop when `k` moves to the beginning of `string`. When that happens, `find` is known not to be found in `string`, and we return an index of 0.

9.9.4. String Matching

`match(string, regexp)` matches `string` against the regular expression `regexp`, and returns the index of the match, or 0 if there is no match. This provides more information than the expression `string ~ regexp`, which returns either 1 or 0. In addition, `match()` has a useful side effect: it sets the global variables `RSTART` to the index in `string` of the match, and `RLENGTH` to the length of the match. The matching substring is then available as `substr(string, RSTART, RLENGTH)`.

9.9.5. String Substitution

`awk` provides two functions for string substitution: `sub(regexp, replacement, target)` and `gsub(regexp, replacement, target)`.

`target`). `sub()` matches `target` against the regular expression `regexp` , and replaces the leftmost long string `replacement` . `gsub()` works similarly, but replaces all matches (the prefix `g` stands for *global*). By the number of substitutions. If the third argument is omitted, it defaults to the current record, `$0` . These functions modify their scalar arguments: consequently, they cannot be written in the *awk* language itself. For writing application might use `gsub(/[^\$-0-9.]/, "*", amount)` to replace with asterisks all characters that can legally appear in the amount.

In a call to `sub(regexp , replacement , target)` or `gsub(regexp , replacement , target)` , each instance of `&` in `replacement` is replaced in `target` by the text matched by `regexp` . Use `\&` to disable this feature, and the backslash if you use it in a quoted string. For example, `gsub(/[aeiouyAEIOUY]/, "&&")` doubles all vowels in the record, `$0` , whereas `gsub(/[aeiouyAEIOUY]/, "\&\&")` replaces each vowel by a pair of ampersands.

gawk provides a more powerful generalized-substitution function, `gensub()` ; see the *gawk* (1) manual page.

Substitution is often a better choice for data reduction than indexing and substring operations. Consider the following example: the string value from an assignment in a file with text like this:

```
composer = "P. D. Q. Bach"
```

With substitution, we can use:

```
value = $0
sub(/^ *[a-z]+ *= */ , "", value)
sub(/" *$/, "", value)
```

whereas with indexing using code like this:

```
start = index($0, "\"") + 1
end = start - 1 + index(substr($0, start), "\"")
value = substr($0, start, end - start)
```

we need to count characters rather carefully, we do not match the data pattern as precisely, and we have to

9.9.6. String Splitting

The convenient splitting into fields `$1` , `$2` , ..., `$NF` that *awk* automatically provides for the current input record is available as a function: `split(string , array , regexp)` breaks `string` into pieces stored in successive elements of `array` , where the pieces lie between substrings matched by the regular expression `regexp` . If `regexp` is omitted,

of the built-in field-separator variable, `FS`, is used. The function return value is the number of elements in `parts` demonstrates `split()`.

Example 9-6. Test program for field splitting

```
{
    print "\nField separator = FS = \"" FS "\""
    n = split($0, parts)
    for (k = 1; k <= n; k++)
        print "parts[" k "] = \"" parts[k] "\""

    print "\nField separator = \"[ ]\""
    n = split($0, parts, "[ ]")
    for (k = 1; k <= n; k++)
        print "parts[" k "] = \"" parts[k] "\""

    print "\nField separator = \":\""
    n = split($0, parts, ":")
    for (k = 1; k <= n; k++)
        print "parts[" k "] = \"" parts[k] "\""

    print ""
}
```

If we put the test program shown in Example 9-6 into a file and run it interactively, we can see how `split()`

```
$ awk -f split.awk
```

Harold and Maude

```
Field separator = FS = " "
```

```
parts[1] = "Harold"
```

```
parts[2] = "and"
```

```
parts[3] = "Maude"
```

```
Field separator = "[ ]"
```

```
parts[1] = ""
```

```
parts[2] = ""
```

```
parts[3] = "Harold"
```

```
parts[4] = ""
```

```
parts[5] = "and"
```

```
parts[6] = "Maude"
```

```
Field separator = ":"
```

```
parts[1] = " Harold and Maude"
```

```
root:x:0:1:The Omnipotent Super User:/root:/sbin/sh
```

```
Field separator = FS = " "
```

```
parts[1] = "root:x:0:1:The"
```

```
parts[2] = "Omnipotent"
```



```
parts[3] = "Super"
parts[4] = "User:/root:/sbin/sh"
```

```
Field separator = "[ ]"
parts[1] = "root:x:0:1:The"
parts[2] = "Omnipotent"
parts[3] = "Super"
parts[4] = "User:/root:/sbin/sh"
```

```
Field separator = ":"
parts[1] = "root"
parts[2] = "x"
parts[3] = "0"
parts[4] = "1"
parts[5] = "The Omnipotent Super User"
parts[6] = "/root"
parts[7] = "/sbin/sh"
```

Notice the difference between the default field-separator value of " ", which causes leading and trailing white space and runs of whitespace to be treated as a single space, and a field-separator value of "[]", which matches most text processing applications, the first of these gives the desired behavior.

The colon field-separator example shows that `split()` produces a one-element array when the field separator is empty and demonstrates splitting of a record from a typical Unix administrative file, `/etc/passwd`.

Recent *awk* implementations provide a useful generalization: `split(string, chars, ",")` breaks `string` into character elements in `chars[1]`, `chars[2]`, ..., `chars[length(string)]`. Older implementations require a loop like this:

```
n = length(string)
for (k = 1; k <= n; k++)
    chars[k] = substr(string, k, 1)
```

The call `split("", array)` deletes all elements in `array`: it is a faster method for array element deletion

```
for (key in array)
    delete array[key]
```

when `delete array` is not supported by your `awk` implementation.

`split()` is an essential function for iterating through multiply subscripted arrays in `awk`. Here is an example

```
for (triple in maildrop)
{
    split(triple, parts, SUBSEP)
    house_number = parts[1]
    street = parts[2]
    postal_code = parts[3]
    ...
}
```

9.9.7. String Reconstruction

There is no standard built-in `awk` function that is the inverse of `split()`, but it is easy to write one, as shown in Example 9-7. The `join()` function ensures that the argument array is not referenced unless the index is known to be in bounds. Otherwise, a zero array length might create `array[1]`, modifying the caller's array. The inserted field separator is an operator, not a regular expression, so for general regular expressions passed to `split()`, `join()` does not reconstruct the string exactly.

Example 9-7. Joining array elements into a string

```

function join(array, n, fs, k, s)
{
    # Recombine array[1]...array[n] into a string, with elements
    # separated by fs

    if (n >= 1)
    {
        s = array[1]

        for (k = 2; k <= n; k++)
            s = s fs array[k]
    }

    return (s)
}

```

9.9.8. String Formatting

The last string functions that we present format numbers and strings under user control: `sprintf(format ,expression 2 ,...)` returns the formatted string as its function value. `printf()` works the same way, except it prints the formatted string on standard output or redirected to a file, instead of returning it as a function value. Newer languages replace format control strings with potentially more powerful formatting functions, but at a significant loss of verbosity. For typical text processing applications, `sprintf()` and `printf()` are nearly always sufficient.

`printf()` and `sprintf()` format strings are similar to those of the shell `printf` command that we describe in Chapter 7. We summarize the `awk` format items in Table 9-4. These items can each be augmented by the same file and flag modifiers discussed in Chapter 7.

The `%i`, `%u`, and `%X` items were not part of the 1987 language redesign, but modern implementations support them. Similarity with the shell `printf` command, `awk`'s handling of the `%c` format item differs for integer arguments. For negative arguments, shell and `awk` arithmetic may disagree because of differences in shell and `awk` arithmetic.

Table 9-5. printf and sprintf format specifiers

Item	Description
<code>%c</code>	ASCII character. Print the first character of the corresponding string argument, or the character whose character set is the corresponding integer argument, usually taken modulo 256.
<code>%d</code> , <code>%i</code>	Decimal integer.
<code>%e</code>	Floating-point format (<code>([-]d.precision e [+]-dd)</code>).
<code>%f</code>	Floating-point format (<code>([-]ddd.precision)</code>).
<code>%g</code>	<code>%e</code> or <code>%f</code> conversion, whichever is shorter, with trailing zeros removed.
<code>%o</code>	Unsigned octal value.
<code>%s</code>	String.
<code>%u</code>	Unsigned value. <i>awk</i> numbers are floating-point values: small negative integer values are output as unsigned because the sign bit is interpreted as a data bit.
<code>%x</code>	Unsigned hexadecimal number. Letters <code>a-f</code> represent 10 to 15.
<code>%X</code>	Unsigned hexadecimal number. Letters <code>A-F</code> represent 10 to 15.
<code>%%</code>	Literal <code>%</code> .

Most of the format items are straightforward. However, we caution that *accurate* conversion of binary floating-point numbers to decimal strings, and the reverse, is a surprisingly difficult problem whose proper solution was only found in 2004 and requires very high intermediate precision. *awk* implementations generally use the underlying C library for these conversions, and although library quality continues to improve, there are still platforms in which floating-point conversions is deficient. In addition, differences in floating-point hardware and instruction set architectures mean that floating-point results from almost any programming language vary slightly across different architectures.

When floating-point numbers appear in `print` statements, *awk* formats them according to the value of the built-in variable `OFMT`, which defaults to `"%.6g"`. You can redefine `OFMT` as needed.

Similarly, when floating-point numbers are converted to strings by concatenation, *awk* formats them according to the value of another built-in variable, `CONVFMT`.^[4] Its default value is also `"%.6g"`.

^[4] Originally, `OFMT` served for both output and string conversions, but POSIX introduced `CONVFMT` to separate their quite distinct uses. Some implementations now have both, but SGI IRIX and Sun Solaris `/usr/bin/nawk` lack `CONVFMT`.

The test program in Example 9-8 produces output like this with a recent *nawk* version on a Sun Solaris SPA:

```
$ nawk -f ofmt.awk
```



```

[ 1] OFMT = "%.6g"      123.457
[ 2] OFMT = "%d"       123
[ 3] OFMT = "%e"       1.234568e+02
[ 4] OFMT = "%f"       123.456789
[ 5] OFMT = "%g"       123.457
[ 6] OFMT = "%25.16e"   1.2345678901234568e+02
[ 7] OFMT = "%25.16f"   123.4567890123456806
[ 8] OFMT = "%25.16g"   123.4567890123457
[ 9] OFMT = "%25d"      123
[10] OFMT = "%.25d"     00000000000000000000000000123
[11] OFMT = "%25d"      2147483647
[12] OFMT = "%25d"      2147483647      Expected 21474
[13] OFMT = "%25d"      2147483647      Expected 90071
[14] OFMT = "%25.0f"    9007199254740991

```

Evidently, despite the availability of 53-bit precision in floating-point values, on this platform *nawk* caps then for `%d` formats. Slightly different values were produced by runs of the same *nawk* version on other architect shows the source for `ofmt.awk`.

Example 9-8. Testing the effect of OFMT

```

BEGIN {
    test( 1, OFMT,      123.4567890123456789)
    test( 2, "%d",      123.4567890123456789)
    test( 3, "%e",      123.4567890123456789)
    test( 4, "%f",      123.4567890123456789)

```

```

test( 5, "%g",      123.4567890123456789)
test( 6, "%25.16e", 123.4567890123456789)
test( 7, "%25.16f", 123.4567890123456789)
test( 8, "%25.16g", 123.4567890123456789)
test( 9, "%25d",    123.4567890123456789)
test(10, "%.25d",   123.4567890123456789)
test(11, "%25d",    2^31 - 1)
test(12, "%25d",    2^31)
test(13, "%25d",    2^52 + (2^52 - 1))
test(14, "%25.0f",  2^52 + (2^52 - 1))
}

```

```

function test(n,fmt,value,    save_fmt)
{
    save_fmt = OFMT
    OFMT = fmt
    printf("[%2d] OFMT = \"%s\"\t", n, OFMT)
    print value
    OFMT = save_fmt
}

```

We found that output for this test was quite sensitive to particular *awk* implementations, and even different one. For example, with *gawk*, we get:

```
$ gawk -f ofmt.awk
```

```

...
[11] OFMT = "%25d"          2147483647          Expected right-
...
[13] OFMT = "%25d"          9.0072e+15          Expected 90071
...

```

The informal language definition in the 1987*awk* book specifies the default value of `OFMT`, but makes no mention of other values. Perhaps in recognition of implementation differences, POSIX says that the result of conversion with `OFMT` is not a floating-point format specification, so *gawk*'s behavior here is allowed.

With *mawk*, we find:

```
$ mawk -f ofmt.awk
```

```

...
[ 2] OFMT = "%d"          1079958844          Expected 123
...
[ 9] OFMT = "%25d"          1079958844          Expected 123
[10] OFMT = "%.25d"        000000000000000001079958844 Expected 00...
[11] OFMT = "%25d"          2147483647          Expected right-
[12] OFMT = "%25d"          1105199104          Expected 21474
[13] OFMT = "%25d"          1128267775          Expected 90071
...

```

There are evidently inconsistencies and idiosyncrasies in the handling of output of large numbers with the various *awk* implementations. In the separate tests, `%i` is used. Fortunately, you can get correct output from all *awk* implementations by using a `%.0f` format.

9.10. Numeric Functions

awk provides the elementary numeric functions listed in [Table 9-5](#). Most of them are common to many programming languages, and their accuracy depends on the quality of the underlying native mathematical-function library.

Table 9-6. Elementary numeric functions

Function	Description
<code>atan2(y, x)</code>	Return the arctangent of y/x as a value in $-\pi$ to $+\pi$.
<code>cos(x)</code>	Return the cosine of x (measured in <i>radians</i>) as a value in -1 to $+1$.
<code>exp(x)</code>	Return the exponential of x , e^x .
<code>int(x)</code>	Return the integer part of x , truncating toward zero.
<code>log(x)</code>	Return the natural logarithm of x .
<code>rand()</code>	Return a uniformly distributed pseudorandom number, r , such that $0 \leq r < 1$.
<code>sin(x)</code>	Return the sine of x (measured in <i>radians</i>) as a value in -1 to $+1$.
<code>sqrt(x)</code>	Return the square root of x .
<code>srand(x)</code>	Set the pseudorandom-number generator seed to x , and return the current seed. If x is omitted, use the current time in seconds, relative to the system epoch. If <code>srand()</code> is not called, <i>awk</i> starts with the same default seed on each run; <i>mawk</i> does not.

The pseudorandom-number generator functions `rand()` and `srand()` are the area of largest variation in library functions in different *awk* implementations because some of them use native system-library functions instead of their own code, and the pseudorandom-number generating algorithms and precision vary. Most algorithms for generation of such numbers step through a sequence from a finite set without repetition, and the sequence ultimately repeats itself after a number of steps called the *period* of the generator. Library documentation sometimes does not make clear whether the unit interval endpoints, 0.0 and 1.0 , are included in the range of `rand()`, or what the period is.

The ambiguity in the generator's result interval endpoints makes programming harder. Suppose that you

want to generate pseudorandom integers between 0 and 100 inclusive. If you use the simple expression `int(rand()*100)`, you will not get the value 100 at all if `rand()` never returns 1.0, and even if it does, you will get 100 much less frequently than any other integer between 0 and 100, since it is produced only once in the generator period, when the generator returns the exact value 1.0. Fudging by changing the multiplier from 100 to 101 does not work either because you might get an out-of-range result of 101 on some systems.

The `irand()` function in [Example 9-9](#) provides a better solution to the problem of generating pseudorandom integers. `irand()` forces integer endpoints and then, if the requested range is empty or invalid, returns one endpoint. Otherwise, `irand()` samples an integer that might be one larger than the interval width, adds it to `low`, and then *retries* if the result is out of range. Now it does not matter whether `rand()` ever returns 1.0, and the return values from `irand()` are as uniformly distributed as the `rand()` values.

Example 9-9. Generating pseudorandom integers

```
function irand(low, high, n)
{
    # Return a pseudorandom integer n such that low <= n <= high

    # Ensure integer endpoints
    low = int(low)
    high = int(high)

    # Sanity check on argument order
    if (low >= high)
        return (low)

    # Find a value in the required range
    do
```

```

        n = low + int(rand( ) * (high + 1 - low))

while ((n < low) || (high < n))

return (n)

}

```

In the absence of a call to `srand(x)`, *gawk* and *nawk* use the same initial seed on each run so that runs are reproducible; *mawk* does not. Seeding with the current time via a call to `srand()` to get different sequences on each run is reasonable, *if* the clock is precise enough. Unfortunately, although machine speeds have increased dramatically, most time-of-day clocks used in current *awk* implementations still tick only once per second, so it is quite possible that successive runs of a simulation execute within the same clock tick. The solution is to avoid calling `srand()` more than once per run, and to introduce a delay of at least one second between runs:

```

$ for k in 1 2 3 4 5

> do

>     awk 'BEGIN {

>         srand( )

>         for (k = 1; k <= 5; k++)

>             printf("%.5f ", rand( ))

>             print ""

>         }'

>     sleep 1

> done

0.29994 0.00751 0.57271 0.26084 0.76031

0.81381 0.52809 0.57656 0.12040 0.60115

0.32768 0.04868 0.58040 0.98001 0.44200

0.84155 0.56929 0.58422 0.83956 0.28288

```

```
0.35539 0.08985 0.58806 0.69915 0.12372
```

Without the `sleep 1` statement, the output lines are often identical.



9.11. Summary

A surprisingly large number of text processing jobs can be handled with the subset of *awk* that we have presented in this chapter. Once you understand *awk*'s command line, and how it automatically handles input files, the programming job reduces to specifying record selections and their corresponding actions. This kind of minimalist *data-driven* programming can be extremely productive. By contrast, most conventional programming languages would burden you with dozens of lines of fairly routine code to loop over a list of input files, and for each file, open the file, read, select, and process records until end-of-file, and finally, close the file.

When you see how simple it is to process records and fields with *awk*, your view of data processing can change dramatically. You begin to divide large tasks into smaller, and more manageable, ones. For example, if you are faced with processing complex binary files, such as those used for databases, fonts, graphics, slide makers, spreadsheets, typesetters, and word processors, you might design, or find, a pair of utilities to convert between the binary format and a suitably marked-up simple text format, and then write small filters in *awk* or other scripting languages to manipulate the text representation.

Chapter 10. Working with Files

In this chapter, we discuss some of the more common commands for working with files: how to list files, modify their timestamps, create temporary files, find files in a directory hierarchy, apply commands to a list of files, determine the amount of filesystem space used, and compare files.

10.1. Listing Files

The *echo* command provides one simple way to list files that match a pattern:

```
$ echo /bin/*sh                Show shells in /bin
/bin/ash /bin/bash /bin/bsh /bin/csh /bin/ksh /bin/sh /bin/tcsh /bin/zsh
```

The shell replaces the wildcard pattern with a list of matching files, and *echo* displays them in a space-separated list. However, *echo* does not interpret its arguments further, and thus does not associate them with files in the file system.

ls

Usage

```
ls [ options ] [ file(s) ]
```

Purpose

List the contents of file directories.

Major options

1

Digit one. Force single-column output. In interactive mode, *ls* normally uses multiple columns of output to fit the current window.

-a

Show all files, including hidden files (those whose names begin with a dot).

-d

Print information about directories themselves, rather than about files that they contain.

-F

Mark certain file types with special suffix characters.

-g

Group only: omit the owner name (implies *-l* (lowercase L)).

-i

List inode numbers.

-L

Follow symbolic links, listing the files that they point to.

-l

Lowercase L. List in long form, with type, protection, owner, group, byte count, last modification time, and filename.

-r

Reverse the default sort order.

-R

List recursively, descending into each subdirectory.

-S

Sort by descending file byte counts. GNU version only.

-s

List file size in (system-dependent) blocks.

-t

Sort by the last-modification timestamp.

-full-time

Show the complete timestamp. GNU version only.

Behavior

ls normally shows only the names of files: additional options are always needed to get information about file attributes. Files are sorted by default in lexicographical order, but that can be changed with the *-S* or *-t* options. Sorting order may also depend on the locale.

Caveats

Most implementations of *ls* offer many more options than we have shown here; consult your local manual for details.

The *ls* command can do much more because it knows that its arguments should be files. In the absence of c

verifies that its arguments exist, and displays them, either one per line if its output is not a terminal, or more columns if it is. We can readily see the difference with three experiments:

```
$ ls /bin/*sh | cat Show shells in output pipe
```

```
/bin/ash
/bin/bash
/bin/bsh
/bin/csh
/bin/ksh
/bin/sh
/bin/tcsh
/bin/zsh
```

```
$ ls /bin/*sh Show shells in 80-character
```

```
/bin/ash /bin/bash /bin/bsh /bin/csh /bin/ksh /bin/sh /bin/tcsh
```

```
$ ls /bin/*sh Show shells in 40-character
```

```
/bin/ash /bin/csh /bin/tcsh
/bin/bash /bin/ksh /bin/zsh
/bin/bsh /bin/sh
```

For terminal output, *ls* uses as many columns as will fit, ordering data by columns. This is merely for human convenience. If you want single-column output to the terminal, you can force it with `ls -1` (digit one). However, programs that can expect to find just the simple case of one filename per line.

On BSD, GNU/Linux, Mac OS X, and OSF/1 systems, *ls* replaces nonprintable characters in filenames with `?` in terminal output, but reports filenames to nonterminal output without changes. Consider a file with the peculiar name `newline`. Here is what GNU *ls* does with it:

```
$ ls one*two
```

List peculiar filename

```
one?two
```

```
$ ls one*two | od -a -b
```

Show the real filename

```
0000000  o  n  e  nl  t  w  o  nl
          157 156 145 012 164 167 157 012
0000010
```

The octal dump utility, *od*, reveals the true filename: the first reported newline is part of the name, and the A program downstream sees two apparently separate names; we show later in Section 10.4. How to deal with

Unlike *echo*, *ls* requires that its file arguments exist and complains if they do not:

```
$ ls this-file-does-not-exist
```

Try to list a nonexistent fi

```
ls: this-file-does-not-exist: No such file or directory
```

```
$ echo $?
```

Show the ls exit code

```
1
```

Without an argument, *echo* displays only an empty line, but *ls* instead lists the contents of the current directory behavior by first making a directory with three empty files:

```
$ mkdir sample
```

Make a new directory

```
$ cd sample
```

Change directory to it

```
$ touch one two three
```

Create empty files

and then applying *echo* and *ls* to its contents:

```
$ echo *
```

Echo matching files

```
one three two
```

```
$ ls *
```

List matching files

```
one three two
```

```
$ echo
```

Echo without arguments

This output line is empty

```
$ ls
```

List current directory

```
one three two
```

Filenames that begin with a dot are hidden from normal shell pattern matching. We can see how such files creating a subdirectory with three hidden files:

```
$ mkdir hidden
```

Make a new directory

```
$ cd hidden
```

Change directory to it

```
$ touch .uno .dos .tres
```

Create three hidden empty fi

and then attempting to display its contents:

```
$ echo *
```

Echo matching files

```
*
```

Nothing matched

```
$ ls
```

List nonhidden files

This output line is empty

```
$ ls *
```

List matching files

```
ls: *: No such file or directory
```

When no files match a pattern, the shell leaves the pattern as the argument: here, *echo* saw an asterisk and tried to find a file named *** and reported its failure to do so.

If we now supply a pattern that matches the leading dot, we can see further differences:

```
$ echo .*                                Echo hidden files
. .. .dos .tres .uno
```

```
$ ls .*                                  List hidden files
.dos .tres .uno
```

```
..:
```

```
...:
```

```
hidden one three two
```

Unix directories always contain the special entries *..* (parent directory) and *.* (current directory), and the shell reports both programs. *echo* merely reports them, but *ls* does something more: when a command-line argument is *..*, it lists the contents of that directory. In our example, the listing therefore includes the contents of the parent directory.

You can print information about a directory itself, instead of its contents, with the *-d* option:

```
$ ls -d .*                                List hidden files, but without contents
. .. .dos .tres .uno
```

```
$ ls -d ../*                              List parent files, but without contents
../hidden ../one ../three ../two
```


Because it is usually not of interest to list the parent directory, *ls* provides the *-a* option to list all files in the hidden ones:

```
$ ls -a                                List all files, including hidden
.  ..  .dos  .tres  .uno
```

The contents of the parent directory were not listed here because there was no argument that named it.

10.1.1. Long File Listings

Because *ls* knows that its arguments are files, it can report further details about them—notably, some of the details normally done with the *-l* (lowercase L) option:

```
$ ls -l /bin/*sh                        List shells in /bin
-rwxr-xr-x  1 root root 110048 Jul 17 2002 /bin/ash
-rwxr-xr-x  1 root root 626124 Apr  9 2003 /bin/bash
lrwxrwxrwx  1 root root      3 May 11 2003 /bin/bsh -> ash
lrwxrwxrwx  1 root root      4 May 11 2003 /bin/csh -> tcsh
-rwxr-xr-x  1 root root 206642 Jun 28 2002 /bin/ksh
lrwxrwxrwx  1 root root      4 Aug  1 2003 /bin/sh -> bash
-rwxr-xr-x  1 root root 365432 Aug  8 2002 /bin/tcsh
-rwxr-xr-x  2 root root 463680 Jun 28 2002 /bin/zsh
```

While this output form is common, additional command-line options can modify its appearance somewhat.

The first character on each line describes the filetype: *-* for ordinary files, *d* for directories, *l* for symbolic link.

The next nine characters report the file permissions for each of user, group, and other: *r* for read, *w* for write, *x* for execute, and *-* for no permission is absent.

The second column contains the link counts: here, only */bin/zsh* has a hard link to another file, but that one is not shown in the output because its name does not match the argument pattern.

The third and fourth columns report the file owner and group, and the fifth column reports the file size in bytes.

The next three columns report the last-modification timestamp. In the historical form shown here, a month, older than six months, and otherwise, the year is replaced by a time of day:

```
$ ls -l /usr/local/bin/ksh           List a recent file
-rwxrwxr-x  1 jones devel 879740 Feb 23 07:33 /usr/local/bin/ksh
```

However, in modern implementations of *ls*, the timestamp is locale-dependent, and may take fewer columns in different versions of *ls* on GNU/Linux:

```
$ LC_TIME=de_CH /usr/local/bin/ls -l /bin/tcsh   List timestamp in Swiss
-rwxr-xr-x  1 root root 365432 2002-08-08 02:34 /bin/tcsh
```

```
$ LC_TIME=fr_BE /bin/ls -l /bin/tcsh           List timestamp in Belgium
-rwxr-xr-x  1 root      root      365432 aoÛ  8  2002 /bin/tcsh
```

Although the timestamps are supposedly internationalized, this system shows its English roots with its bad French: *aoÛt* 2002.

The GNU version permits display of full time precision; this example from an SGI IRIX system shows microsecond precision:

```
$ /usr/local/bin/ls -l --full-time /bin/tcsh   Show high-resolution
-r-xr-xr-x  1 root sys 425756 1999-11-04 13:08:46.282188000 -0700 /bin/tcsh
```

The *ls* sidebar shows more than a dozen options common to *ls* implementations, but most have many more options! This diversity reflects the demands that have been put on *ls* over its more than three decades of existence, so it is worthwhile to reread its manual pages from time to time to refresh your memory. For portable shell scripts, use the more common options, and set the environment variable `LC_TIME` to reduce locale variations.

10.1.2. Listing File Metadata

Whenever computers store data in a compact binary form, it is useful to be able to present that same data in a form that is easily readable both by humans and by simple computer programs. We use the octal dump utility, *od*, to convert streams of unprintable bytes into text, and we will discuss a special filesystem in Section 13.7, that makes binary data more accessible.

It is curious, however, that the metadata in filesystems, long available to the C programmer via the POSIX.

, and `stat()` library calls, remains largely inaccessible to programmers in the shell and scripting language provided by the `ls` command.

In the late 1990s, SGI IRIX introduced `astat` command, and around 2001, independent implementations of `stat` systems and the GNU `coreutils` package. Unfortunately, the output format of the three programs is quite different. B.6.5 in Appendix B . Each has numerous command-line options that can provide more control over what `stat` format. The GNU version is the only one that builds on every flavor of Unix, so if you standardize on it, you can use it in your local shell scripts.



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10.2. Updating Modification Times with touch

We have used the *touch* command a few times to create empty files. For a previously nonexistent file, here's the same thing:

```
cat /dev/null > some-file           Copy empty file to some-file
printf "" > some-file              Print empty string to some-file
cat /dev/null >> some-file          Append empty file to some-file
printf "" >> some-file              Append empty string to some-file
touch some-file                    Update timestamp of some-file
```

However, if the file exists already, the first two truncate the file to a zero size, whereas the last three effectively update its last-modification time. Clearly, the safe way to do that job is with *touch*, because typing `>` when inadvertently destroy the file contents.

touch is sometimes used in shell scripts to create empty files: their existence and possibly their timestamps are significant. A common example is a lock file to indicate that a program is already running, and that a second instance should not start. Another use is to record a file timestamp for later comparison with other files.

By default, or with the `-m` option, *touch* changes a file's last-modification time, but you can use the `-a` option instead. The time used defaults to the current time, but you can override that with the `-t` option, which takes the form `[[CC]YY]MMDDhhmm[.SS]`, where the century, year within the century, and seconds are optional, the month is in the range 01 through 12, the day of the month is in the range 01 through 31, and the time zone is your local one. Here is an example:

```
$ touch -t 197607040000.00 US-bicentennial      Create a birthday file
```

```
$ ls -l US-bicentennial                        List the file
```

```
-rw-rw-r-- 1 jones devel 0 Jul  4 1976 US-bicentennial
```

touch also has the `-r` option to copy the timestamp of a reference file:


```
$ touch -r US-bicentennial birthday           Copy timestamp to the n
```

```
$ ls -l birthday                             List the new file
```

```
-rw-rw-r--  1 jones devel 0 Jul  4  1976 birthday
```

The *touch* command on older systems did not have the *-r* option, but all current versions support it, and PC

For the time-of-day clock, the Unix *epoch* starts at zero at 00:00:00 UTC^[1] on January 1, 1970. Most current time-of-day counter that increments once a second, and allows representation of dates from late 1901 to early in 2038, it will wrap back to 1901. Fortunately, some recent systems have switched to a 64-bit counter: even now can span more than a half-million years! Compare these attempts on systems with 32-bit and 64-bit time-of-day

^[1] UTC is essentially what used to be called GMT; see the glossary entry for *Coordinated Universal Time* .

```
$ touch -t 178907140000.00 first-Bastille-day   Create a file for i
```

```
touch: invalid date format `178907140000.00'   A 32-bit counter i
```

```
$ touch -t 178907140000.00 first-Bastille-day   Try again on syste
```

```
$ ls -l first-Bastille-day                     It worked! List the .
```

```
-rw-rw-r--  1 jones devel 0 1789-07-14 00:00 first-Bastille-day
```

Future dates on systems with 64-bit time-of-day clocks may still be artificially restricted by *touch* , but that is the shortsighted POSIX requirement that the century have two digits:

```
$ touch -t 999912312359.59 end-of-9999        This works
```

```
$ ls -l end-of-9999                           List the file
```

```
-rw-rw-r--  1 jones devel 0 9999-12-31 23:59 end-of-9999
```

```
$ touch -t 1000001010000.00 start-of-10000 This fails
```

```
touch: invalid date format `1000001010000.00'
```

Fortunately, GNU *touch* provides another option that avoids the POSIX restriction:

```
$ touch -d '10000000-01-01 00:00:00' start-of-10000000 Into the nex
```

```
$ ls -l start-of-10000000 List the file
```

```
-rw-rw-r-- 1 jones devel 0 10000000-01-01 00:00 start-of-10000000
```



10.3. Creating and Using Temporary Files

While pipes eliminate much of the need for them, temporary files are still sometimes required. Unlike some has no notion of scratch files that are somehow magically removed when they are no longer needed. Instead directories, `/tmp` and `/var/tmp` (`/usr/tmp` on older systems), where such files are normally stored so that directories in the event that they are not cleaned up. On most systems, `/tmp` is cleared when the system boots survive reboots because some text editors place backup files there to allow data recovery after a system crash.

Because `/tmp` is so heavily used, some systems make it a memory-resident filesystem for faster access, as is a Sun Solaris system:

```
$ df /tmp Show disk free space for /tmp
Filesystem          1K-blocks      Used Available Use% Mounted on
swap                25199032    490168 24708864   2% /tmp
```

Putting the filesystem in the swap area means that it resides in memory until memory resources run low, at which point it may be written to swap.

The temporary-file directories are shared resources, making them subject to denial of service attacks that fill up the filesystem (or swap space), and to snooping or to file removal by other users. System administrators may therefore monitor space usage in those directories, and run *cron* jobs to clean them up. In addition, the sticky permission bit is normally set on the directory so that only `root` and the owner of files can remove them. It is up to you to set file permissions to restrict access to files that you create in those directories. Shell scripts should normally use the *umask* command (see Section B.6.1.3 in the *Shell and Tools* book) to set default permissions. Also, else first create the needed temporary files with *touch*, and then run *chmod* to set suitable permissions.

To ensure that a temporary file is removed on job completion, programmers of compiled languages can first issue an `unlink()` system call. That deletes the file immediately, but because it is still open, it remains accessible until the job terminates, whichever happens first. The technique of unlink-after-open generally does not work on Windows systems, or in foreign filesystems mounted on directories in the Unix filesystem, and is not usable in most



On many systems, `/tmp` and `/var/tmp` are relatively small filesystems that are often mounted *partitions* away from the root partition so that their filling up cannot interfere with, say, `/usr`. In particular, this means that you may not be able to create large temporary files in them, such as for a filesystem image of a CD or DVD. If `/tmp` fills up, you might not even be able to `cd` until your system manager fixes the problem, unless your compiler allows you to redirect to another directory.

10.3.1. The \$\$ Variable

Shared directories, or multiple running instances of the same program, bring the possibility of filename collision. A solution in shell scripts is to use the process ID (see Section 13.2, available in the shell variable `$$`), to form unique filenames. To deal with the possibility of a full temporary filesystem, it is also conventional to allow the default `/tmp` to be overridden by an environment variable, traditionally called `TMPDIR`. In addition, you should use a *trap* command to remove temporary files on job completion (see Section 13.3.2). A common shell-script preamble is:

```
umask 077                                Remove access for all but user

TMPFILE=${TMPDIR-/tmp}/myprog.$$         Generate a temporary filename

trap 'rm -f $TMPFILE' EXIT              Remove temporary file on complet.
```

10.3.2. The mktemp Program

Filenames like `/tmp/myprog.$$` have a problem: they are readily guessable. An attacker only needs to list the contents of `/tmp` while the target is running to figure out what temporary files are being used. By creating a suitably named file, an attacker might be able to get your program to fail, or to read forged data, or to set the file permissions to allow the attacker to write to it.

To deal with this security issue, filenames must be unpredictable. BSD and GNU/Linux systems have the `mktemp` command for creating names of temporary files that are hard to guess. While the underlying `mktemp(3)` library call is standard, the `mktemp` command is not. If your system lacks `mktemp`, we recommend that you install a portable version^[2].

^[2] Available at <ftp://ftp.mktemp.org/pub/mktemp/>.

`mktemp` takes an optional filename template containing a string of trailing `x` characters, preferably at least eight. It replaces them with an alphanumeric string derived from random numbers and the process ID, creates the file with permissions `0600`, and prints the filename on standard output.



Here is why we recommend a dozen or more `x` characters. The easily guessable process ID as many as six or seven of them, so the number of random letters might be as small as five (about 380 million) random strings of letters. However, with just 10 `x`'s (*mktemp*'s default, its manual pages) and a seven-digit PID, only about 140,000 guesses are needed. We tested our fastest machines with a 40-line C program, and found that a million guesses can be checked in three seconds!

Here is an example of the use of *mktemp* :

```
$ TMPFILE=`mktemp /tmp/myprog.XXXXXXXXXXX` || exit 1      Make unique

$ ls -l $TMPFILE                                          List the tempo.

-rw-----    1 jones devel 0 Mar 17 07:30 /tmp/myprog.hJmNZbq25727
```

The process ID, 25727, is visible at the end of the filename, but the rest of the suffix is unpredictable. The *mktemp* command ensures that we terminate immediately with an error if the temporary file cannot be created, or if *mktemp* is not available.

The newest version of *mktemp* allows the template to be omitted; it then uses a default of `/tmp/tmp.XXXXXX`. Older versions require the template, so avoid that shortcut in your shell scripts.

HP-UX has a weak version of *mktemp* : it ignores any user-provided template, and constructs a predictable temporary filename from the username and the process ID. On HP-UX, we strongly recommend that you install the OpenBSD version mentioned earlier in this section.

To eliminate the need to hardcode a directory name, use the `-t` option: *mktemp* then uses whatever directory `TMPDIR` specifies, or else `/tmp`.

The `-d` option requests the creation of a temporary directory:

```
$ SCRATCHDIR=`mktemp -d -t myprog.XXXXXXXXXXX` || exit 1      Create t

$ ls -lFd $SCRATCHDIR                                       List the d

drwx-----    2 jones devel 512 Mar 17 07:38 /tmp/myprog.HStsWoEi6373/
```

Since that directory has no access for group and other, an attacker cannot even find out the names of files there, but still might be able to guess them if your script is publicly readable. However, because the directory is owned by root, an unprivileged attacker cannot confirm the guesses.

10.3.3. The `/dev/random` and `/dev/urandom` Special Files

Some systems provide two random *pseudodevices* : `/dev/random` and `/dev/urandom` . These are currently available on GNU/Linux, IBM AIX 5.2, Mac OS X, and Sun Solaris 9, with two third-party implementations on earlier Solaris versions.^[3] These devices serve as never-empty streams of random bytes: such a data source is useful for cryptographic and security applications. While there are plenty of simple algorithms for generating streams of random numbers, generation of truly random data is a difficult problem: see the book *Cryptographic Security Architecture: Verification* .^[4]

^[3] Available at the following: <http://www.cosy.sbg.ac.at/~andi/SUNrand/pkg/random-0.7a.tar.gz> and [http://sunrmpms.marauk.com/sun/patches/10675\[456\]-01](http://sunrmpms.marauk.com/sun/patches/10675[456]-01) to the SUNWski package to provide them on older Solaris releases; search for them at <http://www.sun.com>

^[4] By Peter Gutmann, Springer-Verlag, 2004, ISBN 0-387-95387-6.

The distinction between the two devices is that `/dev/random` may block until sufficient randomness has been accumulated by the system so that it can guarantee high-quality random data. By contrast, `/dev/urandom` never blocks, but then provides less random (but still good enough to pass many statistical tests of randomness).

Because these devices are shared resources, it is easy to mount a denial-of-service attack against the blocking pseudodevice simply by reading it and discarding the data. Compare these experiments on the two devices, using the `count` arguments:

```
$ time dd count=1 ibs=1024 if=/dev/random > /dev/null          Read 1K
0+1 records in
0+1 records out
0.000u 0.020s 0:04.62 0.4%          0+0k 0+0io 86pf+0w
```

```
$ time dd count=1024 ibs=1024 if=/dev/urandom > /dev/null    Read 1M
1024+0 records in
2048+0 records out
0.000u 0.660s 0:00.66 100.0%       0+0k 0+0io 86pf+0w
```

The more that `/dev/random` is read, the slower it responds. We experimented with these devices on several systems and found that it could take a day or more to extract 10MB from `/dev/random`, and that `/dev/urandom` can produce that much data in a few seconds on our fastest systems.

These pseudodevices provide an alternative to `mktemp` for generating hard-to-guess temporary filenames:

```
$ TMPFILE=/tmp/secret.$(cat /dev/urandom | od -x | tr -d ' ' | head -n 1)
```

```
$ echo $TMPFILE
```

Show the random filename

```
/tmp/secret.00000003024d462705664c043c04410e570492e
```

Here, we read a binary byte stream from `/dev/urandom`, convert it to hexadecimal with `od`, strip spaces with `tr`, and collect one line. Since `od` converts 16 bytes per output line, this gives us a sample of $16 \times 8 = 128$ random bits, or about 3.40×10^{38} possible suffixes. If that filename is created in a directory that is listable only by its owner, the chance of its being guessed by an attacker is very small.

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10.4. Finding Files

Shell pattern matching is not powerful enough to match files recursively through an entire file tree, and *ls* is no better than by shell patterns. Fortunately, Unix provides some other tools that go beyond those commands.

10.4.1. Finding Files Quickly

locate, first introduced in Berkeley Unix, was reimplemented for the GNU *findutils* package.^[5] *locate* uses filenames in the filesystem to quickly find filenames that match shell-like wildcard patterns, without having to search the entire tree. A database is created by *updatedb* in a suitably privileged job, usually run nightly via *cron*. *locate* can be invoked with questions like, Where does the system manager store the *gcc* distribution?:

^[5] Available at <ftp://ftp.gnu.org/gnu/findutils/>.

```
$ locate gcc-3.3.tar                                Find the gcc-3.3 release
/home/gnu/src/gcc/gcc-3.3.tar-lst
/home/gnu/src/gcc/gcc-3.3.tar.gz
```

In the absence of wildcard patterns, *locate* reports files that contain the argument as a substring; here, two files are found. Because *locate*'s output can be voluminous, it is often piped into a pager, such as *less*, or a search filter, such as *fgrep*:

```
$ locate gcc-3.3 | fgrep .tar.gz                    Find gcc-3.3, but report c
/home/gnu/src/gcc/gcc-3.3.tar.gz
```

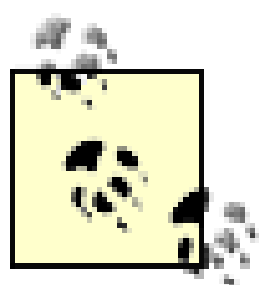
Wildcard patterns must be protected from shell expansion so that *locate* can handle them itself:

```
$ locate '*gcc-3.3*.tar*'                            Find gcc-3.3 using wildcar
...
/home/gnu/src/gcc/gcc-3.3.tar.gz
/home/gnu/src/gcc/gcc-3.3.1.tar.gz
/home/gnu/src/gcc/gcc-3.3.2.tar.gz
```



```
/home/gnu/src/gcc/gcc-3.3.3.tar.gz
```

```
...
```



locate may not be suitable for all sites because it reveals filenames that users might have strict directory permissions. If this is of concern, simply arrange for *updatedb* to be run a filenames are exposed that could not be found by any user by other legitimate means. Be *slocate* ;^[6] it also stores file protections and ownership in the database, and only shows f

^[6] Available at <ftp://ftp.geekreview.org/slocate/>.

updatedb has options to support creation of *locate* databases for selected portions of the filesystem, such as readily be used for personal file lookups.

10.4.2. Finding Where Commands Are Stored

Occasionally, you may want to know the filesystem location of a command that you invoke without a path the job:

```
$ type gcc Where is gcc?
```

```
gcc is /usr/local/bin/gcc
```

```
$ type type What is type?
```

```
type is a shell builtin
```

```
$ type newgcc What is newgcc?
```

```
newgcc is an alias for /usr/local/test/bin/gcc
```

```
$ type mypwd What is mypwd?
```

```
mypwd is a function
```

```
$ type foobar
```

```
What is this (nonexistent) c
```

```
foobar not found
```

Notice that *type* is an internal shell command, so it knows about aliases and functions as well.

The *pathfind* command that we presented in Example 8-1 provides another way to search for files in *any* directory searches.

10.4.3. The find Command

If you want to select, say, files larger than a certain size, or modified in the last three days, belonging to you, you need the *find* command, one of the most powerful in the Unix toolbox.

Implementations of *find* offer as many as 60 different options, so we can discuss only a few of them. The standard *find* options.

If you need to go swinging through the branches of directory trees looking for something, *find* can probably slog through its manual pages to find out how. The GNU version has an extensive manual, and we recommend

find

Usage

```
find [ files-or-directories ] [ options ]
```

Purpose

Find files matching specified name patterns, or having given attributes.

Major options

See the text for a description of the numbers *mask* and *n* that follow some of these options:

-atime n

Select files with access times of *n* days.

-ctime n

Select files with inode-change times of *n* days.

-follow

Follow symbolic links.

-group g

Select files in group *g* (a name or numeric group ID).

-links n

Select files with *n* hard links.

-ls

Produce a listing similar to the *ls* long form, rather than just filenames.

-mtime n

Select files with modification times of *n* days.

-name `pattern`

Select files matching the shell wildcard pattern (quoted to protect it from shell interpretation).

-perm mask

Select files matching the specified octal permission mask.

-prune

Do not descend recursively into directory trees.

-size n

Select files of size *n* .

-type t

Select files of type *t* , a single letter: *d* (directory), *f* (file), or *l* (symbolic link). There are letters for not needed often.

-user u

Select files owned by user *u* (a name or numeric user ID).

find (continued)

Behavior

find descends into directory trees, finding all files in those trees. It then applies selectors defined by choose files for further action, normally printing their names or producing an *ls* -like verbose listing

Caveats

Because of *find* 's default directory descent, it potentially can take a long time to run in a large files!

find 's output is *not* sorted.

find has additional options that can be used to carry out arbitrary actions on the selected files. Because it is dangerous, we do not recommend their use except in tightly controlled situations.

10.4.3.1 Using the *find* command

The most unusual thing about *find* as a Unix command is that the files and directories to search come *first* in (almost) always descending order. The options that select names for ultimate display or action come

Unlike *ls* and the shells, *find* has no concept of hidden files: if a dotted filename is present, *find* will find it.

Also unlike *ls*, *find* does *not* sort filenames. It just takes them in whatever order they are found in directories. random.^[7] Thus, you'll likely want to include a *sort* stage in a pipeline following the *find* command.

^[7] Since users are so used to seeing sorted lists from *ls* and shell wildcard expansions, many assume that directories must sort. This is usually not until you write a program that uses the `opendir()`, `readdir()`, and `closedir()` library calls that you discover.

Again, unlike *ls*, when *find* has a directory to process, it dives with gusto recursively into that directory to process it, and to with the *-prune* option.

When *find* finds a file to process, it first carries out the selection restrictions implied by the command-line options, then passes the name off to an internal action routine. The default action is just to print the name on standard output, but you can specify a template into which the name is substituted, and the command is then executed. An antiquated implementation would produce output, but fortunately, that design blunder has been fixed in every current implementation that we know of.

Automated execution of commands on selected files is both powerful and *extremely dangerous*. If that comes to pass, *find* produce the list in a temporary file first, and then have a competent human carefully examine that list before executing the command for further automated processing.

Shell scripts that use *find* for destructive purposes must be written carefully, and then debugged with dry run mode. A `&&` command at the start of the destructive command so that you can see what would have been done without actually doing it.

We are now ready for the simplest example: a bare *find* finds everything in the current directory tree. As before, we'll first populate it with a few empty files:

```
$ ls
```

Verify that we have an empty directory

```
$ mkdir -p sub/sub1
```

Create a directory tree

```
$ touch one two .uno .dos
```

Create some empty top-level .

```
$ touch sub/three sub/sub1/four
```

Create some empty files dee

```
$ find
```

Find everything from here do

```
.
```

```
./sub
```

```
./sub/sub1
```

```
./sub/sub1/four
```

```
./sub/three
```

```
./one
```

```
./two
```

```
./uno
```

```
./dos
```

That jumbled list is easily sorted:

```
$ find | LC_ALL=C sort
```

Sort find's output into trad

```
.
```

```
./dos
```

```
./uno
```

```
./one
```

```
./sub
```

```
./sub/sub1
```

```
./sub/sub1/four
```

```
./sub/three
```

```
./two
```

We set `LC_ALL` to get the traditional (ASCII) sort order, since modern *sort* implementations are locale-aware. `find` has a useful option, `-ls`, that gives output vaguely similar to what `ls -liRs` would give. However, it lacks this verbose display:

```
$ find -ls Find files, and use ls-style
```

1451550	4	drwxr-xr--	3	jones	devel	4096	Sep 26 09:40	.
1663219	4	drwxrwxr-x	3	jones	devel	4096	Sep 26 09:40	./st
1663220	4	drwxrwxr-x	2	jones	devel	4096	Sep 26 09:40	./s
1663222	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./s
1663221	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./s
1451546	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./o1
1451547	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./tw
1451548	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./1
1451549	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./c

```
$ find -ls | sort -k11 Find files, and sort by file
```

1451550	4	drwxr-xr--	3	jones	devel	4096	Sep 26 09:40	.
1451549	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./c
1451548	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./1
1451546	0	-rw-rw-r--	1	jones	devel	0	Sep 26 09:40	./o1
1663219	4	drwxrwxr-x	3	jones	devel	4096	Sep 26 09:40	./st
1663220	4	drwxrwxr-x	2	jones	devel	4096	Sep 26 09:40	./s

```

1663222    0 -rw-rw-r--    1 jones    devel          0 Sep 26 09:40 ./s
1663221    0 -rw-rw-r--    1 jones    devel          0 Sep 26 09:40 ./s
1451547    0 -rw-rw-r--    1 jones    devel          0 Sep 26 09:40 ./t

```

For comparison, here is how *ls* displays the same file metadata:

```
$ ls -liRs * Show ls recursive verbose ou
```

```

752964    0 -rw-rw-r--    1 jones    devel          0 2003-09-26 09:40
752965    0 -rw-rw-r--    1 jones    devel          0 2003-09-26 09:40

```

sub:

total 4

```

752963    4 drwxrwxr-x    2 jones    devel        4096 2003-09-26 09:40
752968    0 -rw-rw-r--    1 jones    devel          0 2003-09-26 09:40

```

sub/sub1:

total 0

```

752969    0 -rw-rw-r--    1 jones    devel          0 2003-09-26 09:40

```

Now let's give the *find* command some file patterns:

```
$ find 'o*' Find files in this directory
```

one

```
$ find sub Find files in directory sub
```

sub


```
sub/sub1
```

```
sub/sub1/four
```

```
sub/three
```

Next, we suppress directory descent:

```
$ find -prune
```

Find without looking inside

```
.
```

```
$ find . -prune
```

Another way to do the same t.

```
.
```

```
$ find * -prune
```

Find files in this directory

```
one
```

```
sub
```

```
two
```

```
$ ls -d *
```

List files, but not director.

```
one sub two
```

Notice that a missing file or directory argument is equivalent to the current directory, so the first two simple matches every nonhidden file, so the third *find* works like `ls -d`, except that it shows one file per line.

Now it is time to try out some of the more powerful selection options in *find*'s repertoire. Let's start with `o` and `-user` each require a following symbolic name or numeric identifier. Thus, `find / -user root` starts a tree that are owned by `root`. Unless this command is run by `root`, directory permissions will almost certain

You probably expect that all of the files in your login directory tree are owned by you. To make sure, run `find ~ ! -user $USER`. The exclamation argument means *not*, so in English, this command says: start at my home directory and find files that are not owned by me. `HOME` and `USER` are standard shell variables customized to your login, so this command works for everyone.

that the command also works if `$HOME` is a symbolic link.

The `-perm` option requires a following permission mask as an octal string, optionally signed. When the mask permissions is required. If it is negative, then *all* of the bits set are required to match. If it has a plus sign, then only files with those permissions are required. This is pretty complex, so we present some common idioms in Table 10-1

Table 10-1. Common permission settings for find

Option	Meaning
<code>-perm -002</code>	Find files writable by other.
<code>-perm -444</code>	Find files readable by everyone.
<code>! -perm -444</code>	Find files not readable by everyone.
<code>-perm 444</code>	Find files with exact permissions <code>r--r--r--</code> .
<code>-perm +007</code>	Find files accessible by other.
<code>! -perm +007</code>	Find files not accessible by other.

The `-size` option requires a following numeric argument. By default, the size is in 512-byte blocks, although the number to be suffixed by `c` for characters (bytes), or `k` for kilobytes. If the number is unsigned, then only files then only files smaller than that (absolute) size match. Otherwise, with a plus sign, only files bigger than that match. `+1024k` finds all files in your login tree that are bigger than 1MB, and `find . -size 0` finds all files in the

The `-type` option requires a following single-letter argument to specify the file type. The important choices for symbolic link.

The `-follow` option asks `find` to follow symbolic links. You can use this to find broken links:

```
$ ls Show that we have an empty d
```

```
$ ln -s one two Create a soft (symbolic) lin
```

```
$ file two Diagnose this file
```

```
two: broken symbolic link to one
```

```
$ find .                                Find all files
.
./two
```

```
$ find . -type l                        Find soft links only
./two
```

```
$ find . -type l -follow                Find soft links and try to follow
find: cannot follow symbolic link ./two: No such file or directory
```

The *-links* option requires a following integer number. If it is unsigned, it selects only files having that many or fewer than that many (in absolute value) links are selected. If it has a plus sign, then only files with more than that many links are selected. The usual way to find files with hard links is `find . -links +1`.

