2ND EDITION

# THE LINUX COMMAND LINE

A *COMPLETE* INTRODUCTION

WILLIAM SHOTTS

no starch press

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### A Complete Introduction

by William Shotts

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San Francisco

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To Karen

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# INTRODUCTION

I want to tell you a story. No, not the story of how, in 1991, Linus Torvalds wrote the first version of the Linux kernel. You can read that story in lots of Linux books. Nor am I going to tell you the story of how, some years earlier, Richard Stallman began the GNU Project to create a free Unix-like operating system. That's an important story too, but most other Linux books have that one, as well.

No, I want to tell you the story of how you take back control of your computer.

When I began working with computers as a college student in the late 1970s, there was a revolution going on. The invention of the microprocessor had made it possible for ordinary people like you and me to actually own a computer. It's hard for many people today to imagine what the world was like when only big business and big government ran all the computers. Let's just say, you couldn't get much done.

Today, the world is very different. Computers are everywhere, from tiny wristwatches to giant data centers to everything in between. In addition to ubiquitous computers, we also have a ubiquitous network connecting them together. This has created a wondrous new age of personal empowerment and creative freedom, but over the last couple of decades something else has been happening. A few giant corporations have been imposing their control over most of the world's computers and deciding what you can and cannot do with them. Fortunately, people from all over the world are doing something about it. They are fighting to maintain control of their computers by writing their own software. They are building Linux.

Many people speak of "freedom" with regard to Linux, but I don't think most people know what this freedom really means. Freedom is the power to decide what your computer does, and the only way to have this freedom is to know what your computer is doing. Freedom is a computer that is without secrets, one where everything can be known if you care enough to find out.

## Why Use the Command Line?

Have you ever noticed in the movies when the "superhacker"—you know, the guy who can break into the ultra-secure military computer in less than 30 seconds—sits down at the computer, he never touches a mouse? It's because filmmakers realize that we, as human beings, instinctively know the only way to really get anything done on a computer is by typing on a keyboard!

Most computer users today are familiar only with the *graphical user interface* (*GUI*) and have been taught by vendors and pundits that the *command line interface* (*CLI*) is a terrifying thing of the past. This is unfortunate because a good command line interface is a marvelously expressive way of communicating with a computer in much the same way the written word is for human beings. It's been said that "graphical user interfaces make easy tasks easy, while command line interfaces make difficult tasks possible," and this is still very true today.

Since Linux is modeled after the Unix family of operating systems, it shares the same rich heritage of command line tools as Unix. Unix came into prominence during the early 1980s (although it was first developed a decade earlier), before the widespread adoption of the graphical user interface and, as a result, developed an extensive command line interface instead. In fact, one of the strongest reasons early adopters of Linux chose it over, say, Windows NT was the powerful command line interface that made the "difficult tasks possible."

## What This Book Is About

This book is a broad overview of "living" on the Linux command line. Unlike some books that concentrate on just a single program, such as the shell program `bash`, this book will try to convey how to get along with the

command line interface in a larger sense. How does it all work? What can it do? What's the best way to use it?

**This is not a book about Linux system administration.** While any serious discussion of the command line will invariably lead to system administration topics, this book touches on only a few administration issues. It will, however, prepare the reader for additional study by providing a solid foundation in the use of the command line, an essential tool for any serious system administration task.

**This book is Linux-centric.** Many other books try to broaden their appeal by including other platforms such as generic Unix and macOS. In doing so, they "water down" their content to feature only general topics. This book, on the other hand, covers only contemporary Linux distributions. Ninety-five percent of the content is useful for users of other Unix-like systems, but this book is highly targeted at the modern Linux command line user.

## Who Should Read This Book

This book is for new Linux users who have migrated from other platforms. Most likely you are a "power user" of some version of Microsoft Windows. Perhaps your boss has told you to administer a Linux server, or you're entering the exciting new world of single board computers (SBC) such as the Raspberry Pi. You may just be a desktop user who is tired of all the security problems and wants to give Linux a try. That's fine. All are welcome here.

That being said, there is no shortcut to Linux enlightenment. Learning the command line is challenging and takes real effort. It's not that it's so hard, but rather it's so *vast*. The average Linux system has literally *thousands* of programs you can employ on the command line. Consider yourself warned; learning the command line is not a casual endeavor.

On the other hand, learning the Linux command line is extremely rewarding. If you think you're a "power user" now, just wait. You don't know what real power is—yet. And, unlike many other computer skills, knowledge of the command line is long-lasting. The skills learned today will still be useful 10 years from now. The command line has survived the test of time.

It is also assumed that you have no programming experience, but don't worry, we'll start you down that path as well.

## What's in This Book

This material is presented in a carefully chosen sequence, much like a tutor sitting next to you guiding you along. Many authors treat this material in a "systematic" fashion, exhaustively covering each topic in order. This makes sense from a writer's perspective but can be very confusing to new users.

Another goal is to acquaint you with the Unix way of thinking, which is different from the Windows way of thinking. Along the way, we'll go on a few side trips to help you understand why certain things work the way they

do and how they got that way. Linux is not just a piece of software; it's also a small part of the larger Unix culture, which has its own language and history. I might throw in a rant or two, as well.

This book is divided into four parts, each covering some aspect of the command line experience.

- **Part 1, "Learning the Shell,"** starts our exploration of the basic language of the command line including such things as the structure of commands, file system navigation, command line editing, and finding help and documentation for commands.
- **Part 2, "Configuration and the Environment,"** covers editing configuration files that control the computer's operation from the command line.
- **Part 3, "Common Tasks and Essential Tools,"** explores many of the ordinary tasks that are commonly performed from the command line. Unix-like operating systems, such as Linux, contain many "classic" command line programs that are used to perform powerful operations on data.
- **Part 4, "Writing Shell Scripts,"** introduces shell programming, an admittedly rudimentary but easy-to-learn technique for automating many common computing tasks. By learning shell programming, you will become familiar with concepts that can be applied to many other programming languages.

## How to Read This Book

Start at the beginning of the book and follow it to the end. It isn't written as a reference work; it's really more like a story with a beginning, middle, and end.

### *Prerequisites*

To use this book, all you will need is a working Linux installation. You can get this in one of two ways:

**Install Linux on a (not so new) computer.** It doesn't matter which distribution you choose, though most people today start out with either Ubuntu, Fedora, or OpenSUSE. If in doubt, try Ubuntu first. Installing a modern Linux distribution can be ridiculously easy or ridiculously difficult depending on your hardware. I suggest a desktop computer that is a couple of years old and has at least 2GB of RAM and 6GB of free hard disk space. Avoid laptops and wireless networks if at all possible, as these are often more difficult to get working.

**Use a "live CD" or USB flash drive.** One of the cool things you can do with many Linux distributions is run them directly from a CD-ROM or USB flash drive without installing them at all. Just go into your BIOS setup and set your computer to boot from a CD-ROM drive or USB device and reboot. Using this method is a great way to test a computer

for Linux compatibility prior to installation. The disadvantage is that it may be slow compared to having Linux installed on your hard drive. Both Ubuntu and Fedora (among others) have live versions.

Regardless of how you install Linux, you'll need to have occasional superuser (i.e., administrative) privileges to carry out the lessons in this book.

After you have a working installation, start reading and follow along with your own computer. Most of the material in this book is "hands on," so sit down and get typing!

**WHY I DON'T CALL IT "GNU/LINUX"**

In some quarters, it's politically correct to call the Linux operating system the "GNU/Linux operating system." The problem with "Linux" is that there is no completely correct way to name it because it was written by many different people in a vast, distributed development effort. Technically speaking, Linux is the name of the operating system's kernel, nothing more. The kernel is very important, of course, since it makes the operating system go, but it's not enough to form a complete operating system.

Enter Richard Stallman, the genius-philosopher who founded the Free Software movement, started the Free Software Foundation, formed the GNU Project, wrote the first version of the GNU C Compiler (gcc), created the GNU General Public License (the GPL), etc., etc., etc. He *insists* that you call it "GNU/Linux" to properly reflect the contributions of the GNU Project. While the GNU Project predates the Linux kernel and the project's contributions are extremely deserving of recognition, placing them in the name is unfair to everyone else who made significant contributions. Besides, I think "Linux/GNU" would be more technically accurate since the kernel boots first and everything else runs on top of it.

In popular usage, Linux refers to the kernel and all the other free and open source software found in the typical Linux distribution, that is, the entire Linux ecosystem, not just the GNU components. The operating system marketplace seems to prefer one-word names such as DOS, Windows, macOS, Solaris, Irix, and AIX. I have chosen to use the popular format. If, however, you prefer to use "GNU/Linux" instead, please perform a mental search-and-replace while reading this book. I won't mind.

## What's New in the Second Edition

While the basic structure and content remain the same, this edition of *The Linux Command Line* is peppered with various refinements, clarifications, and modernizations, many of which are based on reader feedback. In addition, two particular improvements stand out. First, the book now assumes bash version 4.*x*, which was not in wide use at the time of the original manuscript. This fourth major version of bash added several useful

new features now covered in this edition. Second, Part 4, "Shell Scripting," has been improved to provide better examples of good scripting practice. The scripts included in Part 4 have been revised to make them more robust, and I also fixed a few bugs ;-).

## Your Feedback Is Needed!

This book is an ongoing project, like many open source software projects. If you find a technical error, drop me a line at *bshotts@users.sourceforge.net*.

Be sure to indicate the exact edition of the book you are reading. Your changes and suggestions may get into future releases.

# PART I

## LEARNING THE SHELL

# 1

# WHAT IS THE SHELL?

When we speak of the command line, we are really referring to the *shell*. The shell is a program that takes keyboard commands and passes them to the operating system to carry out. Almost all Linux distributions supply a shell program from the GNU Project called `bash`. The name is an acronym for *b*ourne-*a*gain *sh*ell, a reference to the fact that `bash` is an enhanced replacement for `sh`, the original Unix shell program written by Steve Bourne.

## Terminal Emulators

When using a graphical user interface (GUI), we need another program called a *terminal emulator* to interact with the shell. If we look through our desktop menus, we will probably find one. KDE uses konsole, and GNOME

uses gnome-terminal, though it's likely called simply Terminal on your menu. A number of other terminal emulators are available for Linux, but they all basically do the same thing: give us access to the shell. You will probably develop a preference for one or another terminal emulator based on the number of bells and whistles it has.

## Making Your First Keystrokes

So let's get started. Launch the terminal emulator. Once it comes up, we should see something like this:

```
[me@linuxbox ~]$
```

This is called a *shell prompt*, and it will appear whenever the shell is ready to accept input. While it might vary in appearance somewhat depending on the distribution, it will typically include your *username@machinename*, followed by the current working directory (more about that in a little bit) and a dollar sign.

If the last character of the prompt is a hash mark (#) rather than a dollar sign, the terminal session has superuser privileges. This means either we are logged in as the root user or we selected a terminal emulator that provides superuser (administrative) privileges.

Assuming things are good so far, let's try some typing. Enter some gibberish at the prompt like so:

```
[me@linuxbox ~]$ kaekfjaeifj
```

Because this command makes no sense, the shell tells us so and gives us another chance.

```
bash: kaekfjaeifj: command not found
[me@linuxbox ~]$
```

### Command History

If we press the up arrow, we will see that the previous command entered, `kaekfjaeifj`, reappears after the prompt. This is called *command history*. Most Linux distributions remember the last 1,000 commands by default. Press the down arrow and the previous command disappears.

### Cursor Movement

Recall the previous command by pressing the up arrow again. If we try the left and right arrows, we'll see that we can position the cursor anywhere on the command line. This makes editing commands easy.

### A FEW WORDS ABOUT MICE AND FOCUS

While the shell is all about the keyboard, you can also use a mouse with your terminal emulator. A mechanism built into the X Window System (the underlying engine that makes the GUI go) supports a quick copy-and-paste technique. If you highlight some text by holding down the left mouse button and dragging the mouse over it (or double-clicking a word), it is copied into a buffer maintained by X. Pressing the middle mouse button will cause the text to be pasted at the cursor location. Try it.

Don't be tempted to use CTRL-C and CTRL-V to perform copy and paste inside a terminal window. They don't work. These control codes have different meanings to the shell and were assigned many years before the release of Microsoft Windows.

Your graphical desktop environment (most likely KDE or GNOME), in an effort to behave like Windows, probably has its focus policy set to "click to focus." This means for a window to get focus (become active), you need to click on it. This is contrary to the traditional X behavior of "focus follows mouse," which means that a window gets focus just by passing the mouse over it. The window will not come to the foreground until you click on it, but it will be able to receive input. Setting the focus policy to "focus follows mouse" will make the copy-and-paste technique even more useful. Give it a try if you can (some desktop environments such as Ubuntu's Unity no longer support it). I think if you give it a chance, you will prefer it. You will find this setting in the configuration program for your window manager.

## Try Some Simple Commands

Now that we have learned to enter text in the terminal emulator, let's try a few simple commands. Let's begin with the `date` command, which displays the current time and date.

```
[me@linuxbox ~]$ date
Fri Feb  2 15:09:41 EST 2018
```

A related command is `cal`, which, by default, displays a calendar of the current month.

```
[me@linuxbox ~]$ cal
    February 2018
Su Mo Tu We Th Fr Sa
             1  2  3
 4  5  6  7  8  9 10
11 12 13 14 15 16 17
18 19 20 21 22 23 24
25 26 27 28
```

**THE CONSOLE BEHIND THE CURTAIN**

Even if we have no terminal emulator running, several terminal sessions continue to run behind the graphical desktop. We can access these sessions, called *virtual consoles*, by pressing CTRL-ALT-F1 through CTRL-ALT-F6 on most Linux distributions. When a session is accessed, it presents a login prompt into which we can enter our username and password. To switch from one virtual console to another, press ALT-F1 through ALT-F6. On most systems, we can return to the graphical desktop by pressing ALT-F7.

To see the current amount of free space on our disk drives, enter `df`.

```
[me@linuxbox ~]$ df
Filesystem           1K-blocks      Used Available Use% Mounted on
/dev/sda2             15115452   5012392   9949716  34% /
/dev/sda5             59631908  26545424  30008432  47% /home
/dev/sda1               147764     17370    122765  13% /boot
tmpfs                   256856         0    256856   0% /dev/shm
```

Likewise, to display the amount of free memory, enter the `free` command.

```
[me@linuxbox ~]$ free
         total       used       free     shared    buffers     cached
Mem:    513712     503976       9736          0       5312     122916
-/+ buffers/cache: 375748     137964
Swap:  1052248     104712     947536
```

## Ending a Terminal Session

We can end a terminal session by closing the terminal emulator window, by entering the `exit` command at the shell prompt, or by pressing CTRL-D.

```
[me@linuxbox ~]$ exit
```

## Summing Up

This chapter marked the beginning of our journey into the Linux command line, with an introduction to the shell, a glimpse of the command line, and a brief lesson on how to start and end a terminal session. We also saw how to issue some simple commands and perform a little light command-line editing. That wasn't so scary, was it?