The *-atime* (access time), *-ctime* (inode-change time), and *-mtime* (modification time) options require a following integer number. If unsigned, it means exactly that many days old. If negative, it means less than that absolute value. With a plus sign, it means more than that absolute value. A common idiom is `find . -mtime -7` to find files modified in the last week.

It is regrettable that *find* does not allow the number to have a fractional part or a units suffix. GNU *find* has *-mmin* options which take values in minutes, but units suffixes on the original timestamp are not supported. A more general option is *-newer*.

A related option, *-newer filename*, selects only files modified more recently than the specified file. If you create an empty file with `touch -t date_time timestampfile`, and then use that file with the *-newer* option, negate the selector: `! -newer timestampfile`.

The *find* command selector options can be combined: all must match for the action to be taken. They can be combined in any way you wish. There is also a *-o* (OR) option that specifies that at least one selector of the surrounding pair must match. The use of these Boolean operators:

```
$ find . -size +0 -a -size -10         Find nonempty files smaller
...
```



```
$ find . -size 0 -o -atime +365           Find files that are empty or
```

```
...
```

The `-a` and `-o` operators, together with the grouping options `\(` and `\)`, can be used to create complex Boolean expressions. When you do, you'll find them complex enough that you'll hide them in a script once they are debugged, and

10.4.3.2 A simple find script

So far, we have used `find` just to produce lists of files matching particular selection requirements, possibly to look at a slightly more complex example. In Section 3.2.7.1, we presented a simple `sed` script to (begin to) convert

```
$ cat $HOME/html2xhtml.sed           Show sed commands for converting
```

```
s/<H1>/<h1>/g
```

```
s/<H2>/<h2>/g
```

```
...
```

```
s:</H1>:</h1>:g
```

```
s:</H2>:</h2>:g
```

```
...
```

```
s/<[Hh][Tt][Mm][Ll]>/<html>/g
```

```
s:</[Hh][Tt][Mm][Ll]>:</html>:g
```

```
s:<[Bb][Rr]>:<br/>:g
```

```
...
```

Such a script can automate a large part of the task of converting from HTML to XHTML, the standardized HTML. A `sed` with `find` and a simple loop accomplishes the task in just a few lines of code:

```
cd top level web site directory
```

```
find . -name '*.html' -type f |           Find all HTML files
```



```

while read file                                Read filename
do
    echo $file                                  Print progress
    mv $file $file.save                        Save a backup
    sed -f $HOME/html2xhtml.sed < $file.save > $file Make the cha
done

```

10.4.3.3 A complex find script

In this section, we develop a real working example of *find*'s virtuosity.^[8] It is a shell script named `filesdi` that runs on large home-directory trees run nightly via the *crontab* system (see Section 13.6.4) to create several lists of files and directories of days within which they have been changed. This helps remind them of their recent activities, and provides a way to find particular files by searching a single list file rather than the filesystem itself.

^[8] Our thanks go to Pieter J. Bowman at the University of Utah for this example.

`filesdirectories` requires GNU *find* for access to the *-fprint* option, which permits multiple output files per directory tree, producing a *tenfold speedup* for this script over a version that used multiple invocations of *find*.

The script begins with the usual security features: specify the `-` option in the `#!` line (see Section 2.4):

```
#! /bin/sh -
```

set the `IFS` variable to newline-space-tab:

```
IFS= '
    '

```

and set the `PATH` variable to ensure that GNU *find* is found first:

```
PATH=/usr/local/bin:/bin:/usr/bin # need GNU find for -fprint option
export PATH
```

It then checks for the expected single argument, and otherwise, prints a brief error message on standard error.

```

if [ $# -ne 1 ]
then
    echo "Usage: $0 directory" >&2
    exit 1
fi

```

As a final security feature, the script invokes *umask* to limit access to the owner of the output files:

```
umask 077 # ensure file privacy
```

`filesdirectories` allows the default temporary file directory to be overridden by the `TMPDIR` environment

```
TMP=${TMPDIR:-/tmp} # allow alternate temporary directory
```

It then initializes `TMPFILES` to a long list of temporary files that collect the output:

```

TMPFILES="
    $TMP/DIRECTORIES.all.$$ $TMP/DIRECTORIES.all.$$tmp
    $TMP/DIRECTORIES.last01.$$ $TMP/DIRECTORIES.last01.$$tmp
    $TMP/DIRECTORIES.last02.$$ $TMP/DIRECTORIES.last02.$$tmp
    $TMP/DIRECTORIES.last07.$$ $TMP/DIRECTORIES.last07.$$tmp
    $TMP/DIRECTORIES.last14.$$ $TMP/DIRECTORIES.last14.$$tmp
    $TMP/DIRECTORIES.last31.$$ $TMP/DIRECTORIES.last31.$$tmp
    $TMP/FILES.all.$$ $TMP/FILES.all.$$tmp
    $TMP/FILES.last01.$$ $TMP/FILES.last01.$$tmp
    $TMP/FILES.last02.$$ $TMP/FILES.last02.$$tmp
    $TMP/FILES.last07.$$ $TMP/FILES.last07.$$tmp
    $TMP/FILES.last14.$$ $TMP/FILES.last14.$$tmp

```

```
$TMP/FILES.last31.$$ $TMP/FILES.last31.$$tmp
```

```
"
```

These output files contain the names of directories and files in the entire tree (`*.all.*`), as well as the names of files in the tree (`*.last01.*`), last two days (`*.last02.*`), and so on.

The `WD` variable saves the argument directory name for later use, and then the script changes to that directory:

```
WD=$1
```

```
cd $WD || exit 1
```

Changing the working directory before running *find* solves two problems:

- If the argument is not a directory, or is but lacks the needed permissions, then the *cd* command fails, and the script exits with a nonzero exit value.
- If the argument is a symbolic link, *cd* follows the link to the real location. *find* does not follow symbolic links. There is no way to tell it to do so only for the top-level directory. In practice, we do not want `filesdirectories` to follow symbolic links, although it is straightforward to add an option to do so.

The *trap* commands ensure that the temporary files are removed when the script terminates:

```
trap 'exit 1' HUP INT PIPE QUIT TERM
```

```
trap 'rm -f $TMPFILES' EXIT
```

The exit status value is preserved across the `EXIT` TRap (see Section 13.3.2).

The wizardry, and all of the hard work, come next in the multiline *find* command. The lines with the `-name` options filter out files from a previous run, and the `-true` option causes them to be ignored so that they do not clutter the output results.

```
find . \
    -name DIRECTORIES.all -true \
    -o -name 'DIRECTORIES.last[0-9][0-9]' -true \
    -o -name FILES.all -true \
    -o -name 'FILES.last[0-9][0-9]' -true \
```


The next line matches all ordinary files, and the *-fprint* option writes their names to `$TMP/FILES.all.$$` :

```
-o -type f                -fprint $TMP/FILES.all.$$ \
```

The next five lines select files modified in the last 31, 14, 7, 2, and 1 days (the `type f` selector is still in effect) to the indicated temporary files:

```
-a                -mtime -31 -fprint $TMP/FILES.last31.$$ \
-a                -mtime -14 -fprint $TMP/FILES.last14.$$ \
-a                -mtime  -7  -fprint $TMP/FILES.last07.$$ \
-a                -mtime  -2  -fprint $TMP/FILES.last02.$$ \
-a                -mtime  -1  -fprint $TMP/FILES.last01.$$ \
```

The tests are made in order from oldest to newest because each set of files is a subset of the previous ones, a day-old file will pass the first two *-mtime* tests, but will fail the next three, so it will be included only in the first two files.

The next line matches directories, and the *-fprint* option writes their names to `$TMP/DIRECTORIES.all.$$`

```
-o -type d                -fprint $TMP/DIRECTORIES.all.$$ \
```

The final five lines of the *find* command match subsets of directories (the `-type d` selector still applies) and the command:

```
-a                -mtime -31 -fprint $TMP/DIRECTORIES.last31.$$ \
-a                -mtime -14 -fprint $TMP/DIRECTORIES.last14.$$ \
-a                -mtime  -7  -fprint $TMP/DIRECTORIES.last07.$$ \
-a                -mtime  -2  -fprint $TMP/DIRECTORIES.last02.$$ \
-a                -mtime  -1  -fprint $TMP/DIRECTORIES.last01.$$
```

When the *find* command finishes, its preliminary reports are available in the temporary files, but they have the job with a loop over the report files:

```
for i in FILES.all FILES.last31 FILES.last14 FILES.last07 \
```



```

FILES.last02 FILES.last01 DIRECTORIES.all \
DIRECTORIES.last31 DIRECTORIES.last14 \
DIRECTORIES.last07 DIRECTORIES.last02 DIRECTORIES.last01
do

```

sed replaces the prefix `./` in each report line with the user-specified directory name so that the output files

```
sed -e "s=^[.]/=$WD/=" -e "s=^[.]$=$WD=" $TMP/$i.$$ |
```

sort orders the results from *sed* into a temporary file named by the input filename suffixed with `.tmp`:

```
LC_ALL=C sort > $TMP/$i.$$tmp
```

Setting `LC_ALL` to `C` produces the traditional Unix sort order that we have long been used to, and avoids surprises if locales are set. Using the traditional order is particularly helpful in our diverse environments because our s

The *cmp* command silently checks whether the report file differs from that of a previous run, and if so, rep

```
cmp -s $TMP/$i.$$tmp $i || mv $TMP/$i.$$tmp $i
```

Otherwise, the temporary file is left for cleanup by the *trap* handler.

The final statement of the script completes the loop over the report files:

```
done
```

At runtime, the script terminates via the `EXIT` trap set earlier.

The complete `filesdirectories` script is collected in Example 10-1. Its structure should be clear enough to generate reports of files and directories modified in the last quarter, half year, and year. By changing the script to generate reports of files that have *not* been recently modified, which might be helpful in tracking down obsolete file

Example 10-1. A complex shell script for find

```
#!/bin/sh -
```

```
# Find all files and directories, and groups of
```

```
# recently modified ones, in a directory tree, creating
# lists in FILES.* and DIRECTORIES.* at top level.
#
# Usage:
#     filesdirectories directory

IFS='
'

PATH=/usr/local/bin:/bin:/usr/bin # need GNU find for -fprint option
export PATH

if [ $# -ne 1 ]
then
    echo "Usage: $0 directory" >&2
    exit 1
fi

umask 077 # ensure file privacy
TMP=${TMPDIR:-/tmp} # allow alternate temporary directory
TMPFILES="
    $TMP/DIRECTORIES.all.$$ $TMP/DIRECTORIES.all.$$tmp
    $TMP/DIRECTORIES.last01.$$ $TMP/DIRECTORIES.last01.$$tmp"
```

```
$TMP/DIRECTORIES.last02.$$ $TMP/DIRECTORIES.last02.$$tmp
$TMP/DIRECTORIES.last07.$$ $TMP/DIRECTORIES.last07.$$tmp
$TMP/DIRECTORIES.last14.$$ $TMP/DIRECTORIES.last14.$$tmp
$TMP/DIRECTORIES.last31.$$ $TMP/DIRECTORIES.last31.$$tmp

$TMP/FILES.all.$$ $TMP/FILES.all.$$tmp

$TMP/FILES.last01.$$ $TMP/FILES.last01.$$tmp
$TMP/FILES.last02.$$ $TMP/FILES.last02.$$tmp
$TMP/FILES.last07.$$ $TMP/FILES.last07.$$tmp
$TMP/FILES.last14.$$ $TMP/FILES.last14.$$tmp
$TMP/FILES.last31.$$ $TMP/FILES.last31.$$tmp

"
```

```
WD=$1
```

```
cd $WD || exit 1
```

```
trap 'exit 1' HUP INT PIPE QUIT TERM
```

```
trap 'rm -f $TMPFILES' EXIT
```

```
find . \
```

```
  -name DIRECTORIES.all -true \
```

```
  -o -name 'DIRECTORIES.last[0-9][0-9]' -true \
```

```
  -o -name FILES.all -true \
```

```
  -o -name 'FILES.last[0-9][0-9]' -true \
```

```

-o -type f                -fprint $TMP/FILES.all.$$ \
-a                        -mtime -31 -fprint $TMP/FILES.last31.$$ \
-a                        -mtime -14 -fprint $TMP/FILES.last14.$$ \
-a                        -mtime -7 -fprint $TMP/FILES.last07.$$ \
-a                        -mtime -2 -fprint $TMP/FILES.last02.$$ \
-a                        -mtime -1 -fprint $TMP/FILES.last01.$$ \
-o -type d                -fprint $TMP/DIRECTORIES.all.$$ \
-a                        -mtime -31 -fprint $TMP/DIRECTORIES.last31.$$ \
-a                        -mtime -14 -fprint $TMP/DIRECTORIES.last14.$$ \
-a                        -mtime -7 -fprint $TMP/DIRECTORIES.last07.$$ \
-a                        -mtime -2 -fprint $TMP/DIRECTORIES.last02.$$ \
-a                        -mtime -1 -fprint $TMP/DIRECTORIES.last01.$$

for i in FILES.all FILES.last31 FILES.last14 FILES.last07 \
        FILES.last02 FILES.last01 DIRECTORIES.all \
        DIRECTORIES.last31 DIRECTORIES.last14 \
        DIRECTORIES.last07 DIRECTORIES.last02 DIRECTORIES.last01
do
    sed -e "s=^[.]/=$WD/=" -e "s=^[.]$=$WD=" $TMP/$i.$$ |
        LC_ALL=C sort > $TMP/$i.$$tmp
    cmp -s $TMP/$i.$$tmp $i || mv $TMP/$i.$$tmp $i
done

```

10.4.4. Finding Problem Files

In Section 10.1, we noted the difficulties presented by filenames containing special characters, such as newlines. We can display filenames as NUL-terminated strings. Since pathnames can legally contain any character *except* NUL, there are a lot of filenames that can be parsed unambiguously.

It is hard to parse such lists with typical Unix tools, most of which assume line-oriented text input. However, if you have a programming language, such as C, C++, or Java, it is straightforward to write a program to diagnose the presence of problem characters. Sometimes they get there by simple programmer error, but other times, they are put there by attackers who try to hide things.

For example, suppose that you did a directory listing and got output like this:

```
$ ls                                     List directory
.  ..
```

At first glance, this seems innocuous, since we know that empty directories always contain two special hidden files: `.` and `..`. However, notice that we did not use the `-a` option, so we should not have seen any hidden files, and we only saw a first dot in the output. Something is just not right! Let's apply `find` and `od` to investigate further:

```
$ find -print0 | od -ab                  Convert NUL-terminated files to octal
0000000  . nul  . / sp  . nul  . / sp  . . nul  . / .
          056 000 056 057 040 056 000 056 057 040 056 056 000 056 057
0000020 nl nul  . / . . sp  . . sp  . . sp  . sp nl
          012 000 056 057 056 056 040 056 056 040 056 056 040 056 040
0000040 nl  nl  sp  sp nul
          012 012 040 040 000
0000045
```

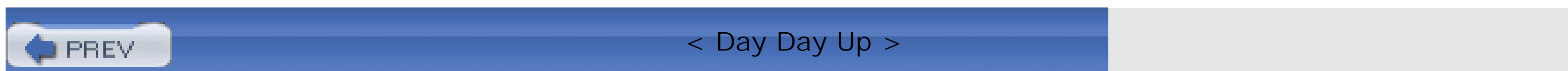
We can make this somewhat more readable with the help of `tr`, turning spaces into `s`, newlines into `N`, and NUL into `\0`:

```
$ find -print0 | tr ' \n\0' 'SN\n'      Make problem characters visible
.
./S.
./S..
```

```
./ .N
```

```
./ ..S..S..S.SNNNSS
```

Now we can see what is going on: we have the normal dot directory, then a file named space-dot, another r
newline, and finally one named dot-dot-space-dot-dot-space-dot-dot-space-dot-space-newline-newline-new
practicing Morse code in your filesystem, these files look awfully suspicious, and you should investigate th



10.5. Running Commands: *xargs*

When *find* produces a list of files, it is often useful to be able to supply that list as arguments to another command. This is done with the shell's command substitution feature, as in this example of searching for the symbol `POSIX_OPEN_MAX` in system header files:

```
$ grep POSIX_OPEN_MAX /dev/null $(find /usr/include -type f | sort)

/usr/include/limits.h:#define    _POSIX_OPEN_MAX                16
```

Whenever you write a program or a command that deals with a list of objects, you should make sure that it can handle an empty list. Because *grep* reads standard input when it is given no file arguments, we supplied an argument of `/dev/null` to ensure that it does not hang waiting for terminal input if *find* produces no output: that will not happen. It is good to develop defensive programming habits.

The output from the substituted command can sometimes be lengthy, with the result that a nasty kernel limit on the length of a command line and its environment variables is exceeded. When that happens, you'll see this instead:

```
$ grep POSIX_OPEN_MAX /dev/null $(find /usr/include -type f | sort)

/usr/local/bin/grep: Argument list too long.
```

That limit can be found with *getconf*:

```
$ getconf ARG_MAX                Get system configuration value for ARG_MAX

131072
```

On the systems that we tested, the reported values ranged from a low of 24,576 (IBM AIX) to a high of 1,048,576 (Solaris).

The solution to the `ARG_MAX` problem is provided by *xargs*: it takes a list of arguments on standard input, and feeds them in suitably sized groups (determined by the host's value of `ARG_MAX`) to another command given as an argument to *xargs*. Here is an example that eliminates the obnoxious `Argument list too long` error:

```
$ find /usr/include -type f | xargs grep POSIX_OPEN_MAX /dev/null

/usr/include/bits/posix1_lim.h:#define    _POSIX_OPEN_MAX                16
```

```
/usr/include/bits/posix1_lim.h:#define    _POSIX_FD_SETSIZE    _POSIX
```

Here, the `/dev/null` argument ensures that *grep* always sees at least two file arguments, causing it to print start of each reported match. If *xargs* gets no input filenames, it terminates silently without even invoking the program.

GNU *xargs* has the `-null` option to handle the NUL-terminated filename lists produced by GNU *find*'s `-print0` passes each such filename as a complete argument to the command that it runs, without danger of shell (mis)newline confusion; it is then up to that command to handle its arguments sensibly.

xargs has options to control where the arguments are substituted, and to limit the number of arguments passed in each invocation of the argument command. The GNU version can even run multiple argument processes in parallel. The simple form shown here suffices most of the time. Consult the *xargs* (1) manual pages for further details, and some of the wizardry possible with its fancier features.



< Day Day Up >

10.6. Filesystem Space Information

With suitable options, the *find* and *ls* commands report file sizes, so with the help of a short *awk* program, how many bytes your files occupy:

```
$ find -ls | awk '{Sum += $7} END {printf("Total: %.0f bytes\n", Sum)}'
```

```
Total: 23079017 bytes
```

However, that report underestimates the space used, because files are allocated in fixed-size blocks, and it says nothing about the used and available space in the entire filesystem. Two other useful tools provide better solutions:

10.6.1. The *df* Command

df (disk free) gives a one-line summary of used and available space on each mounted filesystem. The units are dependent on some systems, and kilobytes on others. Most modern implementations support the *-k* (kilobyte units), and the *-l* (lowercase L) option to include only local filesystems, excluding network-mounted filesystems. Here is a typical example from one of our web servers:

```
$ df -k
```

Filesystem	1K-blocks	Used	Available	Use%	Mounted on
/dev/sda5	5036284	2135488	2644964	45%	/
/dev/sda2	38890	8088	28794	22%	/boot
/dev/sda3	10080520	6457072	3111380	68%	/export
none	513964	0	513964	0%	/dev/shm
/dev/sda8	101089	4421	91449	5%	/tmp
/dev/sda9	13432904	269600	12480948	3%	/var
/dev/sda6	4032092	1683824	2143444	44%	/ww

GNU *df* provides the *-h* (human-readable) option to produce a more compact, but possibly more confusing,

```
$ df -h
```

```
Filesystem      Size  Used Avail Use% Mounted on
/dev/sda5       4.9G  2.1G  2.6G  45% /
/dev/sda2        38M   7.9M   29M  22% /boot
/dev/sda3       9.7G  6.2G  3.0G  68% /export
none            502M     0  502M   0% /dev/shm
/dev/sda8        99M   4.4M   90M   5% /tmp
/dev/sda9       13G   264M  12G   3% /var
/dev/sda6       3.9G  1.7G  2.1G  44% /ww
```

The output line order may be arbitrary, but the presence of the one-line header makes it harder to apply *sort*, preserving that header. Fortunately, on most systems, the output is only a few lines long.

df

Usage

```
df [ options ] [ files-or-directories ]
```

Purpose

Show the inode or space usage in one or more filesystems.

Major options

-i

Show inode counts rather than space.

-k

Show space in kilobytes rather than blocks.

-l

Lowercase L. Show only local filesystems.

Behavior

For each file or directory argument, or for all filesystems if there are no such arguments, *df* produces one-line header that identifies the output columns, followed by a usage report for the filesystem containing that file or directory.

Caveats

The output of *df* varies considerably between systems, making it hard to use reliably in portable shell scripts.

df's output is *not* sorted.

Space reports for remote filesystems may be inaccurate.

Reports represent only a single snapshot that might be quite different a short time later in an active multiuser system.

You can supply a list of one or more filesystem names or mount points to limit the output to just those:

```
$ df -lk /dev/sda6 /var
```

Filesystem	1K-blocks	Used	Available	Use%	Mounted on
/dev/sda6	4032092	1684660	2142608	45%	/ww

```
/dev/sda9          13432904    269704  12480844    3% /var
```

For network-mounted filesystems, entries in the `Filesystem` column are prefixed by `hostname:` , making enough that some `df` implementations split the display into two lines, which is a nuisance for other software output. Here's an example from a Sun Solaris system:

```
$ df
```

```
Filesystem      1k-blocks      Used Available Use% Mounted on
...
/dev/sdd1       17496684  15220472   1387420   92% /export/local
fs:/export/home/0075
                35197586  33528481   1317130   97% /a/fs/export/home/0075
...
```

`df`'s reports about the free space on remote filesystems may be inaccurate, because of software implementation inconsistencies in accounting for the space reserved for emergency use.

In Section B.4.3 in Appendix B, we discuss the issue that the inode table in a filesystem has an immutable when the filesystem is created. The `-i` (inode units) option provides a way to assess inode usage. Here is an example from the same web server:

```
$ df -i
```

```
Filesystem      Inodes    IUsed   IFree IUse% Mounted on
/dev/sda5       640000   106991  533009   17% /
/dev/sda2       10040     35    10005    1% /boot
/dev/sda3       1281696  229304 1052392   18% /export
none            128491     1   128490    1% /dev/shm
/dev/sda8       26104    144   25960    1% /tmp
/dev/sda9       1706880     996 1705884    1% /var
/dev/sda6       513024  218937  294087   43% /ww
```


The `/ww` filesystem is in excellent shape, since its inode use and filesystem space are both just over 40 percent. In a healthy computing system, system managers should routinely monitor inode usage on all local filesystems.

`df` is one of those commands where there is wide variation in the options and output appearance, which again is a problem for portable programs that want to parse its output. Hewlett-Packard's implementation on HP-UX is radical. Fortunately, HP provides a Berkeley-style equivalent, `bdf`, that produces output that is similar to our examples. In light of this variation, we recommend that you install the GNU version everywhere at your site; it is part of the `coreutils` package, as cited in Section 4.1.5.

10.6.2. The `du` Command

`df` summarizes free space by filesystem, but does not tell you how much space a particular directory tree requires. This is done by `du` (disk usage). Like its companion, `df`, `du`'s options tend to vary substantially between systems, and the units also may vary. Two important options are widely implemented: `-k` (kilobyte units) and `-s` (summarize). Here are some examples from our web server system:

```
$ du /tmp
```

```
12      /tmp/lost+found
```

```
1       /tmp/.font-unix
```

```
24      /tmp
```

```
$ du -s /tmp
```

```
24      /tmp
```

```
$ du -s /var/log /var/spool /var/tmp
```

```
204480  /var/log
```

```
236     /var/spool
```

```
8       /var/tmp
```

The GNU version provides the `-h` (human-readable) option:

```
$ du -h -s /var/log /var/spool /var/tmp  
  
200M    /var/log  
236k    /var/spool  
8.0k    /var/tmp
```

du does not count extra hard links to the same file, and normally ignores soft links. However, some implemen provide options to force soft links to be followed, but the option names vary: consult the manual pages for

du

Usage

```
du [ options ] [ files-or-directories ]
```

Purpose

Show the space usage in one or more directory trees.

Major options

-k

Show space in kilobytes rather than (system-dependent) blocks.

-s

Show only a one-line summary for each argument.

Behavior

For each file or directory argument, or for the current directory if no such arguments are given, *du* normally produces one output line containing an integer representing the usage, followed by the name of the file or directory. Unless the *-s* option is given, each directory argument is searched recursively with one report line for each nested directory.

Caveats

du's output is *not* sorted.

One common problem that *du* helps to solve is finding out who the big filesystem users are. Assuming that directory trees reside in `/home/users`, `root` can do this:

```
# du -s -k /home/users/* | sort -k1nr | less           Find large home dirs
```

This produces a list of the top space consumers, from largest to smallest. A `find dirs -size +10000` command can quickly locate files that might be candidates for compression or deletion, and can identify user directory trees that might better be moved to larger quarters.

Some managers automate the regular processing of *du* reports, sending warning mail to users about unexpectedly large directory trees, such as with the script in Example 7-1 in Chapter 7. In my experience, this is much better than using the filesystem quota system (see the manual page `quota (1)`), since it avoids assigning magic numbers (filesystem-space limits) to users; those numbers are invariably wrong, and they inevitably prevent people from getting legitimate work done.

There is nothing magic about how *du* works: like any other program, it has to descend through the filesystem to measure the space used by every file. Thus, it can be slow on large filesystems, and it can be locked out of directories by permissions; if its output contains `Permission denied` messages, its report undercounts the space usage. `root` has sufficient privileges to use *du* everywhere in the local system.

10.7. Comparing Files

In this section, we look at four related topics that involve comparing files:

- Checking whether two files are the same, and if not, finding how they differ
- Applying the differences between two files to recover one from the other
- Using checksums to find identical files
- Using digital signatures for file verification

10.7.1. The `cmp` and `diff` Utilities

A problem that frequently arises in text processing is determining whether the *contents* of two or more files differ.

If you have just two candidates, then the file comparison utility, `cmp`, readily provides the answer:

```
$ cp /bin/ls /tmp Make a private copy of /bin/ls
```

```
$ cmp /bin/ls /tmp/ls Compare the original with the copy
```

No output means that the files are identical

```
$ cmp /bin/cp /bin/ls Compare different files
```

```
/bin/cp /bin/ls differ: char 27, line 1 Output identifies the location of the difference
```

`cmp` is silent when its two argument files are identical. If you are interested only in its exit status, you can use the `-s` option:

```
$ cmp -s /bin/cp /bin/ls Compare different files silently
```

```
$ echo $? Display the exit code
```


1 Nonzero value means that the

If you want to know the differences between two similar files, *diff* does the job:

```
$ echo Test 1 > test.1 Create first test file
```

```
$ echo Test 2 > test.2 Create second test file
```

```
$ diff test.[12] Compare the two files
```

```
1c1
```

```
< Test 1
```

```
---
```

```
> Test 2
```

It is conventional in using *diff* to supply the older file as the first argument.

Difference lines prefixed by a left angle bracket correspond to the left (first) file, and those prefixed by a right angle bracket correspond to the right (second) file. The `1c1` preceding the differences is a compact representation of the input-file line numbers and the operation needed to make the edit: here, `c` means *change*. In larger examples, you will usually also find a file name.

diff's output is carefully designed so that it can be used by other programs. For example, *revision control systems* use *diff* to find differences between successive versions of files under their management.

There is an occasionally useful companion to *diff* that does a slightly different job. *diff3* compares *three* files produced by two different people, and produces an *ed*-command script that can be used to merge both files into a common base version. We do not illustrate it here, but you can find examples in the *diff3* (1) manual pages.

10.7.2. The patch Utility

The *patch* utility uses the output of *diff* and either of the original files to reconstruct the other one. Because difference listings are much smaller than the original files, software developers often exchange difference listings via email, and use *patch* to apply them. *patch* can convert the contents of `test.1` to match those of `test.2`:

```
$ diff -c test.[12] > test.dif Save a context difference listing
```

```
$ patch < test.dif
```

Apply the differences

```
patching file test.1
```

```
$ cat test.1
```

Show the patched test.1 file

```
Test 2
```

patch applies as many of the differences as it can; it reports any failures for you to handle manually.

Although *patch* can use the ordinary output of *diff*, it is more common to use *diff*'s *-c* option to get a *context*. This tells *patch* the filenames, and allows it to verify the change location and to recover from mismatches. Context means that neither of the two files has been changed since the differences were recorded, but in software development files evolve.

10.7.3. File Checksum Matching

If you have lots of files that you suspect have identical contents, using *cmp* or *diff* would require comparing every pair of files, an execution time that grows *quadratically* in the number of files, which is soon intolerable.

You can get nearly linear performance by using *file checksums*. There are several utilities for computing checksums: *sum*, *cksum*, and *checksum*,^[9] the message-digest tools^[10] *md5* and *md5sum*, and the secure-hash algorithm *sha384*. Regrettably, implementations of *sum* differ across platforms, making its output useless for comparing files on different flavors of Unix. The native version of *cksum* on OSF/1 systems produces different checksums than

^[9] Available at <http://www.math.utah.edu/pub/checksum/>.

^[10] R. Rivest, *RFC 1321: The MD5 Message-Digest Algorithm*, available at <ftp://ftp.internic.net/rfc/rfc1321.txt>. *md5sum*

^[11] NIST, FIPS PUB 180-1: Secure Hash Standard, April 1995, available at <http://www.cerberussystems.com/INFOSEC/std:coreutils> package.

Except for the old *sum* command, only a few of these programs are likely to be found on an out-of-the-box installation. Their output formats differ, but here is a typical example:

```
$ md5sum /bin/l?
```

```
696a4fa5a98b81b066422a39204ffea4 /bin/ln
```

```
cd6761364e3350d010c834ce11464779 /bin/lp
```

```
351f5eab0baa6eddae391f84d0a6c192    /bin/ls
```

The long *hexadecimal* signature string is just a many-digit integer that is computed from all of the bytes of unlikely that any other byte stream could produce the same value. With good algorithms, longer signatures uniqueness. The *md5sum* output has 32 hexadecimal digits, equivalent to 128 bits. Thus, the chance^[12] of having two signatures is only about one in $2^{32} = 1.84 \cdot 10^{19}$, which is probably negligible. Recent cryptographic research create families of pairs of files with the same MD5 checksum. However, creating a file with similar, but not identical, contents with the same checksum, is likely to remain a difficult problem.

^[12] If you randomly select an item from a collection of N items, each has a $1/N$ chance of being chosen. If you select M items, the chance of finding a pair with identical elements is $(M(M-1)/2)/N$. That value reaches probability $1/2$ for M about the square root of $2N$; you can find discussions of it in books on cryptography, number theory, and probability, as well as at numerous web sites. I will give some numerical examples.

To find matches in a set of signatures, use them as indices into a table of signature counts, and report just the matches. *awk* is just the tool that we need, and the program in Example 10-2 is short and clear.

Example 10-2. Finding matching file contents

```
#!/bin/sh -

# Show filenames with almost-certainly identical
# contents, based on their MD5 checksums.

#

# Usage:
#     show-identical-files files

IFS='

'

PATH=/usr/local/bin:/usr/bin:/bin

export PATH
```



```
md5sum "$@" /dev/null 2> /dev/null |
awk '{
    count[$1]++
    if (count[$1] == 1) first[$1] = $0
    if (count[$1] == 2) print first[$1]
    if (count[$1] > 1) print $0
}' |
sort |
awk '{
    if (last != $1) print ""
    last = $1
    print
}'
```

Here is what its output looks like on a GNU/Linux system:

```
$ show-identical-files /bin/*
```

```
2df30875121b92767259e89282dd3002    /bin/ed
2df30875121b92767259e89282dd3002    /bin/red

43252d689938f4d6a513a2f571786aa1    /bin/awk
43252d689938f4d6a513a2f571786aa1    /bin/gawk
43252d689938f4d6a513a2f571786aa1    /bin/gawk-3.1.0
```


...

We can conclude, for example, that *ed* and *red* are identical programs on this system, although they may stand for different names that they are invoked with.

Files with identical contents are often links to each other, especially when found in system directories. *show* information when applied to user directories, where it is less likely that files are links and more likely that they are

10.7.4. Digital Signature Verification

The various checksum utilities provide a single number that is characteristic of the file, and is unlikely to be the same with different contents. Software announcements often include checksums of the distribution files so that you can verify that a copy that you just downloaded matches the original. However, checksums alone do not provide *verification*. If you have another file that you downloaded with the software, an attacker could have maliciously changed the software accordingly.

The solution to this problem comes from *public-key cryptography*, where data security is obtained from the use of a private key, known only to its owner, and a public key, potentially known to anyone. Either key may be used for decryption. The security of public-key cryptography lies in the belief that knowledge of the public key, by itself, provides no practical information that can be used to recover the private key. The great breakthrough of modern cryptography is the solution of the biggest problem in historical cryptography: secure exchange of encryption keys among the parties needing

Here is how the private and public keys are used. If Alice wants to sign an open letter, she uses her *private* key to sign the letter. Bob can use Alice's *public* key to decrypt the signed letter, and can then be confident that only Alice could have signed it, provided she has not changed her private key.

If Alice wants to send a letter to Bob that only he can read, she encrypts it with Bob's *public* key, and he then uses his *private* key to decrypt it. As long as Bob keeps his private key secret, Alice can be confident that only Bob can read her letter.

It isn't necessary to encrypt the entire message: instead, if just a file checksum is encrypted, then one has a secure way to verify the message itself can be public, but a way is needed to verify its authenticity.

Several tools for public-key cryptography are implemented in the GNU Privacy Guard^[13] (GnuPG) and PGP. A complete description of these packages requires an entire book; see the Chapter 16. However, it is straightforward to verify the authenticity of *digital signatures*. We illustrate only GnuPG here, since it is under active development on more platforms than PGP.

[13] Available at <ftp://ftp.gnupg.org/gcrypt/gnupg/> and <http://www.gnupg.org/>.

[14] Available at <http://web.mit.edu/network/pgp.html>.

Because computers are increasingly under attack, many software archives now include digital signatures that are verified against a checksum as well as from the signer's private key. It is therefore important to know how to verify such signatures. If a signature is available, you should always verify it. Here is how you can do so with GnuPG:

```
$ ls -l coreutils-5.0.tar*           Show the distribution files
-rw-rw-r--  1 jones devel 6020616 Apr  2  2003 coreutils-5.0.tar.gz
-rw-rw-r--  1 jones devel      65 Apr  2  2003 coreutils-5.0.tar.gz.:
```

```
$ gpg coreutils-5.0.tar.gz.sig      Try to verify the signature
gpg: Signature made Wed Apr  2 14:26:58 2003 MST using DSA key ID D3
gpg: Can't check signature: public key not found
```

The signature verification failed because we have not added the signer's public key to the *gpg* key ring. If you might be able to find the public key at the signer's personal web site or ask the signer for a copy via email. I have here is the key ID. Fortunately, people who use digital signatures generally register their public keys, and that registration is automatically shared with other key servers. Some of the major ones are listed in Table 10-2. Replicated copies of public keys enhance security: if one key server is unavailable or compromised, another one.

Table 10-2. Major public-key servers

Country	URL
Belgium	http://www.keyserver.net/en/
Germany	http://math-www.uni-paderborn.de/pgp/
Germany	http://pgp.zdv.uni-mainz.de/keyserver/pks-commands.html#extract
UK	http://www.cl.cam.ac.uk/PGP/pks-commands.html#extract
USA	http://pgp.mit.edu/

Use a web browser to visit the key server, type the key ID `0xD333CBA1` into a search box (the leading `0x` is

```
Public Key Server -- Index '0xD333CBA1'
```

```
Type bits /keyID      Date          User ID
```

```
pub 1024D/D333CBA1 1999/09/26 Jim Meyering <meyering@ascend.com>
```

```
...
```

Follow the link on the key ID (shown in the preceding code snippet in bold) to get a web page that looks like

```
Public Key Server -- Get '0xD333CBA1'
```

```
-----BEGIN PGP PUBLIC KEY BLOCK-----
```

```
Version: PGP Key Server 0.9.6
```

```
mQGiBDftyYoRBACvICTt5AWe7kdbRtJ37IZ+ED5tBA/IbISfqUPO+HmL/J9JSfkV
```

```
QHbdQR5dj5mrU6BY5YOY7L4KOS6lH3AgvsZ/NhkDBraBPgnMkpDqFb7z4keCIebb
```

```
...
```

```
-----END PGP PUBLIC KEY BLOCK-----
```

Finally, save the key text in a temporary file-say, `temp.key`-and add it to your key ring:

```
$ gpg --import temp.key Add the public key to your keyring
```

```
gpg: key D333CBA1: public key "Jim Meyering <jim@meyering.net>" imported
```

```
gpg: Total number processed: 1
```

```
gpg:             imported: 1
```

Now you can verify the signature successfully:

```
$ gpg coreutils-5.0.tar.gz.sig Verify the digital signature
```

```
gpg: Signature made Wed Apr  2 14:26:58 2003 MST using DSA key ID D333CBA1
```

```
gpg: Good signature from "Jim Meyering <jim@meyering.net>"
```

```
gpg:             aka "Jim Meyering <meyering@na-net.ornl.gov>"
```



```

gpg:          aka "Jim Meyering <meyering@pobox.com>"
gpg:          aka "Jim Meyering <meyering@ascend.com>"
gpg:          aka "Jim Meyering <meyering@lucent.com>"
gpg: checking the trustdb
gpg: checking at depth 0 signed=0 ot(-/q/n/m/f/u)=0/0/0/0/0/1
gpg: next trustdb check due at ????-??-??
gpg: WARNING: This key is not certified with a trusted signature!
gpg:          There is no indication that the signature belongs to the
Primary key fingerprint: D70D 9D25 AF38 37A5 909A 4683 FDD2 DEAC D3

```

The warning in the successful verification simply means that you have not certified that the signer's key really personally know the signer and have good reason to believe that the key is valid, you should not certify key

An attacker could modify and repackage the distribution, but without knowledge of the signer's (secret) private key reproduced, and *gpg* detects the attack:

```

$ ls -l coreutils-5.0.tar.gz          List the maliciously modified
-rw-rw-r--  1 jones devel 6074205 Apr  2 2003 coreutils-5.0.tar.gz

$ gpg coreutils-5.0.tar.gz.sig      Try to verify the digital signature
gpg: Signature made Wed Apr  2 14:26:58 2003 MST using DSA key ID D3
gpg: BAD signature from "Jim Meyering <jim@meyering.net>"

```

Digital signatures ensure that the file at your site matches the one prepared and signed at the remote site. Otherwise, a signer's system before the software was packaged for distribution would not be revealed when the signature is verified.

You do not need to use a web browser to retrieve a public key: the GNU *wget* utility^[15] can do the job once expected by a particular key server. The script in Example 10-3 makes retrieval easy and provides a reminder to update key rings.

[15] Available at [ftp://ftp.gnu.org/gnu/wget/](http://ftp.gnu.org/gnu/wget/).

Example 10-3. Automating public-key retrieval

```
#!/bin/sh -

# Get one or more PGP/GPG keys from a key server.

#

# Usage:

#     getpubkey key-ID-1 key-ID-2 ...

IFS='
'

PATH=/usr/local/bin:/usr/bin:/bin

export PATH

for f in "$@"
do
    g=0x`echo $f | sed -e s'^0x//'\`
    tmpfile=/tmp/pgp-$g.tmp.$$
    wget -q -O - "http://pgp.mit.edu:11371/pks/lookup?op=get&search=$g"
    ls -l $tmpfile
    echo "Try:      pgp -ka $tmpfile"
    echo "          pgpgpg -ka $tmpfile"
    echo "          rm -f $tmpfile"
done
```

Ensui

Here is an example of its use:

```
$ getpubkey D333CBA1           Get the public key for key
-rw-rw-r--  1 jones jones 4567 Apr  6 07:26 /tmp/pgp-0xD333CBA1.tmp.
Try:      pgp -ka /tmp/pgp-0xD333CBA1.tmp.21643
          pgpgpg -ka /tmp/pgp-0xD333CBA1.tmp.21643
          rm -f /tmp/pgp-0xD333CBA1.tmp.21643
```

Some keys can be used with both PGP and GnuPG, but others cannot, so the reminder covers both. Because *pgp* differ, and *pgp* was developed first, *gpg* comes with a wrapper program, *pgpgpg*, that takes the same work. Here, *pgpgpg -ka* is the same as *gpg --import*.

getpubkey allows you to add retrieved keys to either, or both, of your GnuPG and PGP key rings, at the expense of providing a one-step solution, but only updates your GnuPG key ring:

```
$ gpg --keyserver pgp.mit.edu --search-keys 0xD333CBA1

gpg: searching for "0xD333CBA1" from HKP server pgp.mit.edu

Keys 1-6 of 6 for "0xD333CBA1"

(1)      Jim Meyering <meyering@ascend.com>

          1024 bit DSA key D333CBA1, created 1999-09-26

...

Enter number(s), N)ext, or Q)uit > 1

gpg: key D333CBA1: public key "Jim Meyering <jim@meyering.net>" imported
gpg: Total number processed: 1
gpg:
          imported: 1
```

The *-keyserver* option is only required the first time, but you can later use it to specify a different server. The *-keyserver* option accepts an email address, username, or personal name.

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10.8. Summary

In this chapter, we showed how to list files and file metadata with *ls* and *stat*, and how to set file timestamps with *touch*. The *touch* experiments revealed information about the time-of-day clock and its limited range in many current systems.

We showed how to create unique temporary filenames with the shell process ID variable, `$$`, with the *mktemp* utility and a do-it-yourself sampling of streams of random numbers. The computing world can be a hostile environment, so it is worth protecting your programs from attack by giving their temporary files unique and unguessable names.

We described the *locate* and *slocate* commands for fast lookup of filenames in a regularly updated database constructed by complete scans of the filesystem. When you know part or all of a filename and just want to find where it is in the filesystem, *locate* is generally the best way to track it down, unless it was created after the database was constructed.

The *type* command is a good way to find out information about shell commands, and our *pathfind* script from [Chapter 8](#) provides a more general solution for locating files in a specified directory path.

We took several pages to explore the powerful *find* command, which uses brute-force filesystem traversal to find files that match user-specified criteria. Nevertheless, we still had to leave many of its facilities for you to discover on your own from its manual pages and the extensive manual for GNU *find*.

We gave a brief treatment of *xargs*, another powerful command for doing operations on lists of files, often produced upstream in a pipeline by *find*. Not only does this overcome command-line length restrictions on many systems, but it also gives you the opportunity to insert additional filters in the pipeline to further control what files are ultimately processed.

The *df* and *du* commands report the space used in filesystems and directory trees. Learn them well, because you may use them often.

We wrapped up with a description of commands for comparing files, applying patches, generating file checksums, and validating digital signatures.

Chapter 11. Extended Example: Merging User Databases

By now, we've come a long way and seen a number of shell scripts. This chapter aims to tie things together by writing shell programs to solve a moderately challenging task.

11.1. The Problem

The Unix password file, `/etc/passwd`, has shown up in several places throughout the book. System administration tasks often revolve around manipulation of the password file (and the corresponding group file, `/etc/group`). The format is well known:^[1]

^[1] BSD systems maintain an additional file, `/etc/master.passwd`, which has three additional fields: the user's login class, password change time, and account expiration time. These fields are placed between the GID field and the field for the full name.

```
tolstoy:x:2076:10:Leo Tolstoy:/home/tolstoy:/bin/bash
```

There are seven fields: username, encrypted password, user ID number (UID), group ID number (GID), full name, home directory, and login shell. It's a bad idea to leave any field empty: in particular, if the second field is empty, the user can log in without a password, and *anyone* with access to the system or a terminal on it can log in as that user. If the seventh field (the shell) is left empty, Unix defaults to the Bourne shell, `/bin/sh`.

As is discussed in detail in [Appendix B](#), it is the user and group ID numbers that Unix uses for permission checking when accessing files. If two users have different names but the same UID number, then as far as Unix knows, they are *identical*. There are rare occasions when you want such a situation, but usually having two accounts with the same UID number is a mistake. In particular, NFS *requires* a uniform UID space; user number 2076 on all systems accessing each other via NFS had better be the same user (`tolstoy`), or else there will be serious security problems.

Now, return with us for a moment to yesteryear (around 1986), when Sun's NFS was just beginning to become popular and available on non-Sun systems. At the time, one of us was a system administrator of two separate 4.2 BSD Unix minicomputers. These systems communicated via TCP/IP, but did not have NFS. However, a new OS vendor was scheduled to make 4.3 BSD + NFS available for these systems. There were a number of users with accounts on both systems; typically the username was the same, but the UID wasn't! These systems were soon to be sharing filesystems via NFS; it was imperative that their UID spaces be merged. The task was to write a series of scripts that would:

- Merge the `/etc/passwd` files of the two systems. This entailed ensuring that all users from both systems had unique UID numbers.
- Change the ownership of all files to the correct users in the case where an existing UID was to be used for a different user.

It is this task that we recreate in this chapter, from scratch. (The original scripts are long gone, and it's occasionally interesting and instructive to reinvent a useful wheel.) This problem isn't just academic, either: consider two departments in a company that have been separate but that now must merge. It's possible for there to be users with accounts on systems in multiple departments. If you're a system administrator, you may one day face this very task. In any case, we think it is an interesting problem to solve.



11.2. The Password Files

Let's call our two hypothetical Unix systems `u1` and `u2`. [Example 11-1](#) presents the `/etc/passwd` file from `u1`.^[2]

^[2] Any resemblance to actual users, living or dead, is purely coincidental.

Example 11-1. `u1 /etc/passwd` file

```
root:x:0:0:root:/root:/bin/bash
bin:x:1:1:bin:/bin:/sbin/nologin
daemon:x:2:2:daemon:/sbin:/sbin/nologin
adm:x:3:4:adm:/var/adm:/sbin/nologin
tolstoy:x:2076:10:Leo Tolstoy:/home/tolstoy:/bin/bash
camus:x:112:10:Albert Camus:/home/camus:/bin/bash
jhancock:x:200:10:John Hancock:/home/jhancock:/bin/bash
ben:x:201:10:Ben Franklin:/home/ben:/bin/bash
abe:x:105:10:Honest Abe Lincoln:/home/abe:/bin/bash
dorothy:x:110:10:Dorothy Gale:/home/dorothy:/bin/bash
```

And [Example 11-2](#) presents `/etc/passwd` from `u2`.

Example 11-2. `u2 /etc/passwd` file

```
root:x:0:0:root:/root:/bin/bash
bin:x:1:1:bin:/bin:/sbin/nologin
daemon:x:2:2:daemon:/sbin:/sbin/nologin
```



```
adm:x:3:4:adm:/var/adm:/sbin/nologin
george:x:1100:10:George Washington:/home/george:/bin/bash
betsy:x:1110:10:Betsy Ross:/home/betsy:/bin/bash
jhancock:x:300:10:John Hancock:/home/jhancock:/bin/bash
ben:x:301:10:Ben Franklin:/home/ben:/bin/bash
tj:x:105:10:Thomas Jefferson:/home/tj:/bin/bash
toto:x:110:10:Toto Gale:/home/toto:/bin/bash
```

If you examine these files carefully, you'll see they represent the various possibilities that our program has to handle:

- Users for whom the username and UID are the same on both systems. This happens most typically with administrative accounts such as `root` and `bin`.
- Users for whom the username and UID exist only on one system but not the other. In this case, when the files are merged, there is no problem.
- Users for whom the username is the same on both systems, but the UIDs are different.
- Users for whom the username is different on both systems, but the UIDs are the same.

11.3. Merging Password Files

The first step is to create a merged `/etc/passwd` file. This involves several substeps:

1. Physically merge the files, bringing duplicate usernames together. This becomes the input for the following steps.
2. Split the merged file into three separate parts for use in later processing:
 - Users for whom the username and UID are the same go into one file, named `unique1`. Users with no duplicate usernames go into this file.
 - Users with the same username and different UIDs go into a second file, named `dupusers`.
 - Users with the same UID and different usernames go into a third file, named `dupids`.

1. Create a list of all unique UID numbers that already are in use. This will be needed so that we can find unused numbers when a conflict occurs and we need to do a UID change (e.g., users `jhancock` and `ben`).
2. Given the list of in-use UID numbers, write a separate program to find a new, unused UID number.
3. Create a list of (username, old UID, new UID) triples to be used in creating final `/etc/passwd` entries and in generating commands to change the ownership of files in the filesystem.

At the same time, create final password file entries for the users who originally had multiple UIDs and for the multiple users.

4. Create the final password file.
5. Create the list of commands to change file ownership, and then run the commands. As will be seen, these commands require careful planning.

In passing, we note that all the code here operates under the assumption that usernames and UID numbers are unique. This shouldn't be a problem in practice, but it is worth being aware of in case a more complicated situation arises in the future.

11.3.1. Separating Users by Manageability

Merging the password files is easy. The files are named `u1.passwd` and `u2.passwd`, respectively. The `sort` We use `tee` to save the file and simultaneously print it on standard output where we can see it:

```
$ sort u1.passwd u2.passwd | tee merge1
```

```
abe:x:105:10:Honest Abe Lincoln:/home/abe:/bin/bash
```

```
adm:x:3:4:adm:/var/adm:/sbin/nologin
```

```
adm:x:3:4:adm:/var/adm:/sbin/nologin
```

```
ben:x:201:10:Ben Franklin:/home/ben:/bin/bash
```

```
ben:x:301:10:Ben Franklin:/home/ben:/bin/bash
```

```
betsy:x:1110:10:Betsy Ross:/home/betsy:/bin/bash
```

```
bin:x:1:1:bin:/bin:/sbin/nologin
```

```
bin:x:1:1:bin:/bin:/sbin/nologin
```

```
camus:x:112:10:Albert Camus:/home/camus:/bin/bash
```

```
daemon:x:2:2:daemon:/sbin:/sbin/nologin
```

```
daemon:x:2:2:daemon:/sbin:/sbin/nologin
```

```
dorothy:x:110:10:Dorothy Gale:/home/dorothy:/bin/bash
```

```
george:x:1100:10:George Washington:/home/george:/bin/bash
```

```
jhancock:x:200:10:John Hancock:/home/jhancock:/bin/bash
```

```
jhancock:x:300:10:John Hancock:/home/jhancock:/bin/bash
```

```
root:x:0:0:root:/root:/bin/bash
```

```
root:x:0:0:root:/root:/bin/bash
```

```
tj:x:105:10:Thomas Jefferson:/home/tj:/bin/bash
```

```
tolstoy:x:2076:10:Leo Tolstoy:/home/tolstoy:/bin/bash
```

```
toto:x:110:10:Toto Gale:/home/toto:/bin/bash
```

Example 11-3 presents `splitout.awk`. This script separates the merged file into three new files, named `dup`, `unique1`, respectively.

Example 11-3. The `splitout.awk` program

```
#!/bin/awk -f

# $1    $2    $3    $4    $5            $6    $7
# user:passwd:uid:gid:long name:homedir:shell

BEGIN { FS = ":" }

# name[ ]    --- indexed by username
# uid[ ]     --- indexed by uid

# if a duplicate appears, decide the disposition

{
    if ($1 in name) {
        if ($3 in uid)
            ; # name and uid identical, do nothing
        else {
            print name[$1] > "dupusers"
            print $0 > "dupusers"
            delete name[$1]
        }
    }
}
```



```
        # remove saved entry with same name but different uid
        remove_uid_by_name($1)
    }
} else if ($3 in uid) {
    # we know $1 is not in name, so save duplicate ID records
    print uid[$3] > "dupids"
    print $0 > "dupids"
    delete uid[$3]

    # remove saved entry with same uid but different name
    remove_name_by_uid($3)
} else
    name[$1] = uid[$3] = $0      # first time this record was seen
}

END {
    for (i in name)
        print name[i] > "unique1"

    close("unique1")
    close("dupusers")
    close("dupids")
}
```

```
function remove_uid_by_name(n,      i, f)
{
    for (i in uid) {
        split(uid[i], f, ":")
        if (f[1] == n) {
            delete uid[i]
            break
        }
    }
}
```

```
function remove_name_by_uid(id,     i, f)
{
    for (i in name) {
        split(name[i], f, ":")
        if (f[3] == id) {
            delete name[i]
            break
        }
    }
}
```

The program works by keeping a copy of each input line in two arrays. The first is indexed by username, tl

The first time a record is seen, the username and UID number have not been stored in either array, so a copy of both is made.