In the next chapter, we'll learn a few more commands and wander around the Linux file system.

# 2

# NAVIGATION

The first thing we need to learn (besides how to type) is how to navigate the file system on our Linux system. In this chapter, we will introduce the following commands:

- **`pwd`** Print name of current working directory
- **`cd`** Change directory
- **`ls`** List directory contents

## Understanding the File System Tree

Like Windows, a Unix-like operating system such as Linux organizes its files in what is called a *hierarchical directory structure*. This means they are organized in a tree-like pattern of directories (sometimes called *folders* in other systems), which may contain files and other directories. The first directory in the file system is called the *root directory*. The root directory contains files and subdirectories, which contain more files and subdirectories, and so on.

Note that unlike Windows, which has a separate file system tree for each storage device, Unix-like systems such as Linux always have a single file system tree, regardless of how many drives or storage devices are attached to the computer. Storage devices are attached (or more correctly, *mounted*) at various points on the tree according to the whims of the *system administrator*, the person (or people) responsible for the maintenance of the system.

## The Current Working Directory

Most of us are probably familiar with a graphical file manager that represents the file system tree, as illustrated in Figure 2-1.

*Figure 2-1: File system tree as shown by a graphical file manager*

Notice that the tree is usually shown upended, that is, with the root at the top and the various branches descending below.

However, the command line has no pictures, so to navigate the file system tree, we need to think of it in a different way.

Imagine that the file system is a maze shaped like an upside-down tree and we are able to stand in the middle of it. At any given time, we are inside a single directory, and we can see the files contained in the directory and the pathway to the directory above us (called the *parent directory*) and any subdirectories below us. The directory we are standing in is called the *current working directory*. To display the current working directory, we use the `pwd` (print working directory) command.

```
[me@linuxbox ~]$ pwd
/home/me
```

When we first log in to our system (or start a terminal emulator session), our current working directory is set to our *home directory*. Each user account is given its own home directory, and it is the only place a regular user is allowed to write files.

## Listing the Contents of a Directory

To list the files and directories in the current working directory, we use the `ls` command.

```
[me@linuxbox ~]$ ls
Desktop  Documents  Music  Pictures  Public  Templates  Videos
```

Actually, we can use the `ls` command to list the contents of any directory, not just the current working directory, and there are many other fun things it can do as well. We'll spend more time with `ls` in Chapter 3.

## Changing the Current Working Directory

To change our working directory (where we are standing in the tree-shaped maze), we use the `cd` command. To do this, type **`cd`** followed by the pathname of the desired working directory. A pathname is the route we take along the branches of the tree to get to the directory we want. We can specify pathnames in one of two different ways: as *absolute pathnames* or as *relative pathnames*. Let's deal with absolute pathnames first.

### *Absolute Pathnames*

An absolute pathname begins with the root directory and follows the tree branch by branch until the path to the desired directory or file is completed. For example, there is a directory on your system in which most of the system's programs are installed. The directory's pathname is */usr/bin*. This means from the root directory (represented by the leading slash in the pathname) there is a directory called *usr* that contains a directory called *bin*.

```
[me@linuxbox ~]$ cd /usr/bin
[me@linuxbox bin]$ pwd
/usr/bin
[me@linuxbox bin]$ ls
...Listing of many, many files ...
```

Now we can see that we have changed the current working directory to */usr/bin* and that it is full of files. Notice how the shell prompt has changed? As a convenience, it is usually set up to automatically display the name of the working directory.

### *Relative Pathnames*

Where an absolute pathname starts from the root directory and leads to its destination, a relative pathname starts from the working directory. To do this, it uses a couple of special notations to represent relative positions in the file system tree. These special notations are `.` (dot) and `..` (dot dot).

The . notation refers to the working directory, and the .. notation refers to the working directory's parent directory. Here is how it works. Let's change the working directory to */usr/bin* again.

```
[me@linuxbox ~]$ cd /usr/bin
[me@linuxbox bin]$ pwd
/usr/bin
```

Now let's say that we wanted to change the working directory to the parent of */usr/bin*, which is */usr*. We could do that two different ways, either with an absolute pathname:

```
[me@linuxbox bin]$ cd /usr
[me@linuxbox usr]$ pwd
/usr
```

or with a relative pathname:

```
[me@linuxbox bin]$ cd ..
[me@linuxbox usr]$ pwd
/usr
```

Two different methods with identical results. Which one should we use? The one that requires the least typing!

Likewise, we can change the working directory from */usr* to */usr/bin* in two different ways, either using an absolute pathname:

```
[me@linuxbox usr]$ cd /usr/bin
[me@linuxbox bin]$ pwd
/usr/bin
```

or using a relative pathname:

```
[me@linuxbox usr]$ cd ./bin
[me@linuxbox bin]$ pwd
/usr/bin
```

Now, there is something important to point out here. In almost all cases, we can omit the ./ part because it is implied. Typing the following does the same thing:

```
[me@linuxbox usr]$ cd bin
```

In general, if we do not specify a pathname to something, the working directory will be assumed.

**IMPORTANT FACTS ABOUT FILENAMES**

On Linux systems, files are named in a manner similar to that of other systems such as Windows, but there are some important differences.

- Filenames that begin with a period character are hidden. This only means that `ls` will not list them unless you say `ls -a`. When your account was created, several hidden files were placed in your home directory to configure things for your account. In Chapter 11 we will take a closer look at some of these files to see how you can customize your environment. In addition, some applications place their configuration and settings files in your home directory as hidden files.
- Filenames and commands in Linux, like Unix, are case sensitive. The filenames *File1* and *file1* refer to different files.
- Though Linux supports long filenames that may contain embedded spaces and punctuation characters, limit the punctuation characters in the names of files you create to period, dash, and underscore. *Most important, do not embed spaces in filenames.* If you want to represent spaces between words in a filename, use underscore characters. You will thank yourself later.
- Linux has no concept of a "file extension" like some other operating systems. You may name files any way you like. The contents or purpose of a file is determined by other means. Although Unix-like operating systems don't use file extensions to determine the contents/purpose of files, many application programs do.

## *Some Helpful Shortcuts*

Table 2-1 shows some useful ways to quickly change the current working directory.

**Table 2-1:** cd Shortcuts

| Shortcut | Result |
|---|---|
| `cd` | Changes the working directory to your home directory. |
| `cd -` | Changes the working directory to the previous working directory. |
| `cd ~`*`user_name`* | Changes the working directory to the home directory of *`user_name`*. For example, typing `cd ~bob` will change the directory to the home directory of user "bob." |

## Summing Up

This chapter explained how the shell treats the directory structure of the system. We learned about absolute and relative pathnames and the basic commands that we use to move around that structure. In the next chapter, we will use this knowledge to go on a tour of a modern Linux system.

# 3

# EXPLORING THE SYSTEM

Now that we know how to move around the file system, it's time for a guided tour of our Linux system. Before we start, however, we're going to learn some more commands that will be useful along the way.

- **`ls`** List directory contents
- **`file`** Determine file type
- **`less`** View file contents

## More Fun with ls

The `ls` command is probably the most used command, and for good reason. With it, we can see directory contents and determine a variety of important file and directory attributes. As we have seen, we can simply enter `ls` to get a list of files and subdirectories contained in the current working directory.

```
[me@linuxbox ~]$ ls
Desktop  Documents  Music  Pictures  Public  Templates  Videos
```

Besides the current working directory, we can specify the directory to list, like so:

```
me@linuxbox ~]$ ls /usr
bin  games  include  lib  local  sbin  share  src
```

We can even specify multiple directories. In the following example, we list both the user's home directory (symbolized by the ~ character) and the `/usr` directory:

```
[me@linuxbox ~]$ ls ~ /usr
/home/me:
Desktop  Documents  Music  Pictures  Public  Templates  Videos
/usr:
bin  games  include  lib  local  sbin  share  src
```

We can also change the format of the output to reveal more detail.

```
[me@linuxbox ~]$ ls -l
total 56
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Desktop
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Documents
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Music
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Pictures
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Public
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Templates
drwxrwxr-x 2 me me 4096 2017-10-26 17:20 Videos
```

By adding `-l` to the command, we changed the output to the long format.

### Options and Arguments

This brings us to a very important point about how most commands work. Commands are often followed by one or more *options* that modify their behavior and, further, by one or more *arguments*, the items upon which the command acts. So, most commands look kind of like this:

```
command -options arguments
```

Most commands use options, which consist of a single character preceded by a dash, for example, `-l`. Many commands, however, including those from the GNU Project, also support *long options*, consisting of a word preceded by two dashes. Also, many commands allow multiple short options to be strung together. In the following example, the `ls` command is given two options, which are the `l` option to produce long format output, and the `t` option to sort the result by the file's modification time.

```
[me@linuxbox ~]$ ls -lt
```

We'll add the long option `--reverse` to reverse the order of the sort.

```
[me@linuxbox ~]$ ls -lt --reverse
```

**NOTE** *Command options, like filenames in Linux, are case sensitive.*

The `ls` command has a large number of possible options, the most common of which are listed in Table 3-1.

**Table 3-1:** Common `ls` Options

| Option | Long option | Description |
|---|---|---|
| `-a` | `--all` | List all files, even those with names that begin with a period, which are normally not listed (that is, hidden). |
| `-A` | `--almost-all` | Like the `-a` option except it does not list `.` (current directory) and `..` (parent directory). |
| `-d` | `--directory` | Ordinarily, if a directory is specified, `ls` will list the contents of the directory, not the directory itself. Use this option in conjunction with the `-l` option to see details about the directory rather than its contents. |
| `-F` | `--classify` | This option will append an indicator character to the end of each listed name. For example, it will append a forward slash (/) if the name is a directory. |
| `-h` | `--human-readable` | In long format listings, display file sizes in human-readable format rather than in bytes. |
| `-l` | | Display results in long format. |
| `-r` | `--reverse` | Display the results in reverse order. Normally, `ls` displays its results in ascending alphabetical order. |
| `-S` | | Sort results by file size. |
| `-t` | | Sort by modification time. |

## A Longer Look at Long Format

As we saw earlier, the `-l` option causes `ls` to display its results in long format. This format contains a great deal of useful information. Here is the `Examples` directory from an Ubuntu system:

```
-rw-r--r-- 1 root root 3576296 2017-04-03 11:05 Experience ubuntu.ogg
-rw-r--r-- 1 root root 1186219 2017-04-03 11:05 kubuntu-leaflet.png
-rw-r--r-- 1 root root   47584 2017-04-03 11:05 logo-Edubuntu.png
-rw-r--r-- 1 root root   44355 2017-04-03 11:05 logo-Kubuntu.png
-rw-r--r-- 1 root root   34391 2017-04-03 11:05 logo-Ubuntu.png
-rw-r--r-- 1 root root   32059 2017-04-03 11:05 oo-cd-cover.odf
-rw-r--r-- 1 root root  159744 2017-04-03 11:05 oo-derivatives.doc
```

```
-rw-r--r-- 1 root root   27837 2017-04-03 11:05 oo-maxwell.odt
-rw-r--r-- 1 root root   98816 2017-04-03 11:05 oo-trig.xls
-rw-r--r-- 1 root root  453764 2017-04-03 11:05 oo-welcome.odt
-rw-r--r-- 1 root root  358374 2017-04-03 11:05 ubuntu Sax.ogg
```

Table 3-2 provides us with a look at the different fields from one of the files and their meanings.

**Table 3-2:** `ls` Long Listing Fields

| Field | Meaning |
|---|---|
| `-rw-r--r--` | Access rights to the file. The first character indicates the type of file. Among the different types, a leading dash means a regular file, while a `d` indicates a directory. The next three characters are the access rights for the file's owner, the next three are for members of the file's group, and the final three are for everyone else. Chapter 9 discusses the full meaning of this in more detail. |
| `1` | File's number of hard links. See "Symbolic Links" on page 21 and "Hard Links" on page 22. |
| `root` | The username of the file's owner. |
| `root` | The name of the group that owns the file. |
| `32059` | Size of the file in bytes. |
| `2017-04-03 11:05` | Date and time of the file's last modification. |
| `oo-cd-cover.odf` | Name of the file. |

## Determining a File's Type with file

As we explore the system, it will be useful to know what files contain. To do this, we will use the `file` command to determine a file's type. As we discussed earlier, filenames in Linux are not required to reflect a file's contents. While a filename like *picture.jpg* would normally be expected to contain a JPEG-compressed image, it is not required to in Linux. We can invoke the `file` command this way:

```
file filename
```

When invoked, the `file` command will print a brief description of the file's contents. For example:

```
[me@linuxbox ~]$ file picture.jpg
picture.jpg: JPEG image data, JFIF standard 1.01
```

There are many kinds of files. In fact, one of the common ideas in Unix-like operating systems such as Linux is that "everything is a file." As we proceed with our lessons, we will see just how true that statement is.

While many of the files on our system are familiar, for example, MP3 and JPEG files, there are many kinds that are a little less obvious and a few that are quite strange.

## Viewing File Contents with less

The `less` command is a program to view text files. Throughout our Linux system, there are many files that contain human-readable text. The `less` program provides a convenient way to examine them.

Why would we want to examine text files? Because many of the files that contain system settings (called *configuration files*) are stored in this format, and being able to read them gives us insight about how the system works. In addition, some of the actual programs that the system uses (called *scripts*) are stored in this format. In later chapters, we will learn how to edit text files in order to modify system settings and write our own scripts, but for now we will just look at their contents.

The `less` command is used like this:

---

**less** *filename*

---

**WHAT IS "TEXT"?**

There are many ways to represent information on a computer. All methods involve defining a relationship between the information and some numbers that will be used to represent it. Computers, after all, understand only numbers, and all data is converted to numeric representation.

Some of these representation systems are very complex (such as compressed video files), while others are rather simple. One of the earliest and simplest is called ASCII text. ASCII (pronounced "as-key") is short for American Standard Code for Information Interchange. This is a simple encoding scheme that was first used on Teletype machines to map keyboard characters to numbers.

Text is a simple one-to-one mapping of characters to numbers. It is very compact. Fifty characters of text translates to fifty bytes of data. It is important to understand that text only contains a simple mapping of characters to numbers. It is not the same as a word processor document such as one created by Microsoft Word or LibreOffice Writer. Those files, in contrast to simple ASCII text, contain many non-text elements that are used to describe its structure and formatting. Plain ASCII text files contain only the characters themselves and a few rudimentary control codes such as tabs, carriage returns, and line feeds.

Throughout a Linux system, many files are stored in text format, and there are many Linux tools that work with text files. Even Windows recognizes the importance of this format. The well-known NOTEPAD.EXE program is an editor for plain ASCII text files.

Once started, the less program allows us to scroll forward and backward through a text file. For example, to examine the file that defines all the system's user accounts, enter the following command:

```
[me@linuxbox ~]$ less /etc/passwd
```

Once the less program starts, we can view the contents of the file. If the file is longer than one page, we can scroll up and down. To exit less, press q.