When an exact duplicate record (the username and UID are identical) is seen, nothing is done with it, since it is already in the `uid` array. If the username has been seen but the UID is new, both records are written to the `dupusers` file. If the UID of the first record in the `uid` array is removed, since we don't need it. Similar logic applies to records where the UID is new but the username doesn't match.

When the `END` rule is executed, all the records remaining in the `name` array represent unique records. They are written to a file, and then all the files are closed.

`remove_uid_by_name()` and `remove_name_by_uid()` are *awk* functions. User-defined functions in *awk* are described in Section 9.8. These two functions remove unneeded information from the `uid` and `name` arrays, respectively.

Running the program creates the files:

```
awk -f splitout.awk merge1
```

11.3.2. Managing UIDs

Now that we have separated the users by categories, the next task is to create a list of all the UID numbers in use.

```
awk -F: '{ print $3 }' merge1 | sort -n -u > unique-ids
```

We can verify that we have only the unique UID numbers by counting lines in `merge1` and `unique-ids`:

```
$ wc -l merge1 unique-ids
 20 merge1
 14 unique-ids
 34 total
```

Continuing through our task list, the next step is to write a program that produces unused UIDs. By default, the program prints a sorted list of in-use UID numbers and prints the first available UID number. However, since we'll be working with a large number of users, we'll want it to generate a batch of unused UIDs. This is done with the `-c` option, which provides a count of unused UIDs. Example 11-4 presents the `newuids.sh` script.

Example 11-4. The `newuids.sh` program

```
#!/bin/sh -
```

```
# newuids --- print one or more unused uids
#
# usage:
#   newuids [-c N] list-of-ids-file
#   -c N           print N unused uids

count=1          # how many uids to print

# parse arguments, let sh issue diagnostics
# and exit if need be
while getopts "c:" opt
do
    case $opt in
        c) count=$OPTARG ;;
    esac
done

shift $(( $OPTIND - 1 ))

IDFILE=$1

awk -v count=$count '

```



```

BEGIN {
    for (i = 1; getline id > 0; i++)
        uidlist[i] = id
    close(idlist)

    totalids = i

    for (i = 2; i <= totalids; i++) {
        if (uidlist[i-1] != uidlist[i]) {
            for (j = uidlist[i-1] + 1; j < uidlist[i]; j++) {
                print j
                if (--count == 0)
                    exit
            }
        }
    }
} ' $IDFILE

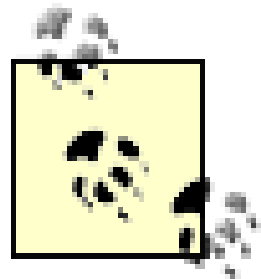
```

Most of the work is done in the inline *awk* program. The first part reads the list of UID numbers into the `uidlist` array. The second loop goes through the array. When it finds two elements whose values are not adjacent, it steps through and prints the numbers between those elements. It decrements `count` each time so that no more than `count` UID numbers are printed.

In shells that have arrays and that support arithmetic more directly, such as *ksh93* and *bash*, it's possible to do this more simply. In fact, this *awk* script was derived from a similar one for *ksh93*: see <http://linux.oreillynet.com/pub/a/linux/2002/05/09/uid.html>.

11.3.3. Creating User-Old UID-New UID Triples

We now have to process the `dupusers` and `dupids` files. The output file lists the username, old UID and new UID separated by whitespace, one record per line, for further processing. For `dupusers`, the processing is pretty straightforward: the first entry encountered will be the old UID, and the next one will be the new chosen UID. (In other words, we assign a second, larger UID for all of the user's files.) At the same time, we can generate the final `/etc/passwd` record for both files.



This plan treats the disks of both systems equally, requiring that file ownerships (potentially on both systems). This is simpler to code, at the (possible) expense of more time spent changing ownerships. A different option would be to leave the files on one system alone, making that "master" system, so to speak, and doing ownership changes only on the second system. That is harder to code; we leave that as one of the infamous "exercises for the reader."

Here's the code:

```
rm -f old-new-list

old_ifs=$IFS
IFS=:

while read user passwd uid gid fullname homedir shell
do
    if read user2 passwd2 uid2 gid2 fullname2 homedir2 shell2
    then
        if [ $user = $user2 ]
        then
            printf "%s\t%s\t%s\n" $user $uid $uid2 >> old-new-list
            echo "$user:$passwd:$uid2:$gid:$fullname:$homedir:$shell"
        else
            echo $0: out of sync: $user and $user2 >&2
        fi
    fi
done
exit 1
```

```

        fi
    else
        echo $0: no duplicate for $user >&2
        exit 1
    fi
done < dupusers > unique2

IFS=$old_ifs

```

We use the shell's *read* command to read pairs of lines from `dupusers`, sending the final password file entry to the new file `old-new-list`. We have to use the `>>` operator for the `read` command to append to the file each time around the loop. To ensure that the file is fresh, we remove it before the loop body.

Setting `IFS` to `:` makes it easy to read password file lines, treating each colon-separated field correctly. The value is saved in `old_ifs` and restored after the loop. (We could also have used `IFS=: read ...`, but we would have had to use *both* `read` statements.)

Similar code applies for the users for whom the UID numbers are the same but the username is different. For simplicity; we give all such users a brand-new, unused UID number. (It would be possible to let, say, the file use the original UID number; however this would require that we do the file ownership changing only on the system files user's files reside. Again, in a real-life situation, this might be preferable.)

```

count=$(wc -l < dupids)      # Total duplicate ids

# This is a hack, it'd be better if POSIX sh had arrays:
set -- $(newuids.sh -c $count unique-ids)

IFS=:

while read user passwd uid gid fullname homedir shell
do
    newuid=$1

```

```
shift
```

```
echo "$user:$passwd:$newuid:$gid:$fullname:$homedir:$shell"
```

```
printf "%s\t%s\t%s\n" $user $uid $newuid >> old-new-list
```

```
done < dupids > unique3
```

```
IFS=$old_ifs
```

In order to have all the new UID numbers handy, we place them into the positional parameters with *set* and Then each new UID is retrieved inside the loop by assigning from \$1 , and the next one is put in place with done, we have three new output files:

```
$ cat unique2
```

Those who ha

```
ben:x:301:10:Ben Franklin:/home/ben:/bin/bash
```

```
jhancock:x:300:10:John Hancock:/home/jhancock:/bin/bash
```

```
$ cat unique3
```

Those who ge

```
abe:x:4:10:Honest Abe Lincoln:/home/abe:/bin/bash
```

```
tj:x:5:10:Thomas Jefferson:/home/tj:/bin/bash
```

```
dorothy:x:6:10:Dorothy Gale:/home/dorothy:/bin/bash
```

```
toto:x:7:10:Toto Gale:/home/toto:/bin/bash
```

```
$ cat old-new-list
```

List of user

```
ben      201      301
```

```
jhancock      200      300
```

```
abe      105      4
```

See next se


```
tj      105      5
dorothy 110      6
toto    110      7
```

The final password file is created by merging the three `unique?` files. While `cat` would do the trick, it'd be in UID order:

```
sort -k 3 -t : -n unique[123] > final.password
```

The wildcard `unique[123]` expands to the three filenames `unique1`, `unique2`, and `unique3`. Here is the

```
$ cat final.password
```

```
root:x:0:0:root:/root:/bin/bash
```

```
bin:x:1:1:bin:/bin:/sbin/nologin
```

```
daemon:x:2:2:daemon:/sbin:/sbin/nologin
```

```
adm:x:3:4:adm:/var/adm:/sbin/nologin
```

```
abe:x:4:10:Honest Abe Lincoln:/home/abe:/bin/bash
```

```
tj:x:5:10:Thomas Jefferson:/home/tj:/bin/bash
```

```
dorothy:x:6:10:Dorothy Gale:/home/dorothy:/bin/bash
```

```
toto:x:7:10:Toto Gale:/home/toto:/bin/bash
```

```
camus:x:112:10:Albert Camus:/home/camus:/bin/bash
```

```
jhancock:x:300:10:John Hancock:/home/jhancock:/bin/bash
```

```
ben:x:301:10:Ben Franklin:/home/ben:/bin/bash
```

```
george:x:1100:10:George Washington:/home/george:/bin/bash
```

```
betsy:x:1110:10:Betsy Ross:/home/betsy:/bin/bash
```

```
tolstoy:x:2076:10:Leo Tolstoy:/home/tolstoy:/bin/bash
```

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11.4. Changing File Ownership

At first blush, changing file ownership is pretty easy. Given the list of usernames and new UID numbers, we are able to write a loop like this (to be run as `root`):

```
while read user old new
do
    cd /home/$user          Change to user's directory
    chown -R $new .         Recursively change ownership, s
done < old-new-list
```

The idea is to change to the user's home directory and recursively *chown* everything to the new UID number. This isn't enough. It's possible for users to have files in places outside their home directory. For example, consider `consid` and `jhancock`, working on a joint project in `/home/ben/declaration`:

```
$ cd /home/ben/declaration
```

```
$ ls -l draft*
```

```
-rw-r--r--    1 ben          fathers      2102 Jul   3 16:00 draft10
-rw-r--r--    1 jhancock     fathers      2191 Jul   3 17:09 draft.final
```

If we just did the recursive *chown*, both files would end up belonging to `ben`, and `jhancock` wouldn't be able to return to work the day after the Great Filesystem Reorganization.

Even worse, though, is the case in which users have files that live outside their home directory. `/tmp` is an example, but consider a source code management system, such as CVS. CVS stores the master files for a project in a directory, typically not in *any* home directory, but in a system directory somewhere. Source files in the repository belong to the users. The ownership of these files should also be changed over.

Thus, the only way to be sure that all files are changed correctly everywhere is to do things the hard way, using *find*, starting from the root directory. The most obvious way to accomplish our goal is to run *chown* from *find*, like this:

```
find / -user $user -exec chown $newuid '{ }' \;
```

This runs an exhaustive file search, examining every file and directory on the system to see if it belongs to a user named by `$user`. For each such file or directory, `find` runs `chown` on it, changing the ownership to the UID `$newuid`. (The `find` command was covered in Section 10.4.3. The `-exec` option runs the rest of the arguments, up to the end of each file that matches the given criteria. The `{ }` in the `find` command means to substitute the found file's name for the `{ }` in the command at that point.) However, using `find` this way is *very* expensive, since it creates a new `chown` process for each file or directory. Instead, we combine `find` and `xargs`:

```
# Regular version:
```

```
find / -user $user -print | xargs chown $newuid
```

```
# If you have the GNU utilities:
```

```
# find / -user $user -print0 | xargs --null chown $newuid
```

This runs the same exhaustive file search, this time printing the name of every file and directory on the system. This list is then piped to `xargs`, which runs `chown` on as many files as possible, changing the ownership to the UID in `$newuid`.

Now, consider a case where the `old-new-list` file contained something like this:

```
juser          25      10
mrwizard      10      30
```

There is an ordering problem here. If we change all of `juser`'s files to have the UID 10 *before* we change `mrwizard`'s files, all of `juser`'s files will end up being owned by `mrwizard`!

This can be solved with the Unix `tsort` program, which does topological sorting. (Topological sorting imposes a total ordering on partially ordered data.) For our purposes, we need to feed the data to `tsort` in the order *new UID*:

```
$ tsort << EOF
```

```
> 30 10
```

```
> 10 25
```

```
> EOF
```

```
30
```


10

25

The output tells us that 10 must be changed to 30 before 25 can be changed to 10. As you might imagine, c required. *However*, we have managed to avoid this problem entirely! Remember the case of duplicate UID different names?

```
$ cat dupids
```

```
abe:x:105:10:Honest Abe Lincoln:/home/abe:/bin/bash
```

```
tj:x:105:10:Thomas Jefferson:/home/tj:/bin/bash
```

```
dorothy:x:110:10:Dorothy Gale:/home/dorothy:/bin/bash
```

```
toto:x:110:10:Toto Gale:/home/toto:/bin/bash
```

We gave all of these users brand-new UIDs:

```
$ cat final.passwd
```

```
...
```

```
abe:x:4:10:Honest Abe Lincoln:/home/abe:/bin/bash
```

```
tj:x:5:10:Thomas Jefferson:/home/tj:/bin/bash
```

```
dorothy:x:6:10:Dorothy Gale:/home/dorothy:/bin/bash
```

```
toto:x:7:10:Toto Gale:/home/toto:/bin/bash
```

```
...
```

By giving them UID numbers that we know are not in use anywhere, we don't have to worry about ordering commands.

The final part of our main program generates the list of *find* and *xargs* commands. We have chosen to write commands into a file, *chown-files*, that can be executed separately in the background. This is because the likely to take a long time to run, and undoubtedly our system administrator, after spending hours developing scripts here, wants to start it running and then go home and get some sleep. Here's the script's conclusion:

```
while read user old new
```

```
do
```

```
    echo "find / -user $user -print | xargs chown $new"
```

```
done < old-new-list > chown-files
```

```
chmod +x chown-files
```

```
rm mergel unique[123] dupusers dupids unique-ids old-new-list
```

Here is what `chown-files` looks like:

```
$ cat chown-files
```

```
find / -user ben -print | xargs chown 301
```

```
find / -user jhancock -print | xargs chown 300
```

```
find / -user abe -print | xargs chown 4
```

```
find / -user tj -print | xargs chown 5
```

```
find / -user dorothy -print | xargs chown 6
```

```
find / -user toto -print | xargs chown 7
```

Remember the `old-new-list` file?

```
$ cat old-new-list
```

```
ben      201      301
```

```
jhancock      200      300
```

```
abe      105      4
```

```
tj      105      5
```

```
dorothy 110      6
```

```
toto    110    7
```

You may have noted that both `abe` and `tj` start out with the same UID. Similarly for `dorothy` and `toto`. When we run `chown-files`? Won't all of `tj`'s files end up belonging to the new UID 4? Won't all of `toto` belonging to the new UID 6? Haven't we just created the mess that we thought we had avoided?

The answer is that we're safe, as long as we run these commands *separately* on each system, *before* we put `/etc/passwd` file in place on each system. Remember that originally, `abe` and `dorothy` were only on `u1`, and `toto` were only on `u2`. Thus, when `chown-files` runs on `u1` with the original `/etc/passwd` in place, `find` won't find `abe`'s or `toto`'s files, since those users don't exist:

```
$ find / -user toto -print
```

```
find: invalid argument `toto' to `-user'
```

Things will fail similarly, but for the opposite pair of users, on `u2`. The full `merge-systems.sh` script is presented in Example 11-5.

Example 11-5. The `merge-systems.sh` program

```
#!/bin/sh
```

```
sort u1.passwd u2.passwd > mergel
```

```
awk -f splitout.awk mergel
```

```
awk -F: '{ print $3 }' mergel | sort -n -u > unique-ids
```

```
rm -f old-new-list
```

```
old_ifs=$IFS
```

```
IFS=:
```

```
while read user passwd uid gid fullname homedir shell
do
    if read user2 passwd2 uid2 gid2 fullname2 homedir2 shell2
    then
        if [ $user = $user2 ]
        then
            printf "%s\t%s\t%s\n" $user $uid $uid2 >> old-new-list
            echo "$user:$passwd:$uid2:$gid:$fullname:$homedir:$shell"
        else
            echo $0: out of sync: $user and $user2 >&2
            exit 1
        fi
    else
        echo $0: no duplicate for $user >&2
        exit 1
    fi
done < dupusers > unique2

IFS=$old_ifs

count=$(wc -l < dupids)      # Total duplicate ids

# This is a hack, it'd be better if POSIX sh had arrays:
set -- $(newuids.sh -c $count unique-ids)
```



```
IFS=:

while read user passwd uid gid fullname homedir shell
do

    newuid=$1

    shift

    echo "$user:$passwd:$newuid:$gid:$fullname:$homedir:$shell"

    printf "%s\t%s\t%s\n" $user $uid $newuid >> old-new-list
done < dupids > unique3

IFS=$old_ifs

sort -k 3 -t : -n unique[123] > final.password

while read user old new
do

    echo "find / -user $user -print | xargs chown $new"
done < old-new-list > chown-files

chmod +x chown-files

rm merge1 unique[123] dupusers dupids unique-ids old-new-list
```

 PREV

< Day Day Up >

11.5. Other Real-World Issues

There are some other issues that are likely to come up in the Real World. For the sake of brevity we wimp out, and instead of writing code, we simply discuss them here.

First, and most obvious, is that the `/etc/group` file is also likely to need merging. With this file, it's necessary to:

- Make sure that all the groups from each individual system exist in the merged `/etc/group` file, and with the same unique GID. This is completely analogous to the username/UID issue we just solved, only the format of the file is different.
- Do a logical merge of users in the same group on the different systems. For example:

```
floppy:x:5:tolstoy,camus           In u1 /etc/group
```

```
floppy:x:5:george,betsy           In u2 /etc/group
```

- When the files are merged, the entry for group `floppy` needs to be:

```
floppy:x:5:tolstoy,camus,george,betsy   Order of users doesn't matter
```

- The GID of all files must be brought into sync with the new, merged `/etc/group` file, just as was done with the UID. If you're clever, it's possible to generate the `find ... | xargs chown ...` command to include the UID and GID so that they need to be run only once. This saves machine processing time at the expense of additional programming time.

Second, any large system that has been in use for some time will have files with UID or GID values that no longer (or never did) exist in `/etc/passwd` and `/etc/group`. It is possible to find such files with:

```
find / '(' -nouser -o -nogroup ')' -ls
```

This produces a list of files in an output format similar to that of `ls -dils`. Such a list probably should be examined manually to determine the users and/or groups to which they should be reassigned, or new users (and/or groups) should be created for them.

In the former case, the file can be further processed to generate `find ... | xargs chown ...` commands to do the work.

In the latter case, it's simple to just add names for the corresponding UID and GIDs to the `/etc/passwd` and `/etc/group` files, but you should be careful that these unused UID and GID numbers don't conflict with UID and GID numbers generated for merging. This in turn implies that by creating the new user and group names on each system *before* merging, you won't have a conflict problem.

Third, the filesystems need to be absolutely *quiescent* during the operations that change the owner and group of the files. This means that there are no other activities occurring while these operations are running. It is thus best if the systems are run in *single-user mode*, whereby the super-user `root` is the only one allowed to log in, and then only on the system's physical console device.

Finally, there may be efficiency issues. Consider the series of commands shown earlier:

```
find / -user ben -print | xargs chown 301
find / -user jhancock -print | xargs chown 300
...
```

Each one of these pipelines traverses *every* file on the computer, for *every* user whose UID or GID needs to be changed. This is tolerable when the number of such users is small, or if the number of files on the system is reasonable (say, one disk's worth). However, if hundreds or thousands of users must have their files changed, or if the system has a nontrivial number of large drives, then another solution is needed. In such a case, it's probably better to use a pipeline similar to this:

```
find / -ls | awk -f make-commands.awk old-to-new.txt - > /tmp/commands.sh
... examine /tmp/commands.sh before running it ...
sh /tmp/commands.sh
```

Here, `make-commands.awk` would be an *awk* program that first reads the old-to-new UID changes from `old-to-new.txt`. (This file would be generated by modifying the scripts earlier in the chapter.) Then, for each file in the output, `make-commands.awk` looks up the owner to find if it needs to be changed. If so, it would print out a `chown` command line. Once all the commands are saved, you could then look them over before executing them. (We leave the actual implementation as yet another one of those famed "exercises for the reader.")

11.6. Summary

In this chapter, we have re-created and solved a "real-world" problem: merging the password files of two separate computers so that their files can be shared via NFS.

Careful study of the password files of both systems allows us to classify users into different categories: those only on the first system, those only on the second, and those with accounts on both. The problem is to ensure that when we're done, each user has an identical unique UID number on both systems, and that each user's files belong only to that user.

Solving the problem requires finding new unused UID numbers to use when there are UID conflicts, and careful ordering of the commands that change the ownership of the files. Furthermore, the entirety of both systems must be searched to be sure that every file's owner is updated correctly.

Other issues would need to be solved in a similar fashion; most notably, the merging of the group files, and assigning owners to any unowned files. For safety, the systems should be quiet while these operations are in progress, and we also outlined a different solution when efficiency is an issue.

The solution involved careful filtering of the original password files, with *awk*, *sort*, *uniq*, and `while read ...` loops being used heavily to process the data and prepare the commands to change the ownership of user files. *find*, *xargs*, and *chown* (of course) do the work.

The total solution represents less than 170 lines of code, including comments! A program in C that solved the same problem would take at least an order of magnitude more code, and most likely considerably longer to write, test, and debug. Furthermore, our solution, by generating commands that are executed separately, provides extra safety, since there is the opportunity for human inspection before making the commitment of changing file ownership. We think it nicely demonstrates the power of the Unix toolset and the Software Tools approach to problem solving.

Chapter 12. Spellchecking

This chapter uses the task of spellchecking to demonstrate several different dimensions of shell scripting. After introducing the *spell* program, we show how a simple but useful spellchecker can be constructed almost entirely out of stock Unix tools. We then proceed to show how simple shell scripts can be used to modify the output of two freely available spellchecking programs to produce results similar to those of the traditional Unix *spell* program. Finally, we present a powerful spellchecker written in *awk*, which nicely demonstrates the elegance of that language.

12.1. The spell Program

The *spell* program does what you think it does: it checks a file for spelling errors. It reads through all the files named on the command line, producing, on standard output, a sorted list of words that are not in its dictionary or that cannot be derived from such words by the application of standard English grammatical rules (e.g., "words" from "word"). Interestingly enough, POSIX does not standardize *spell*. The Rationale document has this to say:

This utility is not useful from shell scripts or typical application programs. The *spell* utility was considered, but was omitted because there is no known technology that can be used to make it recognize general language for user-specified input without providing a complete dictionary along with the input file.

We disagree with the first part of this statement. Consider a script for automated bug or trouble reporting: one might well want to have something along these lines:

```
#!/bin/sh -

# probreport --- simple problem reporting program

file=/tmp/report.$$

echo "Type in the problem, finish with Control-D."

cat > $file

while true
do
    printf "[E]dit, Spell [C]heck, [S]end, or [A]bort: "
    read choice
```

```
case $choice in
[Ee]*)  ${EDITOR:-vi} $file
        ;;
[Cc]*)  spell $file
        ;;
[Aa]*)  exit 0
        ;;
[Ss]*)  break  # from loop
        ;;
esac

done

...          Send report
```

In this chapter, we examine spellchecking from several different angles, since it's an interesting problem, and it gives us an opportunity to solve the problem in several different ways.

12.2. The Original Unix Spellchecking Prototype

Spellchecking has been the subject of more than 300 research papers and books.^[1] In his book *Programming Pearls*,^[2] Jon Bentley reported: Steve Johnson wrote the first version of *spell* in an afternoon in 1975. Bentley then sketched a reconstruction credited to Kernighan and Plauger^[3] of that program as a Unix pipeline that we can rephrase in modern terms like this:

^[1] See <http://www.math.utah.edu/pub/tex/bib/index-table-s.html#spell> for an extensive bibliography.

^[2] Jon Louis Bentley, *Programming Pearls*, Addison-Wesley, 1986, ISBN 0-201-10331-1.

^[3] Brian W. Kernighan and P. J. Plauger, *Software Tools in Pascal*, Addison-Wesley, 1981, ISBN 0-201-10342-7.

```
prepare filename |           Remove formatting commands
tr A-Z a-z |             Map uppercase to lowercase
tr -c a-z '\n' |        Remove punctuation
sort |                   Put words in alphabetical order
uniq |                   Remove duplicate words
comm -13 dictionary -    Report words not in dictionary
```

Here, *prepare* is a filter that strips whatever document markup is present; in the simplest case, it is just *cat*. We assume the argument syntax for the GNU version of the *tr* command.

The only program in this pipeline that we have not seen before is *comm*: it compares two sorted files and selects, or rejects, lines common to both. Here, with the *-13* option, it outputs only lines from the second file (the piped input) that are not in the first file (the dictionary). That output is the spelling-exception report.

comm

Usage

```
comm [ options ... ] file1 file2
```

Purpose

To indicate which lines in the two input files are unique or common.

Major options

-1

Do *not* print column one (lines unique to *file1*).

-2

Do *not* print column two (lines unique to *file2*).

-3

Do *not* print column three (lines common to both files).

Behavior

Read the two files line by line. The input files must be sorted. Produce three columns of output: lines that are only in *file1* , lines that are only in *file2* , and lines that are in both files. Either filename can be `-` , in which case *comm* reads standard input.

Caveats

The options are not intuitive; it is hard to remember to *add* an option in order to *remove* an output column!

Bentley then goes on to discuss a spellchecker developed by Doug McIlroy at Bell Labs in 1981-its design and implementation; how it stores the dictionary in minimal memory; and why checking spelling is hard, especially for a language as muddled as English.

The modern *spell* is written in C for efficiency. However, the original pipeline was in use at Bell Labs for quite a while.



12.3. Improving ispell and aspell

Unix *spell* supports several options, most of which are not helpful for day-to-day use. One exception is the *-b* option, which causes *spell* to prefer British spelling: "centre" instead of "center," "colour" instead of "color," and so on.^[4] See the manual page for the other options.

^[4] The *spell(1)* manual page, in the BUGS section, has long noted that "British spelling was done by an American."

One nice feature is that you can provide your own local spelling list of valid words. For example, it often happens that there may be words from a particular discipline that are spelled correctly, but that are not in *spell*'s dictionary (for example, "POSIX"). You can create, and over time maintain, your own list of valid but unusual words, and then use this list when running *spell*. You indicate the pathname to the local spelling list by supplying it before the file to be checked, and by preceding it with a *+* character:

```
spell +/usr/local/lib/local.words myfile > myfile.errs
```

12.3.1. Private Spelling Dictionaries

We feel that it is an important Best Practice to have a private spelling dictionary for every document that you write: a common one for many documents is not useful because the vocabulary becomes too big and errors are likely to be hidden: "syzygy" might be correct in a math paper, but in a novel, it perhaps ought to have been "soggy." We have found, based on a several-million-line corpus of technical text with associated spelling dictionaries, that there tends to be about one spelling exception every six lines. This tells us that spelling exceptions are common and are worth the trouble of managing along with the rest of a project.

There are some nuisances with *spell*: only one *+* option is permitted, and its dictionaries must be sorted in lexicographic order, which is poor design. It also means that most versions of *spell* break when the locale is changed. (While one might consider this to be bad design, it is really just an unanticipated consequence of the introduction of locales. The code for *spell* on these systems probably has not changed in more than 20 years, and when the underlying libraries were updated to do locale-based sorting, no one realized that this would be an effect.) Here is an example:

```
$ env LC_ALL=en_GB spell +ibmsysj.sok < ibmsysj.bib | wc -l
```

3674


```
$ env LC_ALL=en_US spell +ibmsysj.sok < ibmsysj.bib | wc -l
```

```
3685
```

```
$ env LC_ALL=C spell +ibmsysj.sok < ibmsysj.bib | wc -l
```

```
2163
```

However, if the sorting of the private dictionary matches that of the current locale, *spell* works properly:

```
$ env LC_ALL=en_GB sort ibmsysj.sok > /tmp/foo.en_GB
```

```
$ env LC_ALL=en_GB spell +/tmp/foo.en_GB < ibmsysj.bib | wc -l
```

```
2163
```

The problem is that the default locale can change from one release of an operating system to the next. Thus, it is best to set the `LC_ALL` environment variable to a consistent value for private dictionary sorting, and for running *spell*. We provide a workaround for *spell*'s sorted dictionary requirement in the next section.

12.3.2. *ispell* and *aspell*

There are two different, freely available spellchecking programs: *ispell* and *aspell*. *ispell* is an *interactive* spellchecker; it displays your file, highlighting any spelling errors and providing suggested changes. *aspell* is a similar program; for English it does a better job of providing suggested corrections, and its author would like it to eventually replace *ispell*. Both programs can be used to generate a simple list of misspelled words, and since *aspell* hopes to replace *ispell*, they both use the same options:

```
-l
```

Print a list of misspelled words on standard output.

```
-p file
```

Use *file* as a personal dictionary of correctly spelled words. This is similar to Unix *spell*'s personal file that starts with a +.

The *ispell* home page is <http://ficus-www.cs.ucla.edu/geoff/ispell.html>, and the source may be found at <ftp://ftp.gnu.org/gnu/non-gnu/ispell/>.^[5] The *aspell* home page is <http://aspell.net/>, and the source is at <ftp://ftp.gnu.org/gnu/aspell/>.

^[5] *emacs* uses *ispell* for interactive spellchecking. This is fast, since *ispell* is kept running in the background.

Both programs provide basic batch spellchecking. They also share the same quirk, which is that their results are not sorted, and duplicate bad words are not suppressed. (Unix *spell* has neither of these problems.) Thus, one prominent GNU/Linux vendor has the following shell script in `/usr/bin/spell`:

```
#!/bin/sh

# aspell -l mimicks the standard unix spell program, roughly.
```

```
cat "$@" | aspell -l --mode=none | sort -u
```

The `-mode` option causes *aspell* to ignore certain kinds of markup, such as SGML and TEX. Here, `--mode=none` indicates that no filtering should be done. The `sort -u` command sorts the output and suppresses duplicates, producing output of the nature expected by an experienced Unix user. This could also be done using *ispell*:

```
cat "$@" | ispell -l | sort -u
```

We could enhance this script in two different ways to provide a personal dictionary the same way Unix *spell* does. The first replacement *spell* script is provided in [Example 12-1](#).

Example 12-1. A spell replacement using ispell

```
#!/bin/sh

# Unix spell treats a first argument of '+file' as providing a
# personal spelling list. Let's do that too.
```

```

mydict=

case $1 in

+?*)      mydict=${1#+}      # strip off leading +

          mydict="-p $mydict"

          shift

          ;;

esac

cat "$@" | ispell -l $mydict | sort -u

```

This works by simply looking for a first argument that begins with `+`, saving it in a variable, stripping off the `+` character, and then prepending the `-p` option. This is then passed on to the *ispell* invocation.

Unfortunately, this same technique does not work with *aspell*: it wants its dictionaries to be in a compiled binary format. To use *aspell*, we instead resort to the *fgrep* program, which can match multiple strings provided in a file. We add the `-v` option, which causes *fgrep* to print lines that do not match. The second replacement *spell* script is provided in [Example 12-2](#).

Example 12-2. A spell replacement using *aspell*

```

#!/bin/sh

# Unix spell treats a first argument of `+file' as providing a
# personal spelling list. Let's do that too.

mydict=cat

case $1 in

+?*)      mydict=${1#+}      # strip off leading +

```

```
        mydict="fgrep -v -f $mydict"
    shift
    ;;
esac

# aspell -l mimics the standard Unix spell program, roughly.

cat "$@" | aspell -l --mode=none | sort -u | eval $mydict
```

This same trick of post-processing with *fgrep* can be used with Unix *spell* if you do not want to have to keep your personal dictionary sorted, or if you do not want to have to worry about different locales' sorting order.

The next section presents an *awk* version of *spell*, which provides a simple yet powerful alternative to the various *spell* replacements discussed here.

12.4. A Spellchecker in awk

In this section, we present a program for checking spelling. Even though all Unix systems have *spell*, and many also have *aspell* or *ispell*, it is instructive and useful to implement our own program. This illustrates the power of *awk*, and gives us a valuable program that can be used identically on every platform that has *awk*.

We make a strong distinction between *checking* and *correcting* spelling. The latter requires knowledge of the format of the text, and invariably requires human confirmation, making it completely unsuited to batch processing. The automatic spelling correction offered by some web browsers and word processors is even worse because it is frequently wrong, and its second-guessing your typing quickly becomes extremely annoying.

The *emacs* text editor offers three good solutions to spelling assistance during text entry: dynamic word completion can be invoked on demand to expand a partial word, spelling verification of the current word can be requested with a single keystroke, and the `flyspell` library can be used to request unobtrusive colored highlighting of suspect words.

As long as you can recognize misspellings when they are pointed out to you, it is better to have a spellchecker that reports a list of suspect words, and that allows you to provide a private list of special words not normally present in its dictionary, to reduce the size of that report. You can then use the report to identify errors, repair them, regenerate the report (which should now contain only correct words), and then add its contents to your private dictionary. Because our writing deals with technical material, which is often full of unusual words, in practice we keep a private and document-specific supplemental dictionary for every document that we write.

To guide the programming, here are the desired design goals for our spellchecker. Following the practice of software engineering standards, we use *shall* to indicate a requirement and *should* to mark a desire:

- The program shall be able to read a text stream, isolate words, and report instances of words that are not in a list of known words, called the *spelling dictionary*.
- There shall be a default word list, collected from one or more system dictionaries.
- It shall be possible to replace the default word list.
- It shall be possible to augment the standard word list with entries from one or more user-provided word lists. These lists are particularly necessary for technical documents, which contain acronyms, jargon, and proper nouns, most of which would not be found in the standard list.
- Word lists shall not require sorting, unlike those for Unix *spell*, which behaves incorrectly when the list is changed.

- Although the default word lists are to be in English, with suitable alternate word lists, the program should be capable of handling text in any language that can be represented by ASCII-based character sets encoded as streams of 8-bit bytes, and in which words are separated by whitespace. This eliminates the difficulty of handling languages, such as Lao and Thai, that lack interword spaces, and thus require extensive linguistic analysis to identify words.
- Lettercase shall be ignored to keep the word-list sizes manageable, but exceptions shall be reported in original lettercase.
- Punctuation and digits shall be ignored, but the apostrophe shall be considered a letter.
- The default report shall be a sorted list of unique words that are not found in the combined word lists, displayed one word per line. This is the *spelling exception list*.
- There shall be an option to augment the exception-list report with location information, such as filename and line number, to facilitate finding and correcting misspelled words. The report shall be sorted by location when there are multiple exceptions at one location, sorted further by exception words.
- User-specifiable suffix reduction should be supported to keep word-list sizes manageable.

In Example 12-4 near the end of this section, we present a complete program that meets all of these goals, and more. This program does quite a lot, so in the rest of this section, we describe it in detail as a semiliterate program with explanatory prose and code fragments.

With a test input file containing the first few paragraphs of the manual page for *spell*, a typical run might look like this:

```
$ awk -f spell.awk testfile
```

```
deroff
```

```
eqn
```

```
ier
```

```
nx
```

```
tbl
```

```
thier
```

or in verbose mode, like this:

```
$ awk -f spell.awk -- -verbose testfile
```

```

testfile:7:eqn
testfile:7:tbl
testfile:11:deroff
testfile:12:nx
testfile:19:ier
testfile:19:thier

```

12.4.1. Introductory Comments

The program begins with an extensive commentary, of which we show only the introduction and usage par

```

# Implement a simple spellchecker, with user-specifiable exception
# lists. The built-in dictionary is constructed from a list of
# standard Unix spelling dictionaries, which can be overridden on the
# command line.
#
...
#
# Usage:
#
#     awk [-v Dictionaries="sysdict1 sysdict2 ..."] -f spell.awk --
#         [=suffixfile1 =suffixfile2 ...] [+dict1 +dict2 ...] \
#         [-strip] [-verbose] [file(s)]

```

12.4.2. Main Body

The main body of the program is just three lines, typical of many *awk* programs that initialize, process, and

```

BEGIN { initialize( ) }

```



```
{ spell_check_line( ) }
```

```
END { report_exceptions( ) }
```

All of the details are relegated to functions stored in alphabetical order in the remainder of the program file described in logical order in the following sections.

12.4.3. initialize()

The `initialize()` function handles program startup tasks.

The variable `NonWordChars` holds a regular expression that is later used to eliminate unwanted characters. With the ASCII letters and apostrophe, characters in the range 161 to 255 are preserved as word characters. Files in ASCII, any of the ISO 8859-*n* character sets, and Unicode in UTF-8 encoding all can be handled with further concern for character sets.

Characters 128 to 160 are ignored because in all of those character sets, they serve as additional control characters and a nonbreaking space. Some of those character sets have a few nonalphabetic characters above 160, but undesirable character-set dependence to deal with them. The nonalphabetic ones are rare enough that their effect on our program may be an occasional false report of a spelling exception.

We assume that files to be spellchecked have the same character-set encoding as their associated dictionary. If that is not the case, then use `iconv` to convert them to a consistent encoding.

If all `awk` implementations were POSIX-conformant, we would set `NonWordChars` like this:

```
NonWordChars = "[^'[:alpha:]]"
```

The current locale would then determine exactly which characters could be ignored. However, that assignment is not portable because many `awk` implementations do not yet support POSIX-style regular expressions.

Before locales were introduced to Unix, we could have assigned `NonWordChars` the negation of the set of word characters:

```
NonWordChars = "[^'A-Za-z\241-\377]"
```

However, in the presence of locales, character ranges in regular expressions are interpreted in a locale-dependent fashion so that value would not give consistent results across platforms. The solution is to replace the range

explicit enumerations of characters, writing the assignment as a concatenation of strings, neatly aligned so human can readily identify the characters in the negated set. We use octal representation for values above 127 that is clearer than a jumble of accented characters.

`initialize()` then identifies and loads dictionaries, and processes command-line arguments and suffix r

```
function initialize( )
{
    NonWordChars = "[^" \
        "' " \
        "ABCDEFGHIJKLMNOPQRSTUVWXYZ" \
        "abcdefghijklmnopqrstuvwxyz" \
        "\241\242\243\244\245\246\247\250\251\252\253\254\255\256\257\258\259\260\261\262\263\264\265\266\267\270\271\272\273\274\275\276\277\280\281\282\283\284\285\286\287\290\291\292\293\294\295\296\297\300\301\302\303\304\305\306\307\310\311\312\313\314\315\316\317\320\321\322\323\324\325\326\327\330\331\332\333\334\335\336\337\340\341\342\343\344\345\346\347\350\351\352\353\354\355\356\357\360\361\362\363\364\365\366\367\370\371\372\373\374\375\376\377]"
    get_dictionaries( )
    scan_options( )
    load_dictionaries( )
    load_suffixes( )
    order_suffixes( )
}
```

12.4.4. `get_dictionaries()`

`get_dictionaries()` fills in a list of default system dictionaries: we supply two convenient ones. The user can override that choice by providing a list of dictionaries as the value of the command-line variable `Dictionaries`; the environment variable `DICTIONARIES`.

If `Dictionaries` is empty, we consult the environment array, `ENVIRON`, and use any value set there. If `Dictionaries` is still empty, we supply a built-in list. The selection of that list requires some care because of considerable variation across Unix platforms and because, for small files, most of the runtime of this program is consumed by loading dictionaries. Otherwise, `Dictionaries` contains a whitespace-separated list of dictionary filenames, which we split and store in the global `DictionaryFiles` array. We chose the word list used by some of our systems (about 25,000 entries), and a larger list prepared by Donald Knuth (about 110,000 words).

^[6] Available at <ftp://labrea.stanford.edu/pub/dict/words.gz>.

Notice how the dictionary names are stored: they are array *indices*, rather than array *values*. There are two reasons for this design choice. First, it automatically handles the case of a dictionary that is supplied more than once: if one instance of the filename is saved. Second, it then makes it easy to iterate over the dictionary list with a `key in array` loop. There is no need to maintain a variable with the count of the number of dictionaries.

Here is the code:

```
function get_dictionaries( files, key)
{
    if ((Dictionaries = = "") && ("DICTIONARIES" in ENVIRON))
        Dictionaries = ENVIRON["DICTIONARIES"]

    if (Dictionaries = = "") # Use default dictionary list
    {
        DictionaryFiles["/usr/dict/words"]++
        DictionaryFiles["/usr/local/share/dict/words.knuth"]++
    }

    else # Use system dictionaries from command line
    {
        split(Dictionaries, files)

        for (key in files)
```

```

        DictionaryFiles[files[key]]++
    }
}

```

12.4.5. scan_options()

`scan_options()` handles the command line. It expects to find options (*-strip* and/or *-verbose*), user dictionaries (indicated with a leading `+`, a Unix *spell* tradition), suffix-rule files (marked with a leading `=`), and files to spellchecked. Any `-v` option to set the `Dictionaries` variable has already been handled by *awk*, and is not an argument array, `ARGV`.

The last statement in `scan_options()` requires explanation. During testing, we found that *nawk* does not read standard input if empty arguments are left at the end of `ARGV`, whereas *gawk* and *mawk* do. We therefore read `ARGC` until we have a nonempty argument at the end of `ARGV`:

```

function scan_options( ARGV, k)
{
    for (k = 1; k < ARGC; k++)
    {
        if (ARGV[k] == "-strip")
        {
            ARGV[k] = ""
            Strip = 1
        }
        else if (ARGV[k] == "-verbose")
        {
            ARGV[k] = ""
            Verbose = 1
        }
    }
}

```

```

    }

    else if (ARGV[k] ~ /^=/)          # suffix file
    {

        NSuffixFiles++

        SuffixFiles[substr(ARGV[k], 2)]++

        ARGV[k] = ""
    }

    else if (ARGV[k] ~ /^[+]/)      # private dictionary
    {

        DictionaryFiles[substr(ARGV[k], 2)]++

        ARGV[k] = ""
    }
}

# Remove trailing empty arguments (for nawk)

while ((ARGC > 0) && (ARGV[ARGC-1] = = ""))

    ARGC--

}

```

12.4.6. load_dictionaries()

`load_dictionaries()` reads the word lists from all of the dictionaries. Notice how simple the code is: an outer loop over the `DictionaryFiles` array, and an inner loop that uses `getline` to read a line at a time. Each line contains exactly one word known to be spelled correctly. The dictionaries are created once, and then used repeatedly, so we assume that lines are free of whitespace, and we make no attempt to remove it. Each word is converted to lowercase and stored as an index of the global `Dictionary` array. No separate count of the number of entries in this array is needed because the array is used elsewhere only in membership tests. Among all of t

structures provided by various programming languages, associative arrays are the fastest and most concise handle such tests:

```
function load_dictionaries(          file, word)
{
    for (file in DictionaryFiles)
    {
        while ((getline word < file) > 0)
            Dictionary[tolower(word)]++
        close(file)
    }
}
```

12.4.7. load_suffixes()

In many languages, words can be reduced to shorter root words by stripping suffixes. For example, in English *jumped*, *junper*, *jumpers*, *jumpier*, *jumpiness*, *jumping*, *jumps*, and *jumpy* all have the root word *jump*. Suffixes sometimes change the final letters of a word: *try* is the root of *triable*, *trial*, *tried*, and *trying*. The set of base words that we need to store in a dictionary is several times smaller than the set of words that include suffixes. Since I/O is relatively slow compared to computation, we suspect that it may pay to handle suffixes program, to shorten dictionary size and reduce the number of false reports in the exception list.

`load_suffixes()` handles the loading of suffix rules. Unlike dictionary loading, here we have the possibility of supplying built-in rules, instead of reading them from a file. Thus, we keep a global count of the number of rules in the array that holds the suffix-rule filenames.

The suffix rules bear some explanation, and to illustrate them, we show a typical rule set for English in Example 12-3. We match suffixes with regular expressions, each of which ends with `$` to anchor it to the end of a word. When a suffix is stripped, it may be necessary to supply a replacement suffix, as for the reduction *tr+ied* to *tr+y*. Furthermore, there are often several possible replacements.

Example 12-3. Suffix rules for English: `english.sfx`

```
' $          # Jones' -> Jones
```

```

's$           # it's -> it
ably$        able          # affably -> affable
ed$          "" e         # breaded -> bread, flamed -> flame
edly$        ed           # ashamedly -> ashamed
es$          "" e         # arches -> arch, blues -> blue
gged$        g            # debugged -> debug
ied$         ie y         # died -> die, cried -> cry
ies$         ie ies y     # series -> series, ties -> tie, flies
ily$         y ily        # tidily -> tidy, wily -> wily
ing$         # jumping -> jump
ingly$       "" ing      # alarmingly -> alarming or alarm
lled$        l            # annulled -> annul
ly$          ""          # acutely -> acute
nnily$       n            # funnily -> fun
pped$        p            # handicapped -> handicap
pping$       p            # dropping -> drop
rred$        r            # deferred -> defer
s$           # cats -> cat
tted$        t            # committed -> commit

```

The simplest specification of a suffix rule is therefore a regular expression to match the suffix, followed by whitespace-separated list of replacements. Since one of the possible replacements may be an empty string, represent it by "". It can be omitted if it is the only replacement. English is both highly irregular and rich in words from other languages, so there are many suffix rules, and certainly far more than we have listed in `english.sfx`. However, the suffix list only reduces the incidence of false reports because it effectively ex- the dictionary size; it does not affect the correct operation of the program.

In order to make suffix-rule files maintainable by humans, it is essential that the rules can be augmented with comments to give examples of their application. We follow common Unix practice with comments that run sharp (#) to end-of-line. `load_suffixes()` therefore strips comments and leading and trailing whitespace then discards empty lines. What remains is a regular expression and a list of zero or more replacements that are used elsewhere in calls to the *awk* built-in string substitution function, `sub()`. The replacement list is stored as a space-separated string to which we can later apply the `split()` built-in function.

Suffix replacements can use `&` to represent matched text, although we have no examples of that feature in `english.sfx`.

We considered making `load_suffixes()` supply a missing `$` anchor in the regular expression, but rejected the idea because it might limit the specification of suffix matching required for other languages. Suffix-rule files have to be prepared with considerable care anyway, and that job needs to be done only once for each language.

In the event that no suffix files are supplied, we load a default set of suffixes with empty replacement values. The `split()` built-in function helps to shorten the code for this initialization:

```
function load_suffixes(
    file, k, line, n, parts)
{
    if (NSuffixFiles > 0) # load suffix regexps from files
    {
        for (file in SuffixFiles)
        {
            while ((getline line < file) > 0)
            {
                sub(" *#.*$", "", line) # strip comments
                sub("^[\t]+", "", line) # strip leading whitespace
                sub("[\t]+$", "", line) # strip trailing whitespace
                if (line == "")
                    continue
                n = split(line, parts)
```

```

        Suffixes[parts[1]]++

        Replacement[parts[1]] = parts[2]

    for (k = 3; k <= n; k++)

        Replacement[parts[1]] = Replacement[parts[1]] "

            parts[k]

    }

    close(file)

}

else # load default table of English suffix regexps

{

    split("'s$ 's$ ed$ edly$ es$ ing$ ingly$ ly$ s$", parts)

    for (k in parts)

    {

        Suffixes[parts[k]] = 1

        Replacement[parts[k]] = ""

    }

}

}

```

12.4.8. order_suffixes()

Suffix replacement needs to be handled carefully: in particular, it should be done with a *longest-match-first* algorithm. `order_suffixes()` takes the list of suffix rules saved in the global `Suffixes` array, and copies the `OrderedSuffix` array, indexing that array by an integer that runs from one to `NOrderedSuffix`.

`order_suffixes()` then uses a simple bubble sort to reorder the entries in `OrderedSuffix` by decreasing length, using the `swap()` function in the innermost loop. `swap()` is simple: it exchanges elements `i` and `j` in an argument array. The complexity of this sorting technique is proportional to the square of the number of elements to be sorted, but `NOrderedSuffix` is not expected to be large, so this sort is unlikely to contribute significantly to the program's runtime:

```
function order_suffixes(a, i, j, key)
{
    # Order suffixes by decreasing length
    NOrderedSuffix = 0
    for (key in Suffixes)
        OrderedSuffix[++NOrderedSuffix] = key
    for (i = 1; i < NOrderedSuffix; i++)
        for (j = i + 1; j <= NOrderedSuffix; j++)
            if (length(OrderedSuffix[i]) < length(OrderedSuffix[j]))
                swap(OrderedSuffix, i, j)
}

function swap(a, i, j, temp)
{
    temp = a[i]
    a[i] = a[j]
    a[j] = temp
}
```

12.4.9. `spell_check_line()`

We have now described all of the initialization code required for the program setup. The second pattern/action at the start of the program calls `spell_check_line()` for each line from the input stream.

The first task is to reduce the line to a list of words. The built-in function `gsub()` does the job for us by removing nonalphanumeric characters in just one line of code. The resulting words are then available as `$1`, `$2`, ..., `$NF`, and it just takes a simple `for` loop to iterate over them, handing them off to `spell_check_word()` for individual treatment.

As a general *awk* programming convention, we avoid reference to anonymous numeric field names, like `$1` in function bodies, preferring to restrict their use to short action-code blocks. We made an exception in this function: `$k` is the only such anonymous reference in the entire program. To avoid unnecessary record reassembly when modified, we copy it into a local variable and then strip outer apostrophes and send any nonempty result of `spell_check_word()` for further processing:

```
function spell_check_line( line, k, word)
{
    gsub(NonWordChars, " ")           # eliminate nonword chars

    for (k = 1; k <= NF; k++)
    {
        word = $k

        sub("^'+", "", word)         # strip leading apostrophes
        sub("'+"$, "", word)         # strip trailing apostrophes

        if (word != "")
            spell_check_word(word)
    }
}
```

It is not particularly nice to have character-specific special handling once a word has been recognized. However, the apostrophe is an overloaded character that serves both to indicate contractions in some languages, as with *don't*, and to provide outer quoting. Eliminating its quoting use reduces the number of false reports in the final spelling-exception list.

Apostrophe stripping poses a minor problem for Dutch, which uses it in the initial position in a small number

words: ``n` for *een*, ``s` for *des*, and ``t` for *het*. Those cases are trivially handled by augmenting the exception dictionary.

12.4.10. `spell_check_word()`

`spell_check_word()` is where the real work happens, but in most cases, the job is done quickly. If the word is found in the global `Dictionary` array, it is spelled correctly, and we can immediately return.

If the word is not in the word list, it is probably a spelling exception. However, if the user requested suffix stripping, then we have more work to do. `strip_suffixes()` produces a list of one or more related words as indices of the local `wordlist` array. The `for` loop then iterates over this list, returning if it finds a word in the `Dictionary` array.

If suffix stripping is not requested, or if we did not find any replacement words in the dictionary, then the word is definitely a spelling exception. However, it is a bad idea to write a report at this point because we usually produce a sorted list of unique spelling exceptions. The word *awk*, for example, occurs more than 30 times in this chapter, but is not found in any of the standard Unix spelling dictionaries. Instead, we store the word in the `Exception` array, and when verbose output is requested, we prefix the word with a location defined by a carriage-terminated filename and line number. Reports of that form are common to many Unix tools and are readily understandable both to humans and smart text editors. Notice that the original lettercase is preserved in the report even though it was ignored during the dictionary lookup:

```
function spell_check_word(word, lc_word, key, lc_word, location, w, wordlist)
{
    lc_word = tolower(word)

    if (lc_word in Dictionary)           # acceptable spelling
        return lc_word

    else                                 # possible exception
    {
        if (Strip)
        {
            strip_suffixes(lc_word, wordlist)

            for (w in wordlist)
            {
                if (w in Dictionary)
                    return w
            }
        }
    }
}
```



```

        return

    }

    location = Verbose ? (FILENAME ":" FNR ":") : ""

    if (lc_word in Exception)

        Exception[lc_word] = Exception[lc_word] "\n" location word

    else

        Exception[lc_word] = location word

    }
}

```

12.4.11. strip_suffixes()

When a word has been found that is not in the dictionary, and the *-strip* option has been specified, we call `strip_suffixes()` to apply the suffix rules. It loops over the suffix regular expressions in order of decreasing suffix length. If the word matches, the suffix is removed to obtain the root word. If there are no replacement suffixes, the word is stored as an index of the `wordlist` array. Otherwise, we split the replacement list into members and append each replacement in turn to the root word, adding it to the `wordlist` array. We need a special case in the inner loop, to check for the special two-character string "", which we replace with an error string. If we have a match, the `break` statement leaves the loop, and the function returns to the caller. Otherwise the loop continues with the next suffix regular expression.

We could have made this function do a dictionary lookup for each candidate that we store in `wordlist`, and a match indication. We chose not to because it mixes lookup with suffix processing and makes it harder to the program to display replacement candidates (Unix *spell* has the *-x* option to do that: for every input word it can take suffixes, it produces a list of correctly spelled words with the same root).

While suffix rules suffice for many Indo-European languages, others do not need them at all, and still others have more complex changes in spelling as words change in case, number, or tense. For such languages, the simple solution seems to be a larger dictionary that incorporates all of the common word forms.

Here is the code:

```

function strip_suffixes(word, wordlist, ending, k, n, regexp)
{

```



```
split("", wordlist)

for (k = 1; k <= NOrderedSuffix; k++)
{
    regexp = OrderedSuffix[k]
    if (match(word, regexp))
    {
        word = substr(word, 1, RSTART - 1)
        if (Replacement[regexp] == "")
            wordlist[word] = 1
        else
        {
            split(Replacement[regexp], ending)
            for (n in ending)
            {
                if (ending[n] == "\\\"")
                    ending[n] = ""
                wordlist[word ending[n]] = 1
            }
        }
        break
    }
}
}
```

12.4.12. report_exceptions()

The final job in our program is initiated by the last of the three pattern/action pairs. `report_exceptions()` feeds a pipeline to `sort` with command-line options that depend on whether the user requested a compact listing of exception words, or a verbose report with location information. In either case, we give `sort` the `-f` option to lowercase, and the `-u` option to get unique output lines. A simple `for` loop outputs the exceptions to the pipe and the final `close()` shuts down the pipeline and completes the program.