Table 3-3 lists the most common keyboard commands used by less.

**Table 3-3:** less Commands

| Command | Action |
|---|---|
| PAGE UP or b | Scroll back one page |
| PAGE DOWN or space | Scroll forward one page |
| Up arrow | Scroll up one line |
| Down arrow | Scroll down one line |
| G | Move to the end of the text file |
| 1G or g | Move to the beginning of the text file |
| /characters | Search forward to the next occurrence of characters |
| n | Search for the next occurrence of the previous search |
| h | Display help screen |
| q | Quit less |

**LESS IS MORE**

The less program was designed as an improved replacement of an earlier Unix program called *more*. The name *less* is a play on the phrase "less is more"—a motto of modernist architects and designers.

less falls into the class of programs called *pagers*, programs that allow the easy viewing of long text documents in a page-by-page manner. Whereas the more program could only page forward, the less program allows paging both forward and backward and has many other features as well.

## Taking a Guided Tour

The file system layout on a Linux system is much like that found on other Unix-like systems. The design is actually specified in a published standard called the *Linux Filesystem Hierarchy Standard*. Not all Linux distributions conform to the standard exactly, but most come pretty close.

**REMEMBER THE COPY-AND-PASTE TRICK!**

If you are using a mouse, you can double-click a filename to copy it and middle-click to paste it into commands.

Next, we are going to wander around the file system ourselves to see what makes our Linux system tick. This will give us a chance to practice our navigation skills. One of the things we will discover is that many of the interesting files are in plain human-readable text. As we go about our tour, try the following:

- `cd` into a given directory.
- List the directory contents with `ls -l`.
- If you see an interesting file, determine its contents with `file`.
- If it looks like it might be text, try viewing it with `less`.

If we accidentally attempt to view a non-text file and it scrambles the terminal window, we can recover by entering the `reset` command.

As we wander around, don't be afraid to look at stuff. Regular users are largely prohibited from messing things up. That's the system administrator's job! If a command complains about something, just move on to something else. Spend some time looking around. The system is ours to explore. Remember, in Linux, there are no secrets!

Table 3-4 lists just a few of the directories we can explore. There may be some slight differences depending on our Linux distribution. Don't be afraid to look around and try more!

**Table 3-4:** Directories Found on Linux Systems

| Directory | Comments |
|---|---|
| */* | The root directory, where everything begins. |
| */bin* | Contains binaries (programs) that must be present for the system to boot and run. |
| */boot* | Contains the Linux kernel, initial RAM disk image (for drivers needed at boot time), and the boot loader. Interesting files include */boot/grub/grub.conf*, or *menu.lst*, which is used to configure the boot loader, and */boot/vmlinuz* (or something similar), the Linux kernel. |
| */dev* | This is a special directory that contains *device nodes*. "Everything is a file" also applies to devices. Here is where the kernel maintains a list of all the devices it understands. |

*(continued)*

**Table 3-4:** Directories Found on Linux Systems (continued)

| Directory | Comments |
|---|---|
| */etc* | The */etc* directory contains all the system-wide configuration files. It also contains a collection of shell scripts that start each of the system services at boot time. Everything in this directory should be readable text. While everything in */etc* is interesting, here are some all-time favorites: */etc/crontab*, a file that defines when automated jobs will run; */etc/fstab*, a table of storage devices and their associated mount points; and */etc/passwd*, a list of the user accounts. |
| */home* | In normal configurations, each user is given a directory in */home*. Ordinary users can write files only in their home directories. This limitation protects the system from errant user activity. |
| */lib* | Contains shared library files used by the core system programs. These are similar to dynamic link libraries (DLLs) in Windows. |
| */lost+found* | Each formatted partition or device using a Linux file system, such as ext3, will have this directory. It is used in the case of a partial recovery from a file system corruption event. Unless something really bad has happened to your system, this directory will remain empty. |
| */media* | On modern Linux systems, the */media* directory will contain the mount points for removable media such as USB drives, CD-ROMs, and so on, that are mounted automatically at insertion. |
| */mnt* | On older Linux systems, the */mnt* directory contains mount points for removable devices that have been mounted manually. |
| */opt* | The */opt* directory is used to install "optional" software. This is mainly used to hold commercial software products that might be installed on the system. |
| */proc* | The */proc* directory is special. It's not a real file system in the sense of files stored on your hard drive. Rather, it is a virtual file system maintained by the Linux kernel. The "files" it contains are peepholes into the kernel itself. The files are readable and will give you a picture of how the kernel sees your computer. |
| */root* | This is the home directory for the root account. |
| */sbin* | This directory contains "system" binaries. These are programs that perform vital system tasks that are generally reserved for the superuser. |
| */tmp* | The */tmp* directory is intended for the storage of temporary, transient files created by various programs. Some configurations cause this directory to be emptied each time the system is rebooted. |
| */usr* | The */usr* directory tree is likely the largest one on a Linux system. It contains all the programs and support files used by regular users. |
| */usr/bin* | */usr/bin* contains the executable programs installed by your Linux distribution. It is not uncommon for this directory to hold thousands of programs. |
| */usr/lib* | The shared libraries for the programs in */usr/bin*. |

| Directory | Comments |
|---|---|
| */usr/local* | The */usr/local* tree is where programs that are not included with your distribution but are intended for system-wide use are installed. Programs compiled from source code are normally installed in */usr/local/bin*. On a newly installed Linux system, this tree exists, but it will be empty until the system administrator puts something in it. |
| */usr/sbin* | Contains more system administration programs. |
| */usr/share* | */usr/share* contains all the shared data used by programs in */usr/bin*. This includes things such as default configuration files, icons, screen backgrounds, sound files, and so on. |
| */usr/share/doc* | Most packages installed on the system will include some kind of documentation. In */usr/share/doc*, we will find documentation files organized by package. |
| */var* | With the exception of */tmp* and */home*, the directories we have looked at so far remain relatively static; that is, their contents don't change. The */var* directory tree is where data that is likely to change is stored. Various databases, spool files, user mail, and so forth, are located here. |
| */var/log* | */var/log* contains *log files*, records of various system activity. These are important and should be monitored from time to time. The most useful ones are */var/log/messages* and */var/log/syslog*. Note that for security reasons on some systems, you must be the superuser to view log files. |

## Symbolic Links

As we look around, we are likely to see a directory listing (for example, `/lib`) with an entry like this:

```
lrwxrwxrwx 1 root root   11 2018-08-11 07:34 libc.so.6 -> libc-2.6.so
```

Notice how the first letter of the listing is *l* and the entry seems to have two filenames? This is a special kind of a file called a *symbolic link* (also known as a *soft link* or *symlink*). In most Unix-like systems, it is possible to have a file referenced by multiple names. While the value of this might not be obvious, it is really a useful feature.

Picture this scenario: a program requires the use of a shared resource of some kind contained in a file named "foo," but "foo" has frequent version changes. It would be good to include the version number in the filename so the administrator or other interested party could see what version of "foo" is installed. This presents a problem. If we change the name of the shared resource, we have to track down every program that might use it and change it to look for a new resource name every time a new version of the resource is installed. That doesn't sound like fun at all.

Here is where symbolic links save the day. Suppose we install version 2.6 of "foo," which has the filename "foo-2.6," and then create a symbolic link simply called "foo" that points to "foo-2.6." This means that when a program opens the file "foo," it is actually opening the file "foo-2.6." Now everybody is happy. The programs that rely on "foo" can find it, and we can still see what actual version is installed. When it is time to upgrade to "foo-2.7," we just add the file to our system, delete the symbolic link "foo," and create a new one that points to the new version. Not only does this solve the problem of the version upgrade, it also allows us to keep both versions on our machine. Imagine that "foo-2.7" has a bug (damn those developers!), and we need to revert to the old version. Again, we just delete the symbolic link pointing to the new version and create a new symbolic link pointing to the old version.

The directory listing at the beginning of this section (from the `/lib` directory of a Fedora system) shows a symbolic link called `libc.so.6` that points to a shared library file called *libc-2.6.so*. This means that programs looking for *libc.so.6* will actually get the file *libc-2.6.so*. We will learn how to create symbolic links in the next chapter.

## Hard Links

While we are on the subject of links, we need to mention that there is a second type of link called *hard links*. Hard links also allow files to have multiple names, but they do it in a different way. We'll talk more about the differences between symbolic and hard links in the next chapter.

## Summing Up

With our tour behind us, we have learned a lot about our system. We've seen various files and directories and their contents. One thing you should take away from this is how open the system is. In Linux there are many important files that are plain human-readable text. Unlike many proprietary systems, Linux makes everything available for examination and study.

# 4

# MANIPULATING FILES AND DIRECTORIES

At this point, we are ready for some real work! This chapter will introduce five of the most frequently used Linux commands. The following commands are used for manipulating both files and directories:

- **`cp`** Copy files and directories
- **`mv`** Move/rename files and directories
- **`mkdir`** Create directories
- **`rm`** Remove files and directories
- **`ln`** Create hard and symbolic links

Now, to be frank, some of the tasks performed by these commands are more easily done with a graphical file manager. With a file manager, we can drag and drop a file from one directory to another, cut and paste files, delete files, and so on. So why use these old command line programs?

The answer is power and flexibility. While it is easy to perform simple file manipulations with a graphical file manager, complicated tasks can be easier with the command line programs. For example, how could we copy all the HTML files from one directory to another but copy only files that do not exist in the destination directory or are newer than the versions in the destination directory? It's pretty hard with a file manager but pretty easy with the command line.

```
cp -u *.html destination
```

## Wildcards

Before we begin using our commands, we need to talk about a shell feature that makes these commands so powerful. Because the shell uses filenames so much, it provides special characters to help you rapidly specify groups of filenames. These special characters are called *wildcards*. Using wildcards (which is also known as *globbing*) allows you to select filenames based on patterns of characters. Table 4-1 lists the wildcards and what they select.

**Table 4-1:** Wildcards

| Wildcard | Meaning |
|---|---|
| `*` | Matches any characters |
| `?` | Matches any single character |
| `[characters]` | Matches any character that is a member of the set *characters* |
| `[!characters]` | Matches any character that is not a member of the set *characters* |
| `[[:class:]]` | Matches any character that is a member of the specified *class* |

Table 4-2 lists the most commonly used character classes.

**Table 4-2:** Commonly Used Character Classes

| Character class | Meaning |
|---|---|
| `[:alnum:]` | Matches any alphanumeric character |
| `[:alpha:]` | Matches any alphabetic character |
| `[:digit:]` | Matches any numeral |
| `[:lower:]` | Matches any lowercase letter |
| `[:upper:]` | Matches any uppercase letter |

Using wildcards makes it possible to construct sophisticated selection criteria for filenames. Table 4-3 provides some examples of patterns and what they match.

**Table 4-3:** Wildcard Examples

| Pattern | Matches |
|---|---|
| `*` | All files |
| `g*` | Any file beginning with *g* |
| `b*.txt` | Any file beginning with *b* followed by any characters and ending with *.txt* |
| `Data???` | Any file beginning with *Data* followed by exactly three characters |
| `[abc]*` | Any file beginning with either an *a*, a *b*, or a *c* |
| `BACKUP.[0-9][0-9][0-9]` | Any file beginning with *BACKUP.* followed by exactly three numerals |
| `[[:upper:]]*` | Any file beginning with an uppercase letter |
| `[![:digit:]]*` | Any file not beginning with a numeral |
| `*[[:lower:]123]` | Any file ending with a lowercase letter or the numerals *1*, *2*, or *3* |

**WILDCARDS WORK IN THE GUI, TOO**

Wildcards are especially valuable not only because they are used so frequently on the command line but because they are also supported by some graphical file managers.

- In Nautilus (the file manager for GNOME), you can select files using the Edit ▸ Select Pattern menu item. Just enter a file selection pattern with wildcards and the files in the currently viewed directory will be highlighted for selection.
- In some versions of Dolphin and Konqueror (the file managers for KDE), you can enter wildcards directly on the location bar. For example, if you want to see all the files starting with a lowercase *u* in the */usr/bin* directory, enter `/usr/bin/u*` in the location bar and it will display the result.

Many ideas originally found in the command line interface make their way into the graphical interface, too. It is one of the many things that make the Linux desktop so powerful.

Wildcards can be used with any command that accepts filenames as arguments, but we'll talk more about that in Chapter 7.

**CHARACTER RANGES**

If you are coming from another Unix-like environment or have been reading some other books on this subject, you may have encountered the `[A-Z]` and `[a-z]` character range notations. These are traditional Unix notations and worked in older versions of Linux as well. They can still work, but you have to be careful with them because they will not produce the expected results unless properly configured. For now, you should avoid using them and use character classes instead.

## mkdir—Create Directories

The `mkdir` command is used to create directories. It works like this:

```
mkdir directory...
```

Note that when three periods follow an argument in the description of a command (as in the preceding example), it means that the argument can be repeated. Thus, the following command:

```
mkdir dir1
```

would create a single directory named *dir1*. This command

```
mkdir dir1 dir2 dir3
```

would create three directories named *dir1*, *dir2*, and *dir3*.

## cp—Copy Files and Directories

The `cp` command copies files or directories. It can be used two different ways. The following:

```
cp item1 item2
```

copies the single file or directory *item1* to the file or directory *item2*. This command:

```
cp item... directory
```

copies multiple items (either files or directories) into a directory.

### *Useful Options and Examples*

Table 4-4 describes some of the commonly used options (the short option and the equivalent long option) for `cp`.

**Table 4-4:** cp Options

| Option | Meaning |
|---|---|
| `-a, --archive` | Copy the files and directories and all of their attributes, including ownerships and permissions. Normally, copies take on the default attributes of the user performing the copy. We'll take a look at file permissions in Chapter 9. |
| `-i, --interactive` | Before overwriting an existing file, prompt the user for confirmation. **If this option is not specified, `cp` will silently (meaning there will be no warning) overwrite files.** |
| `-r, --recursive` | Recursively copy directories and their contents. This option (or the -a option) is required when copying directories. |
| `-u, --update` | When copying files from one directory to another, only copy files that either don't exist or are newer than the existing corresponding files in the destination directory. This is useful when copying large numbers of files as it skips files that don't need to be copied. |
| `-v, --verbose` | Display informative messages as the copy is performed. |

Table 4-5 provides some examples of these commonly used options.

**Table 4-5:** cp Examples

| Command | Results |
|---|---|
| `cp file1 file2` | Copy *file1* to *file2*. If *file2* exists, it is overwritten with the contents of *file1*. If *file2* does not exist, it is created. |
| `cp -i file1 file2` | Same as previous command, except that if *file2* exists, the user is prompted before it is overwritten. |
| `cp file1 file2 dir1` | Copy *file1* and *file2* into directory *dir1*. The directory *dir1* must already exist. |
| `cp dir1/* dir2` | Using a wildcard, copy all the files in *dir1* into *dir2*. The directory *dir2* must already exist. |
| `cp -r dir1 dir2` | Copy the contents of directory *dir1* to directory *dir2*. If directory *dir2* does not exist, it is created and, after the copy, will contain the same contents as directory *dir1*. If directory *dir2* does exist, then directory *dir1* (and its contents) will be copied into *dir2*. |

## mv—Move and Rename Files

The `mv` command performs both file moving and file renaming, depending on how it is used. In either case, the original filename no longer exists after the operation. `mv` is used in much the same way as `cp`, as shown here:

```
mv item1 item2
```

to move or rename the file or directory *item1* to *item2*. It's also used as follows:

```
mv item... directory
```

to move one or more items from one directory to another.