Here is the code:

```
function report_exceptions( key, sortpipe)
{
    sortpipe = Verbose ? "sort -f -t: -u -k1,1 -k2n,2 -k3" : \
        "sort -f -u -k1"
    for (key in Exception)
        print Exception[key] | sortpipe
    close(sortpipe)
}
```

Example 12-4 collects the complete code for our spellchecker.

Example 12-4. Spellchecker program

```
# Implement a simple spellchecker, with user-specifiable exception
# lists. The built-in dictionary is constructed from a list of
# standard Unix spelling dictionaries, which can be overridden on the
# command line.
#
...
```

```

#
# Usage:
#     awk [-v Dictionaries="sysdict1 sysdict2 ..."] -f spell.awk --
#         [=suffixfile1 =suffixfile2 ...] [+dict1 +dict2 ...] \
#         [-strip] [-verbose] [file(s)]
#
BEGIN { initialize( ) }
        { spell_check_line( ) }
END { report_exceptions( ) }

function get_dictionaries( files, key)
{
    if ((Dictionaries = = "") && ("DICTIONARIES" in ENVIRON))
        Dictionaries = ENVIRON["DICTIONARIES"]
    if (Dictionaries = = "") # Use default dictionary list
    {
        DictionaryFiles["/usr/dict/words"]++
        DictionaryFiles["/usr/local/share/dict/words.knuth"]++
    }
    else # Use system dictionaries from command line
    {

```

```

        split(Dictionaries, files)

        for (key in files)

            DictionaryFiles[files[key]]++

    }

}

function initialize( )
{
    NonWordChars = "[^" \

        "' " \

        "ABCDEFGHIJKLMNOPQRSTUVWXYZ" \

        "abcdefghijklmnopqrstuvwxyz" \

            "\241\242\243\244\245\246\247\250\251\252\253\254\255\256\257\258\259\260\261\262\263\264\265\266\267\270\271\272\273\274\275\276\277\278\279\300\301\302\303\304\305\306\307\310\311\312\313\314\315\316\317\318\319\320\321\322\323\324\325\326\327\330\331\332\333\334\335\336\337\338\339\340\341\342\343\344\345\346\347\350\351\352\353\354\355\356\357\358\359\360\361\362\363\364\365\366\367\370\371\372\373\374\375\376\377\378\379"

    "]"

    get_dictionaries( )

    scan_options( )

    load_dictionaries( )

    load_suffixes( )

```



```
    order_suffixes( )
}

function load_dictionaries(          file, word)
{
    for (file in DictionaryFiles)
    {
        while ((getline word < file) > 0)
            Dictionary[tolower(word)]++
        close(file)
    }
}

function load_suffixes(          file, k, line, n, parts)
{
    if (NSuffixFiles > 0)          # load suffix regexps from files
    {
        for (file in SuffixFiles)
        {
            while ((getline line < file) > 0)
            {
                sub(" *#.*$", "", line)    # strip comments
                sub("^[ \t]+", "", line)    # strip leading whitespace
            }
        }
    }
}
```

```

        sub("[ \t]+$", "", line) # strip trailing whitespace
        if (line == "")
            continue
        n = split(line, parts)
        Suffixes[parts[1]]++
        Replacement[parts[1]] = parts[2]
        for (k = 3; k <= n; k++)
            Replacement[parts[1]] = Replacement[parts[1]] "
                parts[k]
        }
        close(file)
    }
}
else # load default table of English suffix regexps
{
    split("'s$ 'ed$ edly$ es$ ing$ ingly$ ly$ s$", parts)
    for (k in parts)
    {
        Suffixes[parts[k]] = 1
        Replacement[parts[k]] = ""
    }
}
}
}

```

```
function order_suffixes(          i, j, key)
{
    # Order suffixes by decreasing length
    NOrderedSuffix = 0
    for (key in Suffixes)
        OrderedSuffix[++NOrderedSuffix] = key
    for (i = 1; i < NOrderedSuffix; i++)
        for (j = i + 1; j <= NOrderedSuffix; j++)
            if (length(OrderedSuffix[i]) < length(OrderedSuffix[j]))
                swap(OrderedSuffix, i, j)
}
```

```
function report_exceptions(          key, sortpipe)
{
    sortpipe = Verbose ? "sort -f -t: -u -k1,1 -k2n,2 -k3" : \
        "sort -f -u -k1"
    for (key in Exception)
        print Exception[key] | sortpipe
    close(sortpipe)
}
```

```
function scan_options(          k)
{
```

```
for (k = 1; k < ARGC; k++)
{
    if (ARGV[k] == "-strip")
    {
        ARGV[k] = ""
        Strip = 1
    }
    else if (ARGV[k] == "-verbose")
    {
        ARGV[k] = ""
        Verbose = 1
    }
    else if (ARGV[k] ~ /^=/) # suffix file
    {
        NSuffixFiles++
        SuffixFiles[substr(ARGV[k], 2)]++
        ARGV[k] = ""
    }
    else if (ARGV[k] ~ /^[+]/) # private dictionary
    {
        DictionaryFiles[substr(ARGV[k], 2)]++
        ARGV[k] = ""
    }
}
```



```
}

```

```
# Remove trailing empty arguments (for nawk)

```

```
while ((ARGC > 0) && (ARGV[ARGC-1] == ""))

```

```
    ARGC--

```

```
}

```

```
function spell_check_line(k, word)

```

```
{

```

```
    gsub(NonWordChars, " ") # eliminate nonword chars

```

```
    for (k = 1; k <= NF; k++)

```

```
{

```

```
    word = $k

```

```
    sub("^'+", "", word) # strip leading apostrophes

```

```
    sub("'+"$, "", word) # strip trailing apostrophes

```

```
    if (word != "")

```

```
        spell_check_word(word)

```

```
    }

```

```
}

```

```
function spell_check_word(word, key, lc_word, location, w, word1)

```

```
{

```

```
    lc_word = tolower(word)

```

```

    if (lc_word in Dictionary)                # acceptable spelling
        return

    else                                     # possible exception
    {
        if (Strip)
        {
            strip_suffixes(lc_word, wordlist)

            for (w in wordlist)
                if (w in Dictionary)
                    return
        }

        location = Verbose ? (FILENAME ":" FNR ":") : ""

        if (lc_word in Exception)
            Exception[lc_word] = Exception[lc_word] "\n" location word

        else
            Exception[lc_word] = location word
    }
}

function strip_suffixes(word, wordlist,      ending, k, n, regexp)
{
    split("", wordlist)

    for (k = 1; k <= NOrderedSuffix; k++)

```

```

{
    regexp = OrderedSuffix[k]
    if (match(word, regexp))
    {
        word = substr(word, 1, RSTART - 1)
        if (Replacement[regexp] == "")
            wordlist[word] = 1
        else
        {
            split(Replacement[regexp], ending)
            for (n in ending)
            {
                if (ending[n] == "\\\"")
                    ending[n] = ""
                wordlist[word ending[n]] = 1
            }
        }
        break
    }
}

```

```
function swap(a, i, j, temp)
```

```

{
    temp = a[i]
    a[i] = a[j]
    a[j] = temp
}

```

12.4.13. Retrospective on Our Spellchecker

The first version of a Unix spellchecker was the pipeline that we presented at the beginning of the chapter. The first Unix spelling program in C that we could find in *The Unix Heritage Society* archives^[7] is the 1975 Version 7 Unix *typo* command; it is about 350 lines of C code. *spell* first appeared in the 1979 Version 7 Unix release, and it is about 700 lines of C code. It was accompanied by a 940-word common English dictionary, supplemented by 320 words each of American and British spelling variations. *spell* was omitted from the 1995 4.4 BSD-Lite code release, presumably because of trade secret or copyright issues.

^[7] See <http://www.tuhs.org/>.

The modern OpenBSD *spell* is about 1100 lines of C code, with about 30 more words in each of its three built-in dictionaries.

GNU *ispell* version 3.2 is about 13,500 lines of C code, and GNU *aspell* version 0.60 is about 29,500 lines of C code. Both have been internationalized, with dictionaries for 10 to 40 languages. *ispell* has significant enlarged English dictionaries, with about 80,000 common words, plus 3750 or so American and British variations. The *aspell* dictionaries are even bigger: 142,000 English words plus about 4200 variations for each of American, British, and Canadian.

Our spellchecker, `spell.awk`, is a truly remarkable program, and you will appreciate it even more and understand it even better if you reimplement the program in another programming language. Like Johnson's original *spell* command, its design and implementation took less than an afternoon.

In about 190 lines of code, made up of three pattern/action one-liners and 11 functions, it does most of what a traditional Unix *spell* does, and more:

- With the *-verbose* option, it reports location information for the spelling exceptions.
- User control of dictionaries allows it to be readily applied to complex technical documents, and to text in languages other than English.
- User-definable suffix lists assist in the internationalization of spelling checks, and provide user control over the spelling process.

suffix reduction, something that few other spellcheckers on any platform provide.

- All of the associated dictionary and suffix files are simple text files that can be processed with any text editor and with most Unix text utilities. Some spellcheckers keep their dictionaries in binary form, making the lists hard to inspect, maintain, and update, and nearly impossible to use for other purposes.
- The major dependence on character sets is the assumption in the initialization of `NonWordChars` of ASCII ordering in the lower 128 slots. Although IBM mainframe EBCDIC is not supported, European 8-bit sets pose no problem, and even the two-million-character Unicode set in the multibyte UTF-8 encoding can be handled reasonably, although proper recognition and removal of non-ASCII Unicode punctuation characters require more work. Given the complexity of multibyte character sets, and the likely need for it elsewhere, this functionality would be better implemented in a separate tool used as a prefilter to `spell.awk`.
- Output sort order, which is a complex problem for some languages, is determined entirely by the `sort` command, which in turn is influenced by the locale set in the current environment. That way, a single locale localizes the sorting complexity so that other software, including our program, can remain oblivious to the difficulties. This is another example of the "Let someone else do the hard part" Software Tools principle discussed in Section 1.2.
- Despite being written in an interpreted language, our program is reasonably fast. On a 2 GHz Pentium workstation, with `mawk`, it took just one second to check spelling in all of the files for this book, just a little longer than OpenBSD `spell`, and 2.0 times longer than GNU `ispell`.
- An execution profile (see Section 12.4.14) showed that loading the dictionaries took about 5 percent of the total time, and about one word in 15 was not found in the dictionary. Adding the `strip` option increased runtime by about 25 percent, and reduced the output size by the same amount. Only about one word in 1000 made it past the `match()` test inside `strip_suffixes()`.
- Suffix support accounts for about 90 of the 190 lines of code, so we could have written a usable multi-language spellchecker in about 100 lines of `awk`.

Notably absent from this attribute list, and our program, is the stripping of document markup, a feature that most spellcheckers provide. We have intentionally not done so because it is in complete violation of the Unix tradition of one (small) tool for one job. Markup removal is useful in many other contexts, and therefore deserves to be done in separate filters, such as `dehtml`, `deroff`, `desgml`, `detex`, and `dexml`. Of these, only `deroff` is commonly found on most Unix systems, but workable implementations of the others require only a few lines of `awk`.

Also absent from our program, apart from three simple calls to `substr()`, is handling of individual characters. The necessity for such processing in C, and many other languages, is a major source of bugs.

All that remains to be done for this program is accumulation of a suitable set of dictionaries and suffix lists for other languages, provision of a shell script wrapper to make its user interface more like conventional Unix programs, and writing a manual page. Although we do not present them here, you can find the wrapper and manual page with this book's sample programs.

12.4.14. Efficiency of awk Programs

We close this section with some observations about *awk* program efficiency. Like other scripting language programs are compiled into a compact internal representation, and that representation is then interpreted at by a small *virtual machine*. Built-in functions are written in the underlying implementation language, currently C, in all publicly available versions, and run at native software speeds.

Program efficiency is not just a question of computer time: human time matters as well. If it takes an hour to write a program in *awk* that runs for a few seconds, compared to several hours to write and debug the same program in a compiled language to shave a few seconds off the runtime, then human time is the only thing that matters. In many software tools, *awk* wins by a large measure.

With conventional compiled languages like Fortran and C, most inline code is closely related to the underlying machine language, and experienced programmers soon develop a feel for what is cheap and what is expensive. Number of arithmetic and memory operations, and the depth of loop nesting, are important, easily counted, and directly related to runtimes. With numerical programs, a common rule of thumb is that 90 percent of the runtime is spent in 10 percent of the code: that 10 percent is called the *hot spots*. Optimizations like pulling common expressions out of innermost loops, and ordering computations to match storage layout, can sometimes make dramatic improvements in runtime. However, in higher-level languages, or languages with lots of function calls (like Perl, where every statement is a function), or with interpreted languages, it is much harder to estimate runtimes, and identify the hot spots.

awk programs that do a lot of pattern matching usually are limited by the complexity of that operation, which runs entirely at native speeds. Such programs can seldom be improved much by rewriting in a compiled language like C or C++. Each of the three *awk* implementations that we mentioned in this chapter were written completely independently of one another, and thus may have quite different relative execution times for particular statements.

Because we have written lots of software tools in *awk*, some of which have been used on gigabytes of data, runtime efficiency has sometimes been important to us. A few years ago, one of us (NHFB) prepared a *pawk* profiling version of the smallest implementation, *nawk*. *pawk* reports both statement counts and times. Independently, the other (AR) added similar support with statement counts to GNU *gawk* so that *pgawk* is now standardly available from builds of releases of version 3.1.0 or later. *pgawk* produces an output profile in `awkprof.out` with a program listing annotated with statement execution counts. The counts readily identify hot spots, and zero (or empty) counts identify code that has never been executed, so the profile also serves as a *coverage* report. Such reports are important when test files are prepared to verify that all statements of a program are executed during testing: bugs are likely to lurk in code that is seldom, or never, executed.

[8] Available at <http://www.math.utah.edu/pub/pawk/>.

Accurate execution timing has been harder to acquire because typical CPU timers have resolutions of only a few ticks per second, which is completely inadequate in an era of GHz processors. Fortunately, some Unix systems provide low-cost, nanosecond resolution timers, and *pawk* uses them on those platforms.

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< Day Day Up >

12.5. Summary

The original spellchecking prototype shows the elegance and power of the Unix Software Tools approach. With only one special-purpose program, an afternoon's worth of work created a usable and useful tool. As is often the case, experience with a prototype in shell was then applied to writing a production version in C.

The use of a private dictionary is a powerful feature of Unix *spell*. Although the addition of locales to the Unix milieu introduced some quirks, dictionaries are still a valuable thing to use, and indeed, for each chapter of this book, we created private dictionaries to make spellchecking our work more manageable.

The freely available *ispell* and *aspell* programs are large and powerful, but lack some of the more obvious features to make their batch modes useful. We showed how with simple shell script wrappers, we could work around these deficiencies and adapt the programs to suit our needs. This is one of the most typical uses of shell scripting: to take a program that does almost what you need and modify its results slightly to do the rest of your job. This also fits in well with the "let someone else do the hard part" Software Tools principle.

Finally, the *awk* spellchecker nicely demonstrates the elegance and power of that language. In one afternoon, one of us (NHFB) produced a program of fewer than 200 lines that can be (and is!) used for production spellchecking.

Chapter 13. Processes

A *process* is an instance of a running program. New processes are started by the `fork()` and `execve()` system calls, which normally run until they issue an `exit()` system call. The details of the `fork()` and `execve()` system calls are not needed for this book. Consult their manual pages if you want to learn more.

Unix systems have always supported multiple processes. Although the computer seems to be doing several things at once, in reality, this is an illusion, unless there are multiple CPUs. What really happens is that each process is permitted to run for a short interval, called a *time slice*, and then the process is temporarily suspended while another waiting process has a chance to run. Time slices are quite short, usually only a few milliseconds, so humans seldom notice these switches. Control is transferred from one process to the kernel and then to another process. Processes themselves are not aware of these switches, and programs need not be written to relinquish control periodically to the operating system.

A part of the operating-system kernel, called the *scheduler*, is responsible for managing process execution. When multiple CPUs are present, the scheduler tries to use them all to handle the workload; the human user should see no noticeable improvement in response.

Processes are assigned priorities so that time-critical processes run before less important ones. The `nice` and `renice` commands can be used to adjust process priorities.

The average number of processes awaiting execution at any instant is called the *load average*. You can display the current load average with the `uptime` command:

```
$ uptime                               Show uptime, user count, and load average
1:51pm up 298 day(s), 15:42, 32 users, load average: 3.51, 3.50, 3.48
```

Because the load average varies continually, `uptime` reports three time-averaged estimates, usually for the last 1, 5, and 15 minutes. When the load average continually exceeds the number of available CPUs, there is more work for the system to manage than it can handle, and its response may become sluggish.

Books on operating systems treat processes and scheduling in depth. For this book, and indeed, for most users, these details are largely irrelevant. All that we need in this chapter is a description of how to create, list, and delete processes, how to send signals to them, and how to monitor their execution.

13.1. Process Creation

One of the great contributions of Unix to the computing world is that process creation is cheap and easy. This encourages the practice of writing small programs that each do a part of a larger job, and then combining them to collaborate on the completion of that task. Because programming complexity grows much faster than linearly with program size, small programs are much easier to write, debug, and understand than large ones.

Many programs are started by a shell: the first word in each command line identifies the program to be run. Each process initiated by a command shell starts with these guarantees:

- The process has a *kernel context*: data structures inside the kernel that record process-specific information to allow the kernel to manage and control process execution.
- The process has a *private*, and *protected*, virtual address space that potentially can be as large as the machine is capable of addressing. However, other resource limitations, such as the combined size of physical memory and swap space on external storage, or the size of other executing jobs, or local settings of system-tuning parameters, often impose further restrictions.
- Three file descriptors (standard input, standard output, and standard error) are already open and ready for immediate use.
- A process started from an interactive shell has a *controlling terminal*, which serves as the default source and destination for the three standard file streams. The controlling terminal is the one from which you can send signals to the process, a topic that we cover later in [Section 13.3](#).
- Wildcard characters in command-line arguments have been expanded.
- An environment-variable area of memory exists, containing strings with key/value assignments that can be retrieved by a library call (in C, `getenv()`).

These guarantees are nondiscriminatory: all processes at the same priority level are treated equally and may be written in any convenient programming language.

The private address space ensures that processes cannot interfere with one another, or with the kernel. Operating systems that do not offer such protection are highly prone to failure.

The three already-open files suffice for many programs, which can use them without the burden of having to deal with file opening and closing, and without having to know anything about filename

syntax, or filesystems.

Wildcard expansion by the shell removes a significant burden from programs and provides uniform handling of command lines.

The environment space provides another way to supply information to processes, beyond their command lines and input files.



13.2. Process Listing

The most important command for listing processes is the *process status* command, *ps*. For historical reasons, there are two main flavors of *ps*: a System V style and a BSD style. Many systems provide both, although sometimes one or the other is part of an optional package. On our Sun Solaris systems, we have:

```
$ /bin/ps System V-style process status
```

```

  PID TTY          TIME CMD
 2659 pts/60        0:00 ps
 5026 pts/60        0:02 ksh
12369 pts/92        0:02 bash
```

```
$ /usr/ucb/ps BSD-style process status
```

```

  PID TT          S   TIME COMMAND
 2660 pts/60        O   0:00 /usr/ucb/ps
 5026 pts/60        S   0:01 /bin/ksh
12369 pts/92        S   0:02 /usr/local/bin/bash
```

Without command-line options, their output is quite similar, with the BSD style supplying a few more details. The System V style is limited to just those processes with the same user ID and same controlling terminal as those of the invoking process.

Like the file-listing command, *ls*, the *ps* command has many options, and both have considerable variations across different Unix platforms. With *ls*, the *-l* option requesting the long output form is used frequently. To get verbose *ps* output, you need quite different sets of options. In the System V style, we use:

```
$ ps -efl System V style
```

```

  F S  UID PID PPID C  PRI NI ADDR  SZ WCHAN STIME TTY    TIME CMD
 19 T root  0    0  0  0  0 SY   ?    0      Dec 27 ?    0:00 sched
```



```

 8 S root    1      0 0  41 20    ? 106      ? Dec 27 ?    9:53 /etc/init -
19 S root    2      0 0   0 SY    ?   0      ? Dec 27 ?    0:18 pageout
19 S root    3      0 0   0 SY    ?   0      ? Dec 27 ? 2852:26 fsflush
...

```

whereas in the BSD style, we use:

```

$ ps aux                                BSD style
USER      PID %CPU %MEM    SZ  RSS TT          S    START    TIME COMMAND
root         3  0.4  0.0     0    0 ?          S    Dec 27 2852:28 fsflush
smith 13680  0.1  0.2  1664  1320 pts/25  0  15:03:45    0:00 ps aux
jones 25268  0.1  2.02093619376 pts/24  S    Mar 22    29:56 emacs -bg
brown 26519  0.0  0.3  5424  2944 ?          S    Apr 19    2:05 xterm -nam
...

```

Both styles allow option letters to be run together, and the BSD style allows the option hyphen to be dropped. In the examples, we removed excess whitespace to make the lines fit on the page.

There are some design infelicities in both styles, occasioned by the need to display a lot of information in tight space: process start dates may be abbreviated differently, commands in the last field are truncated, and columns can run together. The latter misfeature makes it hard to filter *ps* output reliably.

The `USER` and `UID` fields identify the owner of a process: that can be critical information if a process is hogging the system.

The `PID` value is the *process ID*, a number that uniquely identifies the process. In the shell, that number is `$$`: we use it in other chapters to form unique names of temporary files. Process ID assignments start out at zero and increment for each new process throughout the run life of the system. When the maximum representable in `int` is reached, process numbering starts again at zero, but avoids values that are still in use for other processes. A single-user system might have a few dozen active processes, whereas a large multiuser system might have a thousand.

The `PPID` value is the *parent process ID*: the number of the process that created this one. Every process, except the kernel, has a parent, and each process may have zero or more child processes, so processes form a tree. Process nu

usually called something like `kernel` , `sched` , or `swapper` , and is not shown in `ps` output on some systems. Process number 1 is rather special; it is called `init` , and is described in the `init (8)` manual pages. A child process who dies prematurely is assigned `init` as its new parent. When a system is shut down properly, processes are killed in approximate order of decreasing process IDs, until only `init` remains. When it exits, the system halts.

The output of `ps` is not guaranteed to be in any particular order, and since the list of processes is continually changing, its output usually differs on each run.

Since the process list is dynamic, many users prefer to see a continually updating `ps` -like text display, or a graphical representation thereof. Several utilities provide such display, but none is universally available. The most common is `top` , now standard in many Unix distributions.^[1] We consider it one of those critical utilities, like GNU `diff` , that should be immediately installed on any new system that does not have a native version. On most systems, `top` requires intimate knowledge of kernel data structures, and thus tends to require updates at each operating system upgrade. A utility like `ps` (like `ps`) is one of those few programs that needs to run with special privileges: on some systems, it may be run as `root` .

^[1] Available at <ftp://ftp.groupsys.com/pub/top/> . Another implementation for GNU/Linux systems only is available at <http://procps.sourceforge.net/> .

Here's a snapshot of `top` output on a moderately busy multiprocessor compute server:

```
$ top Show top resource consumers

load averages:  5.28,  4.74,  4.59 15:42:00

322 processes: 295 sleeping, 4 running, 12 zombie, 9 stopped, 2 on c

CPU states: 0.0% idle, 95.9% user, 4.1% kernel, 0.0% iowait, 0.0% swa

Memory: 2048M real, 88M free, 1916M swap in use, 8090M swap free

  PID USERNAME  THR  PRI  NICE   SIZE   RES STATE   TIME   CPU COMMAND
 2518 jones        1    0    0  506M  505M run    44:43  33.95% Macaula
 1111 owens        1    0   19   21M   21M run    87:19  24.04% ocDom
23813 smith        1    0   19  184M  184M cpu/0  768:57  20.39% mserver
25389 brown        1    1   19   30M   23M run   184:22   1.07% netscap
...
```


By default, *top* shows the most CPU-intensive processes at the top of the list, which is usually what you are in. However, it accepts keyboard input to control sort order, limit the display to certain users, and so on: try a session to see what your version offers.

Other commands useful for listing processes or showing various system loads are shown in Table 13-1

Table 13-1. Useful system load commands

System	Commands
All	<i>iostat</i> , <i>netstat</i> , <i>nfsstat</i> , <i>sar</i> , <i>uptime</i> , <i>vmstat</i> , <i>w</i> , <i>xcpustate</i> , ^[2] <i>xload</i> , and <i>xperfmon</i>
Apple Mac OS X	<i>pstat</i>
BSD	<i>pstat</i> and <i>systat</i>
GNU/Linux	<i>procinfo</i>
HP Alpha OSF/1	<i>vmubc</i>
IBM AIX	<i>monitor</i>
SGI IRIX	<i>gr_osview</i> and <i>osview</i>
Sun Solaris	<i>mpstat</i> , <i>perfmer</i> , <i>proctool</i> , <i>prstat</i> , <i>ptree</i> , and <i>sdtperfmer</i>

^[2] Available at <ftp://ftp.cs.toronto.edu/pub/jdd/xcpustate/> .

In most cases, the shell waits for a process to terminate before processing the next command. However, processes can be made to run in the background by terminating the command with an ampersand instead of a semicolon (as we used that feature in the *build-all* script in Section 8.2 . The *wait* command can be used to wait for a specific process to complete, or, without an argument, for completion of all background processes.

Although this book mostly ignores interactive features of the shell, we note that *bg* , *fg* , *jobs* , and *wait* are commands for dealing with still-running processes created under the current shell.

Four keyboard characters interrupt *foreground processes* . These characters are settable with *stty* command usually to Ctrl-C (*intr* : kill), Ctrl-Y (*dsusp* : suspend, but delay until input is flushed), Ctrl-Z (*susp* : suspend), and Ctrl-\ (*quit* : kill with *core dump*).

It is instructive to examine a simple implementation of *top* , shown in Example 13-1 . The security issues at the `/bin/sh` - option, and the explicit setting of `IFS` (to newline-space-tab) and `PATH` should be familiar from treatment in Section 8.1 . We require a BSD-style *ps* because it provides the `%CPU` column that defines the display order, so `PATH` must be set to find that version first. The `PATH` setting here works for all but one of our systems (IRIX, which lacks a BSD-style *ps* command).

Example 13-1. A simplified version of top

```
#!/bin/sh -

# Run the ps command continuously, with a short pause after
# each redisplay.

#

# Usage:
#       simple-top

IFS='
'

# Customize PATH to get BSD-style ps first
PATH=/usr/ucb:/usr/bin:/bin

export PATH

HEADFLAGS="-n 20"

PSFLAGS=aux

SLEEPFLAGS=5

SORTFLAGS='-k3nr -k1,1 -k2n'

HEADER="`ps $PSFLAGS | head -n 1`"

while true
```



```

do
    clear

    uptime

    echo "$HEADER"

    ps $PSFLAGS |

        sed -e 1d |

            sort $SORTFLAGS |

                head $HEADFLAGS

    sleep $SLEEPFLAGS
done

```

We save command options in `HEADFLAGS`, `PSFLAGS`, `SLEEPFLAGS`, and `SORTFLAGS` to facilitate site-specific customization.

An explanatory header for the *simple-top* output is helpful, but since it varies somewhat between *ps* implementations we do not hardcode it in the script; but instead, we just call *ps* once, saving it in the variable `HEADER`.

The remainder of the program is an infinite loop that is terminated by one of the keyboard interrupt characters mentioned earlier. The *clear* command at the start of each loop iteration uses the setting of the `TERM` environment variable to determine the escape sequences that it then sends to standard output to clear the screen, leaving a cursor in the upper-left corner. *uptime* reports the load average, and *echo* supplies the column headers. The pipeline output, using *sed* to remove the header line, then sorts the output by CPU usage, username, and process ID and only the first 20 lines. The final *sleep* command in the loop body produces a short delay that is still relatively minor compared to the time required for one loop iteration so that the system load imposed by the script is minor.

Sometimes, you would like to know who is using the system, and how many and what processes they are running without all of the extra details supplied by the verbose form of *ps* output. The *puser* script in Example 13-2 reports that looks like this:

```

$ puser                                     Show users and their processes

albert          3          -tcsh

                3          /etc/sshd

```

```

                2      /bin/sh
                1      /bin/ps
                1      /usr/bin/ssh
                1      xload
daemon         1      /usr/lib/nfs/statd
root           4      /etc/sshd
                3      /usr/lib/ssh/sshd
                3      /usr/sadm/lib/smc/bin/smcboot
                2      /usr/lib/saf/ttymon
                1      /etc/init
                1      /usr/lib/autofs/automountd
                1      /usr/lib/dmi/dmispd
                ...
victoria      4      bash
                2      /usr/bin/ssh
                2      xterm

```

The report is sorted by username, and to reduce clutter and enhance visibility, usernames are shown only when they change.

Example 13-2. The puser script

```

#!/bin/sh -

# Show a sorted list of users with their counts of active
# processes and process names, optionally limiting the
# display to a specified set of users (actually, egrep(1))

```

```
# username patterns).  
  
#  
  
# Usage:  
  
#      puser [ user1 user2 ... ]  
  
  
IFS='  
    '  
  
PATH=/usr/local/bin:/usr/bin:/bin  
  
export PATH  
  
EGREPFLAGS=  
  
while test $# -gt 0  
do  
    if test -z "$EGREPFLAGS"  
    then  
        EGREPFLAGS="$1"  
    else  
        EGREPFLAGS="$EGREPFLAGS|$1"  
    fi  
    shift  
done  
  
if test -z "$EGREPFLAGS"
```

```

then
    EGREPFLAGS="."
else
    EGREPFLAGS="^ *($EGREPFLAGS) "
fi

case "`uname -s`" in
*BSD | Darwin)    PSFLAGS="-a -e -o user,ucomm -x" ;;
*)                PSFLAGS="-e -o user,comm" ;;
esac

ps $PSFLAGS |
    sed -e 1d |
        EGREP_OPTIONS= egrep "$EGREPFLAGS" |
            sort -b -k1,1 -k2,2 |
                uniq -c |
                    sort -b -k2,2 -k1nr,1 -k3,3 |
                        awk '{
                            user = (LAST = = $2) ? " " : $2
                            LAST = $2
                            printf("%-15s\t%2d\t%s\n", user, $1, $3)
                        }'
```

After the familiar preamble, the *puser* script uses a loop to collect the optional command-line arguments in

`EGREPFLAGS` variable, with the vertical-bar separators that indicate alternation to *egrep*. The `if` statement in the body handles the initial case of an empty string, to avoid producing an *egrep* pattern with an empty alternant.

When the argument-collection loop completes, we check `EGREPFLAGS`: if it is empty, we reassign it a match pattern. Otherwise, we augment the pattern to match only at the beginning of a line, and to require a trailing space, to prevent false matches of usernames with common prefixes, such as `jon` and `jones`.

The `case` statement handles implementation differences in the *ps* options. We want an output form that displays two values: a username and a command name. The BSD systems and BSD-derived Mac OS X (Darwin) systems require slightly different options from all of the others that we tested.

The seven-stage pipeline handles the report preparation:

1. The output from *ps* contains lines like this:

```

USER  COMMAND
root  sched
root  /etc/init
root  /usr/lib/nfs/nfsd
...
jones dtfile
daemon /usr/lib/nfs/statd
...
```

2. The *sed* command deletes the initial header line.
3. The *egrep* command selects the usernames to be displayed. We clear the `EGREP_OPTIONS` environment variable to avoid conflicts in its interpretation by different GNU versions of *egrep*.
4. The *sort* stage sorts the data by username and then by process.
5. The *uniq* command attaches leading counts of duplicated lines and eliminates duplicates.
6. A second *sort* stage sorts the data again, this time by username, then by descending count, and finally by name.
7. The *awk* command formats the data into neat columns, and removes repeated usernames.

← PREV

< Day Day Up >

13.3. Process Control and Deletion

Well-behaved processes ultimately complete their work and terminate with an `exit()` system call. Sometimes necessary to terminate a process prematurely, perhaps because it was started in error, requires more resources or is misbehaving.

The `kill` command does the job, but it is misnamed. What it really does is send a *signal* to a specified running process. As with exceptions noted later, signals can be caught by the process and dealt with: it might simply choose to ignore a signal, or `root`, or the kernel, or the process itself, can send a signal to it. A process that receives a signal can be terminated.

ISO Standard C defines only a half-dozen signal types. POSIX adds a couple of dozen others, and most systems have 50 different ones. You can list them like this example on an SGI IRIX system:

```
$ kill -l                                List supported signal names (or
HUP INT QUIT ILL TRAP ABRT EMT FPE KILL BUS SEGV SYS PIPE ALRM TERM
USR1 USR2 CHLD PWR WINCH URG POLL STOP TSTP CONT TTIN TTOU VTALRM PRIO
XCPU XFSZ UME RTMIN RTMIN+1 RTMIN+2 RTMIN+3 RTMAX-3 RTMAX-2 RTMAX-1
RTMAX
```

Most are rather specialized, but we've already used a few of the more common ones in *trap* commands in some of the earlier chapters of this book.

Each program that handles signals is free to make its own interpretation of them. Signal names reflect *convention*, so there is some variation in exactly what a given signal means to a particular program.

Uncaught signals generally cause termination, although `STOP` and `TSTP` normally just suspend the process until it receives a signal that it continue execution. You might use `STOP` and `CONT` to delay execution of a legitimate process until a later time.

```
$ top                                    Show top resource consumers
...
  PID USERNAME   THR PRI NICE   SIZE   RES STATE    TIME    CPU COMMAND
17787 johnson      9  58    0  125M  118M cpu/3   109:49 93.67% cruncher
```


...

```
$ kill -STOP 17787
```

Suspend process

```
$ sleep 36000 && kill -CONT 17787 &
```

Resume process in 10 hours

13.3.1. Deleting Processes

For deleting processes, it is important to know about only four signals: `ABRT` (abort), `HUP` (hangup), `KILL`, and `TERM`.

Some programs prefer to do some cleanup before they exit: they generally interpret a `TERM` signal to mean *clean up and exit*. The `kill` command sends that signal if you do not specify one. `ABRT` is like `TERM`, but may suppress cleanup actions, and may write a process memory image in a `core`, `program.core`, or `core.PID` file.

The `HUP` signal similarly requests termination, but with many daemons, it often means that the process should terminate and then get ready for new work, as if it were freshly started. For example, after you make changes to a configuration file, a `HUP` signal makes the daemon reread that file.

The two signals that no process can catch or ignore are `KILL` and `STOP`. These two signals are always delivered, even to sleeping processes,^[3] however, depending on the shell implementation and the operating system, most of the time they are delivered only when the process wakes up. For that reason, you should expect some delay in the delivery of these signals.

^[3] A process that is awaiting an event, such as the completion of I/O, or the expiration of a timer, is in a suspended state called *sleeping*. The scheduler does not consider it runnable. When the event finally happens, the process is again schedulable for execution, and the signal is delivered.

When multiple signals are sent, the order of their delivery, and whether the same signal is delivered more than once, is not guaranteed. The only guarantee that some systems provide is that at least *one* of the signals is delivered. There is such variation in signal handling across Unix platforms that only the simplest use of signals is portable.

We have already illustrated the `STOP` signal for suspending a process. The `KILL` signal causes immediate process termination. As a general rule, you should give the process a chance to shut down gracefully by sending it a `HUP` signal first: if that does not cause exit, then try the `TERM` signal. If that still does not cause exit, use the last-resort `KILL` signal. Here's an example of how to use the `kill` command. Suppose that you experience sluggish response: run the `top` command to see what is happening, and get sorted by CPU usage:

```
$ top
```

Show top resource consumers

...

```
PID USERNAME THR PRI NICE SIZE RES STATE TIME CPU COMMAND
```



```
25094 stevens      1   48      0 456M 414M cpu    243:58 99.64% netscape
...

```

Web browsers normally require relatively little CPU time, so this one certainly looks like a runaway process.

```
$ kill -HUP 25094          Send a HUP signal to process
```

Run *top* again, and if the runaway does not soon disappear from the display, use:

```
$ kill -TERM 25094       Send a TERM signal to process
```

or finally:

```
$ kill -KILL 25094      Send a KILL signal to process
```

Most *top* implementations allow the *kill* command to be issued from inside *top* itself.

Of course, you can do this only if you are `stevens` or `root`. Otherwise, you have to ask your system manager for the process.

Be cautious with the *kill* command. When a program terminates abnormally, it may leave remnants in the file system that have not been cleaned up, and besides wasting space, they might cause problems the next time the program is run. For example, mail clients, text editors, and web browsers all tend to create *locks*, which are just small files that record the program's state while running. If a second instance of the program is started while the first is still active, it detects the existing lock and immediately terminates. Otherwise, havoc could ensue with both instances writing the same files. Unfortunately, many programs do not tell you the name of the lock file, and seldom document it either. If that lock file is a remnant of a long-gone program, the program will not run until you find the lock and remove it. We show how to do that in Section 13.4.

Some systems (GNU/Linux, NetBSD, and Sun Solaris) have *pgrep* and *pkill* commands that allow you to kill processes by name. Without extra command-line options to force it to be more selective, *pkill* sends a signal to all processes with the specified name. For the runaway-process example, we might have issued:

```
$ pgrep netscape          Find process numbers of netscape
25094

```

followed by:

```
$ pkill -HUP netscape     Send netscape processes a HUP
```

```
$ pkill -TERM netscape           Send netscape processes a TE.
$ pkill -KILL netscape          Send netscape processes a KI.
```

However, because process names are not unique, killing them by name is risky: you might zap more than t

13.3.2. Trapping Process Signals

Processes register with the kernel those signals that they wish to handle. They specify in the arguments of t whether the signal should be caught, should be ignored, or should terminate the process, possibly with a co programs from the need to deal with signals, the kernel itself has defaults for each signal. For example, on find:

```
$ man -a signal                 Look at all manual pages for
```

...

Name	Value	Default	Event
SIGHUP	1	Exit	Hangup (see termio(7I))
SIGINT	2	Exit	Interrupt (see termio(7I))
SIGQUIT	3	Core	Quit (see termio(7I))

...

SIGABRT	6	Core	Abort
---------	---	------	-------

...

SIGFPE	8	Core	Arithmetic Exception
--------	---	------	----------------------

...

SIGPIPE	13	Exit	Broken Pipe
---------	----	------	-------------

...

SIGUSR1	16	Exit	User Signal 1
---------	----	------	---------------

SIGUSR2	17	Exit	User Signal 2
---------	----	------	---------------

SIGCHLD	18	Ignore	Child Status Changed
---------	----	--------	----------------------

...

The *trap* command causes the shell to register a *signal handler* to catch the specified signals. *trap* takes a list of commands to be executed when the trap is taken, followed by a list of signals for which the trap is set. You often see those signals expressed as numbers, but that is neither informative nor portable: stick with signal names.

Example 13-3 shows a small shell script, `looper`, that uses *trap* commands to illustrate caught and uncaught signals.

Example 13-3. A sleepy looping script: `looper`

```
#!/bin/sh -

trap 'echo Ignoring HUP ...' HUP
trap 'echo Terminating on USR1 ... ; exit 1' USR1

while true
do
    sleep 2
    date >/dev/null
done
```

`looper` has two *trap* commands. The first simply reports that the `HUP` signal was received, whereas the second exits. The program then enters an infinite loop that spends most of its time asleep. We run it in the background and send it two signals that it handles:

```
$ ./looper &                                Run looper in the background
[1]      24179                                The process ID is 24179

$ kill -HUP 24179                             Send looper a HUP signal
Ignoring HUP ...
```

```
$ kill -USR1 24179 Send looper a USR1 signal
```

```
Terminating on USR1 ...
```

```
[1] + Done(1) ./looper &
```

Now let's try some other signals:

```
$ ./looper & Run looper again in the backg
```

```
[1] 24286
```

```
$ kill -CHLD 24286 Send looper a CHLD signal
```

```
$ jobs Is looper still running?
```

```
[1] + Running ./looper &
```

```
$ kill -FPE 24286 Send looper an FPE signal
```

```
[1] + Arithmetic Exception(coredump) ./looper &
```

```
$ ./looper & Run looper again in the backg
```

```
[1] 24395
```

```
$ kill -PIPE 24395 Send looper a PIPE signal
```

```
[1] + Broken Pipe ./looper &
```

```
$ ./looper & Run looper again in the backg
```



```
[1]      24621
```

```
$ kill 24621 Send looper the default signal
```

```
[1] + Done(208) ./looper &
```

Notice that the `CHLD` signal did not terminate the process; it is one of the signals whose kernel default is to ignore. The floating-point exception (`FPE`) and broken pipe (`PIPE`) signals that we sent are among those that cause termination.

As a final experiment, we add one more *trap* command to `looper` :

```
trap 'echo Child terminated ...' CHLD
```

We give the modified script a new name, and run it:

```
$ ./looper-2 & Run looper-2 in the background
```

```
[1]      24668
```

```
Child terminated ...
```

```
Child terminated ...
```

```
Child terminated ...
```

```
Child terminated ...
```

```
$ kill -ABRT 24668 Send looper-2 an ABRT signal
```

```
[1] + Abort(core dumped) ./looper-2 &
```

Each time the loop body *sleep* and *date* processes terminate, the `CHLD` TRap is taken, producing a report even though the script is still running. We can also send an `ABRT` (abort) signal that terminates the looping process.

In addition to the standard signals listed earlier with *kill -l*, the shell provides one additional signal for the user to catch. That signal is always assigned the number zero, so `trap '...' 0` statements in older shell scripts are equivalent to `trap '...' SIGUSR1`.

The body of a `trap '...' EXIT` statement is invoked just before the `exit()` system call is made, either by a `command`, or implicitly by normal termination of the script. If traps are set for other signals, they are processed before `EXIT`.

The value of the exit status `$?` on entry to the `EXIT` TRap is preserved on completion of the trap, unless another value is given.

`bash`, `ksh`, and `zsh` provide two more signals for `trap`: `DEBUG` traps at every statement, and `ERR` traps after a nonzero `exit` code.

The `DEBUG` trap is quite tricky, however: in `ksh88`, it traps *after* the statement, whereas in later shells, it traps *before*. The domain Korn shell implementation available on several platforms does not support the `DEBUG` trap at all. We illustrate these differences with a short test script:

```
$ cat debug-trap Show the test script
```

```
trap 'echo This is an EXIT trap' EXIT
trap 'echo This is a DEBUG trap' DEBUG
pwd
pwd
```

Now supply this script to several different shells on a Sun Solaris system:

```
$ /bin/sh debug-trap Try the Bourne shell
```

```
test-debug-trap: trap: bad trap
/tmp
/tmp
This is an EXIT trap
```

```
$ /bin/ksh debug-trap Try the 1988 (i) Korn shell
```

```
/tmp
This is a DEBUG trap
/tmp
```

This is a DEBUG trap

This is an EXIT trap

\$ /usr/xpg4/bin/sh debug-trap

Try the POSIX shell (1988

/tmp

This is a DEBUG trap

/tmp

This is a DEBUG trap

This is an EXIT trap

\$ /usr/dt/bin/dtksh debug-trap

Try the 1993 (d) Korn shell

This is a DEBUG trap

/tmp

This is a DEBUG trap

/tmp

This is a DEBUG trap

This is an EXIT trap

\$ /usr/local/bin/ksh93 debug-trap

Try the 1993 (o+) Korn she

This is a DEBUG trap

/tmp

This is a DEBUG trap

/tmp

This is a DEBUG trap

This is an EXIT trap

`$ /usr/local/bin/bash debug-trap`

Try the GNU Bourne-Again she

This is a DEBUG trap

/tmp

This is a DEBUG trap

/tmp

This is a DEBUG trap

This is an EXIT trap

`$ /usr/local/bin/pdksh debug-trap`

Try the public-domain Korn s.

test-debug-trap[2]: trap: bad signal DEBUG

`$ /usr/local/bin/zsh debug-trap`

Try the Z-shell

This is a DEBUG trap

/tmp

This is a DEBUG trap

/tmp

This is a DEBUG trap

This is an EXIT trap

This is a DEBUG trap

We found older versions of *bash* and *ksh* that behaved differently in these tests. Clearly, this variation in be

is problematic, but it is unlikely that you need that trap in portable shell scripts.

The `ERR` trap also has a surprise: command substitutions that fail do not trap. Here's an example:

```
$ cat err-trap Show the test program
```

```
#!/bin/ksh -
trap 'echo This is an ERR trap.' ERR
echo Try command substitution: $(ls no-such-file)
echo Try a standalone command:
ls no-such-file
```

```
$ ./err-trap Run the test program
```

```
ls: no-such-file: No such file or directory
Try command substitution:
Try a standalone command:
ls: no-such-file: No such file or directory
This is an ERR trap.
```

Both `ls` commands failed, but only the second caused a trap.

The most common use of signal trapping in shell scripts is for cleanup actions that are run when the script ends, such as the removal of temporary files. Code like this `trap` command invocation is typical near the start of many shell scripts:

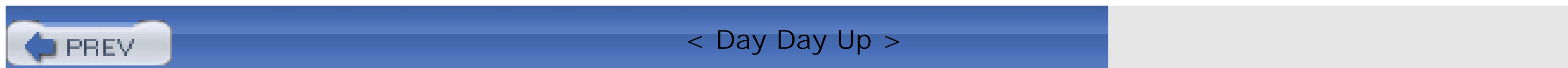
```
trap 'clean up action goes here' EXIT
```

Setting a trap on the shell's `EXIT` signal is usually sufficient, since it is handled after all other signals. In practice, `TERM` signals are often trapped as well.

To find more examples of the use of traps in shell scripts, try this on your system:

```
grep '^trap' /usr/bin/* Find traps in system shell scripts
```

Most scripts that we found this way use old-style signal numbers. The manual pages for the `signal()` function show the correspondence of numbers to names.



13.4. Process System-Call Tracing

Many systems provide *system call tracers*, programs that execute target programs, printing out each system call they make. It is likely you have one on your system; look for one of the following commands: *ktrace*, *par*, *strace*. If used inside shell scripts, they can be helpful for finding out what a process is doing and why it is taking so long. You can make any changes whatsoever to the programs to be traced, so you can use them on any process that you own. This section gives some small examples later in this section.

If you are unfamiliar with the names of Unix system calls, you can quickly discover many of them by examining the manual pages found in Section 2 of the online manuals; e.g. *open* (2). For example, file-existence tests usually involve the `stat` system call, which requires the `unlink()` system call.

Most compiled programming languages have a debugger that allows single stepping, setting of breakpoints, etc. The shells have no debugger, so you sometimes have to use the shell's `-v` option to get shell input lines printed. System-call tracers can provide a useful supplement to that output, since they give a detailed log of system calls.

Whenever you run an unknown program, you run the risk that it will do things to your system that you do not want. Commercial software usually comes with installation programs that customers are expected to trust. If a program is a shell script, you can inspect it, but if it is a black-box binary image, you cannot. Programs like *dpkg* refuse to run them as `root`. A system-call trace log of such an installation can be helpful in finding out exactly what the program did. To recover deleted or changed files, at least you have a record of what files were affected, and if your files are deleted, you can recover from a disaster.

^[4] Snapshots are a recent feature of some advanced filesystems: they permit freezing the state of a filesystem, usually in just a few seconds. This can be used to recover from changes made since the snapshot.

Most long-running processes make a substantial number of system calls, so the trace output is likely to be very large. If only a few system calls are of interest, you can specify them in a command-line option.

Let's follow process creation on a GNU/Linux system, tracing a short Bourne shell session. This can be a bit tedious, but it's worth it. In the trace, the shell, and the commands that we run. We therefore set the prompt variable, `PS1`, to distinguish the trace from the shell. The `trace=process` argument selects a group of process-related system calls:

```
$ PS1='traced-sh$ ' strace -e trace=process /bin/sh          Trace process
execve("/bin/sh", ["/bin/sh"], [/* 81 vars */) = 0          T
```

Now execute a command that we know is built-in:

```
traced-sh$ pwd
/home/jones/book
```

Only the expected output appeared, because no new process was created. Now use the separate program for

```
traced-sh$ /bin/pwd
```

```
fork( ) = 32390
wait4(-1,
/home/jones/book
```

This is trace

```
[WIFEXITED(s) && WEXITSTATUS(s) == 0], WUNTRACED, NULL) = 32390
```

```
--- SIGCHLD (Child exited) ---
```

This is trace ou

Finally, exit from the shell, and the trace:

```
traced-sh$ exit
```

Exit from the s.

```
exit
```

```
_exit(0) = ?
```

We are now back in the original shell session:

```
$ pwd
```

Back in original shell; che

```
/home/jones/book
```

Working directory is unchange

The shell made a `fork()` system call to start the `/bin/pwd` process, whose output got mixed in with the normal command terminated normally, and the shell received a `CHLD` signal, indicating completion of the child process.

Here's an example of profiling system calls on Sun Solaris; the `-c` option requests that a summary report be normal trace output suppressed:

```
$ truss -c /usr/local/bin/pathfind -a PATH truss
```

```
/usr/bin/truss
```

T.


```
/bin/truss
```

```
/usr/5bin/truss
```

syscall	seconds	calls	errors	<i>The truss repo</i>
_exit	.00	1		
fork	.00	2		
read	.00	26		
write	.00	3		
open	.00	5	1	
close	.00	10	1	
brk	.00	42		
stat	.01	19	15	
...				
stat64	.03	33	28	
open64	.00	1		
	-----	-----	-----	
sys totals:	.04	242	50	
usr time:	.01			
elapsed:	.19			

When your program takes longer than expected, output like this can help to identify performance bottlenecks. The `truss` command can be useful in identifying candidates for system-call profiling: it reports user time, system-call

One of the most common applications of system-call tracers is for monitoring file access and `unlink()` call reports in the trace log. On GNU/Linux, use `strace -e trace=file` can be particularly helpful when newly installed software complains that it cannot find a file's name.

System-call tracers are also helpful in finding the lock-file remnants that we discussed earlier. Here is an example of how to locate the lock file produced by a particular web browser:

```
$ truss -f -o foo.log mozilla           Trace browser execution
$ grep -i lock foo.log                 Search the trace for the word lock
...
29028:    symlink("192.168.253.187:29028",
           "/home/jones/.mozilla/jones/c7rboyyz.slt/lock") = 0
...
29028:    unlink("/home/jones/.mozilla/jones/c7rboyyz.slt/lock") = 0
```

This browser makes a lock file that is a symbolic link to a nonexistent filename containing the local machine number. Had the browser process died prematurely, the `unlink()` system call that removed the lock file would always have the word `lock` in them, so you might have to examine the trace log more closely to identify a lock file.

Here is an abbreviated trace on an SGI IRIX system, where we test whether `/bin/sh` is executable:

```
$ /usr/sbin/par /bin/test -x /bin/sh   Trace the test command
...
0mS[ 0] : execve("/bin/test", 0x7ffb7e88, 0x7ffb7e98)
...
6mS[ 0] : access("/bin/sh", X_OK) OK
6mS[ 0] : stat("/bin/sh", 0x7ffb7cd0) OK
...
6mS[ 0] : prctl(PR_LASTSHEXIT) = 1
6mS[ 0] : exit(0)
```

System call summary :

Name	#Calls	Average Time(ms)	Total Time(ms)

execve	1	3.91	3.91
open	2	0.11	0.21
access	1	0.17	0.17
stat	1	0.12	0.12
...			
prctl	1	0.01	0.01
exit	1	0.00	0.00

Once you know what system call you are interested in, you can reduce clutter by restricting trace output to

```
$ /usr/sbin/par -n stat /bin/test -x /bin/sh           Trace only st.
```

```
0mS[ 0] (5399999) : was sent signal SIGUSR1
```

```
0mS[ 3] : received signal SIGUSR1 (handler 0x100029d8)
```

```
6mS[ 3] : stat("/bin/sh", 0x7ffb7cd0) OK
```

System call summary :

...