### *Useful Options and Examples*

`mv` shares many of the same options as `cp`, as described in Table 4-6.

**Table 4-6:** `mv` Options

| Option | Meaning |
|---|---|
| `-i, --interactive` | Before overwriting an existing file, prompt the user for confirmation. **If this option is not specified, mv will silently overwrite files.** |
| `-u, --update` | When moving files from one directory to another, only move files that either don't exist or are newer than the existing corresponding files in the destination directory. |
| `-v, --verbose` | Display informative messages as the move is performed. |

Table 4-7 provides some examples of using the `mv` command.

**Table 4-7:** `mv` Examples

| Command | Results |
|---|---|
| `mv file1 file2` | Move *file1* to *file2*. **If *file2* exists, it is overwritten with the contents of *file1*.** If *file2* does not exist, it is created. **In either case, *file1* ceases to exist.** |
| `mv -i file1 file2` | Same as the previous command, except that if *file2* exists, the user is prompted before it is overwritten. |
| `mv file1 file2 dir1` | Move *file1* and *file2* into directory *dir1*. The directory *dir1* must already exist. |
| `mv dir1 dir2` | If directory *dir2* does not exist, create directory *dir2* and move the contents of directory *dir1* into *dir2* and delete directory *dir1*. If directory *dir2* does exist, move directory *dir1* (and its contents) into directory *dir2*. |

## rm—Remove Files and Directories

The `rm` command is used to remove (delete) files and directories, as shown here:

```
rm item...
```

where *item* is one or more files or directories.

### *Useful Options and Examples*

Table 4-8 describes some of the common options for `rm`.

**Table 4-8:** `rm` Options

| Option | Meaning |
|---|---|
| `-i`, `--interactive` | Before deleting an existing file, prompt the user for confirmation. **If this option is not specified, `rm` will silently delete files.** |
| `-r`, `--recursive` | Recursively delete directories. This means that if a directory being deleted has subdirectories, delete them too. To delete a directory, this option must be specified. |
| `-f`, `--force` | Ignore nonexistent files and do not prompt. This overrides the `--interactive` option. |
| `-v`, `--verbose` | Display informative messages as the deletion is performed. |

**BE CAREFUL WITH RM!**

Unix-like operating systems such as Linux do not have an undelete command. Once you delete something with `rm`, it's gone. Linux assumes you're smart and you know what you're doing.

Be particularly careful with wildcards. Consider this classic example. Let's say you want to delete just the HTML files in a directory. To do this, you type the following:

```
rm *.html
```

This is correct, but if you accidentally place a space between the `*` and the `.html` like so:

```
rm * .html
```

the `rm` command will delete all the files in the directory and then complain that there is no file called *.html*.

Here is a useful tip: whenever you use wildcards with `rm` (besides carefully checking your typing!), test the wildcard first with `ls`. This will let you see the files that will be deleted. Then press the up arrow to recall the command and replace `ls` with `rm`.

Table 4-9 provides some examples of using the `rm` command.

**Table 4-9:** `rm` Examples

| Command | Results |
|---|---|
| `rm` *`file1`* | Delete *`file1`* silently. |
| `rm -i` *`file1`* | Same as the previous command, except that the user is prompted for confirmation before the deletion is performed. |
| `rm -r` *`file1 dir1`* | Delete *`file1`* and *`dir1`* and its contents. |
| `rm -rf` *`file1 dir1`* | Same as the previous command, except that if either *`file1`* or *`dir1`* does not exist, `rm` will continue silently. |

## ln—Create Links

The `ln` command is used to create either hard or symbolic links. It is used in one of two ways. The following creates a hard link:

```
ln file link
```

The following creates a symbolic link:

```
ln -s item link
```

where *`item`* is either a file or a directory.

### *Hard Links*

Hard links are the original Unix way of creating links, compared to symbolic links, which are more modern. By default, every file has a single hard link that gives the file its name. When we create a hard link, we create an additional directory entry for a file. Hard links have two important limitations.

- A hard link cannot reference a file outside its own file system. This means a link cannot reference a file that is not on the same disk partition as the link itself.
- A hard link may not reference a directory.

A hard link is indistinguishable from the file itself. Unlike a symbolic link, when you list a directory containing a hard link, you will see no special indication of the link. When a hard link is deleted, the link is removed, but the contents of the file itself continue to exist (that is, its space is not deallocated) until all links to the file are deleted.

It is important to be aware of hard links because you might encounter them from time to time, but modern practice prefers symbolic links, which we will cover next.

### Symbolic Links

Symbolic links were created to overcome the limitations of hard links. They work by creating a special type of file that contains a text pointer to the referenced file or directory. In this regard, they operate in much the same way as a Windows shortcut, though of course they predate the Windows feature by many years.

A file pointed to by a symbolic link and the symbolic link itself are largely indistinguishable from one another. For example, if you write something to the symbolic link, the referenced file is written to. When you delete a symbolic link, however, only the *link* is deleted, not the *file* itself. If the file is deleted before the symbolic link, the link will continue to exist but will point to nothing. In this case, the link is said to be *broken*. In many implementations, the `ls` command will display broken links in a distinguishing color, such as red, to reveal their presence.

The concept of links can seem confusing, but hang in there. We're going to try all this stuff, and it will, ideally, become clear.

## Building a Playground

Because we are going to do some real file manipulation, let's build a safe place to "play" with our file manipulation commands. First we need a directory to work in. We'll create one in our home directory and call it `playground`.

### Creating Directories

The `mkdir` command is used to create a directory. To create our playground directory, we will first make sure we are in our home directory and will then create the new directory.

```
[me@linuxbox ~]$ cd
[me@linuxbox ~]$ mkdir playground
```

To make our playground a little more interesting, let's create a couple of directories inside it called *dir1* and *dir2*. To do this, we will change our current working directory to `playground` and execute another `mkdir`.

```
[me@linuxbox ~]$ cd playground
[me@linuxbox playground]$ mkdir dir1 dir2
```

Notice that the `mkdir` command will accept multiple arguments allowing us to create both directories with a single command.

### Copying Files

Next, let's get some data into our playground. We'll do this by copying a file. Using the `cp` command, we'll copy the *passwd* file from the */etc* directory to the current working directory.

```
[me@linuxbox playground]$ cp /etc/passwd .
```

Notice how we used shorthand for the current working directory, the single trailing period. So now if we perform an ls, we will see our file.

```
[me@linuxbox playground]$ ls -l
total 12
drwxrwxr-x 2 me  me 4096 2018-01-10 16:40 dir1
drwxrwxr-x 2 me  me 4096 2018-01-10 16:40 dir2
-rw-r--r-- 1 me  me 1650 2018-01-10 16:07 passwd
```

Now, just for fun, let's repeat the copy using the -v option (verbose) to see what it does.

```
[me@linuxbox playground]$ cp -v /etc/passwd .
`/etc/passwd' -> `./passwd'
```

The cp command performed the copy again but this time displayed a concise message indicating what operation it was performing. Notice that cp overwrote the first copy without any warning. Again, this is a case of cp assuming that we know what we're doing. To get a warning, we'll include the -i (interactive) option.

```
[me@linuxbox playground]$ cp -i /etc/passwd .
cp: overwrite `./passwd'?
```

Responding to the prompt by entering a y will cause the file to be overwritten; any other character (for example, n) will cause cp to leave the file alone.

### Moving and Renaming Files

Now, the name *passwd* doesn't seem very playful and this is a playground, so let's change it to something else.

```
[me@linuxbox playground]$ mv passwd fun
```

Let's pass the fun around a little by moving our renamed file to each of the directories and back again. The following moves it first to the directory *dir1*:

```
[me@linuxbox playground]$ mv fun dir1
```

The following then moves it from *dir1* to *dir2*:

```
[me@linuxbox playground]$ mv dir1/fun dir2
```

Finally, this command brings it back to the current working directory:

```
[me@linuxbox playground]$ mv dir2/fun .
```

Next, let's see the effect of `mv` on directories. First we will move our data file into *dir1* again, like this:

```
[me@linuxbox playground]$ mv fun dir1
```

Then we move *dir1* into *dir2* and confirm it with `ls`.

```
[me@linuxbox playground]$ mv dir1 dir2
[me@linuxbox playground]$ ls -l dir2
total 4
drwxrwxr-x 2 me  me   4096 2018-01-11 06:06 dir1
[me@linuxbox playground]$ ls -l dir2/dir1
total 4
-rw-r--r-- 1 me  me   1650 2018-01-10 16:33 fun
```

Note that because *dir2* already existed, `mv` moved *dir1* into *dir2*. If *dir2* had not existed, `mv` would have renamed *dir1* to *dir2*. Lastly, let's put everything back.

```
[me@linuxbox playground]$ mv dir2/dir1 .
[me@linuxbox playground]$ mv dir1/fun .
```

### Creating Hard Links

Now we'll try some links. We'll first create some hard links to our data file, like so:

```
[me@linuxbox playground]$ ln fun fun-hard
[me@linuxbox playground]$ ln fun dir1/fun-hard
[me@linuxbox playground]$ ln fun dir2/fun-hard
```

So now we have four instances of the file *fun*. Let's take a look at our playground directory.

```
[me@linuxbox playground]$ ls -l
total 16
drwxrwxr-x 2 me   me   4096 2018-01-14 16:17 dir1
drwxrwxr-x 2 me   me   4096 2018-01-14 16:17 dir2
-rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun
-rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun-hard
```

One thing we notice is that both the second fields in the listings for *fun* and *fun-hard* contain a *4*, which is the number of hard links that now exist for the file. Remember that a file will always have at least one link because the file's name is created by a link. So, how do we know that *fun* and *fun-hard* are,

in fact, the same file? In this case, `ls` is not very helpful. While we can see that *fun* and *fun-hard* are both the same size (field 5), our listing provides no way to be sure. To solve this problem, we're going to have to dig a little deeper.

When thinking about hard links, it is helpful to imagine that files are made up of two parts.

- The data part containing the file's contents
- The name part that holds the file's name

When we create hard links, we are actually creating additional name parts that all refer to the same data part. The system assigns a chain of disk blocks to what is called an *inode*, which is then associated with the name part. Each hard link therefore refers to a specific inode containing the file's contents.

The `ls` command has a way to reveal this information. It is invoked with the `-i` option.

```
[me@linuxbox playground]$ ls -li
total 16
12353539 drwxrwxr-x 2 me   me   4096 2018-01-14 16:17 dir1
12353540 drwxrwxr-x 2 me   me   4096 2018-01-14 16:17 dir2
12353538 -rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun
12353538 -rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun-hard
```

In this version of the listing, the first field is the inode number and, as we can see, both *fun* and *fun-hard* share the same inode number, which confirms they are the same file.

### Creating Symbolic Links

Symbolic links were created to overcome the two disadvantages of hard links:

- Hard links cannot span physical devices.
- Hard links cannot reference directories, only files.

Symbolic links are a special type of file that contains a text pointer to the target file or directory.

Creating symbolic links is similar to creating hard links.

```
[me@linuxbox playground]$ ln -s fun fun-sym
[me@linuxbox playground]$ ln -s ../fun dir1/fun-sym
[me@linuxbox playground]$ ln -s ../fun dir2/fun-sym
```

The first example is pretty straightforward; we simply add the `-s` option to create a symbolic link rather than a hard link. But what about the next two? Remember that when we create a symbolic link, we are creating a text

description of where the target file is relative to the symbolic link. It's easier to see if we look at the `ls` output, shown here:

```
[me@linuxbox playground]$ ls -l dir1
total 4
-rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun-hard
lrwxrwxrwx 1 me   me      6 2018-01-15 15:17 fun-sym -> ../fun
```

The listing for *fun-sym* in *dir1* shows that it is a symbolic link by the leading `l` in the first field and that it points to *../fun*, which is correct. Relative to the location of *fun-sym*, *fun* is in the directory above it. Notice, too, that the length of the symbolic link file is 6, the number of characters in the string `../fun` rather than the length of the file to which it is pointing.

When creating symbolic links, you can either use absolute pathnames, as shown here:

```
[me@linuxbox playground]$ ln -s /home/me/playground/fun dir1/fun-sym
```

or relative pathnames, as we did in our earlier example. In most cases, using relative pathnames is more desirable because it allows a directory tree containing symbolic links and their referenced files to be renamed and/or moved without breaking the links.

In addition to regular files, symbolic links can also reference directories.

```
[me@linuxbox playground]$ ln -s dir1 dir1-sym
[me@linuxbox playground]$ ls -l
total 16
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir1
lrwxrwxrwx 1 me   me      4 2018-01-16 14:45 dir1-sym -> dir1
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir2
-rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun
-rw-r--r-- 4 me   me   1650 2018-01-10 16:33 fun-hard
lrwxrwxrwx 1 me   me      3 2018-01-15 15:15 fun-sym -> fun
```

### Removing Files and Directories

As we covered earlier, the `rm` command is used to delete files and directories. We are going to use it to clean up our playground a little bit. First, let's delete one of our hard links.

```
[me@linuxbox playground]$ rm fun-hard
[me@linuxbox playground]$ ls -l
total 12
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir1
lrwxrwxrwx 1 me   me      4 2018-01-16 14:45 dir1-sym -> dir1
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir2
-rw-r--r-- 3 me   me   1650 2018-01-10 16:33 fun
lrwxrwxrwx 1 me   me      3 2018-01-15 15:15 fun-sym -> fun
```

That worked as expected. The file *fun-hard* is gone, and the link count shown for *fun* is reduced from four to three, as indicated in the second field of the directory listing. Next, we'll delete the file *fun*, and just for enjoyment, we'll include the `-i` option to show what that does.

```
[me@linuxbox playground]$ rm -i fun
rm: remove regular file `fun'?
```

Enter **y** at the prompt and the file is deleted. But let's look at the output of `ls` now. Notice what happened to `fun-sym`? Because it's a symbolic link pointing to a now-nonexistent file, the link is broken.

```
[me@linuxbox playground]$ ls -l
total 8
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir1
lrwxrwxrwx 1 me   me      4 2018-01-16 14:45 dir1-sym -> dir1
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir2
lrwxrwxrwx 1 me   me      3 2018-01-15 15:15 fun-sym -> fun
```

Most Linux distributions configure `ls` to display broken links. The presence of a broken link is not in and of itself dangerous, but it is rather messy. If we try to use a broken link, we will see this:

```
[me@linuxbox playground]$ less fun-sym
fun-sym: No such file or directory
```

Let's clean up a little. We'll delete the symbolic links here:

```
[me@linuxbox playground]$ rm fun-sym dir1-sym
[me@linuxbox playground]$ ls -l
total 8
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir1
drwxrwxr-x 2 me   me   4096 2018-01-15 15:17 dir2
```

One thing to remember about symbolic links is that most file operations are carried out on the link's target, not the link itself. `rm` is an exception. When you delete a link, it is the link that is deleted, not the target.

Finally, we will remove our playground. To do this, we will return to our home directory and use `rm` with the recursive option (`-r`) to delete `playground` and all of its contents, including its subdirectories.

```
[me@linuxbox playground]$ cd
[me@linuxbox ~]$ rm -r playground
```

**CREATING SYMLINKS WITH THE GUI**

The file managers in both GNOME and KDE provide an easy and automatic method of creating symbolic links. With GNOME, holding the CTRL-SHIFT keys while dragging a file will create a link rather than copying (or moving) the file. In KDE, a small menu appears whenever a file is dropped, offering a choice of copying, moving, or linking the file.

## Summing Up

We've covered a lot of ground here, and it will take a while for it all to fully sink in. Perform the playground exercise over and over until it makes sense. It is important to get a good understanding of basic file manipulation commands and wildcards. Feel free to expand on the playground exercise by adding more files and directories, using wildcards to specify files for various operations. The concept of links is a little confusing at first, but take the time to learn how they work. They can be a real lifesaver!

# 5

# WORKING WITH COMMANDS

Up to this point, we have seen a series of mysterious commands, each with its own options and arguments. In this chapter, we will attempt to remove some of that mystery and even create our own commands. The commands introduced in this chapter are as follows:

- **`type`** Indicate how a command name is interpreted
- **`which`** Display which executable program will be executed
- **`help`** Get help for shell builtins
- **`man`** Display a command's manual page
- **`apropos`** Display a list of appropriate commands
- **`info`** Display a command's info entry
- **`whatis`** Display one-line manual page descriptions
- **`alias`** Create an alias for a command

## What Exactly Are Commands?

A command can be one of four different things.

- **An executable program** like all those files we saw in */usr/bin*. Within this category, programs can be *compiled binaries* such as programs written in C and C++, or programs written in *scripting languages* such as the shell, Perl, Python, Ruby, and so on.
- **A command built into the shell itself**. `bash` supports a number of commands internally called *shell builtins*. The `cd` command, for example, is a shell builtin.
- **A shell function**. Shell functions are miniature shell scripts incorporated into the *environment*. We will cover configuring the environment and writing shell functions in later chapters, but for now, just be aware that they exist.
- **An alias**. Aliases are commands that we can define ourselves, built from other commands.

## Identifying Commands

It is often useful to know exactly which of the four kinds of commands is being used, and Linux provides a couple of ways to find out.

### *type—Display a Command's Type*

The `type` command is a shell builtin that displays the kind of command the shell will execute, given a particular command name. It works like this:

```
type command
```

where *command* is the name of the command you want to examine. Here are some examples:

```
[me@linuxbox ~]$ type type
type is a shell builtin
[me@linuxbox ~]$ type ls
ls is aliased to `ls --color=tty'
[me@linuxbox ~]$ type cp
cp is /bin/cp
```

Here we see the results for three different commands. Notice the one for `ls` (taken from a Fedora system) and how the `ls` command is actually an alias for the `ls` command with the `--color=tty` option added. Now we know why the output from `ls` is displayed in color!

### *which—Display an Executable's Location*

Sometimes there is more than one version of an executable program installed on a system. While this is not common on desktop systems, it's

not unusual on larger servers. To determine the exact location of a given executable, the `which` command is used.

```
[me@linuxbox ~]$ which ls
/bin/ls
```

`which` works only for executable programs, not builtins or aliases that are substitutes for actual executable programs. When we try to use `which` on a shell builtin—for example, `cd`—we either get no response or get an error message.

```
[me@linuxbox ~]$ which cd
/usr/bin/which: no cd in (/usr/local/bin:/usr/bin:/bin:/usr/local/games:/usr/games)
```

This result is a fancy way of saying "command not found."

## Getting a Command's Documentation

With this knowledge of what a command is, we can now search for the documentation available for each kind of command.

### *help—Get Help for Shell Builtins*

`bash` has a built-in help facility available for each of the shell builtins. To use it, type **`help`** followed by the name of the shell builtin. Here's an example:

```
[me@linuxbox ~]$ help cd
cd: cd [-L|[-P [-e]] [-@]] [dir]
    Change the shell working directory.

    Change the current directory to DIR.  The default DIR is the value of the
    HOME shell variable.

    The variable CDPATH defines the search path for the directory containing
    DIR.  Alternative directory names in CDPATH are separated by a colon (:).
    A null directory name is the same as the current directory.  If DIR begins
    with a slash (/), then CDPATH is not used.

    If the directory is not found, and the shell option `cdable_vars' is set,
    the word is assumed to be a variable name.  If that variable has a value,
    its value is used for DIR.

    Options:
        -L  force symbolic links to be followed: resolve symbolic links in
        DIR after processing instances of `..'
        -P  use the physical directory structure without following symbolic
        links: resolve symbolic links in DIR before processing instances
        of `..'
        -e  if the -P option is supplied, and the current working directory
        cannot be determined successfully, exit with a non-zero status
        -@  on systems that support it, present a file with extended attributes
            as a directory containing the file attributes
```

```
    The default is to follow symbolic links, as if `-L' were specified.
    `..' is processed by removing the immediately previous pathname component
    back to a slash or the beginning of DIR.

    Exit Status:
    Returns 0 if the directory is changed, and if $PWD is set successfully when
    -P is used; non-zero otherwise..
```

**A note on notation**: When square brackets appear in the description of a command's syntax, they indicate optional items. A vertical bar character indicates mutually exclusive items. In the case of the `cd` command above:

```
cd [-L|[-P[-e]]] [dir]
```

This notation says that the command `cd` may be followed optionally by either a `-L` or a `-P` and further, if the `-P` option is specified the `-e` option may also be included followed by the optional argument `dir`.

While the output of `help` for the `cd` commands is concise and accurate, it is by no means tutorial and as we can see, it also seems to mention a lot of things we haven't talked about yet! Don't worry. We'll get there.

## *--help—Display Usage Information*

Many executable programs support a `--help` option that displays a description of the command's supported syntax and options. For example:

```
[me@linuxbox ~]$ mkdir --help
Usage: mkdir [OPTION] DIRECTORY...
Create the DIRECTORY(ies), if they do not already exist.

  -Z, --context=CONTEXT (SELinux) set security context to CONTEXT
Mandatory arguments to long options are mandatory for short options too.
  -m, --mode=MODE   set file mode (as in chmod), not a=rwx - umask
  -p, --parents     no error if existing, make parent directories as
                    needed
  -v, --verbose     print a message for each created directory
      --help        display this help and exit
      --version     output version information and exit
Report bugs to <bug-coreutils@gnu.org>.
```

Some programs don't support the `--help` option, but try it anyway. Often it results in an error message that will reveal the same usage information.

## *man—Display a Program's Manual Page*

Most executable programs intended for command line use provide a formal piece of documentation called a *manual* or *man page*. A special paging program called `man` is used to view them. It is used like this:

```
man program
```

where *program* is the name of the command to view.

Man pages vary somewhat in format but generally contain the following:

- A title (the page's name)
- A synopsis of the command's syntax
- A description of the command's purpose
- A listing and description of each of the command's options

Man pages, however, do not usually include examples and are intended as a reference, not a tutorial. As an example, let's try viewing the man page for the `ls` command.

```
[me@linuxbox ~]$ man ls
```

On most Linux systems, `man` uses `less` to display the manual page, so all of the familiar `less` commands work while displaying the page.

The "manual" that `man` displays is broken into sections and covers not only user commands but also system administration commands, programming interfaces, file formats, and more. Table 5-1 describes the layout of the manual.

**Table 5-1:** Man Page Organization

| Section | Contents |
|---|---|
| 1 | User commands |
| 2 | Programming interfaces for kernel system calls |
| 3 | Programming interfaces to the C library |
| 4 | Special files such as device nodes and drivers |
| 5 | File formats |
| 6 | Games and amusements such as screen savers |
| 7 | Miscellaneous |
| 8 | System administration commands |

Sometimes we need to refer to a specific section of the manual to find what we are looking for. This is particularly true if we are looking for a file format that is also the name of a command. Without specifying a section number, we will always get the first instance of a match, probably in section 1. To specify a section number, we use `man` like this:

```
man section search_term
```

Here's an example:

```
[me@linuxbox ~]$ man 5 passwd
```

This will display the man page describing the file format of the */etc/passwd* file.

### apropos—Display Appropriate Commands

It is also possible to search the list of man pages for possible matches based on a search term. It's crude but sometimes helpful. Here is an example of a search for man pages using the search term *partition*:

```
[me@linuxbox ~]$ apropos partition
addpart (8)          - simple wrapper around the "add partition" ioctl
all-swaps (7)        - event signalling that all swap partitions have been ac...
cfdisk (8)           - display or manipulate disk partition table
cgdisk (8)           - Curses-based GUID partition table (GPT) manipulator
delpart (8)          - simple wrapper around the "del partition" ioctl
fdisk (8)            - manipulate disk partition table
fixparts (8)         - MBR partition table repair utility
gdisk (8)            - Interactive GUID partition table (GPT) manipulator
mpartition (1)       - partition an MSDOS hard disk
partprobe (8)        - inform the OS of partition table changes
partx (8)            - tell the Linux kernel about the presence and numbering...
resizepart (8)       - simple wrapper around the "resize partition" ioctl
sfdisk (8)           - partition table manipulator for Linux
sgdisk (8)           - Command-line GUID partition table (GPT) manipulator fo..
```

The first field in each line of output is the name of the man page, and the second field shows the section. Note that the `man` command with the `-k` option performs the same function as `apropos`.

### whatis—Display One-line Manual Page Descriptions

The `whatis` program displays the name and a one-line description of a man page matching a specified keyword.

```
[me@linuxbox ~]$ whatis ls
ls                   (1)  - list directory contents
```

**THE MOST BRUTAL MAN PAGE OF THEM ALL**

As we have seen, the manual pages supplied with Linux and other Unix-like systems are intended as reference documentation and not as tutorials. Many man pages are hard to read, but I think the grand prize for difficulty has got to go to the man page for bash. As I was doing research for this book, I gave the bash man page careful review to ensure that I was covering most of its topics. When printed, it's more than 80 pages long and extremely dense, and its structure makes absolutely no sense to a new user.

On the other hand, it is very accurate and concise, as well as being extremely complete. So check it out if you dare and look forward to the day when you can read it and it all makes sense.

## info—Display a Program's Info Entry

The GNU Project provides an alternative to man pages for their programs, called *info*. Info manuals are displayed with a reader program named, appropriately enough, `info`. Info pages are *hyperlinked* much like web pages. Here is a sample:

```
File: coreutils.info,  Node: ls invocation,  Next: dir invocation, Up:
Directory listing
10.1 `ls': List directory contents
==================================
The `ls' program lists information about files (of any type, including
directories).  Options and file arguments can be intermixed arbitrarily, as
usual.
   For non-option command-line arguments that are directories, by default `ls'
lists the contents of directories, not recursively, and omitting files with
names beginning with `.'.  For other non-option arguments, by default `ls'
lists just the filename.  If no non-option argument is specified, `ls'
operates on the current directory, acting as if it had been invoked with a
single argument of `.'.
   By default, the output is sorted alphabetically, according to the
--zz-Info: (coreutils.info.gz)ls invocation, 63 lines --Top----------
```

The `info` program reads info files, which are tree structured into individual *nodes*, each containing a single topic. Info files contain hyperlinks that can move you from node to node. A hyperlink can be identified by its leading asterisk and is activated by placing the cursor upon it and pressing ENTER.

To invoke `info`, type **`info`** followed optionally by the name of a program. Table 5-2 describes the commands used to control the reader while displaying an info page.

**Table 5-2:** info Commands

| Command | Action |
|---|---|
| ? | Display command help |
| PAGE UP or BACKSPACE | Display previous page |
| PAGE DOWN or spacebar | Display next page |
| n | Next—display the next node |
| p | Previous—display the previous node |
| U | Up—display the parent node of the currently displayed node, usually a menu |
| ENTER | Follow the hyperlink at the cursor location |
| Q | Quit |

Most of the command line programs we have discussed so far are part of the GNU Project's coreutils package, so typing the following:

```
[me@linuxbox ~]$ info coreutils
```

will display a menu page with hyperlinks to each program contained in the coreutils package.

### *README and Other Program Documentation Files*

Many software packages installed on your system have documentation files residing in the */usr/share/doc* directory. Most of these are stored in ordinary text format and can be viewed with the `less` command. Some of the files are in HTML format and can be viewed with a web browser. We may encounter some files ending with a *.gz* extension. This indicates that they have been compressed with the gzip compression program. The gzip package includes a special version of `less` called `zless` that will display the contents of gzip-compressed text files.

## Creating Our Own Commands with alias

Now for our first experience with programming! We will create a command of our own using the `alias` command. But before we start, we need to reveal a small command line trick. It's possible to put more than one command on a line by separating each command with a semicolon. It works like this:

```
command1; command2; command3...
```

Here's the example we will use:

```
[me@linuxbox ~]$ cd /usr; ls; cd -
bin  games  include  lib  local  sbin  share  src
/home/me
[me@linuxbox ~]$
```

As we can see, we have combined three commands on one line. First we change the current working directory to */usr*, then list the directory, and finally return to the original directory (by using `cd -`) so we end up where we started. Now let's turn this sequence into a new command using `alias`. The first thing we have to do is dream up a name for our new command. Let's try `test`. Before we do that, it would be a good idea to find out whether the name `test` is already being used. To find out, we can use the `type` command again.

```
[me@linuxbox ~]$ type test
test is a shell builtin
```

Oops! The name `test` is already taken. Let's try `foo`.

```
[me@linuxbox ~]$ type foo
bash: type: foo: not found
```

Great! foo is not taken. So, let's create our alias.

```
[me@linuxbox ~]$ alias foo='cd /usr; ls; cd -'
```

Notice the structure of this command, shown here:

```
alias name='string'
```

After the command alias, we give our alias a name followed immediately (no whitespace allowed) by an equal sign, followed immediately by a quoted string containing the meaning to be assigned to the name. After we define our alias, we can use it anywhere the shell would expect a command. Let's try it.

```
[me@linuxbox ~]$ foo
bin  games  include  lib  local  sbin  share  src
/home/me
[me@linuxbox ~]$
```

We can also use the type command again to see our alias.

```
[me@linuxbox ~]$ type foo
foo is aliased to `cd /usr; ls; cd -'
```

To remove an alias, the unalias command is used, like so:

```
[me@linuxbox ~]$ unalias foo
[me@linuxbox ~]$ type foo
bash: type: foo: not found
```

While we purposefully avoided naming our alias with an existing command name, it is not uncommon to do so. This is often done to apply a commonly desired option to each invocation of a common command. For instance, we saw earlier how the ls command is often aliased to add color support.

```
[me@linuxbox ~]$ type ls
ls is aliased to `ls --color=tty'
```

To see all the aliases defined in the environment, use the alias command without arguments. Here are some of the aliases defined by default on a Fedora system. Try to figure out what they all do.

```
[me@linuxbox ~]$ alias
alias l.='ls -d .* --color=tty'
alias ll='ls -l --color=tty'
alias ls='ls --color=tty'
```

There is one tiny problem with defining aliases on the command line. They vanish when your shell session ends. In Chapter 11, we will see how to add our own aliases to the files that establish the environment each time we log on, but for now, enjoy the fact that we have taken our first, albeit tiny, step into the world of shell programming!