The BSD and Mac OS X *ktrace* commands work a little differently: they write the trace to a binary file, `ktr` text form. Here's a trace from a NetBSD system, testing for execute permission of `/bin/sh` :

```
$ ktrace test -x /bin/sh           Trace the test command
```

```
$ ls -l ktrace.out           List the trace log
```

```
-rw-rw-r-- 1 jones devel 8698 Jul 27 09:44 ktrace.out
```

```
$ kdump
```

Post-process the trace log

```
...
```

```
19798 ktrace EMUL "netbsd"
```

```
19798 ktrace CALL execve(0xbfbfc650,0xbfbfcb24,0xbfbfcb34)
```

```
19798 ktrace NAMI "/usr/local/bin/test"
```

```
...
```

```
19798 test CALL access(0xbfbfcc80,0x1)
```

```
19798 test NAMI "/bin/sh"
```

```
19798 test RET access 0
```

```
19798 test CALL exit(0)
```

The need to post-process the trace log is unfortunate, since it prevents having a dynamic view of the system system call may be hard to identify.

All of the system-call tracers can take a process ID argument instead of a command name, allowing them to owner and `root` can do that.

There is much more to system-call tracers than we can illustrate here. Consult your local manual pages for

< Day Day Up >

13.5. Process Accounting

Unix systems support process accounting, although it is often disabled to reduce the administrative log-file burden. When it is enabled, on completion of each process, the kernel writes a compact binary record in a system-dependent accounting file, such as `/var/adm/pacct` or `/var/account/pacct`. The accounting file requires processing before it can be turned into a text stream that is amenable to processing with standard tools. For Sun Solaris, `root` might do something like this to produce a human-readable listing:

```
# acctcom -a                                List accounting records
...
COMMAND          START      END          REAL   CPU   MEAN
NAME             USER TTYNAME TIME      TIME      (SECS) (SECS) SIZE(K)
...
cat              jones    ?   21:33:38  21:33:38   0.07   0.04  1046.00
echo             jones    ?   21:33:38  21:33:38   0.13   0.04   884.00
make             jones    ?   21:33:38  21:33:38   0.53   0.05  1048.00
grep             jones    ?   21:33:38  21:33:38   0.14   0.03   840.00
bash            jones    ?   21:33:38  21:33:38   0.55   0.02  1592.00
....
```

Because the output format and the accounting tools differ between Unix implementations, we cannot provide scripts for summarizing accounting data. However, the sample output shows that the text format is relatively uniform. For example, we can easily produce a list of the top ten commands and their usage counts like this:

```
# acctcom -a | cut -d ' ' -f 1 | sort | uniq -c | sort -k1nr -k2 | head

21129 bash

5538 cat
```

```
4669  rm
3538  sed
1713  acomp
1378  cc
1252  cg
1252  iropt
1172  uname
808   gawk
```

Here, we used *cut* to extract the first field, then ordered that list with *sort* , reduced it to counts of duplicate sorted that by descending count, and finally used *head* to display the first tenrecords in the list.

Use the command `apropos accounting` to identify accounting commands on your system. Common ones *lastcomm* , and *sa* : most have options to help reduce the voluminous log data to manageable reports.

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13.6. Delayed Scheduling of Processes

In most cases, users want processes to start immediately and finish quickly. The shell therefore normally starts a new process as soon as the previous one finishes. Command completion speed is essentially resource-limited, and beyond the shell

In interactive use, it is sometimes unnecessary to wait for one command to complete before starting another. The shell provides a simple way to request it: any command that ends with an ampersand is started in the background. In those rare cases in which you need to wait for backgrounded processes to complete, simply issue the `wait` command (see Section 13.2).

There are at least four other situations when it is desirable to delay process start until a future time; we treat these in the following subsections.

13.6.1. `sleep`: Delay Awhile

When a process should not be started until a certain time period has elapsed, use the `sleep` command to suspend execution for a specified number of seconds, then issue the delayed command. The `sleep` command uses few resources, and can be used even when there are other processes with active processes: indeed, the scheduler simply ignores the sleeping process until it finally awakes when the time period has elapsed.

We use a short sleep in Example 13-1 and Example 13-3 to create programs that have an infinite loop, but do not consume the machine's resources in doing so. The short sleep in Section 9.10 ensures that a new pseudorandom-number is generated each process in a loop. The long sleep in Section 13.3 waits until a more convenient time to resume a suspended process.

Most daemons do their work, and then sleep for a short while before waking to check for more work; that way they can run with little effect on other processes for as long as the system is operational. They usually invoke the `sleep` function,^[5] instead of using the `sleep` command directly, unless they are themselves shell scripts.

^[5] Different systems vary as to which of these is a system call and which is a library function.

13.6.2. `at`: Delay Until Specified Time

The `at` command provides a simple way to run a program at a specified time. The syntax varies somewhat between shells, but the following examples give the general flavor:

```
at 21:00          < command-file Run at 9 p.m.
at now           < command-file Run immediately
at now + 10 minutes < command-file Run after 10 minutes
```



```

at now + 8 hours      < command-file  Run after 8 hours
at 0400 tomorrow     < command-file  Run at 4 a.m. tomorrow
at 14 July           < command-file  Run next Bastille Day
at noon + 15 minutes < command-file  Run at 12:15 today
at teatime           < command-file  Run this afternoon

```

In each case, the job to be run is defined by commands in *command-file*. *at* has somewhat eclectic ways of specifying times, as in the last example, which represents 16:00.

atq lists the jobs in the *at* queue and *atrm* removes them. For further details, consult the *at* manual pages or



On some systems, the shell that is used to run the *at* commands is the Bourne shell (`/bin/sh`) on other systems. You can insulate yourself from these variations by making the input command that names an executable script written in whatever language you find convenient to:

```
#! /path/to/script/interpreter
```

Whether the *at* family of commands is available to you depends on management policies. The files *at.all*, *at.crontab*, *at.allow*, and *at.deny* they are stored in `/etc`, `/usr/lib/cron/at`, `/var/adm/cron`, or `/var/at`, depending on the Unix flavor. *root* can use *at*. If your system does not allow you to use the *at* commands, complain to your system manager for a good reason to forbid them.

13.6.3. batch: Delay for Resource Control

Historically, long before computers offered interactive access for humans, operating systems ran all processes. The queue of jobs to be run is accumulated, and then processed in some order that might depend on the position of the job in the queue, how important you are, what resources you need and are permitted to have, how long you are prepared to wait, or how willing to pay. Many mainframe computers and large compute servers still spend most of their CPU cycles in batch mode.

All current Unix systems have a *batch* command that allow processes to be added to one of possibly several queues. The syntax of *batch* varies from system to system, but all support reading commands from standard input:

```
batch < command-file          Run commands in batch
```

On some systems, this is equivalent to:

`at -q b -m now < command-file` *Run commands now under the batch queue*

where `-q b` specifies the batch queue, `-m` requests mail to the user when the job completes, and `now` means immediately.

The problem with *batch* is that it is too simplistic: it offers little control over batch processing order, and no policy. It is rarely needed on smaller systems. On larger ones, and especially on distributed systems, *batch* has sophisticated implementations, such as the ones shown in Table 13-2. Each of those packages has a collection and managing batch jobs.

Table 13-2. Advanced batch queue and scheduler systems

Name	Web site
Generic Network Queueing System	http://www.gnqs.org/
IBM LoadLeveler	http://www.ibm.com/servers/eserver/pseries/lib
Maui Cluster Scheduler	http://supercluster.org/maui/
Platform LSF system	http://www.platform.com/products/LSFfamily/
Portable Batch System	http://www.openpbs.org/
Silver Grid Scheduler	http://supercluster.org/silver/
Sun GridEngine	http://gridengine.sunsource.net/

13.6.4. crontab: Rerun at Specified Times

Most computers have management tasks that need to be run repeatedly, such as filesystem backup every night, directory cleanup every week, account reporting once a month, and so on. Ordinary users may need such a task to synchronize files from a home computer with files on an office computer.

The facility that provides for running jobs at specified times consists of the *cron* daemon started at system boot. The *crontab* command for management of a simple text file that records when jobs are to be run: see the manual pages for *crontab*. You can list your current job schedule with *crontab -l* (lowercase L), and start an editor to update it with *crontab -e*, where the editor is determined by the `EDITOR` environment variable; depending on the system, *crontab* may refuse to run if the editor is not found, or simply start *ed*.

The *crontab* file (see the manual pages for *crontab* (5)) supports shell-style comments, so we find it helpful to include a comment to remind us of the expected syntax:

```
$ crontab -l                                List the current crontab schedule

#      mm      hh      dd      mon      weekday      command

#          00-59 00-23 01-31 01-12 0-6(0=Sunday)

...

```

In the first five fields, instead of a single number you can use either a hyphen-separated inclusive range (e.g., hourly from 08:00 to 17:00), or a comma-separated list of numbers or ranges (e.g., 20,40 in the first field), or an asterisk, meaning every possible number for that field. Here are some sample entries:

```
15 * * * * command           Run hourly at quarter past the hour

0 2 1 * * command           Run at 02:00 at the start of every month

0 8 1 1,7 * command         Run at 08:00 on January 1 and July 1

0 6 * * 1 command           Run at 06:00 every Monday

0 8-17 * * 0,6 command       Run hourly from 08:00 to 17:00 on Saturdays

```

Although POSIX says that blank lines are ignored, some commercial versions of *crontab* actually *deleting* a *crontab* file that contains them! We recommend avoiding them in your *crontab* files.

Commands in the *crontab* file run with a few environment variables already set: `SHELL` is `/bin/sh`, and `HOME` and `USER`, are set according to values in your entry in the `passwd` file or database.

The `PATH` setting is sharply restricted, often to just `/usr/bin`. If you are used to a more liberal setting, you may want to specify paths to commands used in the *crontab* file, or else set the `PATH` explicitly:

```
0 4 * * * /usr/local/bin/updatedb       Update the GNU fast find database

0 4 * * * PATH=/usr/local/bin:$PATH updatedb  Similar, but pass PATH to updatedb

```

Any output produced on standard error or standard output is mailed to you, or in some implementations, to the user specified in the `MAILTO` variable. In practice, you more likely want output redirected to a log file and accumulated over time. A *crontab* entry might look like this:

```
55 23 * * * $HOME/bin/daily >> $HOME/logs/daily.log 2>&1

```

Log files like this continue to grow, so you should do an occasional cleanup, perhaps by using an editor to file, or *tail -n n* to extract the last *n* lines:

```
cd $HOME/logs           Change to log-file directory
mv daily.log daily.tmp  Rename the log file
tail -n 500 daily.tmp > daily.log  Recover the last 500 lines
rm daily.tmp            Discard the old log file
```

Just be sure to do this at a time when the log file is not being updated. Obviously, this repetitive process can lead to another *crontab* entry.

A useful alternative to a cumulative log file is timestamped files with one *cron* job log per file. For a daily entry like this:

```
55 23 * * * $HOME/bin/daily > $HOME/logs/daily.`date +%Y.%m.%d`
```

cron normally changes percent characters in commands to newlines, but the backslashes prevent that from happening.

You can easily compress or remove old log files with the help of the *find* command:

```
find $HOME/logs/*.log -ctime +31 | xargs bzip2 -9  Compress log files
```

```
find $HOME/logs/*.log -ctime +31 | xargs rm          Remove log files older than 31 days
```

To keep your *crontab* file clean and simple, put each of its commands in a separate shell script with a chosen name. You can later revise those scripts without having to tinker with your *crontab* file.

If it is possible that running a second instance of a *cron* job might be harmful (e.g., filesystem updates), you need to make sure to prevent that, either by using a suitable lock file, or by using *at* and having the job submit its successor just before the job itself finishes. Of course, you need to run *at* every run so that in the event of a failure, if you use lock files, you make sure to remove the lock file, and if you use *at*, you reschedule the job.

You can remove your *crontab* file entirely with *crontab -r*. Like *rm*, this is irrevocable and unrecoverable.

copy like this:

```
crontab -l > $HOME/.crontab.`hostname` Save the current crontab
```

```
crontab -r Remove the crontab
```

so that you can later restore it with:

```
crontab $HOME/.crontab.`hostname` Restore the saved crontab
```

Since there is potentially one *crontab* file per host, we include the hostname in the name of the saved file so that the machine it belongs to is clear.

crontab replaces any existing schedule with that in the file given on its command line, provided that no symlinks are present. The old schedule is preserved.

As with the *at* command, there are `cron.allow` and `cron.deny` files in system directories that control who can run them. Complain to your system manager if you find yourself denied access to this useful facility.

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13.7. The /proc Filesystem

Several Unix flavors have borrowed an idea developed at Bell Labs: the `/proc` filesystem. Instead of supplying data via myriad system calls that need continual updating, kernel data is made available through a special call that implements a standard filesystem interface in the `/proc` directory. Each running process has a subdirectory named after its process number, and inside each subdirectory are various small files with kernel data. The contents of these files are described in the manual pages for `proc` (4) (most systems) or `proc` (5) (GNU/Linux).

GNU/Linux has developed this idea more than most other Unix flavors, and its `ps` command gets all of the information by reading files under `/proc`, which you can readily verify by running a system-call trace with `TRace=file ps aux`.

Here's an example of the process files for a text-editor session:

```
$ ls /proc/16521 List proc files for process 16521
```

```
cmdline  environ  fd      mem      root  statm
cwd      exe      maps   mounts  stat  status
```

```
$ ls -l /proc/16521 List them again, verbosely
```

```
total 0
-r--r--r--    1 jones    devel    0 Oct 28 11:38 cmdline
lrwxrwxrwx    1 jones    devel    0 Oct 28 11:38 cwd -> /home/jones
-r-----    1 jones    devel    0 Oct 28 11:38 environ
lrwxrwxrwx    1 jones    devel    0 Oct 28 11:38 exe -> /usr/bin/vi
dr-x-----    2 jones    devel    0 Oct 28 11:38 fd
-r--r--r--    1 jones    devel    0 Oct 28 11:38 maps
-rw-----    1 jones    devel    0 Oct 28 11:38 mem
-r--r--r--    1 jones    devel    0 Oct 28 11:38 mounts
```

```
lrwxrwxrwx    1 jones    devel    0 Oct 28 11:38 root -> /
-r--r--r--    1 jones    devel    0 Oct 28 11:38 stat
-r--r--r--    1 jones    devel    0 Oct 28 11:38 statm
-r--r--r--    1 jones    devel    0 Oct 28 11:38 status
```

Notice that the files all appear to be empty, but in fact, they contain data that is supplied by the device driver; they never really exist on a storage device. Their timestamps are suspicious as well: on GNU/Linux and OS/2, they reflect the current time, but on IRIX and Solaris, they show the time that each process started.

The zero size of `/proc` files confuses some utilities—among them, `scp` and `tar`. You might first have to use `cp` elsewhere into normal files.

Let's look at one of these files:

```
$ cat -v /proc/16521/cmdline           Display the process command
vi^@+273^@ch13.xml^@
```

The `-v` option causes unprintable characters to be displayed in caret notation, where `^@` represents the NUL character. This file contains a sequence of NUL-terminated strings, one for each argument in the command line.

Besides process-specific data, `/proc` may contain other useful files:

```
$ ls /proc | egrep -v '^[0-9]+$' | fmt           List all but process directories
apm bus cmdline cpuinfo devices dma driver execdomains fb
filesystems fs ide interrupts iomem ioports irq isapnp kcore kmsg
ksyms loadavg locks mdstat meminfo misc modules mounts mtrr net
partitions pci scsi self slabinfo speakup stat swaps sys sysvipc
tty uptime version
```

Here's the start of just one of them:

```
$ head -n 5 /proc/meminfo              Show first 5 lines of meminfo
```

```
total:      used:      free:  shared: buffers:  cached:
Mem:  129228800 116523008 12705792          0  2084864 59027456
Swap: 2146787328 28037120 2118750208
MemTotal:          126200 kB
MemFree:           12408 kB
```

Having process data available as files is convenient and makes the data easily available to programs written in shell language, even those that lack a system-call interface. For example, a shell script could collect hardware data from the `/proc/*info` files on all of the machines in your environment that are producing reports somewhat like those from the fancy *sysinfo* ^[6] command. The lack of standardization of these files, however, makes the task of producing uniform reports more difficult than it ought to be.

^[6] Available at <http://www.magnicomp.com/sysinfo/>.

13.8. Summary

In this chapter, we have shown how to create, list, control, schedule, and delete processes, how to send signals to them, and how to trace their system calls. Because processes run in private address spaces, they cannot interfere with one another, and no special effort needs to be made to write programs that can run at the same time.

Processes can catch all but two of several dozen signals, and either ignore them or respond to them with any desired action. The two uncatchable signals, `KILL` and `STOP`, ensure that even badly misbehaving processes can be killed or suspended. Programs that need to perform cleanup actions, such as saving active files, resetting terminal modes, or removing locks, generally catch common signals; otherwise, most uncaught signals cause process termination. The `trap` command makes it easy to add simple signal handling to shell scripts.

Finally, we examined several different mechanisms for delaying or controlling process execution. Of these, `sleep` is the most useful for shell scripting, although the others all have their uses.

Chapter 14. Shell Portability Issues and Extensions

The shell language as defined by POSIX is considerably larger than the original V7 Bourne shell. However, it is considerably smaller than the languages implemented by *ksh93* and *bash*, the two most commonly used extended versions of the Bourne shell.

It is likely that if you'll be doing heavy-duty scripting that takes advantage of shell-language extensions, you'll be using one or the other or both of these two shells. Thus, it's worthwhile to be familiar with features that the shells have in common, as well as their differences.

Over time, *bash* has acquired many of the extensions in *ksh93*, but not all of them. Thus, there is considerable functional overlap, but there are also many differences. This chapter outlines areas where *bash* and *ksh93* differ, as well as where they have common extensions above and beyond the features of the POSIX shell.

Many of the features described here are available only in recent versions of *ksh93*. Some commercial Unix systems have older versions of *ksh93*, particularly as a program called *dtksh* (the desktop Korn shell, `/usr/dt/bin/dtksh`), which won't have the newer features. Your best bet is to download the source for the current *ksh93* and build it from scratch. For more information, see [Section 14.4](#).

14.1. Gotchas

Here is a "laundry list" of things to watch out for:

Saving shell state

Example 14-1 shows how to save the shell's state into a file. An apparent oversight in the POSIX standard is that there's no defined way to save function definitions for later restoration! The example shows how to do that for both *bash* and *ksh93*.

Example 14-1. Saving shell state, including functions, for bash and ksh93

```
{
  set +o                               Option settings
  (shopt -p) 2>/dev/null               bash-specific options, subshell silences
  set                                   Variables and values
  export -p                             Exported variables
  readonly -p                           Read-only variables
  trap                                   Trap settings

  typeset -f                            Function definitions (not POSIX)
} > /tmp/shell.state
```

Note that *bash* and *ksh93* can use different syntaxes for defining functions, so care is required if you wish to dump the state from one shell and restore it in the other!

echo is not portable

As described in Section 2.5.3, the *echo* command may only be used portably for the simplest of uses and various options and/or escape sequences may or may not be available (the POSIX standard notwithstanding).

In *ksh93*, the built-in version of *echo* attempts to emulate whatever external version of *echo* would be found in `$PATH`. The reason behind this is compatibility: on any given Unix system, when the Korn shell executes a Bourne shell script for that system, it should behave identically to the original Bourne shell.

In *bash*, on the other hand, the built-in version behaves the same across Unix systems. The rationale is consistency: a *bash* script should behave the same, no matter what Unix variant it's running on. Thus, for complete portability, *echo* should be avoided, and *printf* is still the best bet.

OPTIND can be a local variable

In Section 6.4.4, we described the *getopts* command and the `OPTIND` and `OPTARG` variables. *ksh93* functions defined with the `function` keyword a *local* copy of `OPTIND`. The idea is that functions can much more like separate scripts, using *getopts* to process their arguments in the same way a script does without affecting the parent's option processing.

`${ var :? message }` may not exit

The `${ variable :? message }` variable expansion checks if *variable* is set. If it isn't, the shell prints *message* and exits. However, when the shell is *interactive*, the behavior varies, since it's not always correct for an interactive shell to just blindly exit, possibly logging the user out. Given the following script, named `x.sh`:

```
echo ${somevar:?somevar is not set}
echo still running
```

bash and *ksh93* show the behaviors listed in Table 14-1.

Table 14-1. Interactivity of `${var:?message}` in *bash* and *ksh93*

Command	Message printed	Subsequent command run
<code>\$ bash x.sh</code>	Yes	No
<code>\$ ksh93 x.sh</code>	Yes	No
<code>bash\$. x.sh</code>	Yes	Yes
<code>ksh93\$. x.sh</code>	Yes	No

This implies that if you know that a script will be executed with the dot command, you should ensure that it exits after using the `${ variable :? message }` construct.

Missing loop items in a for loop

Here's a subtle point. Consider a loop such as:

```
for i in $a $b $c
do
    do something
done
```

If all three variables are empty, there are no values to loop over, so the shell silently does nothing. It's *as if* the loop had been written:

```
for i in          # nothing!
do
    do something
done
```

However, for most versions of the Bourne shell, actually writing a `for` loop that way would produce a syntax error. The 2001 POSIX standard made an empty loop valid when entered directly.

The current versions of both `ksh93` and `bash` accept an empty `for` loop as just shown, and silently do nothing. As this is a recent feature, older versions of both shells, as well as the original Bourne shell, are likely to

produce an error message.

DEBUG traps behave differently

Both *ksh88* and *ksh93* provide a special `DEBUG` trap for shell debugging and tracing. In *ksh88*, the trap on `DEBUG` happens *after* each command is executed. In *ksh93*, the `DEBUG` TRap happens *before* each command. So far so good. More confusing is that earlier versions of *bash* follow the *ksh88* behavior, whereas the current versions follow that of *ksh93*. This is illustrated in Section 13.3.2.

Long and short options for *set*

The *set* command in both shells accepts additional short and long options. The full set of *set* options, both shells, is given in Table 14-2. Items marked POSIX are available in both *bash* and the Korn shell.

Table 14-2. Shell options for *set*

Short option	-o form	Availability	Description
-a	<code>allexport</code>	POSIX	Export all subsequently defined variables.
-A		<i>ksh88</i> , <i>ksh93</i>	Array assignment. <code>set +A</code> does not clear the array. See Section 14.3.6 for more information.
-b	<code>notify</code>	POSIX	Print job completion messages right away, instead of waiting for next prompt. Intended for interactive use.
-B	<code>braceexpand</code>	<i>bash</i>	Enable brace expansion. On by default. See Section 14.3.4 for more information.
-C	<code>noclobber</code>	POSIX	Don't allow <code>></code> redirection to existing files. The <code>> </code> operator overrides the setting of this option. Intended for interactive use.
-e	<code>errexit</code>	POSIX	Exit the shell when a command exits with nonzero status.
-f	<code>noglob</code>	POSIX	Disable wildcard expansion.
-h	<code>hashall</code> (<i>bash</i>)	POSIX	Locate and remember the location of commands called from function bodies when the function is defined, instead of when the function is executed (XSI).

Short option	-o form	Availability	Description
	TRackall (<i>ksh</i>)		
-H	histexpand	<i>bash</i>	Enable ! -style history expansion. On by default. ^[1]
-k	keyword	<i>bash</i> , <i>ksh88</i> , <i>ksh93</i>	Put all variable assignments into the environment, even those in the middle of a command. This is an obsolete feature and should never be used.
-m	monitor	POSIX	Enable job control (on by default). Intended for interactive use.
-n	noexec	POSIX	Read commands and check for syntax errors, but don't execute them. Interactive shells are allowed to ignore this option.
-p	privileged	<i>bash</i> , <i>ksh88</i> , <i>ksh93</i>	Attempt to function in a more secure mode. The details differ among the shells; see your shell's documentation.
-P	physical	<i>bash</i>	Use the physical directory structure for commands that change directory.
-s		<i>ksh88</i> , <i>ksh93</i>	Sort the positional parameters.
-t		<i>bash</i> , <i>ksh88</i> , <i>ksh93</i>	Read and execute one command and then exit. This is obsolete; is for compatibility with the Bourne shell and should not be used.
-u	nounset	POSIX	Treat undefined variables as errors, not as null.
-v	verbose	POSIX	Print commands (verbatim) before running them.
-x	xTRace	POSIX	Print commands (after expansions) before running them.
	bgnice	<i>ksh88</i> , <i>ksh93</i>	Automatically lower the priority of all commands run in the background (with &).
	emacs	<i>bash</i> , <i>ksh88</i> , <i>ksh93</i>	Use <i>emacs</i> -style command-line editing. Intended for interactive use.
	gmacs	<i>ksh88</i> , <i>ksh93</i>	Use GNU <i>emacs</i> -style command-line editing. Intended for interactive use.
	history	<i>bash</i>	Enable command history. On by default.
	ignoreeof	POSIX	Disallow Ctrl-D to exit the shell.
	markdirs	<i>ksh88</i> , <i>ksh93</i>	Append a / to directories when doing wildcard expansion.
	nolog	POSIX	Disable command history for function definitions.

Short option	-o form	Availability	Description
	<code>pipefail</code>	<i>ksh93</i>	Make pipeline exit status be that of the last command that fails, zero if all OK. <i>ksh93n</i> or newer.
	<code>posix</code>	<i>bash</i>	Enable full POSIX compliance.
	<code>vi</code>	POSIX	Use <i>vi</i> -style command-line editing. Intended for interactive use.
	<code>viraw</code>	<i>ksh88</i> , <i>ksh93</i>	Use <i>vi</i> -style command-line editing. Intended for interactive use. This mode can be slightly more CPU-intensive than <code>set -o vi</code> .

[1] We recommend disabling this feature if you use *bash* .

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14.2. The bash shopt Command

The *bash* shell, besides using the *set* command with long and short options, has a separate *shopt* command for enabling and disabling options.

shopt (bash)

Usage

```
shopt [ -pqsu ] [ -o ] [ option-name ... ]
```

Purpose

To centralize control of shell options as they're added to *bash*, instead of proliferating *set* options or shell variables.

Major options

-o

Limit options to those that can be set with `set -o`.

-p

Print output in a form suitable for rereading.

-q

Quiet mode. The exit status indicates if the option is set. With multiple options, the status is zero if they are all enabled, nonzero otherwise.

-s

Set (enable) the given option.

-u

Unset (disable) the given option.

For *-s* and *-u* without named options, the display lists those options which are set or unset, respectively.

Behavior

Control the settings of various internal shell options. With no option or *-p*, print the settings. Use *-p* to print the settings in a form that can be reread later.

Caveats

Only in *bash*, not in *ksh*.

The list of options for *bash* version 3.0 follows. For each option, we describe the behavior when the option is set (enabled):

`cdable_vars`

When an argument to *cd* isn't a directory, *bash* treats it as a variable name, whose value is the target directory.

cdspell

If a *cd* to a directory fails, *bash* attempts several minor spelling corrections to see if it can find the real directory. If it finds a correction, it prints the name and changes to the computed directory. This option works only in interactive shells.

checkhash

As *bash* finds commands after a path search, it stores the path search results in a hash table, to speed up subsequent executions of the same command. The second time a command is executed, *bash* runs the command as stored in the hash table, on the assumption that it's still there. With this option, *bash* verifies that a filename stored in its hash table really exists before trying to execute it. If it's not found, *bash* does a regular path search.

checkwinsize

After each command, *bash* checks the window size, and updates the `LINES` and `COLUMNS` variables when the window size changes.

cmdhist

bash stores all lines of a multiline command in the history file. This makes it possible to reedit multiline commands.

dotglob

bash includes files whose names begin with `.` (dot) in the results of filename expansion.

execfail

bash does not exit if it cannot execute the command given to the *exec* built-in command (see [Section 7.3.2](#)). In any case, interactive shells do not exit if *exec* fails.

expand_aliases

bash expands aliases. This is the default for interactive shells.

extdebug

bash enables behavior needed for debuggers:

- `declare -F` displays the source file name and line number for each function name argument.
- When a command run by the `DEBUG` TRap fails, the next command is skipped.
- When a command run by the `DEBUG` trap inside a shell function or script sourced with `.` (`dot`) or `source` fails, the shell simulates a call to `return`.
- The array variable `BASH_ARGC` is set. Each element holds the number of arguments for the corresponding function or dot-script invocation. Similarly, the `BASH_ARGV` array variable is set. Each element is one of the arguments passed to a function or dot-script. `BASH_ARGV` functions as a stack, with values being pushed on at each call. Thus, the last element is the last argument to the most recent function or script invocation.
- Function tracing is enabled. Command substitutions, shell functions and subshells invoked via `(...)` inherit the `DEBUG` and `RETURN` TRaps. (The `RETURN` trap is run when a `return` is executed, or a script run with `.` [`dot`] or `source` finishes.)
- Error tracing is enabled. Command substitutions, shell functions, and subshells invoked via `(...)` inherit the `ERROR` TRap.

extglob

bash does extended pattern matching similar to that of *ksh88*. This is discussed in more detail in [Section 14.3.3](#).

extquote

bash allows `${!...}` and `@"..."` within `${variable}` expansions inside double quotes.

failglob

When a pattern does not match filenames *bash* produces an error.

`force_ignore`

When doing completion, *bash* ignores words matching the list of suffixes in `FIGNORE`, even if such words are the only possible completions.

`gnu_errfmt`

bash prints error messages in the standard GNU format.

`histappend`

bash appends commands to the file named by the `HISTFILE` variable, instead of overwriting the file.

`histreedit`

When a history substitution fails, if the `readline` library is being used, *bash* allows you to reedit the failed substitution.

`histverify`

With `readline`, *bash* loads the result of a history substitution into the editing buffer for further changing.

`hostcomplete`

bash performs hostname completion with `readline` on words containing an `@` character. This is on by default.

`huponexit`

bash sends `SIGHUP` to all jobs when an interactive login shell exits.

`interactive_comments`

bash treats `#` as starting a comment for interactive shells. This is on by default.

`lithist`

When used together with the `cmdhist` option, *bash* saves multiline commands in the history with embedded newlines, rather than semicolons.

`login_shell`

bash sets this option when it is started as a login shell. It cannot be changed.

`mailwarn`

bash prints the message "The mail in `mailfile` has been read" when the access time has changed on a file that *bash* is checking for mail.

`no_empty_cmd_completion`

bash does not search `$PATH` when command completion is attempted on an empty line.

`nocaseglob`

bash ignores case when doing filename matching.

`nullglob`

bash causes patterns that don't match any files to become the null string, instead of standing for themselves. This null string is then removed from further command-line processing; in effect, a pattern that doesn't match anything disappears from the command line.

`progcomp`

This option enables the programmable completion features. See the *bash(1)* manpage for details. It is on by default.

promptvars

bash performs variable and parameter expansion on the value of the various prompt strings. This is on by default.

restricted_shell

bash sets this to true when functioning as a restricted shell. This option cannot be changed. Startup files can query this option to decide how to behave. See [Section 15.2](#), for more information on restricted shells.

shift_verbose

bash prints a message if the count for a *shift* command is more than the number of positional parameters left.

sourcepath

bash uses `$PATH` to find files for the *source* and `.` (dot) commands. This is on by default. If turned off, you must use a full or relative pathname to find the file.

xpg_echo

bash's built-in *echo* processes backslash escape sequences.

14.3. Common Extensions

Both *bash* and *ksh93* support a large number of extensions over the POSIX shell. This section deals with those extensions, where both shells provide the same features, and in the same way.

14.3.1. The select Loop

bash and *ksh* share the `select` loop, which allows you to generate simple menus easily. It has concise syntax and simple work. The syntax is:

```
select name [in list]
do
    statements that can use $name ...
done
```

This is the same syntax as the regular `for` loop except for the keyword `select`. And like `for`, you can omit the `in` keyword, which defaults to "\$@"; i.e., the list of quoted command-line arguments.

Here is what `select` does:

1. Generate a menu of each item in *list*, formatted with numbers for each choice
2. Print the value of `PS3` as a prompt and waits for the user to enter a number
3. Store the selected choice in the variable *name* and the selected number in the built-in variable `REPLY`
4. Execute the statements in the body
5. Repeat the process forever (but see later for how to exit)

An example should help make this process clearer. Suppose you need to know how to set the `TERM` variable system using different kinds of video display terminals. You don't have terminals hardwired to your computer, but you can communicate through a terminal server. Although the *telnet* protocol can pass the `TERM` environment variable, it is not smart enough to do so. This means, among other things, that the tty (serial device) number does *not* determine

Therefore, you have no choice but to prompt the user for a terminal type at login time. To do this, you can `/etc/profile` (assume you have a fixed set of known terminal types):

```
PS3='terminal?  '

select term in gl35a t2000 s531 vt99

do

    if [ -n "$term" ]

    then

        TERM=$term

        echo TERM is $TERM

        export TERM

        break

    else

        echo 'invalid.'

    fi

done
```

When you run this code, you see this menu:

```
1) gl35a

2) t2000

3) s531

4) vt99

terminal?
```

The built-in shell variable `PS3` contains the prompt string that `select` uses; its default value is the not parti reason, the first line of the preceding code sets it to a more relevant value.

The `select` statement constructs the menu from the list of choices. If the user enters a valid number (from set to the corresponding value; otherwise, it is null. (If the user just presses Enter, the shell prints the menu

The code in the loop body checks if `term` is non-null. If so, it assigns `$term` to the environment variable `TERM`; then the `break` statement exits the `select` loop. If `term` is null, the code prints an error prompt (but not the menu).

The `break` statement is the usual way of exiting a `select` loop. (A user can also type Ctrl-D-for end-of-input loop. This gives the interactive user a uniform way of exiting, but it doesn't help the shell programmer much

We can refine our solution by making the menu more user friendly so that the user doesn't have to know the terminal. We do this by using quoted character strings as menu items, and then using `case` to determine the version is shown in Example 14-2.

Example 14-2. Combining `select` with more user-friendly menu items

```
echo 'Select your terminal type:'

PS3='terminal?  '

select term in \
    'Givalt GL35a' \
    'Tsoris T-2000' \
    'Shande 531' \
    'Vey VT99'
do
    case $REPLY in
        1) TERM=gl35a ;;
        2) TERM=t2000 ;;
        3) TERM=s531 ;;
        4) TERM=vt99 ;;
        *) echo 'invalid.' ;;
    esac
done
```

```

        if [[ -n $term ]]; then

            echo TERM is $TERM

            export TERM

            break

        fi

done

```

This code looks a bit more like a menu routine in a conventional program, though `select` still provides the menu choices into numbers. We list each of the menu choices on its own line for reasons of readability, but characters to keep the shell from complaining about syntax.

Here is what the user sees when this code is run:

```
Select your terminal type:
```

```

1) Givalt  GL35a
2) Tsoris  T-2000
3) Shande  531
4) Vey     VT99

terminal?

```

This is a bit more informative than the previous code's output.

When the body of the `select` loop is entered, `$term` equals one of the four strings (or is null if the user makes no choice). The built-in variable `REPLY` contains the number that the user selected. We need a `case` statement to assign `term` to use the value of `REPLY` as the `case` selector.

Once the `case` statement is finished, the `if` checks to see if a valid choice was made, as in the previous solution. If `term` has already been assigned, so the code just prints a confirmation message, exports `TERM`, and exits. If `term` is not valid, the `select` loop repeats the prompt and goes through the process again.

Within a `select` loop, if `REPLY` is set to the null string, the shell reprints the menu. This happens, as mentioned above. However, you may also explicitly set `REPLY` to the null string to force the shell to reprint the menu.

The variable `TMOUT` (time out) can affect the `select` statement. Before the `select` loop, set it to some number of seconds.

nothing is entered within that amount of time, the `select` will exit.

14.3.2. Extended Test Facility

`ksh` introduced the extended test facility, delineated by `[[` and `]`. These are shell keywords, special to the command. Recent versions of `bash` have adopted this special facility as well.

`[[...]]` differs from the regular `test` and `[...]` commands in that word expansion and pattern expansion (with `~`) means that quoting is much less necessary. In effect, the contents of `[[...]]` form a separate sublanguage, `sh`. Most of the operators are the same as for `test`. The full list is given in Table 14-3

Table 14-3. Extended test operators

Operator	bash/ksh only	True if ...
<code>-a file</code>		<code>file</code> exists. (Obsolete. <code>-e</code> is preferred.)
<code>-b file</code>		<code>file</code> is a block device file.
<code>-c file</code>		<code>file</code> is a character device file.
<code>-C file</code>	<code>ksh</code>	<code>file</code> is a contiguous file. (Not for most Unix versions.)
<code>-d file</code>		<code>file</code> is a directory.
<code>-e file</code>		<code>file</code> exists.
<code>-f file</code>		<code>file</code> is a regular file.
<code>-g file</code>		<code>file</code> has its setgid bit set.
<code>-G file</code>		<code>file</code> 's group ID is the same as the effective group ID of the shell.
<code>-h file</code>		<code>file</code> is a symbolic link.
<code>-k file</code>		<code>file</code> has its sticky bit set.
<code>-l file</code>	<code>ksh</code>	<code>file</code> is a symbolic link. (Works only on systems where <code>/bin/test</code> is a symbolic link.)
<code>-L file</code>		<code>file</code> is a symbolic link.
<code>-n string</code>		<code>string</code> is non-null.
<code>-N file</code>	<code>bash</code>	<code>file</code> was modified since it was last read.
<code>-o option</code>		<code>option</code> is set.
<code>-O file</code>		<code>file</code> is owned by the shell's effective user ID.

Operator	bash/ksh only	True if ...
<code>-p file</code>		<code>file</code> is a pipe or named pipe (FIFO file).
<code>-r file</code>		<code>file</code> is readable.
<code>-s file</code>		<code>file</code> is not empty.
<code>-S file</code>		<code>file</code> is a socket.
<code>-t n</code>		File descriptor <code>n</code> points to a terminal.
<code>-u file</code>		<code>file</code> has its setuid bit set.
<code>-w file</code>		<code>file</code> is writable.
<code>-x file</code>		<code>file</code> is executable, or is a directory that can be searched.
<code>-z string</code>		<code>string</code> is null.
<code>fileA -nt fileB</code>		<code>fileA</code> is newer than <code>fileB</code> , or <code>fileB</code> does not exist.
<code>fileA -ot fileB</code>		<code>fileA</code> is older than <code>fileB</code> , or <code>fileB</code> does not exist.
<code>fileA -ef fileB</code>		<code>fileA</code> and <code>fileB</code> point to the same file.
<code>string = pattern</code>	<i>ksh</i>	<code>string</code> matches <code>pattern</code> (which can contain wildcards). Obsolete
<code>string = = pattern</code>		<code>string</code> matches <code>pattern</code> (which can contain wildcards).
<code>string != pattern</code>		<code>string</code> does not match <code>pattern</code> .
<code>stringA < stringB</code>		<code>stringA</code> comes before <code>stringB</code> in dictionary order.
<code>stringA > stringB</code>		<code>stringA</code> comes after <code>stringB</code> in dictionary order.
<code>exprA -eq exprB</code>		Arithmetic expressions <code>exprA</code> and <code>exprB</code> are equal.
<code>exprA -ne exprB</code>		Arithmetic expressions <code>exprA</code> and <code>exprB</code> are not equal.
<code>exprA -lt exprB</code>		<code>exprA</code> is less than <code>exprB</code> .
<code>exprA -gt exprB</code>		<code>exprA</code> is greater than <code>exprB</code> .
<code>exprA -le exprB</code>		<code>exprA</code> is less than or equal to <code>exprB</code> .
<code>exprA -ge exprB</code>		<code>exprA</code> is greater than or equal to <code>exprB</code> .

The operators can be logically combined with `&&` (AND) and `||` (OR) and grouped with parentheses. They When used with filenames of the form `/dev/fd/ n` , they test the corresponding attribute of open file desc

The operators `-eq` , `-ne` , `-lt` , `-le` , `-gt` , and `-ge` are considered obsolete in *ksh93* ; the *let* command or (

(The *let* command and `((...))` are described briefly in Section 14.3.7 .)

14.3.3. Extended Pattern Matching

ksh88 introduced additional pattern-matching facilities that give the shell power roughly equivalent to *awk* expressions. (Regular expressions are described in detail in Section 3.2 .) With the `extglob` option enabled, operators. (They're always enabled in *ksh* .) Table 14-4 summarizes the additional facilities.

Table 14-4. Shell versus *egrep/awk* regular expression operators

ksh/bash	egrep/awk	Meaning
<code>*(exp)</code>	<code>exp *</code>	0 or more occurrences of <i>exp</i>
<code>+(exp)</code>	<code>exp +</code>	1 or more occurrences of <i>exp</i>
<code>?(exp)</code>	<code>exp ?</code>	0 or 1 occurrences of <i>exp</i>
<code>@(exp1 exp2 ...)</code>	<code>exp1 exp2 ...</code>	<i>exp1</i> or <i>exp2</i> or ...
<code>!(exp)</code>	(none)	Anything that doesn't match

The notations for shell regular expressions and standard regular expressions are very similar, but they're not the same. If you would interpret an expression like `dave | fred | bob` as a pipeline of commands, you must use `@(dave | fred | bob)` themselves.

For example:

- `@(dave | fred | bob)` matches *dave* , *fred* , or *bob* .
- `*(dave | fred | bob)` means 0 or more occurrences of *dave* , *fred* , or *bob* . This expression matches *st* , *davedave* , *fred* , *bobfred* , *bobbobdavefredbobfred* , etc.
- `+(dave | fred | bob)` matches any of the above except the null string.
- `?(dave | fred | bob)` matches the null string *dave* , *fred* , or *bob* .
- `!(dave | fred | bob)` matches anything except *dave* , *fred* , or *bob* .

It is worth emphasizing again that shell regular expressions can still contain standard shell wildcards. Thus any single character) is the equivalent of `.` (dot) in *egrep* or *awk* , and the shell's character set operator `[...]` utilities.^[2] For example, the expression `+([[:digit:]])` matches a number: i.e., one or more digits. The shell equivalent to the standard regular expression `*(?)` . You can even nest the regular expressions: `+([[:digit:]]`

one or more digits or nonuppercase letters.

^[2] And, for that matter, the same as in *grep*, *sed*, *ed*, *vi*, etc. One notable difference is that the shell uses `!` inside `[...]` for negation, while most utilities all use `^`.

Two *egrep* and *awk* regexp operators do not have equivalents in the shell. They are:

- The beginning- and end-of-line operators `^` and `$`
- The beginning- and end-of-word operators `\<` and `\>`

Essentially, the `^` and `$` are implied as always being there. Surround a pattern with `*` characters to disable the difference:

```
$ ls                                List files
biff bob frederick shishkabob

$ shopt -s extglob                  Enable extended pattern matching

$ echo @(dave|fred|bob)           Files that match only dave, fred, or bob
bob

$ echo *@(dave|fred|bob)*         Add wildcard characters
bob frederick shishkabob         More files matched
```

ksh93 supports even more pattern-matching operators. However, since the point of this section is to cover *bash* and *ksh93*, we stop here. For the details, see *Learning the Korn Shell* (O'Reilly).

14.3.4. Brace Expansion

Brace expansion is a feature borrowed from the Berkeley C shell, *cs*. It is supported by both shells. Brace typing when you have strings that are prefixes or suffixes of each other. For example, suppose that you have

```
$ ls
cpp-args.c  cpp-lex.c  cpp-out.c  cpp-parse.c
```

You could type `vi cpp-{args,lex,parse}.c` if you wished to edit three out of the four C files, and the shell would expand to `cpp-args.c cpp-lex.c cpp-parse.c`. Furthermore, brace substitutions may be nested. For example:

```
$ echo cpp-{args,l{e,o}x,parse}.c
cpp-args.c cpp-lex.c cpp-lox.c cpp-parse.c
```

14.3.5. Process Substitution

Process substitution allows you to open multiple process streams and feed them into a single program for processing.

```
awk '...' <(generate_data) <(generate_more_data)
```

(Note that the parentheses are part of the syntax; you type them literally.) Here, *generate_data* and *generate_more_data* are arbitrary commands, including pipelines, that produce streams of data. The *awk* program processes each stream as if the data is coming from multiple sources. This is shown graphically in Figure 14-1 .

Figure 14-1. Process substitution for both input and output data streams

Process substitution may also be used for output, particularly when combined with the *tee* program, which copies output files and to standard output. For example:

```
generate_data | tee >(sort | uniq > sorted_data) \
```



```
>(mail -s 'raw data' joe) > raw_data
```

This command uses *tee* to (1) send the data to a pipeline that sorts and saves the data, (2) send the data to *tee* and (3) redirect the original data into a file. This is represented graphically in Figure 14-1 .b. Process substitution frees you from the straight "one input, one output" paradigm of traditional Unix pipes, letting you split data and coalesce multiple input data streams into one.

Process substitution is available only on Unix systems that support the `/dev/fd/ n` special files for named descriptors. Most modern Unix systems, including GNU/Linux, support this feature. As with brace expansion when *ksh93* is compiled from source code. *bash* always enables it.

14.3.6. Indexed Arrays

Both *ksh93* and *bash* provide an indexed array facility that, while useful, is much more limited than analog programming languages. In particular, indexed arrays can be only one-dimensional (i.e., no arrays of arrays). Furthermore, they may be any arithmetic expression: the shells automatically evaluate the expression to yield a value.

There are three ways to assign values to elements of an array. The first is the most intuitive: you can use the assignment syntax with the array index in brackets (`[]`). For example:

```
nicknames[2]=bob
```

```
nicknames[3]=ed
```

puts the values `bob` and `ed` into the elements of the array `nicknames` with indices 2 and 3, respectively. As with other assignments, values assigned to array elements are treated as character strings.

The second way to assign values to an array is with a variant of the *set* statement. The statement:

```
set -A aname val1 val2 val3 ...
```

creates the array `aname` (if it doesn't already exist) and assigns `val1` to `aname[0]`, `val2` to `aname[1]`, etc. This is more convenient for loading up an array with an initial set of values. This was the first mechanism added to the shells for assigning multiple array elements in one operation, and we mention it primarily so that you'll recognize it if you see it in an example.

bash doesn't support `set -A`.

The third (recommended) way is to use the compound assignment form:


```
aname=(val1 val2 val3)
```

To extract a value from an array, use the syntax `${ aname [i] }`. For example, `${nicknames[2]}` has to be an arithmetic expression. If you use `*` or `@` in place of the index, the value will be all elements, separated by spaces. `index ($nicknames)` is the same as specifying index 0 (`${nicknames[0]}`).

Now we come to the somewhat unusual aspect of arrays. Assume that the only values assigned to `nicknames` earlier. If you type `echo "${nicknames[*]}"`, you will see the output:

```
bob ed
```

In other words, `nicknames[0]` and `nicknames[1]` don't exist. Furthermore, if you were to type:

```
nicknames[9]=pete
```

```
nicknames[31]=ralph
```

and then type `echo "${nicknames[*]}"`, the output would look like this:

```
bob ed pete ralph
```

This is why we said the elements of `nicknames` with indices 2 and 3 earlier, instead of the second and third array elements with unassigned values just don't exist; if you try to access their values, you get null strings.

You can preserve whatever whitespace you put in your array elements by using `"${ aname [@]}"` (with the `aname [*]`), just as you can with `"$@"` rather than `$*` or `"$*"`.

Both shells provide an operator that tells you how many elements an array has defined: `${# aname [*]}`. The value is 4. Note that you need the `[*]` because the name of the array alone is interpreted as the 0th element. `${#nicknames}` equals the length of `nicknames[0]`. Since `nicknames[0]` doesn't exist, the value of `${#nicknames}` is the null string.

You can think of an array as a mathematical function that takes an integer input parameter and returns a corresponding element at that number). If you do so, then you can see why arrays are "number-dominated" data structures. In tasks that are much more often oriented toward character strings and text than toward numbers, the indexed array is useful as it might first appear.

Nevertheless, we can find useful things to do with indexed arrays. For example, here is a cleaner solution to the problem discussed earlier, in Section 14.3.1, in which a user can select a terminal type (`TERM` environment variable) at login time. Here is a user-friendly version of this code that used `select` and a `case` statement.

We can eliminate the entire `case` construct by taking advantage of the fact that the `select` construct stores

the variable `REPLY`. We just need a line of code that stores all of the possibilities for `TERM` in an array, in an items in the `select` menu. Then we can use `$REPLY` to index the array. The resulting code is:

```
termnames=(gl35a t2000 s531 vt99)

echo 'Select your terminal type:'

PS3='terminal?  '

select term in \
    'Givalt GL35a' \
    'Tsoris T-2000' \
    'Shande 531' \
    'Vey VT99'
do
    if [[ -n $term ]]; then
        TERM=${termnames[REPLY-1]}

        echo "TERM is $TERM"

        export TERM

        break
    fi
done
```

This code sets up the array `termnames` so that `${termnames[0]}` is `gl35a`, `${termnames[1]}` is `t2000`, etc. `TERM=${termnames[REPLY-1]}` essentially replaces the entire `case` construct by using `REPLY` to index the array.

Notice that both shells know to interpret the text in an array index as an arithmetic expression, as if it were `termnames[REPLY-1]`, which in turn means that the variable need not be preceded by a dollar sign (`$`). We have to subtract 1 from array indices start at 0, whereas `select` menu item numbers start at 1.

14.3.7. Miscellaneous Extensions

Here is another laundry list, this time of small extensions to the POSIX shell supported by both *bash* and *ksh*:

Additional tilde expansions

POSIX specifies plain `~` as being equivalent to `$HOME` and `~user` as being `user`'s home directory. It also specifies `~-` as short for `$PWD` (the current working directory) and `~-` as short for `$OLDPWD` (the previous working directory).

Arithmetic commands

POSIX specifies the `$((...))` notation for arithmetic expansion, and doesn't provide any other mechanism for doing arithmetic operations. However, both shells provide two notations for doing arithmetic directly, not as an expansion:

```
let "x = 5 + y"
```

The let command, requires quoting

```
((x = 5 + y))
```

No leading \$, automatic quoting inside

It's not clear why POSIX standardizes only arithmetic expansion. Perhaps it's because you can achieve essentially the same result using the `:` (do-nothing) command and arithmetic expansion:

```
: $(x = 5 + y)
```

Almost the same as let or ((...))

```
x=$((5 + y))
```

Similar, no spaces allowed around the

One difference is that *let* and `((...))` have an exit status: zero for a true value and one for a false value. This is not the case for `while` statements:

```
while ((x != 42))
```

```
do
```

```
    ... whatever ...
```

```
done
```

Arithmetic for loop

Both shells support the *arithmetic for* loop, which is similar to the `for` loop in *awk*, C, and C++. It


```
for ((init; condition; increment))
do
    loop body
done
```

Each one of *init* , *condition* , and *increment* can be shell arithmetic expressions, exactly the same as *v*. The use of `((...))` in the `for` loop is purposely similar to the arithmetic evaluation syntax.

Use the arithmetic `for` loop when you need to do something a fixed number of times:

```
for ((i = 1; i <= limit; i += 1))
do
    whatever needs doing
done
```

Additional arithmetic operators

POSIX specifies the list of operators that are allowed inside arithmetic expansion with `$((...))`. Both shells support the same set of operators, to provide full compatibility with C. In particular, both allow `++` and `--` to increment and decrement, and both support prefix and postfix forms. (According to POSIX, `++` and `--` are optional.) Both shells also support `+=` and `-=`, which lets you perform multiple operations in one expression. Also, as an extension over and above POSIX, both shells support `**` for exponentiation. The full list of operators is provided in Table 14-5 .

Optional matching parentheses for case statements

The `$(...)` syntax for command substitution (see Section 7.6) is standardized by POSIX. It was introduced in *bash* . *ksh88* had a problem with `case` statements inside `$(...)` . In particular, the closing parenthesis of each case pattern could terminate the entire command substitution. To get around this, *ksh88* requires `case` statements enclosed in matching parentheses when inside a command substitution:

```
some command $( ...
    case $var in
```



```
( foo | bar )    some other command ;;
( stuff | junk ) something else again ;;

esac

... )
```

ksh93, *bash*, and POSIX allow an optional open parenthesis on `case` selectors, but do not require it. (Thus which required the open parenthesis inside `$(...)`.)

Printing traps with `trap -p`

According to POSIX, an unadorned *trap* command prints out the state of the shell's traps, in a form that can be used later to restore the same traps. Both shells also allow you to use `trap -p` to print out the traps.

Here strings with `<<<`

It's common to use *echo* to generate a single line of input for further processing. For example:

```
echo $myvar1 $mvar2 | tr ... | ...
```

Both shells support a notation we term *here strings*, taken from the Unix version of the *rc* shell.^[3] Here string. The string becomes the standard input to the associated command, with the shell automatically supplying the input.

^[3] See <http://www.star.le.ac.uk/~tjg/rc/>.

```
tr ... <<< "$myvar1 $myvar2" | ...
```

This potentially saves the creation of an extra process and is also notationally clear.

Extended string notation

Both *bash* and *ksh93* support a special string notation that understands the usual set of C-like (or *echo*) escape sequences. This notation consists of a `$` in front of a single-quoted string. Such strings behave like regular single-quoted strings, but the shell interprets escape sequences inside the string. For example:

```

$ echo $'A\tB'           A, tab, B
A           B

$ echo $'A\nB'          A, newline, B
A
B

```

Table 14-5 lists the arithmetic operators supported by both *bash* and *ksh93*.