## Summing Up

Now that we have learned how to find the documentation for commands, look up the documentation for all the commands we have encountered so far. Study what additional options are available and try them!

# 6

# REDIRECTION

In this lesson we are going to unleash what may be the coolest feature of the command line. It's called *I/O redirection*. The "I/O" stands for *input/output*, and with this facility you can redirect the input and output of commands to and from files, as well as connect multiple commands together into powerful command *pipelines*. To show off this facility, we will introduce the following commands:

- **`cat`** Concatenate files
- **`sort`** Sort lines of text
- **`uniq`** Report or omit repeated lines
- **`grep`** Print lines matching a pattern
- **`wc`** Print newline, word, and byte counts for each file
- **`head`** Output the first part of a file
- **`tail`** Output the last part of a file
- **`tee`** Read from standard input and write to standard output and files

## Standard Input, Output, and Error

Many of the programs that we have used so far produce output of some kind. This output often consists of two types.

- The program's results; that is, the data the program is designed to produce
- Status and error messages that tell us how the program is getting along

If we look at a command like `ls`, we can see that it displays its results and its error messages on the screen.

Keeping with the Unix theme of "everything is a file," programs such as `ls` actually send their results to a special file called *standard output* (often expressed as *stdout*) and their status messages to another file called *standard error (stderr)*. By default, both standard output and standard error are linked to the screen and not saved into a disk file.

In addition, many programs take input from a facility called *standard input (stdin)*, which is, by default, attached to the keyboard.

I/O redirection allows us to change where output goes and where input comes from. Normally, output goes to the screen and input comes from the keyboard, but with I/O redirection, we can change that.

## Redirecting Standard Output

I/O redirection allows us to redefine where standard output goes. To redirect standard output to another file instead of the screen, we use the > redirection operator followed by the name of the file. Why would we want to do this? It's often useful to store the output of a command in a file. For example, we could tell the shell to send the output of the `ls` command to the file *ls-output.txt* instead of the screen.

```
[me@linuxbox ~]$ ls -l /usr/bin > ls-output.txt
```

Here, we created a long listing of the */usr/bin* directory and sent the results to the file *ls-output.txt*. Let's examine the redirected output of the command, shown here:

```
[me@linuxbox ~]$ ls -l ls-output.txt
-rw-rw-r-- 1 me   me   167878 2018-02-01 15:07 ls-output.txt
```

Good—a nice, large, text file. If we look at the file with `less`, we will see that the file *ls-output.txt* does indeed contain the results from our `ls` command.

```
[me@linuxbox ~]$ less ls-output.txt
```

Now, let's repeat our redirection test, but this time with a twist. We'll change the name of the directory to one that does not exist.

```
[me@linuxbox ~]$ ls -l /bin/usr > ls-output.txt
ls: cannot access /bin/usr: No such file or directory
```

We received an error message. This makes sense since we specified the nonexistent directory */bin/usr*, but why was the error message displayed on the screen rather than being redirected to the file *ls-output.txt*? The answer is that the `ls` program does not send its error messages to standard output. Instead, like most well-written Unix programs, it sends its error messages to standard error. Because we redirected only standard output and not standard error, the error message was still sent to the screen. We'll see how to redirect standard error in just a minute, but first let's look at what happened to our output file.

```
[me@linuxbox ~]$ ls -l ls-output.txt
-rw-rw-r-- 1 me   me   0 2018-02-01 15:08 ls-output.txt
```

The file now has zero length! This is because when we redirect output with the > redirection operator, the destination file is always rewritten from the beginning. Because our `ls` command generated no results and only an error message, the redirection operation started to rewrite the file and then stopped because of the error, resulting in its truncation. In fact, if we ever need to actually truncate a file (or create a new, empty file), we can use a trick like this:

```
[me@linuxbox ~]$ > ls-output.txt
```

Simply using the redirection operator with no command preceding it will truncate an existing file or create a new, empty file.

So, how can we append redirected output to a file instead of overwriting the file from the beginning? For that, we use the >> redirection operator, like so:

```
[me@linuxbox ~]$ ls -l /usr/bin >> ls-output.txt
```

Using the >> operator will result in the output being appended to the file. If the file does not already exist, it is created just as though the > operator had been used. Let's put it to the test.

```
[me@linuxbox ~]$ ls -l /usr/bin >> ls-output.txt
[me@linuxbox ~]$ ls -l /usr/bin >> ls-output.txt
[me@linuxbox ~]$ ls -l /usr/bin >> ls-output.txt
[me@linuxbox ~]$ ls -l ls-output.txt
-rw-rw-r-- 1 me   me   503634 2018-02-01 15:45 ls-output.txt
```

We repeated the command three times, resulting in an output file three times as large.

## Redirecting Standard Error

Redirecting standard error lacks the ease of a dedicated redirection operator. To redirect standard error, we must refer to its *file descriptor*. A program can produce output on any of several numbered file streams. While we have referred to the first three of these file streams as standard input, output, and error, the shell references them internally as file descriptors 0, 1, and 2, respectively. The shell provides a notation for redirecting files using the file descriptor number. Because standard error is the same as file descriptor number 2, we can redirect standard error with this notation:

```
[me@linuxbox ~]$ ls -l /bin/usr 2> ls-error.txt
```

The file descriptor 2 is placed immediately before the redirection operator to perform the redirection of standard error to the file *ls-error.txt*.

### Redirecting Standard Output and Standard Error to One File

There are cases in which we may want to capture all of the output of a command to a single file. To do this, we must redirect both standard output and standard error at the same time. There are two ways to do this. Shown here is the traditional way, which works with old versions of the shell:

```
[me@linuxbox ~]$ ls -l /bin/usr > ls-output.txt 2>&1
```

Using this method, we perform two redirections. First we redirect standard output to the file *ls-output.txt*, and then we redirect file descriptor 2 (standard error) to file descriptor 1 (standard output) using the notation `2>&1`.

**NOTICE THAT THE ORDER OF THE REDIRECTIONS IS SIGNIFICANT**

The redirection of standard error must always occur *after* redirecting standard output or it doesn't work. The following example redirects standard error to the file *ls-output.txt*:

```
>ls-output.txt 2>&1
```

If the order is changed to the following, then standard error is directed to the screen:

```
2>&1 >ls-output.txt
```

Recent versions of bash provide a second, more streamlined method for performing this combined redirection, shown here:

```
[me@linuxbox ~]$ ls -l /bin/usr &> ls-output.txt
```

In this example, we use the single notation &> to redirect both standard output and standard error to the file *ls-output.txt*. You may also append the standard output and standard error streams to a single file like so:

```
[me@linuxbox ~]$ ls -l /bin/usr &>> ls-output.txt
```

### *Disposing of Unwanted Output*

Sometimes "silence is golden" and we don't want output from a command; we just want to throw it away. This applies particularly to error and status messages. The system provides a way to do this by redirecting output to a special file called */dev/null*. This file is a system device often referred to as a *bit bucket*, which accepts input and does nothing with it. To suppress error messages from a command, we do this:

```
[me@linuxbox ~]$ ls -l /bin/usr 2> /dev/null
```

**/DEV/NULL IN UNIX CULTURE**

The bit bucket is an ancient Unix concept, and because of its universality, it has appeared in many parts of Unix culture. When someone says they are sending your comments to */dev/null*, now you know what it means. For more examples, see the Wikipedia article on */dev/null*.

## Redirecting Standard Input

Up to now, we haven't encountered any commands that make use of standard input (actually we have, but we'll reveal that surprise a little bit later), so we need to introduce one.

### *cat: Concatenate Files*

The cat command reads one or more files and copies them to standard output like so:

```
cat filename
```

In most cases, you can think of cat as being analogous to the TYPE command in DOS. You can use it to display files without paging. For example, the following will display the contents of the file *ls-output.txt*:

```
[me@linuxbox ~]$ cat ls-output.txt
```

cat is often used to display short text files. Because cat can accept more than one file as an argument, it can also be used to join files together. Suppose we have downloaded a large file that has been split into multiple parts (multimedia files are often split this way on Usenet), and we want to join them back together. If the files were named as follows:

```
movie.mpeg.001 movie.mpeg.002 ... movie.mpeg.099
```

we could join them back together with this command:

```
cat movie.mpeg.0* > movie.mpeg
```

Because *wildcards* always expand in sorted order, the arguments will be arranged in the correct order.

This is all well and good, but what does this have to do with standard input? Nothing yet, but let's try something else. What happens if we enter **cat** with no arguments?

```
[me@linuxbox ~]$ cat
```

Nothing happens; it just sits there like it's hung. It might seem that way, but it's really doing exactly what it's supposed to do.

If cat is not given any arguments, it reads from standard input, and since standard input is, by default, attached to the keyboard, it's waiting for us to type something! Try adding the following text and pressing ENTER:

```
[me@linuxbox ~]$ cat
The quick brown fox jumped over the lazy dog.
```

Next, type CTRL-D (i.e., hold down the CTRL key and press D) to tell cat that it has reached end of file (EOF) on standard input.

```
[me@linuxbox ~]$ cat
The quick brown fox jumped over the lazy dog.
The quick brown fox jumped over the lazy dog.
```

In the absence of filename arguments, cat copies standard input to standard output, so we see our line of text repeated. We can use this behavior to create short text files. Let's say we wanted to create a file called *lazy_dog.txt* containing the text in our example. We would do this:

```
[me@linuxbox ~]$ cat > lazy_dog.txt
The quick brown fox jumped over the lazy dog.
```

Type the command followed by the text we want to place in the file. Remember to type CTRL-D at the end. Using the command line, we have implemented the world's dumbest word processor! To see our results, we can use cat to copy the file to stdout again.

```
[me@linuxbox ~]$ cat lazy_dog.txt
The quick brown fox jumped over the lazy dog.
```

Now that we know how cat accepts standard input, in addition to filename arguments, let's try redirecting standard input.

```
[me@linuxbox ~]$ cat < lazy_dog.txt
The quick brown fox jumped over the lazy dog.
```

Using the < redirection operator, we change the source of standard input from the keyboard to the file *lazy_dog.txt*. We see that the result is the same as passing a single filename argument. This is not particularly useful compared to passing a filename argument, but it serves to demonstrate using a file as a source of standard input. Other commands make better use of standard input, as we will soon see.

Before we move on, check out the man page for cat because it has several interesting options.

## Pipelines

The capability of commands to read data from standard input and send to standard output is utilized by a shell feature called *pipelines*. Using the pipe operator |, the standard output of one command can be *piped* into the standard input of another.

```
command1 | command2
```

To fully demonstrate this, we are going to need some commands. Remember how we said there was one we already knew that accepts standard input? It's less. We can use less to display, page by page, the output of any command that sends its results to standard output.

```
[me@linuxbox ~]$ ls -l /usr/bin | less
```

This is extremely handy! Using this technique, we can conveniently examine the output of any command that produces standard output.

### Filters

Pipelines are often used to perform complex operations on data. It is possible to put several commands together into a pipeline. Frequently, the commands used this way are referred to as *filters*. Filters take input, change it somehow, and then output it. The first one we will try is sort. Imagine we

wanted to make a combined list of all the executable programs in */bin* and */usr/bin*, put them in sorted order, and view the resulting list.

```
[me@linuxbox ~]$ ls /bin /usr/bin | sort | less
```

Because we specified two directories (*/bin* and */usr/bin*), the output of `ls` would have consisted of two sorted lists, one for each directory. By including `sort` in our pipeline, we changed the data to produce a single, sorted list.

**THE DIFFERENCE BETWEEN > AND |**

At first glance, it may be hard to understand the redirection performed by the pipeline operator | versus the redirection operator >. Simply put, the redirection operator connects a command with a file, while the pipeline operator connects the output of one command with the input of a second command.

```
command1 > file1
command1 | command2
```

A lot of people will try the following when they are learning about pipelines, "just to see what happens":

```
command1 > command2
```

Answer: sometimes something really bad.

Here is an actual example submitted by a reader who was administering a Linux-based server appliance. As the superuser, he did this:

```
# cd /usr/bin
# ls > less
```

The first command put him in the directory where most programs are stored, and the second command told the shell to overwrite the file *less* with the output of the `ls` command. Since the */usr/bin* directory already contained a file named *less* (the `less` program), the second command overwrote the *less* program file with the text from `ls`, thus destroying the `less` program on his system.

The lesson here is that the redirection operator silently creates or overwrites files, so you need to treat it with a lot of respect.

## uniq: Report or Omit Repeated Lines

The `uniq` command is often used in conjunction with `sort`. `uniq` accepts a sorted list of data from either standard input or a single filename argument (see the `uniq` man page for details) and, by default, removes any duplicates from the list. So, to make sure our list has no duplicates (that

is, any programs of the same name that appear in both the */bin* and */usr/bin* directories), we will add `uniq` to our pipeline.

```
[me@linuxbox ~]$ ls /bin /usr/bin | sort | uniq | less
```

In this example, we use `uniq` to remove any duplicates from the output of the `sort` command. If we want to see the list of duplicates instead, we add the `-d` option to `uniq` like so:

```
[me@linuxbox ~]$ ls /bin /usr/bin | sort | uniq -d | less
```

### wc: Print Line, Word, and Byte Counts

The `wc` (word count) command is used to display the number of lines, words, and bytes contained in files. Here's an example:

```
[me@linuxbox ~]$ wc ls-output.txt
 7902  64566 503634 ls-output.txt
```

In this case, it prints out three numbers: lines, words, and bytes contained in *ls-output.txt*. Like our previous commands, if executed without command line arguments, `wc` accepts standard input. The `-l` option limits its output to report only lines. Adding it to a pipeline is a handy way to count things. To see the number of items we have in our sorted list, we can do this:

```
[me@linuxbox ~]$ ls /bin /usr/bin | sort | uniq | wc -l
2728
```

### grep: Print Lines Matching a Pattern

`grep` is a powerful program used to find text patterns within files. It's used like this:

```
grep pattern filename
```

When `grep` encounters a "pattern" in the file, it prints out the lines containing it. The patterns that `grep` can match can be very complex, but for now we will concentrate on simple text matches. We'll cover the advanced patterns, called *regular expressions*, in Chapter 19.

Suppose we wanted to find all the files in our list of programs that had the word *zip* embedded in the name. Such a search might give us an idea of some of the programs on our system that had something to do with file compression. We would do this:

```
[me@linuxbox ~]$ ls /bin /usr/bin | sort | uniq | grep zip
bunzip2
bzip2
gunzip
```

```
gzip
unzip
zip
zipcloak
zipgrep
zipinfo
zipnote
zipsplit
```

There are a couple of handy options for grep.

- -i, which causes grep to ignore case when performing the search (normally searches are case sensitive)
- -v, which tells grep to print only those lines that do not match the pattern

### head/tail: Print First/Last Part of Files

Sometimes you don't want all the output from a command. You might want only the first few lines or the last few lines. The head command prints the first 10 lines of a file, and the tail command prints the last 10 lines. By default, both commands print 10 lines of text, but this can be adjusted with the -n option.

```
[me@linuxbox ~]$ head -n 5 ls-output.txt
total 343496
-rwxr-xr-x 1 root root       31316 2017-12-05 08:58 [
-rwxr-xr-x 1 root root        8240 2017-12-09 13:39 411toppm
-rwxr-xr-x 1 root root      111276 2017-11-26 14:27 a2p
-rwxr-xr-x 1 root root       25368 2016-10-06 20:16 a52dec
[me@linuxbox ~]$ tail -n 5 ls-output.txt
-rwxr-xr-x 1 root root        5234 2017-06-27 10:56 znew
-rwxr-xr-x 1 root root         691 2015-09-10 04:21 zonetab2pot.py
-rw-r--r-- 1 root root         930 2017-11-01 12:23 zonetab2pot.pyc
-rw-r--r-- 1 root root         930 2017-11-01 12:23 zonetab2pot.pyo
lrwxrwxrwx 1 root root           6 2016-01-31 05:22 zsoelim -> soelim
```

These can be used in pipelines as well:

```
[me@linuxbox ~]$ ls /usr/bin | tail -n 5
znew
zonetab2pot.py
zonetab2pot.pyc
zonetab2pot.pyo
zsoelim
```

tail has an option that allows you to view files in real time. This is useful for watching the progress of log files as they are being written. In the following example, we will look at the *messages* file in */var/log* (or the */var/log/syslog* file if *messages* is missing). Superuser privileges are required to do this on some Linux distributions because the */var/log/messages* file might contain security information.

```
[me@linuxbox ~]$ tail -f /var/log/messages
Feb  8 13:40:05 twin4 dhclient: DHCPACK from 192.168.1.1
Feb  8 13:40:05 twin4 dhclient: bound to 192.168.1.4 -- renewal in 1652 seconds.
Feb  8 13:55:32 twin4 mountd[3953]: /var/NFSv4/musicbox exported to both 192.168.1.0/24 and
twin7.localdomain in 192.168.1.0/24,twin7.localdomain
Feb  8 14:07:37 twin4 dhclient: DHCPREQUEST on eth0 to 192.168.1.1 port 67
Feb  8 14:07:37 twin4 dhclient: DHCPACK from 192.168.1.1
Feb  8 14:07:37 twin4 dhclient: bound to 192.168.1.4 -- renewal in 1771 seconds.
Feb  8 14:09:56 twin4 smartd[3468]: Device: /dev/hda, SMART Prefailure Attribute: 8 Seek_Time_
Performance changed from 237 to 236
Feb  8 14:10:37 twin4 mountd[3953]: /var/NFSv4/musicbox exported to both 192.168.1.0/24 and
twin7.localdomain in 192.168.1.0/24,twin7.localdomain
Feb  8 14:25:07 twin4 sshd(pam_unix)[29234]: session opened for user me by (uid=0)
Feb  8 14:25:36 twin4 su(pam_unix)[29279]: session opened for user root by me(uid=500)
```

Using the -f option, tail continues to monitor the file, and when new lines are appended, they immediately appear on the display. This continues until you type CTRL-C.

### *tee: Read from Stdin and Output to Stdout and Files*

In keeping with our plumbing metaphor, Linux provides a command called tee that creates a "tee" fitting on our pipe. The tee program reads standard input and copies it to both standard output (allowing the data to continue down the pipeline) and to one or more files. This is useful for capturing a pipeline's contents at an intermediate stage of processing. Here we repeat one of our earlier examples, this time including tee to capture the entire directory listing to the file *ls.txt* before grep filters the pipeline's contents:

```
[me@linuxbox ~]$ ls /usr/bin | tee ls.txt | grep zip
bunzip2
bzip2
gunzip
gzip
unzip
zip
zipcloak
zipgrep
zipinfo
zipnote
zipsplit
```

## Summing Up

As always, check out the documentation of each of the commands we have covered in this chapter. We have seen only their most basic usage. They all have a number of interesting options. As we gain Linux experience, we will see that the redirection feature of the command line is extremely useful

for solving specialized problems. There are many commands that make use of standard input and output, and almost all command line programs use standard error to display their informative messages.

**LINUX IS ABOUT IMAGINATION**

When I am asked to explain the difference between Windows and Linux, I often use a toy analogy.

Windows is like a Game Boy. You go to the store and buy one all shiny new in the box. You take it home, turn it on, and play with it. Pretty graphics, cute sounds. After a while, though, you get tired of the game that came with it, so you go back to the store and buy another one. This cycle repeats over and over. Finally, you go back to the store and say to the person behind the counter, "I want a game that does this!" only to be told that no such game exists because there is no "market demand" for it. Then you say, "But I only need to change this one thing!" The person behind the counter says you can't change it. The games are all sealed up in their cartridges. You discover that your toy is limited to the games that others have decided you need.

Linux, on the other hand, is like the world's largest Erector Set. You open it, and it's just a huge collection of parts. There's a lot of steel struts, screws, nuts, gears, pulleys, motors, and a few suggestions on what to build. So, you start to play with it. You build one of the suggestions and then another. After a while you discover that you have your own ideas of what to make. You don't ever have to go back to the store, as you already have everything you need. The Erector Set takes on the shape of your imagination. It does what you want.

Your choice of toys is, of course, a personal thing, so which toy would you find more satisfying?

# 7

# SEEING THE WORLD AS THE SHELL SEES IT

In this chapter, we are going to look at some of the "magic" that occurs on the command line when we press the ENTER key. While we will examine several interesting and complex features of the shell, we will do it with just one new command:

**echo** Display a line of text

## Expansion

Each time we type a command and press the ENTER key, `bash` performs several substitutions upon the text before it carries out our command. We have seen a couple of cases of how a simple character sequence, for example *, can have a lot of meaning to the shell. The process that makes this happen is called *expansion*. With expansion, we enter something, and it is expanded into something else before the shell acts upon it. To

demonstrate what we mean by this, let's take a look at the echo command. echo is a shell builtin that performs a very simple task. It prints its text arguments on standard output.

```
[me@linuxbox ~]$ echo this is a test
this is a test
```

That's pretty straightforward. Any argument passed to echo gets displayed. Let's try another example.

```
[me@linuxbox ~]$ echo *
Desktop Documents ls-output.txt Music Pictures Public Templates Videos
```

So what just happened? Why didn't echo print *? As we recall from our work with wildcards, the * character means match any characters in a filename, but what we didn't see in our original discussion was how the shell does that. The simple answer is that the shell expands the * into something else (in this instance, the names of the files in the current working directory) before the echo command is executed. When the ENTER key is pressed, the shell automatically expands any qualifying characters on the command line before the command is carried out, so the echo command never saw the *, only its expanded result. Knowing this, we can see that echo behaved as expected.

### Pathname Expansion

The mechanism by which wildcards work is called *pathname expansion*. If we try some of the techniques that we employed in earlier chapters, we will see that they are really expansions. Given a home directory that looks like this:

```
[me@linuxbox ~]$ ls
Desktop    ls-output.txt  Pictures  Templates
Documents  Music          Public    Videos
```

we could carry out the following expansions:

```
[me@linuxbox ~]$ echo D*
Desktop Documents
```

and this:

```
[me@linuxbox ~]$ echo *s
Documents Pictures Templates Videos
```

or even this:

```
[me@linuxbox ~]$ echo [[:upper:]]*
Desktop Documents Music Pictures Public Templates Videos
```

and looking beyond our home directory, we could do this:

```
[me@linuxbox ~]$ echo /usr/*/share
/usr/kerberos/share /usr/local/share
```

**PATHNAME EXPANSION OF HIDDEN FILES**

As we know, filenames that begin with a period character are hidden. Pathname expansion also respects this behavior. An expansion such as the following does not reveal hidden files:

```
echo *
```

It might appear at first glance that we could include hidden files in an expansion by starting the pattern with a leading period, like this:

```
echo .*
```

It almost works. However, if we examine the results closely, we will see that the names `.` and `..` will also appear in the results. Because these names refer to the current working directory and its parent directory, using this pattern will likely produce an incorrect result. We can see this if we try the following command:

```
ls -d .* | less
```

To better perform pathname expansion in this situation, we have to employ a more specific pattern.

```
echo .[!.]*
```

This pattern expands into every filename that begins with only one period followed by any other characters. This will work correctly with most hidden files (though it still won't include filenames with multiple leading periods). The `ls` command with the `-A` option ("almost all") will provide a correct listing of hidden files.

```
ls -A
```

## *Tilde Expansion*

As we may recall from our introduction to the `cd` command, the tilde character (~) has a special meaning. When used at the beginning of a word, it expands into the name of the home directory of the named user or, if no user is named, the home directory of the current user.

```
[me@linuxbox ~]$ echo ~
/home/me
```

If user "foo" has an account, then it expands into this:

```
[me@linuxbox ~]$ echo ~foo
/home/foo
```

### Arithmetic Expansion

The shell allows arithmetic to be performed by expansion. This allows us to use the shell prompt as a calculator.

```
[me@linuxbox ~]$ echo $((2 + 2))
4
```

Arithmetic expansion uses the following form:

```
$((expression))
```

where *expression* is an arithmetic expression consisting of values and arithmetic operators.

Arithmetic expansion supports only integers (whole numbers, no decimals) but can perform quite a number of different operations. Table 7-1 describes a few of the supported operators.

**Table 7-1:** Arithmetic Operators

| Operator | Description |
|---|---|
| + | Addition |
| - | Subtraction |
| * | Multiplication |
| / | Division (but remember, since expansion supports only integer arithmetic, results are integers) |
| % | Modulo, which simply means "remainder" |
| ** | Exponentiation |

Spaces are not significant in arithmetic expressions, and expressions may be nested. For example, to multiply 5 squared by 3, we can use this:

```
[me@linuxbox ~]$ echo $(($((5**2)) * 3))
75
```

Single parentheses may be used to group multiple subexpressions. With this technique, we can rewrite the previous example and get the same result using a single expansion instead of two.

```
[me@linuxbox ~]$ echo $(((5**2) * 3))
75
```

Here is an example using the division and remainder operators. Notice the effect of integer division.

```
[me@linuxbox ~]$ echo Five divided by two equals $((5/2))
Five divided by two equals 2
[me@linuxbox ~]$ echo with $((5%2)) left over.
with 1 left over.
```

Arithmetic expansion is covered in greater detail in Chapter 34.

### Brace Expansion

Perhaps the strangest expansion is called *brace expansion*. With it, you can create multiple text strings from a pattern containing braces. Here's an example:

```
[me@linuxbox ~]$ echo Front-{A,B,C}-Back
Front-A-Back Front-B-Back Front-C-Back
```

Patterns to be brace expanded may contain a leading portion called a *preamble* and a trailing portion called a *postscript*. The brace expression itself may contain either a comma-separated list of strings or a range of integers or single characters. The pattern may not contain unquoted whitespace. Here is an example using a range of integers:

```
[me@linuxbox ~]$ echo Number_{1..5}
Number_1 Number_2 Number_3 Number_4 Number_5
```

In bash version 4.0 and newer, integers may also be *zero-padded* like so:

```
[me@linuxbox ~]$ echo {01..15}
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
[me@linuxbox ~]$ echo {001..15}
001 002 003 004 005 006 007 008 009 010 011 012 013 014 015
```

Here is a range of letters in reverse order:

```
[me@linuxbox ~]$ echo {Z..A}
Z Y X W V U T S R Q P O N M L K J I H G F E D C B A
```

Brace expansions may be nested.

```
[me@linuxbox ~]$ echo a{A{1,2},B{3,4}}b
aA1b aA2b aB3b aB4b
```

So, what is this good for? The most common application is to make lists of files or directories to be created. For example, if we were

photographers and had a large collection of images that we wanted to organize into years and months, the first thing we might do is create a series of directories named in numeric "Year-Month" format. This way, the directory names would sort in chronological order. We could type out a complete list of directories, but that's a lot of work, and it's error-prone. Instead, we could do this:

```
[me@linuxbox ~]$ mkdir Photos
[me@linuxbox ~]$ cd Photos
[me@linuxbox Photos]$ mkdir {2007..2009}-{01..12}
[me@linuxbox Photos]$ ls
2007-01  2007-07  2008-01  2008-07  2009-01  2009-07
2007-02  2007-08  2008-02  2008-08  2009-02  2009-08
2007-03  2007-09  2008-03  2008-09  2009-03  2009-09
2007-04  2007-10  2008-04  2008-10  2009-04  2009-10
2007-05  2007-11  2008-05  2008-11  2009-05  2009-11
2007-06  2007-12  2008-06  2008-12  2009-06  2009-12
```

Pretty slick!

### Parameter Expansion

We're going to touch only briefly on parameter expansion in this chapter, but we'll be covering it extensively later. It's a feature that is more useful in shell scripts than directly on the command line. Many of its capabilities have to do with the system's ability to store small chunks of data and to give each chunk a name. Many such chunks, more properly called *variables*, are available for your examination. For example, the variable named `USER` contains your username. To invoke parameter expansion and reveal the contents of `USER`, you would do this:

```
[me@linuxbox ~]$ echo $USER
me
```

To see a list of available variables, try this:

```
[me@linuxbox ~]$ printenv | less
```

You may have noticed that with other types of expansion, if you mistype a pattern, the expansion will not take place, and the `echo` command will simply display the mistyped pattern. With parameter expansion, if you misspell the name of a variable, the expansion will still take place but will result in an empty string.

```
[me@linuxbox ~]$ echo $SUER

[me@linuxbox ~]$
```

### *Command Substitution*

Command substitution allows us to use the output of a command as an expansion.

```
[me@linuxbox ~]$ echo $(ls)
Desktop Documents ls-output.txt Music Pictures Public Templates Videos
```

One of my favorites goes something like this:

```
[me@linuxbox ~]$ ls -l $(which cp)
-rwxr-xr-x 1 root root 71516 2007-12-05 08:58 /bin/cp
```

Here we passed the results of `which cp` as an argument to the `ls` command, thereby getting the listing of the `cp` program without having to know its full pathname. We are not limited to just simple commands. Entire pipelines can be used (only partial output is shown here).

```
[me@linuxbox ~]$ file $(ls -d /usr/bin/* | grep zip)
/usr/bin/bunzip2:      symbolic link to `bzip2'
/usr/bin/bzip2:        ELF 32-bit LSB executable, Intel 80386, version 1
(SYSV), dynamically linked (uses shared libs), for GNU/Linux 2.6.9, stripped
/usr/bin/bzip2recover: ELF 32-bit LSB executable, Intel 80386, version 1
(SYSV), dynamically linked (uses shared libs), for GNU/Linux 2.6.9, stripped
/usr/bin/funzip:       ELF 32-bit LSB executable, Intel 80386, version 1
(SYSV), dynamically linked (uses shared libs), for GNU/Linux 2.6.9, stripped
/usr/bin/gpg-zip:      Bourne shell script text executable
/usr/bin/gunzip:       symbolic link to `../../bin/gunzip'
/usr/bin/gzip:         symbolic link to `../../bin/gzip'
/usr/bin/mzip:         symbolic link to `mtools'
```

In this example, the results of the pipeline became the argument list of the `file` command.