Table 14-5. bash and ksh93 arithmetic operators

Operator	Meaning
++ --	Increment and decrement, prefix and postfix
+ - ! ~	Unary plus and minus; logical and bitwise negation
**	Exponentiation ^[4]
* / %	Multiplication, division, and remainder
+ -	Addition and subtraction
<< >>	Bit-shift left and right
< <= > >=	Comparisons
= = !=	Equal and not equal
&	Bitwise AND
^	Bitwise Exclusive OR
	Bitwise OR
&&	Logical AND (short-circuit)
	Logical OR (short-circuit)
? :	Conditional expression
= += -= *= /= %= &= ^= <<= >>= =	Assignment operators
,	Sequential evaluation

[4] *ksh93m* and newer. In *bash* versions prior to 3.1, `**` is left-associative. It will be right-associative starting with version 3.1 language.

Parentheses can be used to group subexpressions. The arithmetic expression syntax (like C) supports relational operators of 1 for true and 0 for false.

For example, `$(3 > 2)` has the value 1; `$((3 > 2) || (4 <= 1))` also has the value 1, since at least one of the subexpressions is true.



14.4. Download Information

This section *briefly* describes where to find source code for *bash* and *ksh93*, and how to build each shell for It assumes that you have a C compiler and the *make* program available on your system.

14.4.1. bash

bash is available from the Free Software Foundation GNU Project's FTP server. As of this writing, the curri You can use *wget* (if you have it) to retrieve the distribution *tar* file:

```
$ wget ftp://ftp.gnu.org/gnu/bash/bash-3.0.tar.gz
--17:49:21--      ftp://ftp.gnu.org/gnu/bash/bash-3.0.tar.gz
                  => `bash-3.0.tar.gz'
...

```

Alternatively, you can use good old-fashioned anonymous FTP to retrieve the file:

```
$ ftp ftp.gnu.org                                     FTP to server
Connected to ftp.gnu.org (199.232.41.7).
220 GNU FTP server ready.
Name (ftp.gnu.org:tolstoy): anonymous             Anonymous login
230 Login successful.
230-Due to U.S. Export Regulations, all cryptographic software on th
230-site is subject to the following legal notice:
...
Remote system type is UNIX.
Using binary mode to transfer files.

```



```

ftp> cd /gnu/bash Change to bash d

250 Directory successfully changed.

ftp> binary Ensure binary mo

200 Switching to Binary mode.

ftp> hash Print # marks fo

Hash mark printing on (1024 bytes/hash mark).

ftp> get bash-3.0.tar.gz Retrieve file

local: bash-3.0.tar.gz remote: bash-3.0.tar.gz

227 Entering Passive Mode (199,232,41,7,149,247)

150 Opening BINARY mode data connection for bash-3.0.tar.gz (2418293
#####
#####
...

226 File send OK.

2418293 bytes received in 35.9 secs (66 Kbytes/sec)

ftp> quit All done

221 Goodbye.

```

Besides the *bash* distribution itself, you should also retrieve any patches. For Version 3.0 of *bash*, the patch source code that should be applied-must be retrieved from a different site. They're found in `ftp://ftp.cwru.edu/3.0-patches/`. You can retrieve all of them into a temporary directory as follows:

```

$ mkdir /tmp/p Make temporary directory

$ cd /tmp/p Move there

$ for i in 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16

> do wget ftp://ftp.cwru.edu/pub/bash/bash-3.0-patches/bash30-0$i

```

```
> done Retrieve all patches
```

```
... lots of output omitted ...
```

As of this writing, there are 16 patches. There may be more or fewer, depending upon the version of *bash* and the patches made available.

Now you're ready to extract the distribution and apply the patches. First, extract the source code:

```
$ gzip -d < bash-3.0.tar.gz | tar -xpvzf - Decompress and
```

```
bash-3.0/
```

```
bash-3.0/CWRU/
```

```
bash-3.0/CWRU/misc/
```

```
bash-3.0/CWRU/misc/open-files.c
```

```
bash-3.0/CWRU/misc/sigs.c
```

```
... lots of output omitted ...
```

Now apply the patches:

```
$ cd bash-3.0 Change to source directory
```

```
$ for i in /tmp/p/* Apply all patches
```

```
> do patch -p0 --verbose --backup < $i
```

```
> done
```

```
... lots of output omitted ...
```

```
$ find . -name '*.rej' Check for failed patches
```

```
$ find . -name '*.orig' -print | xargs rm Clean up
```

The invocation of *patch* just shown assumes the GNU version of *patch*. Beware of the older versions that exist on some commercial Unix systems. After applying the patches, we check for failed patches by looking for *.rej* files. Here, there were none, so we're OK. We then remove the *.orig* (original) files. Building *bash* follows the :

recipe:

```
$ ./configure && make && make check Configure, build
checking build system type... i686-pc-linux-gnu
checking host system type... i686-pc-linux-gnu
... lots of output omitted ...
```

If all the tests pass (they should), that's it, you're all set! Use `make install` to install the freshly built `bash` (you may need to do the installation step as `root`.)

14.4.2. ksh93

`ksh93` can be downloaded in source code form from the AT&T Research web site. The URL is <http://www.research.att.com/sw/download>. Building `ksh93` is relatively straightforward, but the process is more manual than for `bash`. We show the steps for `ksh93p`, from February 2004. The steps will be similar for `current`. We've chosen here to just build the Korn shell, although you may wish to download and build the "Open" package, because that provides a full set of tools.

1. From the web site, download the packages `INIT.2004-02-29.tgz` and `ast-ksh.2004-02-29.tgz` into an otherwise empty directory that you will use for building the software.

2. Make the directory `lib/package/tgz` and move the two files there:

```
$ mkdir -p lib/package/tgz
```

```
$ mv *.tgz lib/package/tgz
```

3. Extract the `INIT` package manually:

```
$ gzip -d < lib/package/tgz/INIT.2004-02-29.tgz | tar -xvf -
```

```
... lots of output omitted ...
```

4. Start the build process using the AT&T tools by reading which packages are available:

```
$ bin/package read
```

```
package:  update  /home/tolstoy/ksh93/bin/execrate
```

... lots and lots of output omitted ...

5. Start the compilation, again using the AT&T tools:

```
$ bin/package make
```

```
package: initialize the /home/tolstoy/ksh93/arch/linux.i386 view
```

... lots and lots and lots of output omitted ...

This step can take quite a while, depending upon the speed of your system and your compiler.

6. The newly built *ksh93* binary is in the file `arch/ ARCH /bin/ksh`, where *ARCH* represents the architecture machine on which you're building *ksh93*. For an x86 GNU/Linux system, it's `linux.i386`. For exam

```
$ arch/linux.i386/bin/ksh
```

Run newly built ksh93

```
$ echo ${.sh.version}
```

Show version

```
Version M 1993-12-28 p
```

7. You may wish to move the newly built Korn shell to a directory in your path, such as your personal b

```
$ cp arch/linux.i386/bin/ksh $HOME/bin/ksh93
```

That's it! Enjoy.

< Day Day Up >

14.5. Other Extended Bourne-Style Shells

Two other shells are popular and worthy of note:

The Public Domain Korn Shell

Many of the Open Source Unix-like systems, such as GNU/Linux, come with the Public Domain Korn Shell, *pdksh*. *pdksh* is available as source code; start at its home page: <http://web.cs.mun.ca/~michael/pdksh/>. It comes with instructions for building and installing on various Unix platforms.

pdksh was originally written by Eric Gisin, who based it on Charles Forsyth's public-domain clone of the Version 7 Bourne shell. It is mostly compatible with the 1988 Korn shell and POSIX, with some extensions of its own.

The Z-Shell

zsh is a powerful interactive shell and scripting language with many features found in *ksh*, *bash*, and *tcsh*, as well as several unique features. *zsh* has most of the features of *ksh88* but few of *ksh93*. It is freely available and should compile and run on just about any modern version of Unix. Ports for other operating systems are also available. The *zsh* home page is <http://www.zsh.org/>.

Both of these shells are described in more detail in *Learning the Korn Shell* (O'Reilly).

14.6. Shell Versions

Our exploration of extended shells brings up the good point that it's useful occasionally to be able to find the version number of various shells. Here's how:

```
$ bash --version                                bash
GNU bash, version 3.00.16(1)-release (i686-pc-linux-gnu)
...

$ ksh --version                                Recent ksh93 only
version          sh (AT&T Labs Research) 1993-12-28 p

$ ksh                                           Older ksh
$ ^V                                           Type ^V
$ Version 11/16/88f                             ksh shows version

$ echo 'echo $KSH_VERSION' | pdksh             pdksh
@(#)PD KSH v5.2.14 99/07/13.2

$ echo 'echo $ZSH_VERSION' | zsh               zsh
4.1.1
```

There appears to be no way to get a version number from `/bin/sh`. This is not surprising. Most true Bourne shells on commercial Unix systems are descended from the System V Release 3 (1987) or

Release 4 (1989) Bourne shell, and have changed little or not at all since then. Commercial vendors wishing to supply a POSIX-compliant shell generally do so by adapting some version of the Korn shell for that purpose.



14.7. Shell Initialization and Termination

In order to support user customization, shells read certain specified files on startup, and for some shells, also has different conventions, so we discuss them in separate sections.

If you write shell scripts that are intended to be used by others, you *cannot* rely on startup customizations. As we develop in this book set up their own environment (e.g., the value of `$PATH`) so that anyone can run the

Shell behavior depends on whether it is a *login shell*. When you sit at a terminal and enter a username and prompt from the computer, you get a login shell. Similarly, when you use `ssh hostname`, you get a login shell by name, or implicitly as the command interpreter named in the initial `#!` line in a script, or create a new window, or run a command in a remote shell with—for example, `ssh hostname command`—then that shell is

The shell determines whether it is a login shell by examining the value of `$0`. If the value begins with a hyphen, it is a login shell; otherwise, it is not. You can tell whether you have a login shell by this simple experiment:

```
$ echo $0                                Display shell name
-ksh                                     Yes, this is a login shell
```

The hyphen does *not* imply that there is a file named `/bin/-ksh`. It just means that the parent process set the shell when it ran the `exec()` system call to start the shell.

If you routinely deal with only a single shell, then the initialization and termination files described in the following sections solve much of a problem: once you get them suitably customized, you can probably leave them untouched for years. If you use multiple shells, you need to consider more carefully how to set up your customizations to avoid duplication and headaches. The `.` (dot) and `test` commands are your friends: use them in your customization scripts to read and write files that have carefully written to be acceptable to all Bourne-family shells, and on all hosts to which you have access. You will need to make the system-wide customization scripts in `/etc` work for all users.

14.7.1. Bourne Shell (sh) Startup

When it is a login shell, the Bourne shell, `sh`, does the equivalent of:

```
test -r /etc/profile && . /etc/profile      Try to read /etc/profile
test -r $HOME/.profile && . $HOME/.profile Try to read $HOME/.profile
```


That is, it potentially reads two startup files in the context of the current shell, but does not require that either home-directory file is a dot file, but the system-wide one in `/etc` is not.

The system shell-startup file created by local management might look something like this:

```
$ cat /etc/profile           Show system shell startup fi
PATH=/usr/local/bin:$PATH   Add /usr/local/bin to start o
export PATH                 Make it known to child proces
umask 022                   Remove write permission for
```

A typical `$HOME/.profile` file could then modify the local system's default login environment with commands like:

```
$ cat $HOME/.profile       Show personal shell startup .
PATH=$PATH:$HOME/bin       Add personal bin directory to
export PATH                 Make it known to child proces
alias rm='rm -i'           Ask for confirmation of file
umask 077                   Remove all access for group
```

When a child shell is subsequently created, it inherits the parent's environment strings, including `PATH`. It also inherits the current working directory and the current file-permission mask, both of which are recorded in the process-specific `environ` table. However, it does *not* inherit other customizations, such as command abbreviations made with the `alias` command. These customizations were not exported.

The Bourne shell provides no way to automatically read a startup file when the shell is not a login shell, so you cannot even expect `PATH` to be set. Since remote command execution also does not create a login shell, you may be as simple as `/bin:/usr/bin`. We have to deal with this in the `build-all` script in Section 8.2.

On exit, the Bourne shell does not read a standard termination file, but you can set a trap to make it do so (see Section 13.3.2). For example, if you put this statement in `$HOME/.profile`:

```
trap '. $HOME/.logout' EXIT
```

then the `$HOME/.logout` script can do any cleanup actions that you need, such as wiping the screen with `clear`. Since there can be only one trap for any given signal, the trap will be lost if it is overridden later in the session. However, the `trap` command guarantees that a termination script will be executed. For nonlogin shells, each script or session that needs e

explicit `EXIT` trap, and that too cannot be guaranteed to be in effect on exit.

These limitations, the lack of support for command history,^[5] and in some older implementations, job control are considered undesirable as a login shell for most interactive users. On most commercial Unix systems, it therefore tends to be used for system and other system-administration accounts that are used interactively only for brief sessions. Nevertheless, it is still expected by portable shell scripts.

^[5] On many systems, `/bin/sh` is just a link to `bash`, in which case command history is available. However, the original Unix shell does not have a command history.

14.7.2. Korn Shell Startup

Like the Bourne shell, the Korn shell, `ksh`, reads `/etc/profile` and `$HOME/.profile`, if they exist and are executable, before starting a login shell.

When `ksh93` starts as an interactive shell (either login or nonlogin), it then does the equivalent of:

```
test -n "$ENV" && eval . "$ENV"           Try to read $ENV
```

`ksh88` does the `$ENV` processing *unconditionally*, for all shells.

The `eval` command is described in Section 7.8. For now, it is enough to know that it first evaluates its arguments, then expands them, and then executes the resulting string as a command. The effect is that the file named by the argument is read in the context of the current shell. The `PATH` directories are not searched for the file, so `$ENV` should generally be a relative pathname.

The `ENV` feature solves the problem that the Bourne shell has in setting up private aliases for child shell sessions. It also solves the customization problem for nonlogin remote sessions: their shells never read any initialization files.

Like the Bourne shell, a noninteractive `ksh93` shell does not read any startup scripts, nor does it read any initialization files when it exits, unless you issue a suitable `trap` command. (As we said before, even a noninteractive `ksh88` reads initialization files on startup.)

14.7.3. Bourne-Again Shell Startup and Termination

While GNU `bash` is often used as a login shell in its own right, it can also masquerade as the Bourne shell by using the name `sh`. It then behaves on startup largely as described in Section 14.7.1, in which case most of the rest of the section applies. On GNU/Linux systems, `/bin/sh` is invariably a symbolic link to `/bin/bash`.

The `bash` emulation of the Bourne shell is not perfect because `bash` hides only *some* of its extended features when invoked as `sh`. We have occasionally found shell scripts in software packages that were designed for a GNU/Linux environment for execution by `/bin/sh`, but were not tested in real Bourne shell environments where they fail because of their use of extended features.

When *bash* is a login shell, on startup it does the equivalent of:

```
test -r /etc/profile && . /etc/profile           Try to read /etc/pr
if test -r $HOME/.bash_profile ; then          Try three more poss.
    . $HOME/.bash_profile
elif test -r $HOME/.bash_login ; then
    . $HOME/.bash_login
elif test -r $HOME/.profile ; then
    . $HOME/.profile
fi
```

The system-wide file is the same as for the Bourne shell, but the search order in `$HOME` allows you to put *bash* in either of two files. Otherwise, *bash* falls back to reading your personal Bourne-shell startup file.

On exit, a *bash* login shell effectively does this:

```
test -r $HOME/.bash_logout && . $HOME/.bash_logout  Try to read a termi.
```

Unlike the Bourne shell, *bash* reads an initialization file on startup when it is an interactive nonlogin shell,

```
test -r $HOME/.bashrc && . $HOME/.bashrc           Try to read $HOME/..
```

In this case, login-shell startup files are not read.

When *bash* is used noninteractively, instead of reading a `.bashrc` file or login-shell startup files, it reads a `BASH_ENV` variable, like this:

```
test -r "$BASH_ENV" && eval . "$BASH_ENV"          Try to read $BASH_E
```

As with *ksh*, the `PATH` directories are not searched for this file.

Notice the difference: the Korn shell's `ENV` variable is used only for nonlogin *interactive* shells, whereas *bash* for *noninteractive* shells.

To clarify the startup-file processing order, we fitted each of them with an *echo* command. A login session

```
$ login                                Start a new login session
login: bones
Password:                               Echo suppressed to hide passw
DEBUG: This is /etc/profile
DEBUG: This is /home/bones/.bash_profile
$ exit                                  Terminate the session
logout
DEBUG: This is /home/bones/.bash_logout
```

An interactive session invokes only a single file:

```
$ bash                                  Start an interactive se.
DEBUG: This is /home/bones/.bashrc
$ exit                                  Terminate the session
exit
```

A noninteractive session normally does not invoke any file:

```
$ echo pwd | bash                       Run a command under bas.
/home/bones
```

However, it will if the `BASH_ENV` value points to a startup file:

```
$ echo pwd | BASH_ENV=$HOME/.bashenv bash Run a command under bas.
DEBUG: This is /home/bones/.bashenv
/home/bones
```


14.7.4. Z-Shell Startup and Termination

The Z-shell, *zsh*, can masquerade as either the Bourne shell or the Korn shell. When invoked under the name that begins with the letters *s* or *k*, optionally preceded by a single *r* (for restricted), it has the same startup and the rest of this section does not apply. (When mimicking *ksh*, it follows the *ksh88* behavior of always]

The Z-shell has the most complex, and most flexible, customization procedure. Every Z-shell startup, whether interactive shell, or a noninteractive shell, begins by trying to read two initialization files, like this:

```
test -r /etc/zshenv && . /etc/zshenv           Read system-wide sc.

if test -n "$ZDOTDIR" && test -r $ZDOTDIR/.zshenv ; then
    . $ZDOTDIR/.zshenv                       Read this file
elif test -r $HOME/.zshenv ; then
    . $HOME/.zshenv                          Or else this file
fi
```

The `ZDOTDIR` variable provides a way for system management to prevent *zsh* from automatically reading startup directories, and instead, to force reading them from somewhere else that is under management control. If this would be set in `/etc/zshenv`, so you can look there to see what your system does.

Assuming that `ZDOTDIR` is not set, the best place to put personal customizations that you want to be in effect in the file `$HOME/.zshenv`.

If the shell is a login shell, it next does the equivalent of these commands to read two startup profiles:

```
test -r /etc/zprofile && . /etc/zprofile       Read system-wide sc.

if test -n "$ZDOTDIR" && test -r $ZDOTDIR/.zprofile ; then
    . $ZDOTDIR/.zprofile                     Read this file
elif test -r $HOME/.zprofile ; then
    . $HOME/.zprofile                        Or else this file
fi
```

If the shell is a login shell or an interactive shell, it then tries to read two startup scripts like this:

```

test -r /etc/zshrc && . /etc/zshrc           Read system-wide sc.

if test -n "$ZDOTDIR" && test -r $ZDOTDIR/.zshrc ; then
    . $ZDOTDIR/.zshrc                       Read this file
elif test -r $HOME/.zshrc ; then
    . $HOME/.zshrc                          Or else this file
fi

```

Finally, if the shell is a login shell, it tries to read two login scripts like this:

```

test -r /etc/zlogin && . /etc/zlogin       Read system-wide sc.

if test -n "$ZDOTDIR" && test -r $ZDOTDIR/.zlogin ; then
    . $ZDOTDIR/.zlogin                     Read this file
elif test -r $HOME/.zlogin ; then
    . $HOME/.zlogin                       Or else this file
fi

```

When *zsh* exits, if it is a login shell, and it is not terminating due to *exec*'ing another process, it finishes by scripts: a user one and a system one, in that order:

```

if test -n "$ZDOTDIR" && test -r $ZDOTDIR/.zlogout ; then  Read this f.
    . $ZDOTDIR/.zlogout
elif test -r $HOME/.zlogout ; then                       Or else thi.
    . $HOME/.zlogout
fi

test -r /etc/zlogout && . /etc/zlogout                   Read system

```

The Z-shell initialization and termination procedures are complex. To make it easier to see what is happening with the files with an `echo` command, and we left `ZDOTDIR` unset so that files are looked for only in `/etc` and `$HOME`.

looks likes this:

```
$ login
```

Start a new login session

```
login: zabriski
```

```
Password:
```

Echo suppressed to hide passw

```
DEBUG: This is /etc/zshenv
```

```
DEBUG: This is /home/zabriski/.zshenv
```

```
DEBUG: This is /etc/zprofile
```

```
DEBUG: This is /home/zabriski/.zprofile
```

```
DEBUG: This is /etc/zshrc
```

```
DEBUG: This is /home/zabriski/.zshrc
```

```
DEBUG: This is /etc/zlogin
```

```
DEBUG: This is /home/zabriski/.zlogin
```

```
$ exit
```

Terminate the session

```
DEBUG: This is /home/zabriski/.zlogout
```

```
DEBUG: This is /etc/zlogout
```

An interactive session invokes fewer files:

```
$ zsh
```

Start a new interactive sess

```
DEBUG: This is /etc/zshenv
```

```
DEBUG: This is /home/zabriski/.zshenv
```

```
DEBUG: This is /etc/zshrc
```

```
DEBUG: This is /home/zabriski/.zshrc
```

```
$ exit
```

Terminate the session

Silence: no termination files

A noninteractive session uses only two files:

```
$ echo pwd | zsh
```

Run a command under zsh

```
DEBUG: This is /etc/zshenv
```

```
DEBUG: This is /home/zabriski/.zshenv
```

```
/home/zabriski
```



< Day Day Up >

14.8. Summary

The POSIX standard makes a yeoman effort to make portable shell scripting possible. And if you stay within the bounds of what it defines, you have a fighting chance at writing portable scripts. However, the real world remains a messy place. While *bash* and *ksh93* provide a number of extensions above and beyond POSIX, things aren't always 100 percent compatible between the two shells. There are a large number of small [Section 14.1](#) to watch out for, even in simple areas like *set* options or saving the shell's complete state.

The *shopt* command lets you control *bash*'s behavior. We particularly recommend enabling the `extglob` option for interactive use.

bash and *ksh93* share a number of common extensions that are very useful for shell programming: the `select` loop, the `[[...]]` extended test facility, extended pattern matching, brace expansion, process substitution, and indexed arrays. We also described a number of small but useful miscellaneous extensions. The arithmetic `for` loop and the `((...))` arithmetic command are perhaps the most notable of these.

Source code for *bash* and *ksh93* is available for download from the Internet, and we showed how to build both shells. We also mentioned two other popular extended Bourne-style shells, *pdksh* and *zsh*.

We showed how to determine the version of the shell you're running for the popular extended Bourne-style shells. This is important for when you need to know exactly what program you're using.

Finally, different implementations of the Bourne shell language have different startup and termination customization features and files. Shell scripts intended for general use should not rely on features or variables being set by each individual user, but should instead do all required initialization on their own.

Chapter 15. Secure Shell Scripts: Getting Started

Unix security is a problem of legendary notoriety. Just about every aspect of a Unix system has some security issue associated with it, and it's usually the system administrator's job to worry about this issue.

In this chapter, we first present a list of "tips" for writing shell scripts that have a better chance of avoiding security problems. Next we cover the *restricted shell*, which attempts to put a straitjacket around the user's environment. Then we present the idea of a "Trojan horse," and why such things should be avoided. Finally we discuss setuid shell scripts, including the Korn shell's *privileged mode*.



This is not a textbook on Unix system security. Be aware that this chapter merely touches the tip of the iceberg and that there are myriad other aspects to Unix system security besides how the shell is set up.

If you would like to learn more about Unix security, we recommend *Practical UNIX & Internet Security* (O'Reilly).

15.1. Tips for Secure Shell Scripts

Here are some tips for writing more-secure shell scripts, courtesy of Professor Eugene (Gene) Spafford, the director of Purdue University's Center for Education and Research in Information Assurance and Security:^[1]

^[1] See <http://www.cerias.purdue.edu/>.

Don't put the current directory (dot) in PATH

Executable programs should come only from standard system directories. Having the current directory (dot) in `PATH` opens the door wide for "Trojan horses," described in [Section 15.3](#).

Protect bin directories

Make sure that every directory in `$PATH` is writable only by its owner and by no one else. The same applies to all the programs *in* the `bin` directories.

Design before you code

Spend some time thinking about what you want to do and how to do it. Don't just type stuff in with a text editor and keep hacking until it seems to work. Include code to handle errors and failures gracefully.

Check all input arguments for validity

If you expect a number, verify that you got a number. Check that the number is in the correct range. Do the same thing for other kinds of data; the shell's pattern-matching facilities are particularly useful for this.

Check error codes from all commands that can return errors

Things you may not expect to fail might be mischievously forced to fail to cause the script to misbehave. For instance, it is possible to cause some commands to fail even as `root` if the argument is an NFS-mounted disk or a character-oriented device file.

Don't trust passed-in environment variables

Check and reset them to known values if they are used by subsequent commands (e.g., `TZ`, `PATH`, `IFS`, etc.). `ksh93` automatically resets `IFS` to its default upon startup, ignoring whatever was in the environment, but many other shells don't. In all cases, it's an excellent idea to explicitly set `PATH` to contain just the system `bin` directories and `IFS` to space-tab-newline.

Start in a known place

Explicitly `cd` to a known directory when the script starts so that any subsequent relative pathnames are to a known location. Be sure that the `cd` succeeds:

```
cd app-dir || exit 1
```

Use full pathnames for commands

Do this so that you know which version you are getting, regardless of `$PATH`.

Use syslog(8) to keep an audit trail

Log the date and time of invocation, username, etc.; see the manual pages for `logger(1)`. If you don't have `logger`, create a function to keep a log file:

```
logger( ) {
    printf "%s\n" "$*" >> /var/adm/logsysfile
}

logger "Run by user " $(id -un) " ($USER) at " $(/bin/date)
```


Always quote user input when using that input

E.g., "\$1" and "\$*". This prevents malicious user input from being further evaluated and executed.

Don't use eval on user input

Even after quoting user input, *don't* hand it to the shell to reprocess with *eval*. If the user reads your script and sees that it uses *eval*, it's easy to subvert the script into doing almost anything.

Quote the results of wildcard expansion

You can do several nasty things to a system administrator by creating files with spaces, semicolons, backquotes, and so on, in the filenames. If administrative scripts don't quote the filename arguments, the scripts can trash-or give away-the system.

Check user input for metacharacters

Look for metacharacters such as \$ or ` (old-style command substitution) if using the input in an *eval* or \$(...).

Test your code and read it critically

Look for assumptions and mistakes that can be exploited. Put yourself into a nasty mood, and read your code with the intent of trying to figure out how to subvert it. Then fix whatever problems you find.

Be aware of race conditions

If an attacker can execute arbitrary commands between any two commands in your script, will it compromise security? If so, find another way to do it.

Suspect symbolic links

When *chmod*-ing or editing a file, check it to be sure that it is a file and not a symbolic link to a

critical system file. (Use [`-L file`] or [`-h file`] to test if `file` is a symbolic link.)

Have someone else review your code for mistakes

Often a fresh pair of eyes can spot things that the original author of a program missed.

Use `setgid` rather than `setuid`, if possible

These terms are discussed later in this chapter. In brief, by using `setgid`, you restrict the amount of damage that can be done to the group that is compromised.

Use a new user rather than `root`

If you must use `setuid` to access a group of files, consider making a new, non-`root` user for that purpose, and `setuid` to it.

Limit `setuid` code as much as possible

Make the amount of `setuid` code as small as you can. Move it into a separate program, and invoke that from within a larger script when necessary. However, be sure to code defensively as if the script can be invoked by anyone from anywhere else!

Chet Ramey, the maintainer of `bash`, offers the following prolog for use in shell scripts that need to be more secure:

```
# Reset IFS. Even though ksh doesn't import IFS from the environment,
# $ENV could set it. This uses special bash and ksh93 notation,
# not in POSIX.
IFS=$' \t\n'

# Make sure unalias is not a function, since it's a regular built-in.
# unset is a special built-in, so it will be found before functions.
```

```
unset -f unalias

# Unset all aliases and quote unalias so it's not alias-expanded.
\unalias -a

# Make sure command is not a function, since it's a regular built-in.
# unset is a special built-in, so it will be found before functions.
unset -f command

# Get a reliable path prefix, handling case where getconf is not
# available.
SYSPATH="$(command -p getconf PATH 2>/dev/null)"

if [[ -z "$SYSPATH" ]]; then
    SYSPATH="/usr/bin:/bin"           # pick your poison
fi

PATH="$SYSPATH:$PATH"
```

This code uses several non-POSIX extensions, all of which are described in [Section 14.3](#).

15.2. Restricted Shell

A *restricted shell* is designed to put the user into an environment where the ability to move around and write files is severely limited. It's usually used for guest accounts. POSIX does not specify that environments provide a restricted shell, "because it does not provide the level of security restriction that is implied by historical documentation." Nevertheless, both *ksh93* and *bash* do provide this facility. We describe it here for both of them.

When invoked as *rksh* (or with the *-r* option), *ksh93* acts as a restricted shell. You can make a user's login shell restricted by putting the full pathname to *rksh* in the user's */etc/passwd* entry. The *ksh93* executable file must have a link to it named *rksh* for this to work.

The specific constraints imposed by the restricted *ksh93* disallow the user from doing the things described in the following list. Some of these features are specific to *ksh93*; for more information see *Learning the Korn Shell*.

- Changing working directories: *cd* is inoperative. If you try to use it, you will get the error message `ksh: cd: restricted.`
- Redirecting output to a file: the redirectors `>`, `>|`, `<>`, and `>>` are not allowed. This includes using *exec*.
- Assigning a new value to the environment variables `ENV`, `FPATH`, `PATH`, or `SHELL`, or trying to change their attributes with *typeset*.
- Specifying any pathnames of commands with slashes (`/`) in them. The shell only runs commands found along `$PATH`.
- Adding new built-in commands with the *builtin* command.

Similar to *ksh93*, when invoked as *rbash*, *bash* acts as a restricted shell, and the *bash* executable file must have a link to it named *rbash* for this to work. The list of restricted operations for *bash* (taken from the *bash(1)* manpage) is similar to those for *ksh93*. Here too, some of the features mentioned here are specific to *bash* and haven't been covered in this book. For more information, see the *bash(1)* manpage:

- Changing directories with *cd*
- Setting or unsetting the values of `SHELL`, `PATH`, `ENV`, or `BASH_ENV`

- Specifying command names containing /
- Specifying a filename containing a / as an argument to the . (dot) built-in command
- Specifying a filename containing a / as an argument to the -p option to the hash built-in command
- Importing function definitions from the shell environment at startup
- Parsing the value of SHELLOPTS from the shell environment at startup
- Redirecting output using the >, >|, <>, >&, &>, and >> redirection operators
- Using the exec built-in command to replace the shell with another command
- Adding or deleting built-in commands with the -f and -d options to the enable built-in command
- Using the enable built-in command to enable disabled shell built-in commands
- Specifying the -p option to the command built-in command
- Turning off restricted mode with set +r or set +o restricted

For both shells, these restrictions go into effect *after* the user's `.profile` and environment files are run. This means that the restricted shell user's entire environment is set up in `.profile`. This lets the system administrator configure the environment as she sees fit.

To keep the user from overwriting `~/ .profile`, it is not enough to make the file read-only by the user. Either the home directory should *not* be writable by the user, or the commands in `~/ .profile` should `cd` to a different directory.

Two common ways of setting up such environments are to set up a directory of "safe" commands and have that directory be the only one in `PATH`, and to set up a command menu from which the user can't escape without exiting the shell. In any case, make sure that there is no other shell in any directory listed in `$PATH`; otherwise, the user can just run that shell and avoid the restrictions listed earlier. Also make sure that there isn't any program in `$PATH` that allows the user to start a shell, such as a "shell escape" from the `ed`, `ex`, or `vi` text editors.

Although the ability to restrict the shell has been available (if not necessarily compiled in or documented) since the original Version 7 Bourne shell, it is rarely used. Setting up a usable yet correctly restricted environment is difficult in practice. So, caveat emptor.

15.3. Trojan Horses

A *Trojan horse* is something that looks harmless, or even useful, but that contains a hidden danger.

Consider the following scenario. User John Q. Programmer (login name `jprog`) is an excellent programmer, and he has quite a collection of personal programs in `~jprog/bin`. This directory occurs first in the `PATH` variable in `~jprog/.profile`. Since he is such a good programmer, management recently promoted him to system administrator.

This is a whole new field of endeavor, and John-not knowing any better-has unfortunately left his `bin` directory writable by other users. Along comes W.M. Badguy, who creates the following shell script, named `grep`, in John's `bin` directory:

```
/bin/grep "$@"

case $(whoami) in
    root)    nasty stuff here           Danger Will Robinson, danger!
            rm ~/jprog/bin/grep        Hide the evidence
            ;;
esac
```

In and of itself, this script can do no damage when `jprog` is working *as himself*. The problem comes when `jprog` uses the `su` command. This command allows a regular user to "switch user" to a different user. By default, it allows a regular user to become `root` (as long as that user knows the password, of course). The problem is that normally, `su` uses whatever `PATH` it inherits.^[2] In this case, `$PATH` includes `~jprog/bin`. Now, when `jprog`, working as `root`, runs `grep`, he actually executes the Trojan horse version in his `bin`. This version runs the real `grep`, so `jprog` gets the results he expects. More importantly, it also silently executes the *nasty stuff here* part, as `root`. This means that Unix will let the script do anything it wants to. *Anything*. And to make things worse, by removing the Trojan horse when it's done, there's no longer any evidence.

^[2] Get in the habit of using `su - user` to switch to `user` as if the user were doing a real login. This prevents import of the existing `PATH`.

Writable `bin` directories open one door for Trojan horses, as does having dot in `PATH`. (Consider what

happens if `root` does a `cd` to a directory containing a Trojan script, and dot is in `root`'s `PATH` *before* the system directories!) Having writable shell scripts in any `bin` directory is another door. Just as you close and lock the doors of your house at night, you should make sure that you close any doors on your system!



15.4. Setuid Shell Scripts: A Bad Idea

Many problems with Unix security hinge on a Unix file attribute called the *setuid* (set user ID) bit. This is a special permission bit: when an executable file has it turned on, the file runs with an effective user ID equal to the owner of the file. The effective user ID is distinct from the real user ID of the process, and Unix applies its permission tests to the process's effective user ID.

For example, suppose that you've written a really nifty game program that keeps a private score file showing the top 15 players on your system. You don't want to make the score file world-writable because anyone could just come along and edit the file to make themselves the high scorer. By making your game setuid to your user ID, the game program can update the file, which you own, but no one else can update it. (The game program can determine who ran it by looking at its real user ID, and using that to determine the login name.)

The setuid facility is a nice feature for games and score files, but it becomes much more dangerous when used for *root*. Making programs setuid *root* lets administrators write programs that do certain things that require *root* privilege (e.g., configure printers) in a controlled way. To set a file's setuid bit, type `chmod u+s filename`. Setuid is dangerous when *root* owns the file; thus `chown root file` followed by `chmod u+s file` is the problem.

A similar facility exists at the group level, known (not surprisingly) as *setgid* (set group ID). Use `chmod g+s filename` to turn on setgid permissions. When you do an `ls -l` on a setuid or setgid file, the *x* in the permission mode is replaced with an *s*; for example, `-rws--s--x` for a file that is readable and writable by the owner, executable by everyone, and has both the setuid and setgid bits set (octal mode 6711).

Modern system administration wisdom says that creating setuid and setgid shell scripts is a terrible idea. This has been especially true under the C shell because its `.cshrc` environment file introduces numerous opportunities for break-ins. In particular, there are multiple ways of tricking a setuid shell script into becoming an *interactive* shell with an effective user ID of *root*. This is about the best thing a *cracker* could hope for: the ability to run any command as *root*. Here is one example, borrowed from the discussion in <http://www.faqs.org/faqs/unix-faq/faq/part4/section-7.html>:

... Well, suppose that the script is called `/etc/setuid_script`, starting with:

```
#!/bin/sh
```

Now let us see what happens if we issue the following commands:


```
$ cd /tmp
$ ln /etc/setuid_script -i
$ PATH=.
$ -i
```

We know the last command will be rearranged to:

```
/bin/sh -i
```

However, this command will give us an interactive shell, setuid to the owner of the script! Fortunately, this security hole can easily be closed by making the first line:

```
#!/bin/sh -
```

The `-` signals the end of the option list: the next argument `-i` will be taken as the name of the file to read commands from, just like it should!

Because of this, POSIX explicitly permits the single `-` character to end the options for `/bin/sh`.

There is an important difference between a setuid shell script, and a *setuid shell*. The latter is a copy of the shell executable, which has been made to belong to `root` and had the setuid bit applied. In the previous section on Trojan horses, suppose that the *nasty stuff here* was this code:

```
cp /bin/sh ~badguy/bin/myls
chown root ~badguy/bin/myls
chmod u+s ~badguy/bin/myls
```

Remember, this code executes as `root`, so it will work. When `badguy` executes `myls`, it's a machine-code executable file, and the setuid bit *is* honored. Hello shell that runs as `root`. Goodbye security!

In fact, the dangers of setuid and setgid shell scripts are so great that modern Unix systems, meaning both commercial Unix systems and freeware clones (4.4 BSD-derived and GNU/Linux), disable the setuid and setgid bits on shell scripts. Even if you apply the bits to the file, the operating system does not

honor them.^[3]

^[3] Mac OS X and at least one version of OpenBSD that we tried seem to be notable exceptions. Be extra careful if you run one or more such systems! We found that Solaris 9 honors the setuid bit only if `root` is *not* the owner of the file.

We also note that many modern systems have options to the `mount` command that disable the setuid/setgid bit for entire filesystems. This can be a good idea for network-mounted filesystems, as well as for removable media such as floppy disks and CD-ROMs.



< Day Day Up >

15.5. ksh93 and Privileged Mode

The Korn shell's *privileged mode* was designed to protect against setuid shell scripts. This is a `set -o` option (`set -o privileged` or `set -p`), but the shell enters it automatically whenever it executes a script whose setuid bit is set; i.e., when the effective user ID is different from the real user ID.

In privileged mode, when a setuid Korn shell script is invoked, the shell runs the file `/etc/suid_profile`. This file should be written to restrict setuid shell scripts in much the same way as the restricted shell does. At a minimum, it should make `PATH` read-only (`typeset -r PATH` or `readonly PATH`) and set it to one or more "safe" directories. Once again, this prevents any decoys from being invoked.

Since privileged mode is an option, it is possible to turn it off with the command `set +o privileged` (or `set +p`). However, this doesn't help the potential system cracker: the shell automatically changes its effective user ID to be the same as the real user ID-i.e., if you turn off privileged mode, you also turn off setuid.

In addition to privileged mode, *ksh* provides a special "agent" program, `/etc/suid_exec`, that runs setuid shell scripts (or shell scripts that are executable but not readable).

For this to work, the script should *not* start with `#!/bin/ksh`. When the program is invoked, *ksh* attempts to run the program as a regular binary executable. When the operating system fails to run the script (because it isn't binary, and because it doesn't have the name of an interpreter specified with `#!`), *ksh* realizes that it's a script, and invokes `/etc/suid_exec` with the name of the script and its arguments. It also arranges to pass an authentication "token" to `/etc/suid_exec`, indicating the real and effective user and group IDs of the script. `/etc/suid_exec` verifies that it is safe to run the script and then arranges to invoke *ksh* with the proper real and effective user and group IDs on the script.

Although the combination of privileged mode and `/etc/suid_exec` allows you to avoid many of the attacks on setuid scripts, writing scripts that safely can be run setuid is a difficult art, requiring a fair amount of knowledge and experience. It should be done carefully.

Although setuid shell scripts don't work on modern systems, there are occasions when privileged mode is still useful. In particular, there is a widely used third-party program named *sudo*, which, to quote the web page, allows a system administrator to give certain users (or groups of users) the ability to run some (or all) commands as `root` or another user while logging the commands and arguments. The home page for *sudo* is <http://www.courtesan.com/sudo>. A system administrator could easily execute `sudo /bin/ksh -p` in order to get a known environment for performing administrative tasks.



15.6. Summary

Writing secure shell scripts is just one part of keeping a Unix system secure. This chapter merely scratches the surface of the issues involved, and we recommend reading up on Unix system security. As a beginning, we presented a list of tips for writing secure shell scripts provided by a recognized expert in the field of Unix security.

We then described restricted shells, which disable a number of potentially dangerous operations. The environment for a restricted shell should be built within the user's `.profile` file, which is executed when a restricted user logs in. In practice, restricted shells are difficult to set up correctly and use, and we recommend finding a different way to set up restricted environments.

Trojan horses are programs that look harmless but that actually perform an attack on your system. We looked at some of the ways that Trojan horses can be created, but there are others.

Setuid shell scripts are a bad idea, and just about all modern Unix systems disallow them, since it's very difficult to close the security holes they open up. It is worth verifying, however, that your system does indeed disallow them, and if not, to periodically search your system for such files.

Finally, we looked briefly at the Korn shell's privileged mode, which attempts to solve many of the security issues associated with shell scripts.

Appendix A. Writing Manual Pages

Users of programs require documentation, and the programs' authors do too, if they haven't used the software recently. Regrettably, software documentation is neglected in most computer books, so even users who want to write good documentation for their programs often don't know how, or even where, to begin. This appendix helps to remedy that deficiency.

In Unix, brief programming documentation has traditionally been supplied in the form of manual pages, written in *nroff/troff*^[1] markup, and displayed as simple ASCII text with `man`, `nroff -man`, or `groff -man`, typeset for some device `xxx` with `ditroff -man -Txxx`, `groff -man -Txxx`, or `troff -man -Txxx`, or viewed in an X window in typeset form with `groff -TX -man`.

[1] Although *nroff* was developed before *troff*, from the user's point of view, both systems are similar: *ditroff* and *groff* each emulate both of them.

Longer software documentation has historically been provided as manuals or technical reports, often in *troff* markup, with printed pages in PostScript or PDF form. *troff* markup is definitely not user-friendly, however, so the GNU Project chose a different approach: the Texinfo documentation system.^[2] Texinfo markup is considerably higher-level than common *troff* packages, and like *troff*, allows documents to be prepared both for viewing as simple ASCII text, as well as typeset by the TEX typesetting system.^[3] Most importantly, it supports hypertext links to allow much better navigation through online documentation.

[2] See Robert J. Chassell and Richard M. Stallman, *Texinfo: The GNU Documentation Format*, Free Software Foundation, 1999, ISBN 1-882114-67-1.

[3] See Donald E. Knuth, *The TEXbook*, Addison-Wesley, 1984, ISBN 0-201-13448-9.

Most documentation that you read online in Unix systems probably has been marked up for either *troff*^[4] or Texinfo.^[5] The *makeinfo* program from the Texinfo system can produce output in ASCII, HTML, XML, and DocBook/XML. Texinfo files can be typeset directly by TEX, which outputs a device-independent (DVI) file that can be translated into a wide variety of device formats by back-end programs called DVI drivers.

[4] See <http://www.troff.org/>.

[5] See <http://www.gnu.org/software/texinfo/>.

These are not the only markup formats, however. Sun Microsystems from Solaris 7 ships almost all of its manual pages in SGML form, and the Linux Documentation Project^[6] promotes XML (an SGML subset) markup to facilitate its goal of translating GNU/Linux documentation into many of the world's

human languages.

[6] See <http://www.tldp.org/>.

So, what markup system should a Unix program author adopt? Experience has definitely shown that high-level markup, even if more verbose, has great value. SGML (and thus, HTML and XML) is based on rigorous grammars, so it is possible to validate the logical structure of documents before compiling them into displayable pages. With sufficiently detailed markup, SGML documents can be translated reliably into other markup systems, and indeed, several book and journal publishers today do just that: authors submit material in any of several formats, publishers convert it to SGML, and then use *troff*, TEX, or some other typesetting system at the back end to produce printer-ready pages.

Unfortunately, the SGML software toolbox is still pretty deficient and not widely standardized, so the best choice for maximum software document portability is still likely to be either *troff* or Texinfo markup, and for manual pages, the format has to be *troff*, if the *man* command is to work everywhere.

Ultimately, one would like to be able to do reliable automated transformations between any pair of markup systems, but that goal remains elusive. What you *can* do today, however, is write manual pages in a restricted subset of *troff* markup, and have them converted automatically to HTML and Texinfo. To do so, you need two easily installable packages, *man2html* and *man2texi*.^[7]

[7] Available at <http://www.math.utah.edu/pub/man2html/> and <http://www.math.utah.edu/pub/man2texi/>.

A.1. Manual Pages for pathfind

Even though complete documentation for markup systems fills one or more books, you can get by quite nicely with a small, well-learned *troff* subset that we present here. We show it step by step, as a semiliterate document to accompany the *pathfind* program from Section 8.1, and then collect the pieces into the complete manual-page file shown in Example A-1.

Before we begin, some explanatory remarks about *nroff* /*troff* markup are in order. *nroff* was built on the lessons learned from earlier formatting systems, such as DEC's *runoff*, and produced output for ASCII printing devices. When Bell Labs had a phototypesetter, a new program, *troff*, was created to produce typeset pages. *troff* was one of the earliest systems for computer-based typesetting. Both programs accept the same input, so from now on, when we say *troff*, we mean *nroff*.

Early Unix systems ran on small-memory minicomputers, and those severe constraints cramped the design. Like many Unix commands, *troff* commands are short and cryptic. Most appear at the beginning of a line, followed by one or two letters or digits. The font choice is limited: just roman, bold, italic, and later, fixed-width, in a few sizes. Unlike later systems, in *troff* documents, spaces and blank lines are *significant*: two input spaces (approximately) two output spaces. That fact, plus the command position, prevent indentation and spacing from making input more readable.

However, the simple command format makes it easy to parse *troff* documents, at least superficially, and several processors have been developed that provide for easy specification of equations, graphs, pictures, and tables. Some processors take a *troff* data stream, and output a slightly augmented one.

While the full *troff* command repertoire is large, the manual-page style, selected by the *-man* option, has only a few features. No frontend processors are required, so there are no equations or pictures in manual pages, and tables are rare.

A manual-page document has a simple layout, with a half-dozen standard top-level section headings, interspersed with formatted paragraphs of text, and occasionally, indented, and often labeled, blocks. You've seen that layout used by the *man* command.

Examination of manual pages from a broad range of historical and current sources shows considerable style variation. It is to be expected when the markup is visual, rather than logical. Our font choices therefore should be taken as *recommendations*, rather than as rigid requirements.

It's now time to get started writing the manual page for *pathfind*, which is simple enough that the text does not need much markup.

We begin with a comment statement, since every computer language should have one: *troff* comments begin with a `%` character, followed by a quote and continue up to, but not including, end-of-line. However, when they follow an initial dot, their line

disappears from the output as well:

```
.\" = = = = = = = = = = = = = = = = = = = = = = = = = = =
= =
= = = = = = = = = = = = = = = = = = = = = = = = = = =
```

Because *troff* input cannot be indented, it looks awfully dense. We find that a comment line of equals signs headings makes them much easier to spot, and we often use comparatively short input lines.

Every manual-page document starts with a *Text Header* command (`.TH`) containing up to four arguments: a command name, a manual section number (1 [digit one] for user commands), and optionally, a revision date and number. These arguments are used to construct the running page headers and footers in the formatted output.

```
.TH PATHFIND 1 "" "1.00"
```

The *Section Heading* command (`.SH`) takes a single argument, quoted if it contains spaces, and uppercases the argument to conform to manual page conventions:

```
.\" = = = = = = = = = = = = = = = = = = = = = = = = = = =
= = = = = = = = = = = = = = = = = = = = = = = = = = =
.SH NAME
```

The body of the NAME section provides fodder for the *apropos* (or equivalently, *man -k*) command, and is one line long, without trailing punctuation. It takes the form `command -- description:`

```
pathfind \(\em find files in a directory path
```

The markup `\(\em` is one of the few inline *troff* commands seen in manual pages: it stands for an em dash, a dash about the width of the letter m. One space precedes and follows the em dash. Older manual pages often use just `-`, but an em dash is conventional in English-language typography.

The second section gives a brief synopsis of the command line that invokes the program. It begins with the

```
.\" = = = = = = = = = = = = = = = = = = = = = = = = = = =
= = = = = = = = = = = = = = = = = = = = = = = = = = =
.SH SYNOPSIS
```

and is followed with a sometimes lengthy markup display that provides mostly font information:

```
.B pathfind
[
.B \-\^\-all
]
[
.B \-\^\-?
]
[
.B \-\^\-help
]
[
.B \-\^\-version
]
```

The option hyphen is marked with `\-` to get a minus sign, which looks better typeset than the shorter ordinary hyphen. We use the half-narrow space command, `\^`, to prevent the hyphens from running together in *troff* output. The program name, and options, are set in a bold font. The font-switching commands, such as `.B`, take up to six arguments (quoted if they contain spaces), and then typeset them adjacent to one another. When there are multiple arguments, this means that any spacing needed must be explicitly supplied. Here, the square brackets are in a bold font; in manual pages, they delimit optional values. Although we could have put the closing and opening brackets for consecutive options on the same line, we prefer not to because having each option complete on three consecutive lines facilitates editing. The font-pair commands to be introduced shortly could shrink them to a single line, but that is not done in option lists.

Despite the line breaks, *troff* is still typesetting in filled-paragraph mode, so everything so far fits on one line. However, we find that the *nroff* ASCII output has a line break after the `-version` option, but since we are in paragraph mode, the line continues at the left margin. That is objectionable here, so we put in a conditional statement that applies only when *troff* is not used. It uses the *temporary indentation* command (`.ti`) with an argument of `+9n`, meaning that the following text is indented by nine lines.


```
.B \-^\-version
```

are equivalent.

That fragment exhibits a new feature: the font-pair command (`.BR`), which sets its arguments alternately in text, *without* intervening space. There are similar commands `.IR` and `.RI` for the italic-roman pair, `.IB` and italic pair, and of course, `.RB` for the mate of the one that we used. There are no analogues for the fixed-width got added later (the original Bell Labs typesetter lacked that font); you have to use `\fC... \fP` instead.

It is now time for a paragraph break:

```
.PP
```

In *nroff* output, a blank line and a paragraph break are identical, but *troff* uses less vertical space for a paragraph considered good form to use `.PP` between paragraphs; in general, manual-page input files should never cor

The next paragraph follows:

To avoid confusion with options, if a filename begins with a hyphen, it must be disguised by a leading absolute or relative directory path, e.g.,

```
.I /tmp/-foo
```

or

```
.IR ./-foo .
```

We are now ready for the option descriptions. Their markup is about the most complex that is used in manual pages, but it becomes familiar. Essentially, we want to have labeled indented paragraphs, with the label normally set at the beginning of the paragraph line. More recent markup systems would structure this as a list of items: `begin-option-list`, `begin-option`, `end-option`, and so on, ending with `end-option-list`. The manual-page markup doesn't quite do that; the items, and they end at the next paragraph break (`.PP`) or section heading (`.SH`).

The command to start an item (`.TP`) takes an optional width argument that sets the indentation of the description from the left margin. If the argument is omitted, a default indentation is used. If a label is longer than the indentation, the line is started immediately after the label. The paragraph indentation remains in effect for subsequent `.TP` commands; the first in the option list needs it. As with the indentation of a wrapped command line in the SYNOPSIS section, we use dynamic indentation that depends on the length of the longest option name. Also, since we have several options, we set them off with a comment line of dashes:


```
.\" -----
.TP  \w'\fB\-\^\-version\fP'u+3n
```

The line following the `.TP` command provides the item label:

```
.B \-all
```

The label is followed by the option description:

Search all directories for each specified file, instead of reporting just the first instance of each found in the search path.

If the description needs a paragraph break, use the *Indented Paragraph* command (`.IP`) instead of the ordinary break command (`.PP`), so as not to terminate the list. This manual page is short enough that we don't require

The remaining option descriptions require no new markup, so here they are, completing the options section

```
.\" -----
.TP
.B \-?
```

Same as

```
.BR \-help .
```

```
.\" -----
.TP
.B \-help
```

Display a brief help message on

```
.IR stdout ,
```

giving a usage description, and then terminate immediately with a success return code.

.\" -----

.TP

.B \-version

Display the program version number and release date on

.IR stdout ,

and then terminate immediately with a success return code.

The fourth manual-page section is the program description. It can be as long as you like: the shell's runs on Nevertheless, brevity is desirable, since manual pages are consulted often. *pathfind* is simple enough that it suffice. The first two have markup that should be familiar by now:

.\" =
= =

.SH DESCRIPTION

.B pathfind

searches a colon-separated directory search path defined by

the value of the environment variable, `\fIenvvar\fP`, for

specified files or file patterns, reporting their full path on

.IR stdout ,

or complaining `\fIfilename: not found\fP` on

.I stderr

if a file cannot be found anywhere in the search path.

.PP

.BR pathfind 's

exit status is 0 on success, and otherwise is the number of

files that could not be found, possibly capped at the exit code limit of 125.

.PP

The last bit of manual-page markup that we need to know shows up in the last paragraph, where we want to lines in a fixed-width font indicative of computer input and output, without the normal paragraph filling. This is similar to what we have seen before, `\fC...\fP`. We prefix it with a *troff* no-op command, `\&`, when it appears at the beginning of the line, because that no-op is necessary when the text that follows begins with a period. It does not follow the general rules are easier to remember than special cases. We want the computer samples to be indented, so we use an indented region bounded by *Begin Right Shift* (`.RS`) and *End Right Shift* (`.RE`) commands. Furthermore, we want to suppress paragraph filling, so we surround the text with *no fill* (`.nf`) and *fill* (`.fi`) commands:

For example,

.RS

.nf

\&\fCpathfind PATH ls\fP

.fi

.RE

reports

.RS

.nf

\&\fC/bin/ls\fP

.fi

.RE

on most Unix systems, and

.RS

.nf

\&\fCpathfind --all PATH gcc g++\fP

.fi

.RE

reports

.RS

.nf

\&\fC/usr/local/bin/gcc

/usr/bin/gcc

/usr/local/gnat/bin/gcc

/usr/local/bin/g++

/usr/bin/g++\fP

.fi

.RE

on some systems.

.PP

Wildcard patterns also work:

.RS

.nf

\&\fCpathfind --all PATH '??tex'\fP

.fi

.RE

reports

.RS

.nf


```
\&\fC/usr/local/bin/detex
```

```
/usr/local/bin/dotex
```

```
/usr/local/bin/latex
```

```
/usr/bin/latex\fp
```

```
.fi
```

```
.RE
```

on some systems.

The final section provides cross references to other related commands; this information can be extremely useful if it is important to do a thorough job of it. Its format is simple: just a single paragraph of alphabetically ordered names with parenthesized manual section numbers, separated by commas, and ending with a period:

```
.\" = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
.SH "SEE ALSO"
.BR find (1),
.BR locate (1),
.BR slocate (1),
.BR type (1),
.BR whence (1),
.BR where (1),
.BR whereis (1).
```

```
.\" = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
= = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = = =
```

We've introduced almost all of the markup that is required for virtually any manual page. The only significant

Subsection Heading command (`.SS`), but it is comparatively rare, showing up only in long manual-page files. The `.SH` command, but uses a somewhat smaller font in the typeset output. There is no visible difference in output from `nroff`. Two other inline commands that are occasionally needed are `.\|.\|` for an ellipsis (...), and `\L` often used as the label in a list of labeled paragraphs, like this:

```
.TP  \w' \ (bu 'u+2n  
  
\ (bu
```

We have now examined the anatomy of a manual page. The complete `troff` input for our example is collected in Figure A-1, and the typeset output (from `groff -man`, which produces PostScript by default) is shown as a half-size page in Figure A-2. With our description as a guide, you should be ready to document your own programs in manual pages.

Figure A-1. Typeset manual-page markup for pathfind

Example A-1. troff manual-page markup for pathfind

```
.\| = = = = = = = = = = = = = = = = = = = = = = = = = = = = =  
= = = = = = = = = = = = = = = = = = = = = = = = = = = = =
```

.TH PATHFIND 1 "" "1.00"

.\" =
= =

.SH NAME

pathfind \(\em find files in a directory path

.\" =
= =

.SH SYNOPSIS

.B pathfind

[

.B \-\^\-all

]

[

.B \-\^\-?

]

[

.B \-\^\-help

]

[

.B \-\^\-version

]

.if n .ti +9n

.\" .if t .ti +\w'\fBpathfind\fP\ 'u

reporting just the first instance of each found in the search path.

.\ " -----

.TP

.B \-?

Same as

.BR \-help .

.\ " -----

.TP

.B \-help

Display a brief help message on

.IR stdout ,

giving a usage description, and then terminate immediately with a success return code.

.\ " -----

.TP

.B \-version

Display the program version number and release date on

.IR stdout ,

and then terminate immediately with a success return code.

.\ " =

= =

.SH DESCRIPTION

`.B pathfind`

searches a colon-separated directory search path defined by the value of the environment variable, `\fIenvvar\fP`, for specified files or file patterns, reporting their full path on

`.IR stdout ,`

or complaining `\fIfilename: not found\fP` on

`.I stderr`

if a file cannot be found anywhere in the search path.

`.PP`

`.BR pathfind 's`

exit status is 0 on success, and otherwise is the number of files that could not be found, possibly capped at the exit code limit of 125.

`.PP`

For example,

`.RS`

`.nf`

`\&\fCpathfind PATH ls\fP`

`.fi`

`.RE`

reports

`.RS`

`.nf`

```
\&\fC/bin/ls\fP
```

```
.fi
```

```
.RE
```

on most Unix systems, and

```
.RS
```

```
.nf
```

```
\&\fCpathfind --all PATH gcc g++\fP
```

```
.fi
```

```
.RE
```

reports

```
.RS
```

```
.nf
```

```
\&\fC/usr/local/bin/gcc
```

```
/usr/bin/gcc
```

```
/usr/local/gnat/bin/gcc
```

```
/usr/local/bin/g++
```

```
/usr/bin/g++\fP
```

```
.fi
```

```
.RE
```

on some systems.

```
.PP
```

Wildcard patterns also work:

```
.RS
```

.nf

\&\fCpathfind --all PATH '??tex'\fP

.fi

.RE

reports

.RS

.nf

\&\fC/usr/local/bin/detex

/usr/local/bin/dotex

/usr/local/bin/latex

/usr/bin/latex\fP

.fi

.RE

on some systems.

.\ " =

= =

.SH "SEE ALSO"

.BR find (1),

.BR locate (1),

.BR slocate (1),

.BR type (1),

.BR whence (1),

.BR where (1),

A.2. Manual-Page Syntax Checking

Checking correct formatting of manual pages is usually done visually, with printed output from either of these commands:

```
groff -man -Tps pathfind.man | lp
```

```
troff -man -Tpost pathfind.man | /usr/lib/lp/postscript/dpost | lp
```

or on the screen as ASCII or typeset material, with commands like this:

```
nroff -man pathfind.man | col | more
```

```
groff -man -Tascii pathfind.man | more
```

```
groff -man -TX100 pathfind.man &
```

The *col* command handles certain special escape sequences that *nroff* generates for horizontal and vertical motion. *col* is not needed for *groff* output.

Some Unix systems have a simple-minded syntax checker, *checknr*; the command:

```
checknr pathfind.man
```

produces no complaints on our systems. *checknr* is good at catching font mismatches, but knows little about the manual-page format.

Most Unix systems have *deroff*, which is a simple filter that strips *troff* markup. You can do a spellcheck like this:

```
deroff pathfind.man | spell
```

to avoid lots of complaints from the spellchecker about *troff* markup. Other handy tools for catching hard-to-spot errors in documentation are a doubled-word finder^[8] and a delimiter-balance checker.^[9]

[8] Available at <http://www.math.utah.edu/pub/dw/>.

[9] Available at <http://www.math.utah.edu/pub/chkdelim/>.



A.3. Manual-Page Format Conversion

Conversion to HTML, Texinfo, Info, XML, and DVI files is simple:

```
man2html pathfind.man
```

```
man2texi --batch pathfind.man
```

```
makeinfo pathfind.texi
```

```
makeinfo --xml pathfind.texi
```

```
tex pathfind.texi
```

We don't show the output `.html`, `.texi`, `.info`, and `.xml` files here because of their length. If you are curious, make them yourself and peek inside them to get an idea of what those markup formats look like.

A.4. Manual-Page Installation

Historically, the *man* command expected to find manual pages in subdirectories of a search path defined by the environment variable `MANPATH`, typically something like `/usr/man:/usr/local/man`.

Some recent *man* versions simply assume that each directory in the program search path, `PATH`, can be suffixed with the string `../man` to identify a companion manual-page directory, eliminating the need for `MANPATH`.

In each manual-page directory, it is common to find pairs of subdirectories prefixed `man` and `cat` and suffixed with the section number. Within each subdirectory, filenames are also suffixed by the section number. Thus, `/usr/man/man1/ls.1` is the *troff* file that documents the *ls* command, and `/usr/man/cat1/ls.1` holds *nroff*'s formatted output. *man* use the latter, when it exists, to avoid rerunning the formatter unnecessarily.

While some vendors have since adopted quite different organization of the manual-page trees, their *man* implementations still recognize the historical practice. Thus, installation of most GNU software puts executables in `$prefix/bin` and manual pages in `$prefix/man/man1`, where `prefix` defaults to `/usr/local`, and that seems to work nicely everywhere.

System managers normally arrange to run *catman* or *makewhatis* at regular intervals to update a file containing the one-line descriptions from the manual-page `NAME` sections. That file is used by the *apropos*, *man -k*, and *whatis* commands to provide a simple index of manual pages. If that doesn't turn up what you're looking for, then you may have to resort to a full-text search with *grep*.

Appendix B. Files and Filesystems

Effective use of computers requires an understanding of files and filesystems. This appendix presents an overview of the important features of Unix filesystems: what a file is, how files are named and what they contain, how they are grouped into a filesystem hierarchy, and what properties they have.

B.1. What Is a File?

Simply put, a file is a collection of data that resides in a computer system, and that can be referenced as a single entity from a computer program. Files provide a mechanism for data storage that survives process execution, and generally, restarts of the computer.^[1]

^[1] Some systems offer special fast filesystems that reside in central *random-access memory (RAM)*, allowing temporary files to be shared between processes. With common RAM technologies, such filesystems require a constant electrical supply, and thus are generally created anew on system restart. However, some *embedded computer systems* use nonvolatile RAM to provide a long-term filesystem.

In the early days of computers, files were external to the computer system: they usually resided on magnetic tape, paper tape, or punched cards. Their management was left up to their owner, who was expected to try very hard not to drop a stack of punched cards on the floor!

Later, magnetic disks became common, and their physical size decreased sharply, from as large as the span of your arms, to some as small as the width of your thumb, while their capacity increased by several orders of magnitude, from about 5MB in the mid-1950s to about 400,000MB in 2004. Costs and access times have dropped by at least three orders of magnitude. Today, there are about as many magnetic disks in existence as there are humans.

Optical storage devices, such as CD-ROMs and DVDs, are inexpensive and capacious: in the 1990s, CD-ROMs largely replaced removable flexible magnetic disks (floppies) and tapes for commercial software distribution.

Nonvolatile solid-state storage devices are also available; they may eventually replace devices that have moving mechanical parts, which wear out and fail. However, at the time of this writing, they remain considerably more expensive than alternatives, have lower capacity, and can be rewritten only a limited number of times.

B.2. How Are Files Named?

Early computer operating systems did not name files: files were submitted by their owners for processing, time by human computer operators. It soon became evident that something better was needed if file processing files need names that humans can use to classify and manage them, and that computers can use to identify

Once we can assign names to files, we soon discover the need to handle *name collisions* that arise when the two or more different files. Modern filesystems solve this problem by grouping sets of uniquely named files called *directories*, or *folders*. We look at these in Section B.4 later in this Appendix.

We name files using *characters* from the host operating system's character set. In the early days of computer variation in character sets, but the need to exchange data between unlike systems made it evident that stand-

In 1963, the *American Standards Association* ^[2] proposed a 7-bit character set with the ponderous name *American Information Interchange*, thankfully known ever since by its initial letters, ASCII (pronounced *ask-ee*). See representation of $2^7 = 128$ different characters, which is sufficient to handle uppercase and lowercase letters and digits, and a couple of dozen special symbols and punctuation characters, including space, with 33 left over. The latter have no assigned printable graphic representation. Some of them serve for marking line and page specialized uses. ASCII is supported on virtually all computer systems today. For a view of the ASCII character set, see `man ascii`.

^[2] Later renamed the *American National Standards Institute* (ANSI).

ASCII, however, is inadequate for representing text in most of the world's languages: its character repertoire is limited to 128 characters. Most computer systems now use 8-bit bytes as the smallest addressable unit of storage, and since that byte size is 256 characters, systems designers acted quickly to populate the upper half of that 256-element set, leaving ASCII characters unused. Unfortunately, they weren't guided by international standards, so hundreds of different assignments of various characters were made into use; they are sometimes known as *code pages*. Even a single set of 128 additional character slots does not cover all the languages of Europe, so the *International Organization for Standardization* (ISO) has developed a family of standards: ISO 8859-1,^[3] ISO 8859-2, ISO 8859-3, and so on.

^[3] Search the ISO Standards catalog at <http://www.iso.ch/iso/en/CatalogueListPage.CatalogueList>.

In the 1990s, collaborative efforts were begun to develop the ultimate single universal character set, known as Unicode. Unicode eventually require about 21 bits per character, but current implementations in several operating systems use only 16 bits. To use a variable-byte-width encoding called *UTF-8* ^[5] that permits existing ASCII files to be valid Unicode files.

^[4] *The Unicode Standard, Version 4.0*, Addison-Wesley, 2003, ISBN 0-321-18578-1.

^[5] See *RFC 2279: UTF-8, a transformation format of ISO 10646*, available at <ftp://ftp.internic.net/rfc/rfc2279.txt>.

The point of this digression into character sets is this: with the sole exception of the IBM mainframe *EBCDIC* current ones include the ASCII characters in the lower 128 slots. Thus, by voluntarily restricting filenames make it much more likely that the names are usable everywhere. The existence of the Internet and the World Wide Web provides evidence that files are exchanged across unlike systems; even though they can always be renamed to match, this increases the human maintenance task to do so.

[6] EBCDIC = Extended Binary-Coded Decimal Interchange Code, pronounced *eb-see-dick* , or *eb-kih-dick* , an 8-bit character set used by the IBM System/360 in 1964, containing the old 6-bit IBM BCD set as a subset. System/360, and its descendants, is by far the longest-lived architecture in history, and much of the world's business uses it. IBM supports a superb GNU/Linux implementation on it, use <http://www.ibm.com/linux/> .

The designers of the original Unix filesystem chose to permit all but *two* characters from a 256-element set: the control character NUL (the character with all bits set to zero), which is used to mark end-of-stream in many languages, including the ones used to write most of Unix, and forward slash (/), which is reserved for an inode to describe a directory. I describe shortly.

This choice is quite permissive, but you are strongly advised to impose further restrictions, for at least these reasons:

- Since filenames are used by people, the names should require only visible characters: invisible control characters are not candidates.
- Filenames get used by both humans and computers: a human might well recognize a string of characters in its surrounding context, but a computer program needs more precise rules.
- Shell metacharacters (i.e., most punctuation characters) in filenames require special handling, and are avoided altogether.
- Initial hyphens make filenames look like Unix command options.

Some non-Unix filesystems permit both uppercase and lowercase characters to be used in filenames, but ignore case when comparing names. Unix native filesystems do not: `readme` , `Readme` , and `README` are distinct filenames.

[7] The old HFS-type filesystem supported on Mac OS X is case-*insensitive* , and that can lead to nasty surprises when software expects case-sensitivity. Mac OS X also supports normal case-sensitive Unix filesystems.

Unix filenames are conventionally written entirely in lowercase, since that is both easier to read and easier to type. Some important filenames, such as `AUTHORS` , `BUGS` , `ChangeLog` , `COPYRIGHT` , `INSTALL` , `LICENSE` , `Makefile` , `NEWS` , are conventionally spelled in uppercase, or occasionally, in mixed case. Because uppercase precedes lowercase in ASCII, these files occur at the beginning of a directory listing, making them even more visible. However, in modern systems, sort order depends on the locale; set the environment variable `LC_ALL` to `C` to get the traditional ASCII sort order.

For portability to other operating systems, it is a good idea to limit characters in filenames to Latin letters, digits, and at most, a single dot.

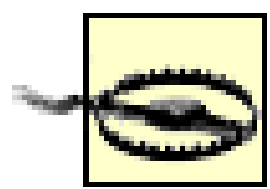
How long can a filename be? That depends on the filesystem, and on lots of software that contains fixed-size buffers for filenames.

be big enough to hold filenames. Early Unix systems imposed a 14-character limit. However, Unix systems do have generally permitted up to 255 characters. POSIX defines the constant `NAME_MAX` to be that length, *excluding* the terminating null character, and requires a minimum value of 14. The X/Open Portability Guide requires a minimum of 255. Use the `getconf` command to find out the limit on your system. Here is what most Unix systems report:

^[8] Available on almost all Unix systems, except Mac OS X and FreeBSD (before release 5.0). Source code for `getconf` can be found at <ftp://ftp.gnu.org/gnu/glibc/>.

```
$ getconf NAME_MAX .           What is longest filename in system?
255
```

The full specification of file locations has another, and larger, limit discussed in Section B.4.1 later in this Appendix.



We offer a warning here about spaces in filenames. Some window-based desktop operating systems, where filenames are selected from scrolling menus, or typed into dialog boxes, have led their users to believe that spaces in filenames are just fine. They are not! Filenames get used in many other contexts, such as in command-line shells, and the only sensible way to recognize a filename is that it is a *word chosen from a character set*. Unix shells, in particular, assume that commands can be parsed into words separated by spaces.

Because of the possibility of whitespace and other special characters in filenames, in shell scripts you should always quote the evaluation of any shell variable that might contain a filename.

B.3. What's in a Unix File?

One of the tremendous successes of Unix has been its simple view of files: Unix files are just *streams of zero or more anonymous bytes of data*.

Most other operating systems have different types of files: binary versus text data, counted-length versus fixed-length versus variable-length records, indexed versus random versus sequential access, and so on. This rapidly produces the nightmarish situation that the conceptually simple job of copying a file must be done differently depending on the file type, and since virtually all software has to deal with files, the complexity is widespread.

A Unix file-copy operation is trivial:

```
try-to-get-a-byte

while (have-a-byte)
{
    put-a-byte
    try-to-get-a-byte
}
```

This sort of loop can be implemented in many programming languages, and its great beauty is that the program need not be aware of where the data is coming from: it could be from a file, or a magnetic tape device, or a pipe, or a network connection, or a kernel data structure, or any other data source that designers dream up in the future.

Ahh, you say, but I need a special file that has a trailing directory of pointers into the earlier data, and that data is itself encrypted. In Unix the answer is: Go for it! Make your application program understand your fancy file format, but don't trouble the filesystem or operating system with that complexity. They do not need to know about it.

There is, however, a mild distinction between files that Unix does admit to. Files that are created by humans usually consist of lines of text, ended by a line break, and devoid of most of the unprintable ASCII control characters. Such files can be edited, displayed on the screen, printed, sent in electronic mail, and transmitted across networks to other computing systems with considerable assurance that the integrity

of the data will be maintained. Programs that expect to deal with text files, including many of the software tools that we discuss in this book, may have been designed with large, but fixed-size, buffers to hold lines of text, and they may behave unpredictably if given an input file with unexpectedly long lines, or with nonprintable characters.^[9] A good rule of thumb in dealing with text files is to limit line lengths to something that you can read comfortably—say, 50 to 70 characters.

^[9] See the interesting article by Barton P. Miller, Lars Fredriksen, and Bryan So, *An Empirical Study of the Reliability of UNIX Utilities*, *Comm. ACM* **33** (12), 32-44, December 1990, ISSN 0001-0782, and its 1995 and 2001 follow-up technical reports. Both are available, together with their associated test software, at <ftp://ftp.cs.wisc.edu/pub/paradyn/fuzz/> and ftp://ftp.cs.wisc.edu/pub/paradyn/technical_papers/fuzz*. The 2001 work extends the testing to the various Microsoft Windows operating systems.

Text files mark line boundaries with the ASCII linefeed (LF) character, decimal value 10 in the ASCII table. This character is referred to as the newline character. Several programming languages represent this character by `\n` in character strings. This is simpler than the carriage-return/linefeed pair used by some other systems. The widely used C and C++ programming languages, and several others developed later, take the view that text-file lines are terminated by a single newline character; they do so because of their Unix roots.

In a mixed operating-system environment with shared filesystems, there is a frequent need to convert text files between different line-terminator conventions. The *dosmacux* package^[10] provides a convenient suite of tools to do this, while preserving file timestamps.

^[10] Available at <http://www.math.utah.edu/pub/dosmacux/>.

All other files in Unix can be considered binary files: each of the bytes contained therein may take on any of 256 possible values. Text files are thus a subset of binary files.

Unlike some other operating systems, no character is foolishly usurped to mark end-of-file: the Unix filesystem simply keeps a count of the number of bytes in the file.

Attempts to read beyond the file byte count return an end-of-file indication, so it is not possible to see any previous contents of disk blocks.

Some operating systems forbid empty files, but Unix does not. Sometimes, it is the *existence* of a file, rather than its *contents*, that matters. Timestamps, file locks, and warnings such as `THIS-PROGRAM-IS-OBSOLETE` are examples of useful empty files.

The Unix files-as-byte-streams view has encouraged operating-system designers to implement file-like views of data that conventionally are not thought of as files. Several Unix flavors implement a process information pseudofilesystem: try `man proc` to see what your system offers. We discuss it in more detail in Section 13.7. Files in the `/proc` Tree are not files on mass storage but rather, views into the process tables and memory space of running processes, or into information known to the operating system, such as details of the processor, network, memory, and disk systems.

For example, on one of the systems used to write this book, we can find out storage device details like this

(the meaning of the slashes in the command argument is discussed in the next section):

```
$ cat /proc/scsi/scsi Show disk device information
```

Attached devices:

```
Host: scsi0 Channel: 00 Id: 00 Lun: 00
```

```
Vendor: IBM Model: DMVS18V Rev: 0077
```

```
Type: Direct-Access ANSI SCSI revision: 03
```

```
Host: scsi1 Channel: 00 Id: 01 Lun: 00
```

```
Vendor: TOSHIBA Model: CD-ROM XM-6401TA Rev: 1009
```

```
Type: CD-ROM ANSI SCSI revision: 02
```



< Day Day Up >

B.4. The Unix Hierarchical Filesystem

Large collections of files bring the risk of filename collisions, and even with unique names, make manager this by permitting files to be grouped into *directories* : each directory forms its own little name space, independent directories. Directories can also supply default attributes for files, a topic that we discuss briefly in Section B.

B.4.1. Filesystem Structure

Directories can be nested almost arbitrarily deep, so the Unix filesystem forms a *tree structure* . Unix avoids this because paper file folders do not nest. The base of the filesystem tree is called the *root directory* , and is given the name: / (ASCII slash). The name `/myfile` then refers to a file named `myfile` in the root directory. Slash also acts as a delimiter *between* names to record directory nesting. Figure B-1 shows a tiny portion of the top-level filesystem.

Figure B-1. Filesystem tree

Unix directories can contain arbitrary numbers of files. However, most current Unix filesystem designs, and their interfaces, assume that directories are searched sequentially, so the time to find a file in a large directory is proportional to the number of files in that directory, even though much faster lookup schemes are known. If a directory contains more files than can be searched in a reasonable amount of time, it is probably time to reorganize it into subdirectories.

The complete list of nested directories to reach a file is referred to as the *pathname* , or just the path. It may include the filename itself, depending on context. How long can the complete path to a filename, including the name of the file, be? The documentation does not supply the answer, but POSIX defines the constant `PATH_MAX` to be that length, in characters. It requires a minimum value of 256, but the X/Open Portability Guide requires 1024. You can use the following command to find out the limit on your system. One of our systems gave this result:

```
$ getconf PATH_MAX .
```

What is longest pathname in ...

1023

Other Unix systems that we tried this on reported 1024 or 4095.

The ISO Standards for the C programming language call this value `FILENAME_MAX`, and require it to be defined in file `stdio.h`. We examined a dozen or so flavors of Unix, and found values of 255, 1024, and 4095. Hewlett-Packard and 11.23 have only 14, but their `getconf` reports 1023 and 1024.

Because Unix systems can support multiple filesystems, and filename length limits are a property of the file operating system, it really does not make sense for these limits to be defined by compile-time constants. Hence programmers are therefore advised to use the `pathconf()` or `fpathconf()` library calls to obtain these limits for a pathname, or an open file descriptor, so that the particular filesystem can be identified. That is the reason we used `getconf` in the previous example.

Unix directories are themselves files, albeit ones with special properties and restricted access. All Unix systems have a directory named `bin` that holds (often binary) executable programs, including many of the ones that we use. The pathname of this directory is `/bin`, and it rarely contains subdirectories.

Another universal top-level directory is `usr`, but it always contains other directories. The pathname of one which is distinct from `/bin`, although some magic, discussed later in this Appendix in Section B.4.3 can make them look the same.^[11]

[11] DEC/Compaq/Hewlett-Packard OSF/1 (Tru64), IBM AIX, SGI IRIX, and Sun Solaris all do this. Apple Mac OS X, BSD, and Hewlett-Packard HP-UX do not.

All Unix directories, even if otherwise empty, contain at least two special directories: `.` (dot) and `..` (dot dot) which refer to the directory itself: we used that earlier in the `getconf` example. The second refers to the parent directory. For example, `../usr` means `/usr`, and `../lib/libc.a` means `/usr/lib/libc.a`, the customary location of the C programming library.

The root directory is its own parent, so `/`, `/. .`, `/.../..`, `/.../.../..`, and so on, are equivalent.

A path that ends in a slash is of necessity a directory. If the last character is not a slash, whether the last component is a directory or some other type of file can be determined only by consulting the filesystem.

POSIX requires that consecutive slashes in a path be equivalent to a single slash. This requirement is not explicitly mentioned in the documentation that we consulted, but the original Version 6 source code from the mid-1970s does slash reduction. For example, `/tmp//x`, and `//tmp//x` are the same file.

[12] See John Lions' book, *Lions' Commentary on UNIX 6th Edition, with Source Code*, Peer-to-Peer Communications, 1992. The slash reduction happens at kernel line 7535 (sheet 75), with the commentary on p. 19-2. "Multiple slashes are acceptable." If the `while` loop were not there, this reduction would not happen!

Footnotes sprinkled through this book contain World Wide Web *uniform resource locators (URLs)* whose pathnames. URLs prefix a protocol^[13] name and a hostname in the form `proto://host` to an absolute Unix

host's web directory tree. Web servers are then required to map that path to whatever is appropriate for their widespread use of URLs since the late 1990s in broadcast and print media has thus made the Unix pathnames have never used a computer.

^[13] The protocol is called a *scheme* in standards documents, but both terms are in wide use.

B.4.2. Layered Filesystems

If slash is the root directory, and there is one in each filesystem, how does Unix support multiple filesystem name collisions? The answer is simple: Unix permits one filesystem to be logically layered on top of another filesystem. This action is called *mounting*, and the commands *mount* and *umount*, respectively, manage filesystems.

When another filesystem is mounted on top of a directory, any previous contents of that directory become hidden; they are exposed again when the unmount is done.

Filesystem mounting gives the illusion of a single filesystem tree that can grow without limit, simply by adding devices. The regular file-naming convention */a/b/c/d/...* means that human users, and software, are concerned with an irrelevant notion of devices, unlike several other operating systems that embed the device name in the path.

A fair amount of information is needed to complete a mount command, so a system manager stores the details in a file called */etc/fstab* or */etc/vfstab*, depending on the Unix flavor. As with most Unix configuration files, its format is documented in the manual pages for *fstab* (4 or 5) or *vfstab* (4).

When shared magnetic disks were the only filesystem media available, mounting and unmounting required privileges—normally those accorded only to system management. However, with user-owned media such as CDs and DVDs, ordinary users with desktop computers need to be able to do this themselves. Many Unix systems allow so that certain devices can be flagged as permitting mounts and unmounts by unprivileged users. Here are some examples from a GNU/Linux system:

```
$ grep owner /etc/fstab | sort                                Which devices allow user mounts
```

<code>/dev/cdrom</code>	<code>/mnt/cdrom</code>	<code>iso9660</code>	<code>noauto,owner,kudzu,ro</code>	<code>0 0</code>
<code>/dev/fd0</code>	<code>/mnt/floppy</code>	<code>auto</code>	<code>noauto,owner,kudzu</code>	<code>0 0</code>
<code>/dev/sdb4</code>	<code>/mnt/zip100.0</code>	<code>auto</code>	<code>noauto,owner,kudzu</code>	<code>0 0</code>

These make the CD-ROM, floppy disk, and Iomega Zip disk available for user mounts, which might be done like this:

```
mount /mnt/cdrom                                Make the CD-ROM available
cd /mnt/cdrom                                   Change to its top-level directory
```



```
ls                               List its files
...
cd                               Change to home directory
umount /mnt/cdrom               Release the CD-ROM
```

The *mount* command issued without arguments requires no special privileges: it simply reports all of the *cd* filesystems. Here is an example from a standalone web server:

```
$ mount | sort                   Show sorted list of mounted .
/dev/sda2 on /boot type ext3 (rw)
/dev/sda3 on /export type ext3 (rw)
/dev/sda5 on / type ext3 (rw)
/dev/sda6 on /ww type ext3 (rw)
/dev/sda8 on /tmp type ext3 (rw)
/dev/sda9 on /var type ext3 (rw)
none on /dev/pts type devpts (rw,gid=5,mode=620)
none on /dev/shm type tmpfs (rw)
none on /nue/proc type proc (rw)
none on /proc/sys/fs/binfmt_misc type binfmt_misc (rw)
none on /proc type proc (rw)
```

This shows, for example, that the root filesystem is mounted on disk device */dev/sda5* . Other filesystems */export* , and so on.

A system manager could unmount the */ww* tree by issuing the command:

```
# umount /ww                    Here, # is the root prompt
```

The command would fail if any files in the */ww* subtree were still in use. The list-open-files command, *lsof*

down processes that are preventing the unmount.

^[14] Available at <ftp://vic.cc.purdue.edu/pub/tools/unix/lsof/>. Alternative commands available in some Unix flavors are *fstat*

B.4.3. Filesystem Implementation Overview

The details of how filesystems are implemented are interesting, but are quite complex and beyond the need to see the excellent books *The Design and Implementation of the 4.4BSD Operating System* ^[15] and *UNIX Internals* ^[16].

^[15] By Marshall Kirk McKusick, Keith Bostic, Michael J. Karels, and John S. Quarterman, Addison-Wesley, 1996, ISBN 0-201-54993-1.

^[16] By Uresh Vahalia, Prentice-Hall, 1996, ISBN 0-13-101908-2.

There is one aspect of the filesystem implementation that is useful to know about at a higher level, however, for several user-visible aspects of Unix filesystems. When a filesystem is created, a table of manager-specific information is written on disk to hold information about the files in the filesystem. Each file is associated with one entry in this table, a filesystem data structure called an *inode* (a contraction of *index node*, and pronounced *eye node*). The contents of the inode vary according to the particular filesystem design, so a single system might have different flavors. Programmers are isolated from these details by the `stat()` and `fstat()` system calls (see the manual pages for `stat(2)`). The command `man inode` may show the actual structure on your system.

^[17] Some advanced filesystem designs permit that table to grow as needed.

Since the inode structure, and other low-level details of storage devices, are system-dependent, it is generally not possible to move a disk containing a Unix filesystem from one vendor on a system from another vendor. However, through a *Network File System (NFS)*, across networks it is virtually always possible to share Unix filesystems between different vendors.

Because the inode table has a fixed size, it is possible for a filesystem to fill up even when there is plenty of free space on the device: there is room for the file's data, but not for its *metadata* (data about the data).

As shown in Figure B-2, the inode entry contains everything that the system needs to know about the file, including the filename. This might seem surprising, and indeed, several other operating systems with a similar filesystem design store the filename in their analogues of inodes.

Figure B-2. Inode table contents

In Unix, the filename is stored in the directory, together with its inode number, and not much else, as illustrated in Figure B-3. Early Unix systems on the small computers of the 1970s allocated only 16 bytes in a directory for each file: 2 bytes for the inode number (limiting the number of files to $2^{16} = 65,536$), and 14 bytes gave the filename, only marginally better than the systems.

Figure B-3. Directory table contents

Modern Unix filesystems allow longer filename lengths, although there is typically a maximum length, as shown in Appendix with the *getconf* example in Section B.4.1.

Directories can be read, but not written, by their owners, and some early Unix software opened and read directories directly. When a more complex directory design was introduced in the 1980s, the `opendir()`, `readdir()`, and `closedir()` were created to hide the structure from programmers, and those calls are now part of POSIX (see the manual page for `opendir(3)`). To enforce library access, some current Unix implementations prohibit read operations on directory files.

Why is the filename separated from the rest of the file metadata in Unix? There are at least two reasons:

- Users commonly list the contents of directories simply to remind themselves of what files are available. If filenames were stored in inodes, finding each filename in the directory might take one or more disk accesses. By storing the filenames in a separate block, many names can be retrieved from a single disk block.
- If the filename is separate from the inode, then it is possible to have multiple filenames for the same inode. Those filenames having different directory entries reference the same inode. Those references need not even be in the same directory.

of file aliases, called *links* in Unix, is extremely convenient, and is widely used. On six different flavors of Unix, 10 percent to 30 percent of the files under `/usr` were links.

A useful consequence of the Unix filesystem design is that renaming a file or directory, or moving it *within* the filesystem, is fast: only the name needs to be changed or moved, not the contents. Moving a file *between* filesystems requires reading and writing all of the file's blocks.

If files can have multiple names, what does it mean to delete a file? Should all of them disappear at once, or should only the one that was named be removed? Both choices have been made by designers of filesystems that support aliases or links; Unix uses the latter. Each Unix inode entry contains a count of the number of links to the file contents. File deletion causes the link count to be decremented; only when it reaches zero are the file blocks finally reassigned to the list of free space.

Since the directory entry contains just an inode number, it can refer only to files within the same physical filesystem. One solution is a different kind of link, called a *soft link*, or *symbolic link*, or just *symlink*, to distinguish it from a *hard link*. A symbolic link is represented by a *directory entry that points to another directory entry*,^[18] rather than a file. The pointed-to entry is given by its normal Unix pathname, and thus, may point anywhere in the filesystem.

^[18] The file type in the inode records that the file is a symbolic link, and in most filesystem designs, the name of the file that the symbolic link's data block points to.

Symbolic links make it possible to create infinite loops in the filesystem, so to prevent that, a chain of symbolic links is limited to only a few (typically, eight) steps. Here is what happens with a two-element loop:

```
$ ls -l                                Show the link loop
total 0
lrwxrwxrwx  1 jones  devel  3 2002-09-26 08:44 one -> two
lrwxrwxrwx  1 jones  devel  3 2002-09-26 08:44 two -> one
$ file one                               What is file one?
one: broken symbolic link to two
$ file two                               What is file two?
two: broken symbolic link to one
$ cat one                                Try to display file one
cat: one: Too many levels of symbolic links
```

For technical reasons (among them, the possibility of loops), directories normally cannot have hard links, but

links. The exceptions to this rule are the dot and dot-dot directory entries, which are created automatically

B.4.4. Devices as Unix Files

One of the advances over earlier systems that Unix made was to extend the file notion to attached devices. A top-level directory named `/dev`, underneath which are oddly named files like `/dev/audio`, `/dev/sda1`, and other device files are handled by special software modules, called *device drivers*, that know how to communicate with devices. Although device names tend to be highly system-dependent, collectively they provide a convenient model similar to normal files.



The integration of devices into the hierarchical file system was the best idea in Unix. - Robert M. K. in *Use of Name Spaces in Plan 9*, 1992.

Entries in the `/dev` tree are created by a special tool, *mknod*, often hidden inside a shell script, *MAKEDEV*. You need root system-manager privileges to run: see the manual pages for *mknod* (1) and *MAKEDEV* (8).

Most Unix users only rarely refer to members of the `/dev` tree, with the exception of `/dev/null` and `/dev/random`. See Section 2.5.5.2.

In the 1990s, several Unix flavors introduced a random pseudodevice, `/dev/urandom`, that serves as a never-ending source of random bytes. Such a data source is needed in many cryptographic and security applications. We showed in Chapter 2 how `/dev/urandom` can be used to construct hard-to-guess temporary filenames.

Files Without Names

A peculiarity of the Unix operating system is that the names of files that are opened for input or output are stored in kernel data structures. Thus, the names of files that are redirected on the command line for standard input, standard output, or standard error are unknown to the invoked process. Think of it: we have a filesystem that might contain millions of files, yet exactly three of them cannot be named! To partially remedy this deficiency, some recent Unix systems provide the names `/dev/stdin`, `/dev/stdout`, and `/dev/stderr`, or sometimes less mnemonic names like `/dev/fd/0`, `/dev/fd/1`, and `/dev/fd/2`. On GNU/Linux and Sun Solaris, they are also available as `/proc/self/fd/0`, and so on. Here is how to see whether your system supports them; you'll get either a successful run

```
$ echo Hello, world > /dev/stdout
```

```
Hello, world
```

or a failure like this:

```
$ echo Hello, world > /dev/stdout
```

```
/dev/stdout: Permission denied.
```

Many Unix programs found the need for names for these redirected files, so a common convention is that filename does not mean a file of that name, but rather, standard input or standard output, depending on context. We emphasize that this is merely a *convention*, and not universally implemented by Unix software. If you are using such a file, just disguise its name with a directory prefix; e.g., `./--data`. Some programs follow the convention (described in Section 2.5.1) that a double hyphen option, `--`, means that everything that follows on the command line is a file, and not an option, but that practice is not universal either.

[← PREV](#)[< Day Day Up >](#)

B.5. How Big Can Unix Files Be?

The size of Unix files is normally constrained by two hard limits: the number of bits allocated in the inode the file size in bytes, and the size of the filesystem itself. In addition, some Unix kernels have manager-settable file sizes. The data structure used on most Unix filesystems to record the list of data blocks in a file impose about 16.8 million blocks, where the block size is typically 1024 to 65,536 bytes, settable, and fixed at file creation time. Finally, the capacity of filesystem backup devices may impose further site-dependent limits.

Most current Unix filesystems use a 32-bit integer to hold the file size, and because the file-positioning system move forward or backward in the file, that integer must be signed. Thus, the largest-possible file is $2^{31} - 1$ about 2GB.^[19] Until about the early 1990s, most disks were smaller than that size, but disks containing 100 became available by about 2000, and by combining multiple physical disks into a single logical disk, much larger filesystems are now feasible.

^[19] GB = gigabyte, approximately 1 billion (one thousand million) bytes. Despite the metric prefix, in computer use G usually $2^{30} = 1,073,741,824$.

Unix vendors are gradually migrating to filesystems with 64-bit size fields, potentially supporting about 8 billion gigabytes. Just in case you think that might not be enough in the near future, consider that writing such a file at a currently reasonable rate of 10MB/s would take more than 27,800 years! This migration is decidedly nontrivial: all existing software that uses random-access file-positioning system calls must be updated. To avoid the need for massive upgrades, most vendors allow the old 32-bit sizes to be used in newer systems, which works as long as the limit is not reached.

When a Unix filesystem is created, for performance reasons a certain fraction of the space, often 10 percent is reserved for use by processes running as `root`. The filesystem itself requires space for the inode table, and there may be special low-level blocks that are accessible only by the disk-controller hardware. Thus, the effective capacity of a disk is often only about 80 percent of the size quoted by the disk vendor.

Commands exist on some systems to decrease the reserved space: doing so may be advisable on large disks; see the manual pages for `tunefs` (8) on BSD and commercial Unix systems, and `tune2fs` (8) on GNU/Linux systems.

The `ulimit` built-in shell command controls system resource limits. The `-a` option prints the value of all resource limits. On our systems, we get this result concerning file sizes:

```
$ ulimit -a Show the current user process limits.
...
file size (blocks)          unlimited
```


...

Your system might be different because of local management policies.

At some Unix sites, disk quotas are enabled (see the manual pages for *quota* (1) for details), putting further limits on the total amount of filesystem space that a single user can occupy.



B.6. Unix File Attributes

Earlier in this Appendix, in Section B.4.3, we described the Unix filesystem implementation, and said that it is now time to discuss some of these attributes because they can be highly relevant to users of the filesystem.

B.6.1. File Ownership and Permissions

Perhaps the biggest difference from single-user personal-computer filesystems is that Unix files have *ownership*.

B.6.1.1 Ownership

On many personal computers, any process or user can read or overwrite any file, and the term computer virus has never been used. Because Unix users have restricted access to the filesystem, it is not a problem on Unix systems.

Unix files have two kinds of ownership: *user* and *group*, each with its own permissions. Normally, the owner of the file might have limited access, and everyone else, even less access. This last category is called *others*. The `ls` command.

New files normally inherit owner and group membership from their creator, but with suitable permissions to change those attributes.

In the inode entry, the user and group are identified by numbers, not names. Since humans generally prefer names, the `passwd` file, `/etc/passwd`, and the group file, `/etc/group`. At large sites, these files are generally replaced by so-called `shadow` files, although the preferred access is now via library calls to `setpwent()`, `getpwent()`, and `endpwent()` for the group database: see the manual pages for `getpwent(3)` and `getgrent(3)`. If your site uses `yp`, you can examine the password database, or `ypmatch jones passwd` to find just the entry for user `jones`. If your site uses `nis`, you can use `nismatch name=jones passwd.org_dir`.

The important point is that it is the *numeric values* of the user and group identifiers that control access. If a filesystem with user ID 100 assigned to user `jones`, then `jones` would have full access to `smith`'s files. These considerations can become important as large organizations move toward globally accessible Unix filesystems and group identifiers. This is not as simple as it appears: not only are there turf wars, but there are severe limitations: only 16 bits for each, giving a total of $2^{16} = 65,536$ values. Newer Unix systems allow 32-bit identifiers, which sharply limit the number of identifiers to many fewer than the hundreds of thousands to millions required by large organizations.

B.6.1.2 Permissions

Unix filesystem permissions are of three types: *read* , *write* , and *execute* . Each requires only a single bit in There is one such set for each of user, group, and other. File permissions are shown with the verbose forms permissions requires only three bits, it can be represented by a single *octal* ^[20] digit, and the *chmod* comm

[20] Just in case octal (base-8) and binary (base-2) number systems are unfamiliar to you, octal notation with digits 0-7 is sim 111₂ . Think of an automobile odometer with only two digits on each wheel, instead of ten.

chmod

Usage

```
chmod [ options ] mode file(s)
```

Major options

-f

Force changes if possible (and don't complain if they fail).

-R

Apply changes recursively through directories.

Purpose

Change file or directory permissions.

Behavior

The mandatory *mode* argument is either an absolute permission mask of three or four octal digits, o (group), o (other), or u (user), followed by = (set), + (add), or - (subtract), followed by one or more c

may be given, provided that they are separated by commas. Thus, modes of 755 and `u=rwx,go=rx` a

Caveats

The recursive form is dangerous: use it with extreme caution! It may take a file-tree restore from ba



Some operating systems support additional permissions. One useful permission that Unix log files, to ensure that data can only be added to them, but existing data can never be copied with altered data, so append permission may only give the illusion of security.

^[21] BSD systems are an exception: they provide the *sappnd* and *uappnd* flags, settable with *chflags*.

B.6.1.3 Default permissions

A set of default permissions is always applied to newly created files: they are controlled by the *umask* command. The *umask* value is three octal digits that represent permissions to be *taken away*: a common value is 022, meaning that write permission should be removed for other users. The result is that access to newly created files is restricted to just the user and other have them all taken away.

It is now time for some experiments with file permissions:

```
$ umask                                Show the current permission mask
2
$ touch foo                             Create an empty file
$ ls -l foo                             List information about the file
-rw-rw-r--  1 jones   devel   0 2002-09-21 16:16 foo
$ rm foo                                 Delete the file
$ ls -l foo                             List information about the file
ls: foo: No such file or directory
```

Initially, the permission mask is 2 (really 002), meaning that write permission should be removed for other users. This is necessary. The `ls -l` command is a common idiom for asking for a verbose file listing. It reports a *file type*

permission for user and group, and read permission for other).

When we re-create the file after changing the mask to 023, to remove write access from the group and write permissions for other, with write permissions for group and other removed as expected:

```
$ umask 023                                Reset the permission mask

$ touch foo                                Create an empty file

$ ls -l foo                                List information about the file

-rw-r--r--      1 jones      devel      0 2002-09-21 16:16 foo
```

B.6.1.4 Permissions in action

What about the execute permission? Files don't normally have that permission, unless they are intended to be such programs, but for scripts, you have to use *chmod* yourself.

When we copy a file that already has execute permissions-e.g., `/bin/pwd`-the permissions are preserved

```
$ umask                                    Show the current permission mask

023

$ rm -f foo                                Delete any existing file

$ cp /bin/pwd foo                          Make a copy of a system command

$ ls -l /bin/pwd foo                       List information about the files

-rwxr-xr-x      1 root       root       10428 2001-07-23 10:23 /bin/pwd
-rwxr-xr--      1 jones      devel     10428 2002-09-21 16:37 foo
```

The resulting permission string `rwxr-xr--` reflects the loss of privileges: group lost write access, and other

Finally, we use the symbolic form of an argument to *chmod* to add execute permission for all:

```
$ chmod a+x foo                            Add execute permission for all

$ ls -l foo                                List verbose file information

-rwxr-xr-x      1 jones      devel     10428 2002-09-21 16:37 foo
```


The resulting permission string is then `rwxr-xr-x`, so user, group, and other have execute access. Notice that this is only at file-creation time. The copied file behaves exactly like the original `pwd` command:

```
$ /bin/pwd                                Try the system version
/tmp

$ pwd                                       And the shell built-in version
/tmp

$ ./foo                                     And our copy of the system version
/tmp

$ file foo /bin/pwd                       Ask for information about the files
foo: ELF 32-bit LSB executable, Intel 80386, version 1,
      dynamically linked (uses shared libs), stripped
/bin/pwd: ELF 32-bit LSB executable, Intel 80386, version 1,
      dynamically linked (uses shared libs), stripped
```

Notice that we invoked `foo` with a directory prefix: for security reasons, it is *never* a good idea to include the

If you try this experiment yourself, you might get a permission-denied response when the capability, such as GNU/Linux, system managers sometimes mount that directory option in `/etc/fstab`. One reason for that option to be used is that it prevents Trojan horses. You can still execute them by feeding them into the shell, but then you presumably know

Here is what happens if you remove the execute permission, and then try to run the program:

```
$ chmod a-x foo                            Remove execute permission for foo
$ ls -l foo                                List verbose file information
-rw-r--r--  1 jones   devel    10428 2002-09-21 16:37 foo
$ ./foo                                     Try to run the program
```

```
bash: ./foo: Permission denied
```

That is, it is not the *ability* of a file to function as an executable program, but rather, its *possession of execute* important safety feature in Unix.

Here is what happens when you give execute permission to a file that doesn't deserve it:

```
$ umask 002                                Remove default for world writ
$ rm -f foo                                 Delete any existing file
$ echo 'Hello, world' > foo                 Create a one-line file
$ chmod a+x foo                             Make it executable
$ ls -l foo                                  Show our changes
-rwxrwxr-x   1 jones   devel          13 2002-09-21 16:51 foo
$ ./foo                                     Try to run the program
./foo: line 1: Hello,: command not found
$ echo $?                                   Display the exit status code
127
```

What happened was that the shell asked the kernel to execute `./foo`, and got a failure report back, with the In the command line `Hello, world`, it interpreted `Hello`, as the name of a command to run, and `world` as shell reported that conclusion in an error message, and returned an exit status code of 127 (see Chapter 6 for

When permissions are checked, the order is user, then group, then other. The first of these to which the program have a file that belongs to you, but which you cannot read, even though fellow group members, and everyone

```
$ echo 'This is a secret' > top-secret      Create one-line file
$ chmod 044 top-secret                       Remove all but read for group
$ ls -l                                       Show our changes
----r--r--   1 jones   devel          17 2002-10-11 14:59 top-secret
$ cat top-secret                             Try to display file
```

```

cat: top-secret: Permission denied

$ chmod u+r top-secret           Allow owner to read file

$ ls -l                           Show our changes

-r--r--r--    1 jones    devel    17 2002-10-11 14:59 top-secret

$ cat top-secret                 This time, display works!

This is a secret

```

All Unix filesystems contain additional permission bits, called *set-user-ID*, *set-group-ID*, and *sticky* bits. In its default output length, *ls* does not show these permissions with three extra permission characters, but instead, changes the manual pages. For security reasons, shell scripts should *never* have the set-user-ID or set-group-ID permission bits. We cover these permission bits and shell-script security in Chapter 15.

Execute-only permission (`--x--x--x`) is sometimes used for commercial software to discourage copying,

B.6.1.5 Directory permissions

So far, we have discussed permissions only of ordinary files. For directories, the permissions are given slightly different meanings. Write access means that you can create or delete files in the directory, even if the directory is not executable. Execute access means that you can access files in a particular directory. In particular, you can follow a pathname through that directory.

Since the distinction between execute and read access on a directory is subtle, here is an experiment to clarify it.

```

$ umask                               Show the current permission mask

22

$ mkdir test                           Create a subdirectory

$ ls -Fld test                          Show the directory permissions

drwxr-xr-x    2 jones    devel    512 Jul 31 13:34 test/

$ touch test/the-file                   Create an empty file there

```



```
$ ls -l test List the directory contents
-rw-r--r-- 1 jones devel 0 Jul 31 13:34 test/the-file
```

So far, this is just normal behavior. Now remove read access, but leave execute access:

```
$ chmod a-r test Remove directory read access
```

```
$ ls -lFd test Show the directory permissions
```

```
d-wx--x--x 2 jones devel 512 Jan 31 16:39 test/
```

```
$ ls -l test Try to list the directory contents
```

```
ls: test: Permission denied
```

```
$ ls -l test/the-file List the file itself
```

```
-rw-r--r-- 1 jones devel 0 Jul 31 13:34 test/the-file
```

The second *ls* failed because of the lack of read permission, but execute permission allowed the third *ls* to succeed. It cannot prevent access to a file contained therein, if its filename is already known.

Here is what happens when we remove execute access, without restoring read access:

```
$ chmod a-x test Remove directory execute access
```

```
$ ls -lFd test List the directory
```

```
d-w----- 3 jones devel 512 Jul 31 13:34 test/
```

```
$ ls -l test Try to list the directory contents
```

```
ls: test: Permission denied
```

```
$ ls -l test/the-file Try to list the file
```



```
ls: test/the-file: Permission denied
```

```
$ cd test
```

Try to change to the directo.

```
test: Permission denied.
```

The directory tree has been effectively cut off from view by any user, *except* root .

Finally, restore read access, but not execute access, and repeat the experiment:

```
$ chmod a+r test
```

Add directory read access fo.

```
$ ls -lFd test
```

Show the directory permissio.

```
drw-r--r--  2 jones devel 512 Jul 31 13:34 test/
```

```
$ ls -l test
```

Try to list the directory co.

```
ls: test/the-file: Permission denied
```

```
total 0
```

```
$ ls -l test/the-file
```

Try to list the file

```
ls: test/the-file: Permission denied
```

```
$ cd test
```

Try to change to the directo.

```
test: Permission denied.
```

Lack of execute access on the directory has blocked attempts to see its contents, or to make it the current w

When the sticky bit is set on a directory, files contained therein can be removed only by their owner, or by directories-notably, /tmp , /var/tmp (formerly called /usr/tmp), and incoming mail directories-to preve

On some systems, when the set-group-ID bit is set on a directory, the group ID of newly created files is set

this permission bit is not handled the same on all systems. On some, its behavior depends on how the filesy the details on your system. The set-group-ID bit is useful when several users share write access to a directc created for that project, and the group of the project directory is set to that group.

Some systems use a combination of the set-group-ID bit being set and the group-execute bit being clear to

Directory Read and Execute F

Why is there a distinction between reading the directory, and passing through it to a subdirectory? The an even though its parent directories are not. A common example today is a user's web tree. The home direct group and other from listing its contents, or examining its files, but the web tree starting at, say, `$HOME/pu` `rw-r-xr-x`, and files within it would have at least `rw-r--r--` permissions.

As another example, suppose that, for security reasons, a system manager wants to read-protect an entire d be done is to remove read and execute access for the *single directory* at the root of the subtree, with `chmod` inaccessible to new open attempts (already-open files are not affected), even though their individual perm

Some Unix systems support a feature called *access control lists* (ACLs). These provide be assigned nondefault permissions. Unfortunately, the tools for setting and displaying heterogeneous environments, and too messy for further discussion in this book. If you `control list` ' to identify the relevant commands on your system.

B.6.2. File Timestamps

The inode entry for a Unix file contains three important timestamps: access time, inode-change time, and n ,^[22] which for Unix systems is 00:00:00 UTC, January 1, 1970, although some Unix implementations offer fi formerly Greenwich Mean Time, GMT) means that the timestamps are independent of the local time zone.

^[22] **epoch**, ep'ok, *n*. A fixed point of time from which succeeding years are numbered [*The New Webster Encyclopedic Dic*

^[23] In the interests of committee harmony, UTC is a language-independent acronym; the French expansion is Temps Univers <http://aa.usno.navy.mil/faq/docs/UT.html>, and <http://www.boulder.nist.gov/timefreq/general/misc.htm> for some interesting

The access time is updated by several system calls, including those that read and write files.

The inode-change time is set when the file is created, and when the inode metadata is modified.

The modification time is changed when the file blocks are altered, but not when the metadata (filename, us

The `touch` command, or the `utime()` system call, can be used to change file access and modification time

specify the time as that of a particular file. The `ls -l` command shows the modification time, but with the `ls -la` command, you can also see the access and inode-change times. These timestamps are not optimal. The inode-change time serves two quite distinct purposes which should have come into existence in a Unix filesystem.

The access time is updated when the file is read with a `read()` system call, but might not be updated when the file is written.

The modification time is somewhat more reliable, but the `file-copy` command normally resets the output-file's modification time to the current time. This is usually undesirable. For this reason, the `copy` command, `cp`, has a `-p` option for preserving file-modification times.

There is no time of last backup recorded: this means that the backup system must retain auxiliary data to track which files have been backed up.



Filesystem backup software is carefully written to preserve the timestamps of the files being backed up. Systems that use archive utilities, like `tar`, for backup update the inode-change time for backup purposes.

For some purposes, one would like to have separate timestamps for read, write, renaming, change of metadata, etc.

B.6.3. File Links

Despite the considerable utility of the hard and soft (symbolic) filesystem links that we discussed earlier in this chapter, the fact that multiple names for the same thing serve only to confuse users, since links create connections between previously isolated files, producing a filesystem inconsistency that did not exist before the move. Figure B-4 shows how a soft link is broken when a file is moved, depending on whether relative or absolute paths are used in the links.

Figure B-4. Breaking relative symbolic links

Figure B-5. Moves can preserve absolute symbolic links

There are several other problems with both hard and soft links:

- When a linked file is updated, either by replacement with a file-copy command or by a program, such as `cp`, the existing file is opened for output and rewritten, its inode number remains unchanged, and hard links might result in the loss of the entire file. A cautious programmer might therefore write the new version, remove the original (thus decrementing its link count by one) and rename the copy. The renaming operation on the replacement file will have a new inode number and a link count of one, breaking hard links.
- We tested several text editors, and found that all seemed to use the first approach, preserving hard links. If you rewrite a file that is a soft link, then you are modifying the original data, and as long as its pathname is

^[24] Set the variable `backup-by-copying-when-linked` to `non-nil`, and the variable `backup-by-copying` to `nil`, to

- For hard links, the two update methods can also result in the new file having a different owner and group, changing them to values for the user who performed that action. Thus, the behavior of the two kinds of links is different.
- Consider symbolic links for directories: if you have a symbolic link from `subdir` to `/home/jones/somedir` in one filesystem, and another filesystem where `/home/jones/somedir` does not exist, the link is broken.
- It is generally better to use relative paths in the link, and then only to directories at the same level, or beginning at least one directory higher in the tree if a directory is moved. Otherwise, the link is broken.
- Broken symbolic links are not diagnosed at the time of the break, but are only discovered later when you try to use them. This is the same problem with personal address books: your friends can move without informing you, breaking the link. See Chapter 10.
- Symbolic links to directories pose a problem for relative directory changes as well: changing to the parent directory, rather than to the parent of the link itself.
- Symbolic links are a problem when file archives are created: sometimes the links should be preserved, sometimes not. See Chapter 10.

B.6.4. File Size and Timestamp Variations

The inode entry for each file includes its size in bytes, which can be zero if the file is empty. The long form


```
$ ls -l /bin/ksh List verbose file informatio.
-rwxr-xr-x    1 root    root      172316 2001-06-24 21:12 /bin/ksh
```

GNU versions of *ls* provide the *-S* option to sort the listing by descending file size:

```
$ ls -lS /bin | head -n 8 Show the 8 largest, in ord
total 7120
-rwxr-xr-x    1 rpm      rpm      1737960 2002-02-15 08:31 rpm
-rwxr-xr-x    1 root    root      519964 2001-07-09 06:56 bash
-rwxr-xr-x    1 root    root      472492 2001-06-24 20:08 ash.stat:
-rwxr-xr-x    2 root    root      404604 2001-07-30 12:46 zsh
-rwxr-xr-x    2 root    root      404604 2001-07-30 12:46 zsh-4.0..
-rwxr-xr-x    1 root    root      387820 2002-01-28 04:10 vi
-rwxr-xr-x    1 root    root      288604 2001-06-24 21:45 tcsh
```

The *-S* option can be handy when you fill up a filesystem and you want to find which files are possible culprits (you can also get the same result.

If you suspect that a currently running process has filled up the filesystem, on Sun Solaris (you can also get the same result than your own files):

```
# ls -lS /proc/*/fd/* List all open files-rw-----
-r--r--r--  1 smith  smith  946643 Dec  2 03:25 /proc/15993/fd/16
-r--r--r--  1 smith  smith  835284 Dec  2 03:32 /proc/15993/fd/9
...
```



In this example, killing process 2965 might remove that large file, but at least you know GNU/Linux has a similar `/proc` facility, but alas, the Solaris solution doesn't work bec

The disk-free command, `df`, reports the current disk usage, or with the `-i` option, the inode usage. The disk-directories, or with the `-s` option, a compact summary. Examples are given in Chapter 10. The `find` commands are unusually large: see Chapter 10.

The `-s` option to `ls` shows an additional leading column that gives the file size in blocks:

```
$ ls -lgs /lib/lib* | head -n 4           List verbose file informatio
2220 -r-xr-xr-t      1 sys  2270300 Nov  4 1999 /lib/libc.so.1
   60 -r--r--r--      1 sys    59348 Nov  4 1999 /lib/libcpr.so
  108 -r--r--r--      1 sys   107676 Nov  4 1999 /lib/libdisk.so
   28 -r--r--r--      1 sys    27832 Nov  4 1999 /lib/libmalloc.so
```

Block sizes are operating- and filesystem-dependent: to find the block size, divide the file size in bytes by the block count. In the example, we find $2270300/2220 = 1022.6$, so the block size is $2^{10} = 1024$ bytes. Storage devices are getting smaller, and from what is present on the device. Also, vendor and GNU versions of `ls` on some systems disagree as well as comparisons on the same system with the same `ls` command.

Occasionally, you may encounter files for which the block count seems too small: such as files that contain only a few bytes at specified positions. Database programs often do this, since they store sparse tables with holes properly, but programs that simply read such a file sequentially see zero bytes.

Copying such a file fills the holes with physical zeroed disk blocks, possibly increasing the size of the file. If you created the original file, it is a filesystem feature that well-written backup utilities need to handle. GNU `cp` has the `-sparse` option to handle such files, but most other `tar` implementations do not.

Use of the administrative dump/restore tools may be the only way on some systems to handle sparse files, but they can be highly system-dependent, so we ignore them in this book.

You might have spotted another difference between the last two sample outputs: the timestamp is displayed as `hh:mm` for a timestamp within the last six months, and otherwise, as `Mmm ddyyyy` for an older one. Some systems have a character line-width limit of old-style ASCII terminals,^[25] there is little need for that economization. Most systems are harder to keep the output lines short.

[25] And they in turn got that limit from computer punched cards, which were invented by Hermann Hollerith in the 1880s to Austrian, *Herman Hollerith-Forgotten Giant of Information Processing*, Columbia University Press, 1982, ISBN 0-231-05 Bantam Books, 1990, ISBN 0-553-07011-8, for interesting stories of the early days of computing.

Depending on the locale, GNU *ls* may produce something close to the *yyyy-mm-ddhh:mm:ss* format defined in *interchange-Representation of dates and times*, but without the seconds field, as shown in earlier sample

The GNU *ls* option *-full-time* can be used to expose the complete timestamp recorded in the filesystem, as

B.6.5. Other File Metadata

There are a few remaining file properties recorded in inode entries that we have not yet mentioned. However, the first character of the line, immediately before the permissions. This is *-* (hyphen) for an ordinary file, *d* for a dir

Those three characters are about the only ones that you'll see in ordinary directories. However, in */dev*, you'll see *l*, *b*, and *s*. Neither of them is relevant for anything in this book.

Two other rarely seen file types are *p* for a named pipe, and *s* for socket (a special network connection). Sockets are occasionally useful in programs and shell scripts: they allow for client-server communication via the file system between two or more unrelated processes. They generalize ordinary pipes, which have only one writer and one reader.

The GNU *stat* command from the *coreutils* package displays the results of the `stat()` system call, which was first introduced from SGI IRIX that we used earlier:

```
$ stat /bin/true                                Report inode information about
File: `/bin/true'
Size: 312                Blocks: 8                IO Block: 65536   regular file
Device: eeh/238d        Inode: 380                Links: 1
Access: (0755/-rwxr-xr-x)  Uid: (   0/   root)   Gid: (   0/   root)
Access: 2003-12-09 09:02:56.572619600 -0700
Modify: 1999-11-04 12:07:38.887783200 -0700
Change: 1999-11-04 12:07:38.888253600 -0700
```

The information shown more compactly by *ls* is just a subset of *stat*'s more detailed report.

GNU *stat* supports fancy format sequences that allow you to select any subset of the data in the full report. Consult the *stat* manual pages for details. Make sure the filesystem has sufficient free space to proceed.

Only a few Unix flavors (FreeBSD, GNU/Linux, NetBSD, and SGI IRIX) supply a native *stat* command. E

```
$ /usr/bin/stat /usr/bin/true           FreeBSD 5.0 (one long outpu
```

```
1027 1366263 -r-xr-xr-x 1 root wheel 5464488 3120 "Dec  2 18:48:36 2
```

```
"Jan 16 13:29:56 2003" "Apr  4 09:14:03 2003" 16384 8 /usr/bin/true
```

```
$ stat -t /bin/true           GNU/Linux terse inode inform
```

```
/bin/true 312 8 81ed 0 0 ee 380 1 0 0 1070985776 941742458 941742458
```

```
$ /sbin/stat /bin/true       SGI IRIX system utility
```

```
/bin/true:
```

```
inode 380; dev 238; links 1; size 312
```

```
regular; mode is rwxr-xr-x; uid 0 (root); gid 0 (sys)
```

```
projid 0          st_fstype: xfs
```

```
change time - Thu Nov  4 12:07:38 1999 <941742458>
```

```
access time - Tue Dec  9 09:02:56 2003 <1070985776>
```

```
modify time - Thu Nov  4 12:07:38 1999 <941742458>
```

```
< Day Day Up >
```


B.7. Unix File Ownership and Privacy Issues

We have made numerous mentions of file permissions, showing how they control read, write, and execute access to files and directories. By careful choice of file permissions, you can, and should, control who can access your files.

The most important tool for access control is the *umask* command, since it limits the permissions assigned to all files that you subsequently create. Normally, you pick a default value and set it in the file that your shell reads on startup: `$HOME/.profile` for *sh*-like shells (see [Section 14.7](#)). System managers usually pick a *umask* setting in a corresponding system-wide startup file, when the shell supports one. In a collaborative research environment, you might choose a mask value of 022, removing write access for group and other. In a student environment, a mask of 077 might be more appropriate, eliminating all access except for the file owner (and `root`).

When nondefault permissions are likely to be required, shell scripts should issue an explicit *umask* command near the beginning, and *before* any files are created. However, such a setting does not affect files that are redirected on the command line, since they are already open when the script starts.

The second most important tool is the *chmod* command: learn it well. Even in a permissive environment where read access is granted to everyone, there are still files and directories that must be more restricted. These include mail files, web browser history and cache, private correspondence, financial and personnel data, marketing plans, and so on. Mail clients and browsers generally set restrictive permissions by default, but for files that you create with a text editor, you may need to issue a *chmod* command yourself. If you are really paranoid, don't create the file with the text editor: instead, create an empty file with *touch*, run *chmod*, and then edit the file. That eliminates a window when there might be data in the file during initial editing that is more visible to others than you want.

You must also remember that system managers have full access to your filesystem, and can read any file. While most system managers consider it unethical to look inside user files without explicit permission from the file owners, some organizations consider all computer files, including electronic mail, their property, and subject to monitoring at any time. The legal issues on this remain fuzzy, and certainly vary around the world. Also, your site may have backups that go back a long time, and files can be recovered from them, possibly at the order of a court of law.

Encryption and Data Security

If you are really intent on storing files that (almost) no one but you can read, you need to use encryption. Because of various government export rules that classify cryptography as a weapon, most Unix vendors normally do not ship encryption software in standard distributions. Before you go off and install encryption software that you may have found on the Web, or bought commercially, we issue these caveats:

- *Security is a process, not a product*. There is a fine book that you can read to learn more about this: *Secrets and Lies: Digital Security in a Networked World* (Wiley).
- Should you ever forget your encryption key, or have an employee who leaves without passing on encryption keys, you have probably lost your data as well: good encryption methods generally cannot be broken in the time that you have available.
- Just as you might change door locks when an employee leaves, you must also accept that the ex-employee's encryption keys are compromised, and with new keys, re-encrypt all files previously secured with the no-longer-trusted keys.
- If the enhanced security of encrypted files makes life harder for users, they may simply stop using encryption. The same thing happens with complicated door locks: the doors just get propped open.

If you'd like to learn more about the fascinating history of (mostly failed) encryption algorithms, a good place to start is *The Code Book: The Evolution of Secrecy from Mary, Queen of Scots, to Quantum Cryptography* (Doubleday). If you are interested, you can then move on to the algorithmic details in *Applied Cryptography: Protocols, Algorithms, and Source Code in C* (Wiley). There are also extensive bibliographies that cover much of the literature of the field at <http://www.math.utah.edu/pub/tex/bib/index-table.html>.

Finally, in an era of networked computers, it is likely that you will at some time be separated from your filesystem, or your operating system, by a network, and unless traffic on that network is secure, your data is not safe. Wireless networks are particularly vulnerable, and software that can silently eavesdrop, and exploit weaknesses of some current wireless encryption protocols to decipher encrypted traffic, is readily available. Remote access to your electronic mail, and interactive messaging systems, are also likely to be insecure. If you are still using *telnet* or nonanonymous *ftp* to connect to your computer(s), you should immediately switch to a *secure shell* replacement.^[26] The old-style communications software passes all data, including usernames and passwords, in clear text; a network attacker can easily recover such data. Secure-shell software uses strong public-key cryptography to accomplish a

secure exchange of a randomly generated lengthy encryption key for use with any of several simpler and faster encryption algorithms. No user data is transmitted until the encrypted channel is established, and the standard encryption methods are well studied and believed to be quite secure; an attacker sees an apparently random stream of bytes in your packets, although source and destination address are still visible, and can be used for traffic analysis. Secure shell also creates a secure channel for X Window System data, protecting input keystrokes and window output from attackers. Of course, this won't help if the attacker sits between you and your computer: Internet cafes, keyboard sniffers, wireless networks, and thin clients can all open up avenues of attack that even the secure shell cannot protect against. Even the varying reflection of a monitor against a wall has been demonstrated to permit the screen image to be read by an attacker 80 meters away.^[27]

[26] See, for example, <http://www.columbia.edu/kermit/>, <http://www.ssh.com/>, and <http://www.openssh.org/>. For an in-depth treatment of this important software *SSH, The Secure Shell: The Definitive Guide* (O'Reilly).

[27] Markus Kuhn, *Optical Time-Domain Eavesdropping Risks of CRT Displays* Proceedings: 2002 IEEE Symposium on Security and Privacy, 12-15 May, 2002, Berkeley, California, IEEE Computer Society Press, 2002, pp. 3-18, ISBN 0-7695-1543-6. Also available at <http://www.cl.cam.ac.uk/~mgk25/ieee02-optical.pdf>.



B.8. Unix File Extension Conventions

Some other operating systems have filenames of the form of a base name, a dot, and a one- to three-character file type or file extension. These extensions serve an important purpose: they indicate that the file contents belong to a particular class of data. For example, an extension `pas` could mean that the file contains Pascal source code, and `exe` would identify a binary executable program.

There is no guarantee that file contents are reflected in their file extensions, but most users find them a useful custom, and follow convention.

Unix too has a substantial number of common file extensions, but Unix filenames are not forced to have at most one dot. Sometimes, the extensions are merely conventional (e.g., for most scripting languages). However, compilers generally require particular extensions, and use the base name (after stripping the extension) to form the names of other related files. Some of the more common extensions are shown in [Table B-1](#).

Table B-1. Common Unix file extensions

Extension	Contents
1	Digit one. Manual page for section 1 (user commands)
a	Library archive file
awk	<i>awk</i> language source file
bz2	File compressed by <i>bzip2</i>
c	C language source file
cc C cpp cxx	C++ language source file
eps ps	PostScript page-description language source file
f	Fortran 77 language source file
gz	File compressed by <i>gzip</i>
f90	Fortran 90/95/200x language source file

Extension	Contents
<code>h</code>	C language header file
<code>html htm</code>	HyperText Markup Language file
<code>o</code>	Object file (from most compiled programming languages)
<code>pdf</code>	Portable Document Format file
<code>s</code>	Assembly language source file (e.g., output by compilers in response to the symbolic code option, <code>-S</code>)
<code>sh</code>	Bourne-family shell script
<code>so</code>	Shared-object library (called a dynamic load library on some systems)
<code>tar</code>	Tape archive file (from the <i>tar</i> utility)
<code>,v</code>	<i>cvs</i> and <i>rcs</i> history file
<code>z</code>	Compressed file from <i>pack</i> (rare)
<code>Z</code>	Compressed file from <i>compress</i>

Notably absent from this table is `exe`. While several other operating systems use that extension for binary executable programs, and permit the extension to be omitted when using the filename as a command name, Unix does not use any particular extension for executable files (file permissions serve that purpose), and Unix software rarely permits file extensions to be dropped.

Several Unix text editors offer the user the option of creating temporary backup files so that the state of a long editing session can be safely recorded in the filesystem at suitable intervals. There are several conventions for naming these backup files: prefixes and/or suffixes of sharp (`#`) and tilde (`~`), or a suffix that includes tildes and a number, such as `~1~`, `~2~`, and so on. The latter mimic the file generation numbers provided by some other filesystems, a feature that Unix does not explicitly provide, but effectively permits through flexible file-naming rules.

File generation numbers used in other systems provide a way to retain multiple versions of a file, with the convention that an omitted generation number refers to the highest-numbered generation. Unix offers better ways of handling file version histories: software tools that preserve the history as differences from a base version, together with commentary that describes why the change was made. The original such package was AT&T's *Source Code Control System* (*sccs*), but today, the *Revision Control System* (*rcs*) (see [Section C.5](#) in [Appendix C](#)) and the *Concurrent Versions System* (*cvs*) are more common.

B.9. Summary

This completes our tour of the workings of the Unix filesystem. By now, you should be familiar with its main features:

- Files are streams of zero or more 8-bit bytes, without any additional structure other than the use of newline characters to mark line boundaries in text files.
- Bytes are usually interpreted as ASCII characters, but the UTF-8 encoding and the Unicode character set permit graceful evolution of the Unix filesystem, pipes, and network communications to support millions of different characters from all of the world's writing systems, *without invalidating the majority of existing files or software*.
- Files have attributes, such as timestamps, ownership, and permissions, allowing a much greater degree of access control and privacy than is available on some other desktop operating systems, and eliminating most computer virus problems.
- Access to entire directory trees can be controlled at a single point by suitable settings of directory permissions.
- The maximum file size is large enough to rarely be a problem, and newer filesystem designs raise the maximum well beyond the limits of current technology.
- The maximum filename and pathname lengths are much longer than you are likely to need in practice.
- A clean hierarchical directory structure with slash-separated path components, together with the *mount* command, allows logical filesystems of potentially unbounded size.
- File-like views of other data are possible, and encouraged, to simplify data processing and use by humans.
- Filenames may use any character other than NUL or slash, but practical considerations of portability, readability, and shell wildcarding sharply limit the characters that should be used.
- Filenames are case-sensitive (except in Mac OS X's non-Unix HFS filesystems).
- Although the filesystem does not impose rules on filename structure, many programs expect files to be named with particular dotted extensions, and they replace the extensions with other ones when creating related files. The shells encourage this practice through their support of wildcard

patterns like `ch01.*` and `*.xml`.

- Filenames are stored in a directory file, whereas information about the file, the file *metadata*, is stored separately in an inode entry.
- Moving or renaming files and directories within the same filesystem is fast, since only their containing directory entries are updated; the file data blocks themselves are not accessed.
- Hard and soft links allow multiple names for the same physical file. Hard links are restricted to a single physical filesystem, but soft links may point anywhere in the logical filesystem.
- The inode table size is fixed when the filesystem is created, so the filesystem can be full even when plenty of storage is available for file data.



Appendix C. Important Unix Commands

Modern Unix systems come with hundreds and hundreds of commands. Many of them are specialized, but many are also generally useful, both in everyday interactive use and in shell scripts. It's impossible to cover every program on every system in existence, nor would that be useful. (Although books like *Unix in a Nutshell* make a valiant effort to describe a large cross section of what's out there.)

It is possible, however, to identify certain valuable commands, the ones that a Unix user or programmer should come to understand first, before moving on to the rest of the programs out there. Not surprisingly, many of these are the older commands that have been around since the early days of Unix. This appendix is our recommended list of commands that you should go out and study in order to improve your skills as a Unix developer. For brevity, we have resorted to simple, sorted, tabular lists of commands.

C.1. Shells and Built-in Commands

First and foremost, it pays to understand the Bourne shell language, particularly as codified by POSIX. Both *bash* and *ksh93* are POSIX-compliant, and several other shells are compatible syntactically with the Bourne shell:

<i>bash</i>	The GNU Project's Bourne-Again Shell.
<i>ksh</i>	The Korn shell, either an original or clone, depending upon the operating system.
<i>pdksh</i>	The Public Domain Korn shell.
<i>sh</i>	The original Bourne shell, particularly on commercial Unix systems.
<i>zsh</i>	The Z-shell.

Along similar lines, you should understand the way the shell's built-in commands work:

.	Read and execute a given file, in the current shell.
<i>break</i>	Break out of a <i>for</i> , <i>select</i> , <i>until</i> , or <i>while</i> loop.
<i>cd</i>	Change the current directory.
<i>command</i>	Bypass the search for functions to run a regular built-in command.
<i>continue</i>	Start the next iteration of a <i>for</i> , <i>select</i> , <i>until</i> , or <i>while</i> loop.
<i>eval</i>	Evaluate given text as a shell command.
<i>exec</i>	With no arguments, change the shell's open files. With arguments, replace the shell with another program.
<i>exit</i>	Exit a shell script, optionally with a specific exit code.
<i>export</i>	Export a variable into the environment of subsequent programs.
<i>false</i>	Do nothing, unsuccessfully. For use in shell loops.
<i>getopts</i>	Process command-line options.
<i>read</i>	Read lines of input into one or more shell variables.

<i>readonly</i>	Mark a variable as read-only; i.e., unchangeable.
<i>return</i>	Return a value from a shell function.
<i>set</i>	Print shell variables and values; set shell options; set the command-line parameters (\$1, \$2, ...).
<i>shift</i>	Move the command-line parameters down by one or more.
<i>test</i>	Evaluate expressions, which may be string-, numeric-, or file-attribute-related.
<i>trap</i>	Manage operating system signals.
<i>true</i>	Do nothing, successfully. For use in shell loops.
<i>type</i>	Indicate the nature of a command (keyword, built-in, external, etc.).
<i>typeset</i>	Declare variables and manage their type and attributes.
<i>ulimit</i>	Set or display various per-process system-imposed limits.
<i>unset</i>	Remove shell variables and functions.

The following commands are useful in day-to-day shell scripting:

<i>basename</i>	Print the last component of a pathname, optionally removing a suffix. Mainly used in command substitution.
<i>dirname</i>	Print all but the last component of a pathname. Mainly used in command substitution.
<i>env</i>	Manipulate the environment of a command.
<i>id</i>	Print user and group ID and name information.
<i>date</i>	Print the current date and time, optionally under control of a user-supplied format string.
<i>who</i>	Print a list of logged-on users.
<i>stty</i>	Manipulate the state of the current terminal device.

C.2. Text Manipulation

The following commands are used for text manipulation:

<i>awk</i>	An elegant and useful programming language in its own right, it is also an important component of many large shell scripts.
<i>cat</i>	Concatenate files.
<i>cmp</i>	Simple file comparison program.
<i>cut</i>	Cut out selected columns or fields.
<i>dd</i>	A more specialized program for blocking and unblocking data, and converting between ASCII and EBCDIC. <i>dd</i> is especially good for making raw copies of device files. Note that <i>iconv</i> is a better program for doing character set conversions.
<i>echo</i>	Print arguments to standard output.
<i>egrep</i>	Extended <i>grep</i> . Matching uses Extended Regular Expressions (EREs).
<i>expand</i>	Expand tabs to spaces.
<i>fgrep</i>	Fast <i>grep</i> . This program uses a different algorithm than <i>grep</i> for matching fixed strings. Most, but not all, Unix systems can search simultaneously for multiple fixed strings.
<i>fmt</i>	Simple tool for formatting text into paragraphs.
<i>grep</i>	From the original <i>ed</i> line editor's command <i>g/re/p</i> , "Globally match RE and Print." Matching uses Basic Regular Expressions (BREs).
<i>iconv</i>	General-purpose character-encoding conversion tool.
<i>join</i>	Join matching records from multiple files.
<i>less</i>	A sophisticated interactive <i>pager</i> program for looking at information on a terminal, one screenful (or "page") at a time. It is now available from the GNU Project. The name is a pun on the <i>more</i> program.
<i>more</i>	The original BSD Unix interactive pager program.
<i>pr</i>	Format files for printing on line printers.

<i>printf</i>	A more sophisticated version of <i>echo</i> that provides control over the way each argument is printed.
<i>sed</i>	A stream editor, based on the original <i>ed</i> line editor's command set.
<i>sort</i>	Sort text files. Command-line arguments provide control over sort key specification and priority.
<i>spell</i>	A batch spellchecker. You may have <i>aspell</i> or <i>ispell</i> , with a shell script wrapper named <i>spell</i> , instead.
<i>tee</i>	Copy standard input to standard output and to one or more named output files.
<i>tr</i>	Transliterate, delete, or reduce runs of duplicate characters.
<i>unexpand</i>	Convert runs of spaces into the appropriate number of tabs.
<i>uniq</i>	Remove or count duplicate lines in sorted input.
<i>wc</i>	Count lines, words, characters, and/or bytes.

C.3. Files

The following commands work with files:

<i>bzip2</i> , <i>bunzip2</i>	Very high quality file compression and decompression.
<i>chgrp</i>	Change the group of files and directories.
<i>chmod</i>	Change the permissions (mode) of files and directories.
<i>chown</i>	Change the owner of files and directories.
<i>cksum</i>	Print a file checksum, POSIX standard algorithm.
<i>comm</i>	Print or omit lines that are unique or common between two sorted files.
<i>cp</i>	Copy files and directories.
<i>df</i>	Show free disk space.
<i>diff</i>	Compare files, showing differences.
<i>du</i>	Show disk block usage of files and directories.
<i>file</i>	Guess the type of data in a file by examining the first part of it.
<i>find</i>	Descend one or more directory hierarchies finding filesystem objects (files, directories, special files) that match specified criteria.
<i>gzip</i> , <i>gunzip</i>	High-quality file compression and decompression.
<i>head</i>	Print the first <i>n</i> lines of one or more files.
<i>locate</i>	Find a file somewhere on the system based on its name. The program uses a database of files that is usually rebuilt automatically, nightly.
<i>ls</i>	List files. Options control the information shown.
<i>md5sum</i>	Print a file checksum using the Message Digest 5 (MD5) algorithm.
<i>mkdir</i>	Make directories.
<i>mktemp</i>	Create a unique temporary file and print its name. Not universally available.

<i>od</i>	Octal dump; print file contents in octal, hexadecimal, or as character data.
<i>patch</i>	Update the contents of a given file to a newer version by reading the output of <i>diff</i> .
<i>pwd</i>	Print the current working directory. Usually built into modern shells.
<i>rm</i>	Remove files and directories.
<i>rmdir</i>	Remove just empty directories.
<i>strings</i>	Search binary files for printable strings and print them.
<i>tail</i>	Show the last <i>n</i> lines of a file. With <i>-f</i> , keep printing the (growing) contents of the file.
<i>tar</i>	Tape archiver. Now used mostly as a software distribution format.
<i>touch</i>	Update the modification or access time of a file.
<i>umask</i>	Set the default file-creation permissions mask.
<i>zip, unzip</i>	File archiver and compressor/decompressor. The ZIP format is portable across a broad range of operating systems.

C.4. Processes

The following commands create, remove, or manage processes:

<i>at</i>	Executes jobs at a specified time. <i>at</i> schedules jobs to be executed just once, whereas <i>cron</i> schedules them to be executed regularly.
<i>batch</i>	Executes jobs when the system is not too overloaded.
<i>cron</i>	Executes jobs at specified times.
<i>crontab</i>	Edit per-user " <i>cron</i> table" files that specify what commands to run, and when.
<i>fuser</i>	Find processes using particular files or sockets.
<i>kill</i>	Send a signal to one or more processes.
<i>nice</i>	Change the priority of a process before starting it.
<i>ps</i>	Process status. Print information about running processes.
<i>renice</i>	Change the priority of a process that has already been started.
<i>sleep</i>	Stop execution for the given number of seconds.
<i>top</i>	Interactively display the most CPU-intensive jobs on the system.
<i>wait</i>	Shell built-in command to wait for one or more processes to complete.
<i>xargs</i>	Read strings on standard input, passing as many as possible as arguments to a given command. Most often used together with <i>find</i> .

C.5. Miscellaneous Programs

There's always a "miscellaneous" category:

<i>cvs</i>	The Concurrent Versions System, a powerful source-code management program.
<i>info</i>	The GNU Info system for online documentation.
<i>locale</i>	Print information about available locales.
<i>logger</i>	Send messages to system logs, usually via <i>syslog(3)</i> .
<i>lp, lpr</i>	Spool files to a printer.
<i>lpq</i>	Show the list of print jobs in progress and waiting in the queue.
<i>mail</i>	Send electronic mail.
<i>make</i>	Control compilation and recompilation of files.
<i>man</i>	Print the online manual page(s) for commands, library functions, system calls, devices, file formats, and administrative commands.
<i>scp</i>	Secure remote copy of files.
<i>ssh</i>	Secure shell. Provide an encrypted connection between machines for program execution or interactive login.
<i>uptime</i>	Tell how long the system has been up, and show system load information.

Also in the miscellaneous category are the commands for the Revision Control System (RCS):

<i>ci</i>	Check in a file to RCS.
<i>co</i>	Check out a file from RCS.
<i>rcs</i>	Manipulate a file that is under RCS control.
<i>rcsdiff</i>	Run <i>diff</i> on two different versions of a file controlled by RCS.
<i>rlog</i>	Print the check-in log for one or more RCS-managed files.

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Chapter 16. Bibliography

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Section 16.8. Miscellaneous Books

16.1. Unix Programmer's Manuals

1. *UNIX Time-sharing System: UNIX Programmers Manual*, Seventh Edition, Volumes 1, 2A, 2B. Bell Telephone Laboratories, Inc., January 1979.

These are the reference manuals (Volume 1) and descriptive papers (Volumes 2A and 2B) for the landmark Seventh Edition Unix system, the direct ancestor of all current commercial Unix systems.

They were reprinted by Holt Rinehart & Winston, but are now long out of print. However, they are available online from Bell Labs in *troff* source, PDF, and PostScript formats. See <http://plan9.bell-labs.com/7thEdMan>.

2. Your Unix programmer's manual. One of the most instructive things that you can do is to read your manual from front to back.^[1] (This is harder than it used to be, as Unix systems have grown.) It is easier to do if your Unix vendor makes printed copies of its documentation available. Otherwise, start with the Seventh Edition manual, and then read your local documentation as needed.

^[1] One summer, while working as a contract programmer, I spent my lunchtimes reading the manual for System III (yes, that long ago), from cover to cover. I don't know that I ever learned so much in so little time. ADR.

16.2. Programming with the Unix Mindset

We expect that this book has helped you learn to "think Unix" in a modern context. The first two books in this list are the original presentations of the Unix "toolbox" programming methodology. The third book looks at the broader programming facilities available under Unix. The fourth and fifth are about programming in general, and also very worthwhile. We note that any book written by Brian Kernighan deserves careful reading, usually several times.

1. *Software Tools*, Brian W. Kernighan and P. J. Plauger. Addison-Wesley, Reading, MA, U.S.A., 1976. ISBN 0-201-03669-X.

A wonderful book^[2] that presents the design and code for programs equivalent to Unix's *grep*, *sort*, *ed*, and others. The programs use Ratfor (Rational Fortran), a preprocessor for Fortran with C-like control structures.

^[2] One that changed my life forever. ADR.

2. *Software Tools in Pascal*, Brian W. Kernighan and P. J. Plauger. Addison-Wesley, Reading, MA, U.S.A., 1981. ISBN 0-201-10342-7.

A translation of the previous book into Pascal. Still worth reading; Pascal provides many things that Fortran does not.

3. *The Unix Programming Environment*, Brian W. Kernighan and Rob Pike. Prentice-Hall, Englewood Cliffs, NJ, U.S.A., 1984. ISBN 0-13-937699-2 (hardcover), 0-13-937681-X (paperback).

This book focuses explicitly on Unix, using the tools in that environment. In particular, it adds important material on the shell, *awk*, and the use of *lex* and *yacc*. See <http://cm.bell-labs.com/cm/cs/upe>.

4. *The Elements of Programming Style*, Second Edition, Brian W. Kernighan and P. J. Plauger. McGraw-Hill, New York, NY, U.S.A., 1978. ISBN 0-07-034207-5.

Modeled after Strunk & White's famous *The Elements of Style*, this book describes good programming practices that can be used in any environment.

5. *The Practice of Programming*, Brian W. Kernighan and Rob Pike. Addison-Wesley Longman, Reading, MA, U.S.A., 1999. ISBN 0-201-61586-X.

Similar to the previous book, with a somewhat stronger technical focus. See <http://cm.bell-labs.com/cm/cs/tpop>.

6. *The Art of UNIX Programming*, Eric S. Raymond. Addison-Wesley, Reading, MA, U.S.A., 2003. ISBN 0-13-124085-4.
7. *Programming Pearls*, First Edition, Jon Louis Bentley. Addison-Wesley, Reading, MA, U.S.A., 1986. ISBN 0-201-10331-1.
8. *Programming Pearls*, Second Edition, Jon Louis Bentley. Addison-Wesley, Reading, MA, U.S.A. 2000. ISBN 0-201-65788-0. See <http://www.cs.bell-labs.com/cm/cs/pearls/>.
9. *More Programming Pearls: Confessions of a Coder*, Jon Louis Bentley. Addison-Wesley, Reading, MA, U.S.A., 1988. ISBN 0-201-11889-0.

Bentley's excellent books epitomize the Unix mindset, and are wonderful examples of little languages, algorithm design, and much more. These should be on every serious programmer's bookshelf.

10. *Linux and the Unix Philosophy*, Mike Gancarz. Digital Press, Bedford, MA, U.S.A., 2003. ISBN 1-55558-273-7.

16.3. Awk and Shell

1. *The AWK Programming Language*, Alfred V. Aho, Brian W. Kernighan, and Peter J. Weinberger. Addison-Wesley, Reading, MA, U.S.A., 1987. ISBN 0-201-07981-X.

The original definition for the `awk` programming language. Extremely worthwhile. See <http://cm.bell-labs.com/cm/cs/awkbook>.

Effective awk Programming, Third Edition, Arnold Robbins. O'Reilly, Sebastopol, CA, U.S.A., 2001. ISBN 0-596-00070-7.

A more tutorial treatment of `awk` that covers the POSIX standard for `awk`. It also serves as the user's guide for `gawk`.

2. *The New KornShell Command and Programming Language*, Morris I. Bolsky and David G. Korn. Prentice-Hall, Englewood Cliffs, NJ, U.S.A., 1995. ISBN 0-13-182700-6.

The definitive work on the Korn shell, by its author.

3. *Hands-On KornShell93 Programming*, Barry Rosenberg. Addison-Wesley Longman, Reading, MA, U.S.A., 1998. ISBN 0-201-31018-X.

16.4. Standards

Formal standards documents are important, as they represent "contracts" between implementors and users of computer systems.

1. *IEEE Standard 1003.1-2001: Standard for Information Technology-Portable Operating System Interface (POSIX®)*. IEEE, New York, NY, U.S.A., 2001.

This is the next-to-most recent POSIX standard. It combines both the system call interface standard and the shell and utilities standard in one document. Physically, the standard consists of several volumes, available online,^[3] in print,^[4] electronically as PDF, and on CD-ROM:

[3] See <http://www.opengroup.org/onlinepubs/007904975>.

[4] See <http://www.standards.ieee.org/>.

Base Definitions

This provides the history of the standard, definitions of terms, and specifications for file formats and input and output formats. ISBN 0-7381-3047-8; PDF: 0-7381-3010-9/SS94956; CD-ROM: 0-7381-3129-6/SE94956.

Rationale (Informative)

Not a formal part of the standard, in the sense that it does not impose requirements upon implementations, this volume provides the *why* for the way things are in the POSIX standard. ISBN 0-7381-3048-6; PDF: 0-7381-3010-9/SS94956; CD-ROM: 0-7381-3129-6/SE94956.

System Interfaces

This volume describes the interface to the operating system as seen by the C or C++ programmer. ISBN 0-7381-3094-4; PDF: 0-7381-3010-9/SS94956; CD-ROM: 0-7381-3129-6/SE94956.

Shell and Utilities

This volume is more relevant for readers of this book: it describes the operating system at the level of the shell and utilities. ISBN 0-7381-3050-8; PDF: 0-7381-3010-9/SS94956; CD-ROM: 0-7381-3129-6/SE9.

1. *IEEE Standard 1003.1-2004: Standard for Information Technology-Portable Operating System Interface (POSIX®)*. IEEE, New York, NY, U.S.A., 2004.

The current POSIX standard, released as this book was going to press. It is a revision of the previous one, and is organized similarly. The standard consists of several volumes: *Base Definitions* (Volume 1), *System Interfaces* (Volume 2), *Shell and Utilities* (Volume 3), and *Rationale* (Volume 4).

The standard may be ordered from <http://www.standards.ieee.org/> on CD-ROM (Product number SE95238, ISBN 0-7381-4049-X) or as PDF (Product number SS95238, ISBN 0-7381-4048-1).

2. *The Unicode Standard, Version 4.0*, The Unicode Consortium. Addison-Wesley, Reading, MA, U.S.A., 2003. ISBN 0-321-18578-1.
3. The standard for XML, available online at <http://www.w3.org/TR/REC-xml/>.

16.5. Security and Cryptography

1. *PGP: Pretty Good Privacy*, Simson Garfinkel. O'Reilly, Sebastopol, CA, U.S.A., 1995. ISBN 1-56592-098-8.
2. *The Official PGP User's Guide*, Philip R. Zimmermann. MIT Press, Cambridge, MA, U.S.A., 1995. ISBN 0-262-74017-6.
3. *Practical UNIX & Internet Security*, Third Edition, Simson Garfinkel, Gene Spafford, and Alan Schwartz. O'Reilly, Sebastopol, CA, U.S.A., 2003. ISBN 0-596-00323-4.
4. *SSH, The Secure Shell: The Definitive Guide*, Second Edition, Daniel J. Barrett, Richard E. Silverman, and Robert G. Byrnes. O'Reilly Media, Sebastopol, CA, U.S.A., 2005. ISBN 0-596-00895-3.
5. *Secrets and Lies: Digital Security in a Networked World*, Bruce Schneier. Wiley, New York, NY, U.S.A., 2000. ISBN 0-471-25311-1.

This book is an outstanding exposition for every world citizen of the implications of computer security on their lives, their data, and their personal freedom. Bruce Schneier, like Brian Kernighan, Jon Bentley, and Donald Knuth, is one of those authors who is always worth reading.

6. *The Code Book: The Evolution of Secrecy from Mary, Queen of Scots, to Quantum Cryptography* Simon Singh. Doubleday, New York, NY, U.S.A., 1999. ISBN 0-385-49531-5.
7. *Applied Cryptography: Protocols, Algorithms, and Source Code in C*, Second Edition, Bruce Schneier. Wiley, New York, NY, U.S.A., 1996. ISBN 0-471-12845-7 (hardcover), 0-471-11709-9 (paperback).
8. *Cryptographic Security Architecture: Design and Verification*, Peter Gutmann. Springer-Verlag, New York, NY, U.S.A., 2004. ISBN 0-387-95387-6.

16.6. Unix Internals

1. *Lions' Commentary on UNIX 6th Edition, with Source Code* John Lions. Peer-to-Peer Communications, 1996. ISBN 1-57398-013-7.
2. *The Design and Implementation of the 4.4BSD Operating System*, Marshall Kirk McKusick, Keith Bostic, Michael J. Karels, and John S. Quarterman. Addison-Wesley, Reading, MA, U.S.A., 1996. ISBN 0-201-54979-4.
3. *UNIX Internals: The New Frontiers*, Uresh Vahalia. Prentice Hall, Englewood Cliffs, NJ, U.S.A., 1996. ISBN 0-13-101908-2.

16.7. O'Reilly Books

Here is a list of O'Reilly books. There are, of course, many other O'Reilly books relating to Unix. See <http://www.oreilly.com/catalog>.

1. *Learning the bash Shell*, Second Edition, Cameron Newham and Bill Rosenblatt. O'Reilly, Sebastopol, CA, U.S.A., 1998. ISBN 1-56592-347-2.
2. *Learning the Korn Shell*, Second Edition, Bill Rosenblatt and Arnold Robbins. O'Reilly, Sebastopol, CA, U.S.A., 2002. ISBN 0-596-00195-9.
3. *Learning the Unix Operating System*, Fifth Edition, Jerry Peek, Grace Todino, and John Strang. O'Reilly, Sebastopol, CA, U.S.A., 2001. ISBN 0-596-00261-0.
4. *Linux in a Nutshell*, Third Edition, Ellen Siever, Stephen Spainhour, Jessica P. Hekman, and Stephen Figgins. O'Reilly, Sebastopol, CA, U.S.A., 2000. ISBN 0-596-00025-1.
5. *Mastering Regular Expressions*, Second Edition, Jeffrey E. F. Friedl. O'Reilly, Sebastopol, CA, U.S.A., 2002. ISBN 0-596-00289-0.
6. *Managing Projects with GNU make*, Third Edition, Robert Mecklenburg, Andy Oram, and Steve Talbott. O'Reilly Media, Sebastopol, CA, U.S.A., 2005. ISBN: 0-596-00610-1.
7. *sed and awk*, Second Edition, Dale Dougherty and Arnold Robbins. O'Reilly, Sebastopol, CA, U.S.A., 1997. ISBN 1-56592-225-5.
8. *sed and awk Pocket Reference*, Second Edition, Arnold Robbins. O'Reilly, Sebastopol, CA, U.S.A., 2002. ISBN 0-596-00352-8.
9. *Unix in a Nutshell*, Third Edition, Arnold Robbins. O'Reilly, Sebastopol, CA, U.S.A., 1999. ISBN 1-56592-427-4.

16.8. Miscellaneous Books

1. *CUPS: Common UNIX Printing System*, Michael R. Sweet. SAMS Publishing, Indianapolis, IN, U.S.A., 2001. ISBN 0-672-32196-3.
2. *SQL in a Nutshell*, Kevin Kline and Daniel Kline. O'Reilly, Sebastopol, CA, U.S.A., 2000. ISBN 1-56592-744-3.
3. *HTML & XHTML: The Definitive Guide*, Chuck Musciano and Bill Kennedy. O'Reilly, Sebastopol, CA, U.S.A., 2002. ISBN 0-596-00026-X.
4. *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*, Eric S. Raymond. O'Reilly, Sebastopol, CA, U.S.A., 2001. ISBN 0-596-00131-2 (hardcover), 0-596-00108-8 (paperback).
5. *Texinfo: The GNU Documentation Format*, Robert J. Chassell and Richard M. Stallman. Free Software Foundation, Cambridge, MA, U.S.A., 1999. ISBN 1-882114-67-1.
6. *The TEXbook*, Donald E. Knuth. Addison-Wesley, Reading, MA, U.S.A., 1984. ISBN 0-201-13448-9.
7. *The Art of Computer Programming, Volume 2: Seminumerical Algorithms*, Third Edition, Donald E. Knuth. Addison-Wesley, Reading, MA, U.S.A., 1997. ISBN 0-201-89684-2.
8. *Literate Programming*, Donald E. Knuth. Stanford University Center for the Study of Language and Information, Stanford, CA, U.S.A., 1992. ISBN 0-937073-80-6 (paperback) and 0-937073-814 (hardcover).
9. *Herman Hollerith-Forgotten Giant of Information Processing*, Geoffrey D. Austrian. Columbia University Press, New York, NY, U.S.A. 1982. ISBN 0-231-05146-8.
10. *Father Son & Co.-My Life at IBM and Beyond*, Thomas J. Watson Jr. and Peter Petre. Bantam Books, New York, NY, U.S.A., 1990. ISBN 0-553-07011-8.
11. *A Quarter Century of UNIX*, Peter H. Salus. Addison-Wesley, Reading, MA, U.S.A., 1994. ISBN 0-201-54777-5.

Colophon

Our look is the result of reader comments, our own experimentation, and feedback from distribution channels. Distinctive covers complement our distinctive approach to technical topics, breathing personality and life into potentially dry subjects.

The animal on the cover of *Classic Shell Scripting* is the knobby geometric or African tent tortoise (*Psammobates tentorius*). The genus *Psammobates* literally means "sand-loving," so it isn't surprising that the tent tortoise is found only in the steppes and outer desert zones of southern Africa. All species in this genus are small, ranging in size from five to ten inches, and have yellow radiating marks on their carapace. The tent tortoise is particularly striking, with arched scutes that look like tents.

Tortoises are known for their long lifespan, and turtles and tortoises are also among the most ancient animal species alive today. They existed in the era of dinosaurs some 200 million years ago. All tortoises are temperature dependent, which means they eat only when the temperature is not too extreme. During hot summer and cold winter days, tortoises go into a torpor and stop feeding altogether. In the spring, the tent tortoise's diet consists of succulent, fibrous plants and grasses.

In captivity, this species may hibernate from June to September, and will sometimes dig itself into a burrow and remain there for quite a long time. All "sand-loving" tortoises are very difficult to maintain in captivity. They are highly susceptible to shell disease and respiratory problems brought on by cold or damp environments, so their enclosures must be extremely sunny and dry. The popularity of these species among tortoise enthusiasts and commercial traders, along with the continued destruction of their natural habitat, has made the African tent tortoise among the top twenty-five most endangered tortoises in the world.

Adam Witwer was the production editor and Audrey Doyle was the copyeditor for *Classic Shell Scripting*. Ann Schirmer proofread the text. Colleen Gorman and Claire Cloutier provided quality control. Angela Howard wrote the index.

Emma Colby designed the cover of this book, based on a series design by Edie Freedman. The cover image is a 19th-century engraving from the Dover Pictorial Archive. Karen Montgomery produced the cover layout with Adobe InDesign CS using Adobe's ITC Garamond font.

David Futato designed the interior layout. This book was converted by Keith Fahlgren to FrameMaker 5.5.6 with a format conversion tool created by Erik Ray, Jason McIntosh, Neil Walls, and Mike Sierra that uses Perl and XML technologies. The text font is Linotype Birka; the heading font is Adobe Myriad Condensed; and the code font is LucasFont's TheSans Mono Condensed. The illustrations that appear in the book were produced by Robert Romano, Jessamyn Read, and Lesley Borash using Macromedia FreeHand MX and Adobe Photoshop CS. The tip and warning icons were drawn by Christopher Bing. This colophon was written by Lydia Onofrei.

The online edition of this book was created by the Digital Books production group (John Chodacki, Ken Douglass, and Ellie Cutler) using a set of Frame-to-XML conversion and cleanup tools written and maintained by Erik Ray, Benn Salter, John Chodacki, Ellie Cutler, and Jeff Liggett.



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. (dot)

- in Basic Regular Expressions
- special built-in command

! (exclamation mark)

- != (comparison operator) 2nd 3rd
- != (expr operator)
- != (test expression) 2nd
- !~ (matches operator, awk)
- arithmetic operator 2nd 3rd
- in wildcard set 2nd
- logical NOT operator
- variable

"..." (double quotes)

- enclosing string constants, awk
- grouping text

(hash mark)

- #! (specifying interpreter in shell script)
- ## (pattern-matching operator)
- pattern-matching operator
- preceding comments
- preceding comments, awk
- prefixing temporary backup file name
- printf flag
- string-length operator
- variable

\$ (dollar sign)

- "\$*" (variable)
- "\$@" (variable)
- \$# (variable)
- \$\$ (variable) 2nd 3rd
- \$((...)) (arithmetic expansion)
- \${...} (command substitution)
- * (variable)
- \$_ (variable)
- \$@ (variable)
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- preceding variables 2nd
- variable

\$0 ... \$NF field references, awk

\$1...\$9 [See positional parameters]
% (percent sign)
 %% (format specifier)
 %% (format specifier, awk)
 %% (pattern-matching operator)
 %= (assignment operator) 2nd 3rd
 arithmetic operator 2nd 3rd
 expr operator
 pattern-matching operator
 preceding format specifications
 preceding printf format specifiers
%b format specifier
%c format specifier 2nd
%d format specifier 2nd 3rd
%e format specifier
%E format specifier
%e format specifier
%E format specifier
%e format specifier
%f format specifier 2nd 3rd
%g format specifier
%G format specifier
%g format specifier
%G format specifier
%g format specifier
%i format specifier 2nd 3rd
%o format specifier 2nd 3rd
%s format specifier 2nd 3rd
%u format specifier 2nd 3rd
%x format specifier
%X format specifier
%x format specifier
%X format specifier
%x format specifier
%X format specifier
& (ampersand)
 && (logical AND operator) 2nd 3rd 4th
 &= (assignment operator) 2nd
 beginning HTML entities
 bitwise AND operator 2nd
 expr operator
 in sed replacement text
 preceding file descriptor
 run in background
'...' (single quotes), literal interpretation
(...) (parentheses)
 ((...)) (arithmetic command)
 grouping arithmetic expressions
 grouping, expr expressions
 in Extended Regular Expressions
 in regular expressions
 subshell

- * (asterisk)
 - ** (arithmetic operator) 2nd 3rd
 - **= (assignment operator)
 - *= (assignment operator) 2nd 3rd
 - arithmetic operator 2nd 3rd
 - expr operator
 - in regular expressions 2nd
 - variable
 - wildcard
- + (plus sign)
 - ++ (arithmetic operator) 2nd 3rd 4th
 - += (assignment operator) 2nd 3rd
 - arithmetic operator 2nd 3rd 4th 5th
 - expr operator
 - in Extended Regular Expressions
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 - in trace output
 - printf flag
- , (comma)
 - sequential evaluation
- ,v file extension
- (hyphen)
 - (arithmetic operator) 2nd 3rd 4th
 - (end of options)
 - = (assignment operator) 2nd 3rd
 - arithmetic operator 2nd 3rd 4th 5th
 - as bare option
 - expr operator
 - in filenames
 - preceding command options
 - preceding file type in listing
 - printf flag
 - variable
- help option
- version option
- a logical AND, test expression
- a shell option
- a test expression
- b shell option
- b test expression 2nd
- C shell option
- c test expression 2nd
- C test expression
- d test expression 2nd
- e shell option
- e test expression 2nd
- ef test expression
- eq test expression 2nd
- f shell option
- f test expression 2nd
- g test expression 2nd
- G test expression

- ge test expression 2nd
- gt test expression 2nd
- h shell option
- h test expression 2nd
- k test expression
- L test expression
- l test expression
- L test expression
- le test expression 2nd
- lt test expression 2nd
- m shell option
- n shell option
- n test expression 2nd
- N test expression
- ne test expression 2nd
- nt test expression
- o logical OR, test expression
- o test expression
- O test expression
- ot test expression
- p test expression 2nd
- r test expression 2nd
- S test expression
- s test expression 2nd
- S test expression
- t test expression 2nd
- u shell option
- u test expression 2nd
- v shell option
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