There is an alternate syntax for command substitution in older shell programs that is also supported in `bash`. It uses *backquotes* instead of the dollar sign and parentheses.

```
[me@linuxbox ~]$ ls -l `which cp`
-rwxr-xr-x 1 root root 71516 2007-12-05 08:58 /bin/cp
```

## Quoting

Now that we've seen how many ways the shell can perform expansions, it's time to learn how we can control it. Take, for example, the following:

```
[me@linuxbox ~]$ echo this is a     test
this is a test
```

or this one:

```
[me@linuxbox ~]$ echo The total is $100.00
The total is 00.00
```

In the first example, *word splitting* by the shell removed extra whitespace from the `echo` command's list of arguments. In the second example, parameter expansion substituted an empty string for the value of `$1` because it was an undefined variable. The shell provides a mechanism called *quoting* to selectively suppress unwanted expansions.

### Double Quotes

The first type of quoting we will look at is *double quotes*. If we place text inside double quotes, all the special characters used by the shell lose their special meaning and are treated as ordinary characters. The exceptions are `$` (dollar sign), `\` (backslash), and `` ` `` (backtick). This means that word splitting, pathname expansion, tilde expansion, and brace expansion are suppressed; however, parameter expansion, arithmetic expansion, and command substitution are still carried out. Using double quotes, we can cope with filenames containing embedded spaces. Say we were the unfortunate victim of a file called `two words.txt`. If we tried to use this on the command line, word splitting would cause this to be treated as two separate arguments rather than the desired single argument.

```
[me@linuxbox ~]$ ls -l two words.txt
ls: cannot access two: No such file or directory
ls: cannot access words.txt: No such file or directory
```

By using double quotes, we stop the word splitting and get the desired result; further, we can even repair the damage.

```
[me@linuxbox ~]$ ls -l "two words.txt"
-rw-rw-r-- 1 me   me   18 2018-02-20 13:03 two words.txt
[me@linuxbox ~]$ mv "two words.txt" two_words.txt
```

There! Now we don't have to keep typing those pesky double quotes.

Remember, parameter expansion, arithmetic expansion, and command substitution still take place within double quotes.

```
[me@linuxbox ~]$ echo "$USER $((2+2)) $(cal)"
me 4    February 2020
Su Mo Tu We Th Fr Sa
                   1
 2  3  4  5  6  7  8
 9 10 11 12 13 14 15
16 17 18 19 20 21 22
23 24 25 26 27 28 29
```

We should take a moment to look at the effect of double quotes on command substitution. First let's look a little deeper at how word splitting works. In our earlier example, we saw how word splitting appears to remove extra spaces in our text.

```
[me@linuxbox ~]$ echo this is a     test
this is a test
```

By default, word splitting looks for the presence of spaces, tabs, and newlines (line feed characters) and treats them as *delimiters* between words. This means unquoted spaces, tabs, and newlines are not considered to be part of the text. They serve only as separators. Because they separate the words into different arguments, our example command line contains a command followed by four distinct arguments. If we add double quotes:

```
[me@linuxbox ~]$ echo "this is a     test"
this is a     test
```

then word splitting is suppressed and the embedded spaces are not treated as delimiters; rather, they become part of the argument. Once the double quotes are added, our command line contains a command followed by a single argument.

The fact that newlines are considered delimiters by the word-splitting mechanism causes an interesting, albeit subtle, effect on command substitution. Consider the following:

```
[me@linuxbox ~]$ echo $(cal)
February 2020 Su Mo Tu We Th Fr Sa 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
18 19 20 21 22 23 24 25 26 27 28 29
[me@linuxbox ~]$ echo "$(cal)"
   February 2020
Su Mo Tu We Th Fr Sa
                   1
 2  3  4  5  6  7  8
 9 10 11 12 13 14 15
16 17 18 19 20 21 22
23 24 25 26 27 28 29
```

In the first instance, the unquoted command substitution resulted in a command line containing 38 arguments. In the second, it resulted in a command line with one argument that includes the embedded spaces and newlines.

## Single Quotes

If we need to suppress *all* expansions, we use *single quotes*. Here is a comparison of unquoted, double quotes, and single quotes:

```
[me@linuxbox ~]$ echo text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER
text /home/me/ls-output.txt a b foo 4 me
```

```
[me@linuxbox ~]$ echo "text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER"
text ~/*.txt {a,b} foo 4 me
[me@linuxbox ~]$ echo 'text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER'
text ~/*.txt {a,b} $(echo foo) $((2+2)) $USER
```

As we can see, with each succeeding level of quoting, more and more of the expansions are suppressed.

### Escaping Characters

Sometimes we want to quote only a single character. To do this, we can precede a character with a backslash, which in this context is called the *escape character*. Often this is done inside double quotes to selectively prevent an expansion.

```
[me@linuxbox ~]$ echo "The balance for user $USER is: \$5.00"
The balance for user me is: $5.00
```

It is also common to use escaping to eliminate the special meaning of a character in a filename. For example, it is possible to use characters in filenames that normally have special meaning to the shell. These would include `$`, `!`, `&`, spaces, and others. To include a special character in a filename, we can do this:

```
[me@linuxbox ~]$ mv bad\&filename good_filename
```

To allow a backslash character to appear, escape it by typing `\\`. Note that within single quotes, the backslash loses its special meaning and is treated as an ordinary character.

### Backslash Escape Sequences

In addition to its role as the escape character, the backslash is used as part of a notation to represent certain special characters called *control codes*. The first 32 characters in the ASCII coding scheme are used to transmit commands to Teletype-like devices. Some of these codes are familiar (tab, backspace, line feed, and carriage return), while others are not (null, end-of-transmission, and acknowledge).

Table 7-2 lists some of the common backslash escape sequences.

**Table 7-2:** Backslash Escape Sequences

| Escape sequence | Meaning |
|---|---|
| `\a` | Bell (an alert that causes the computer to beep) |
| `\b` | Backspace |
| `\n` | Newline; on Unix-like systems, this produces a line feed |
| `\r` | Carriage return |
| `\t` | Tab |

The idea behind this representation using the backslash originated in the C programming language and has been adopted by many others, including the shell.

Adding the `-e` option to `echo` will enable interpretation of escape sequences. You can also place them inside `$' '`. Here, using the `sleep` command, a simple program that just waits for the specified number of seconds and then exits, we can create a primitive countdown timer:

```
sleep 10; echo -e "Time's up\a"
```

We could also do this:

```
sleep 10; echo "Time's up" $'\a'
```

## Summing Up

As we move forward with using the shell, we will find that expansions and quoting will be used with increasing frequency, so it makes sense to get a good understanding of the way they work. In fact, it could be argued that they are the most important subjects to learn about the shell. Without a proper understanding of expansion, the shell will always be a source of mystery and confusion, with much of its potential power wasted.

# 8

# ADVANCED KEYBOARD TRICKS

I often kiddingly describe Unix as "the operating system for people who like to type." Of course, the fact that it even has a command line is a testament to that; however, command line users don't like to type *that* much. Why else would so many commands have such short names like `cp`, `ls`, `mv`, and `rm`? In fact, one of the most cherished goals of the command line is laziness—doing the most work with the fewest number of keystrokes. Another goal is never having to lift your fingers from the keyboard and reach for the mouse. In this chapter, we will look at `bash` features that make keyboard use faster and more efficient.

The following commands will make an appearance:

**`clear`** Clear the terminal screen

**`history`** Display or manipulate the history list

## Command Line Editing

bash uses a library (a shared collection of routines that different programs can use) called *Readline* to implement command line editing. We have already seen some of this. We know, for example, that the arrow keys move the cursor, but there are many more features. Think of these as additional tools that we can employ in our work. It's not important to learn all of them, but many of them are very useful. Pick and choose as desired.

**NOTE** *Some of the key sequences covered in this chapter (particularly those that use the* ALT *key) may be intercepted by the GUI for other functions. All of the key sequences should work properly when using a virtual console.*

### Cursor Movement

Table 8-1 describes the keys used to move the cursor.

**Table 8-1:** Cursor Movement Commands

| Key | Action |
|---|---|
| CTRL-A | Move cursor to the beginning of the line. |
| CTRL-E | Move cursor to the end of the line. |
| CTRL-F | Move cursor forward one character; same as the right arrow key. |
| CTRL-B | Move cursor backward one character; same as the left arrow key. |
| ALT-F | Move cursor forward one word. |
| ALT-B | Move cursor backward one word. |
| CTRL-L | Clear the screen and move the cursor to the top-left corner. The `clear` command does the same thing. |

### Modifying Text

Because it's possible we might make a mistake while composing commands, we need a way to correct them efficiently. Table 8-2 describes keyboard commands that are used to edit characters on the command line.

**Table 8-2:** Text Editing Commands

| Key | Action |
|---|---|
| CTRL-D | Delete the character at the cursor location. |
| CTRL-T | Transpose (exchange) the character at the cursor location with the one preceding it. |
| ALT-T | Transpose the word at the cursor location with the one preceding it. |
| ALT-L | Convert the characters from the cursor location to the end of the word to lowercase. |
| ALT-U | Convert the characters from the cursor location to the end of the word to uppercase. |

## *Cutting and Pasting (Killing and Yanking) Text*

The Readline documentation uses the terms *killing* and *yanking* to refer to what we would commonly call cutting and pasting (see Table 8-3). Items that are cut are stored in a buffer (a temporary storage area in memory) called the *kill-ring*.

**Table 8-3:** Cut-and-Paste Commands

| Key | Action |
|---|---|
| CTRL-K | Kill text from the cursor location to the end of line. |
| CTRL-U | Kill text from the cursor location to the beginning of the line. |
| ALT-D | Kill text from the cursor location to the end of the current word. |
| ALT-BACKSPACE | Kill text from the cursor location to the beginning of the current word. If the cursor is at the beginning of a word, kill the previous word. |
| CTRL-Y | Yank text from the kill-ring and insert it at the cursor location. |

**THE META KEY**

If you venture into the Readline documentation, which can be found in the "READLINE" section of the bash man page, you will encounter the term *meta key*. On modern keyboards, this maps to the ALT key; however, this wasn't always the case.

Back in the dim times (before PCs but after Unix), not everybody had their own computer. What they might have had was a device called a *terminal*. A terminal was a communication device that featured a text display screen and a keyboard and just enough electronics inside to display text characters and move the cursor around. It was attached (usually by serial cable) to a larger computer or the communication network of a larger computer. There were many different brands of terminals, and they all had different keyboards and display feature sets. Because they all tended to at least understand ASCII, software developers wanting portable applications wrote to the lowest common denominator. Unix systems have an elaborate way of dealing with terminals and their different display features. Because the developers of Readline could not be sure of the presence of a dedicated extra control key, they invented one and called it *meta*. While the ALT key serves as the meta key on modern keyboards, you can also press and release the ESC key to get the same effect as holding down the ALT key if you're still using a terminal (which you can still do in Linux!).

## Completion

Another way that the shell can help you is through a mechanism called *completion*. Completion occurs when you press the TAB key while typing a command. Let's see how this works. Given a home directory that looks like this:

```
[me@linuxbox ~]$ ls
Desktop    ls-output.txt  Pictures  Templates      Videos
Documents  Music          Public
```

try typing the following, but *don't press* ENTER:

```
[me@linuxbox ~]$ ls l
```

Now press TAB.

```
[me@linuxbox ~]$ ls ls-output.txt
```

See how the shell completed the line for you? Let's try another one. Again, don't press ENTER.

```
[me@linuxbox ~]$ ls D
```

Press TAB.

```
[me@linuxbox ~]$ ls D
```

No completion, just nothing. This happened because `D` matches more than one entry in the directory. For completion to be successful, the "clue" you give it has to be unambiguous. If we go further, as with the following:

```
[me@linuxbox ~]$ ls Do
```

and then press TAB:

```
[me@linuxbox ~]$ ls Documents
```

the completion is successful.

While this example shows completion of pathnames, which is its most common use, completion will also work on variables (if the beginning of the word is a `$`), usernames (if the word begins with `~`), commands (if the word is the first word on the line), and hostnames (if the beginning of the word is `@`). Hostname completion works only for hostnames listed in */etc/hosts*.

A number of control and meta key sequences are associated with completion, as listed in Table 8-4.

**Table 8-4:** Completion Commands

| Key | Action |
|---|---|
| ALT-? | Display a list of possible completions. On most systems, you can also do this by pressing the TAB key a second time, which is much easier. |
| ALT-* | Insert all possible completions. This is useful when you want to use more than one possible match. |

There are quite a few more that are rather obscure. A list appears in the bash man page under "READLINE."

**PROGRAMMABLE COMPLETION**

Recent versions of bash have a facility called *programmable completion*. Programmable completion allows you (or more likely, your distribution provider) to add more completion rules. Usually this is done to add support for specific applications. For example, it is possible to add completions for the option list of a command or match particular file types that an application supports. Ubuntu has a fairly large set defined by default. Programmable completion is implemented by shell functions, a kind of mini shell script that we will cover in later chapters. If you are curious, try the following:

```
set | less
```

Now see whether you can find them. Not all distributions include them by default.

## Using History

As we discovered in Chapter 1, bash maintains a history of commands that have been entered. This list of commands is kept in your home directory in a file called *bash_history*. The history facility is a useful resource for reducing the amount of typing you have to do, especially when combined with command line editing.

### *Searching History*

At any time, we can view the contents of the command history list by doing the following:

```
[me@linuxbox ~]$ history | less
```

By default, bash stores the last 500 commands we have entered, though most modern distributions set this value to 1,000. We will see how to adjust this value in Chapter 11. Let's say we want to find the commands we used to list */usr/bin*. This is one way we could do this:

```
[me@linuxbox ~]$ history | grep /usr/bin
```

And let's say that among our results we got a line containing an interesting command like this:

```
   88  ls -l /usr/bin > ls-output.txt
```

The 88 is the line number of the command in the history list. We could use this immediately using another type of expansion called *history expansion*. To use our discovered line, we could do this:

```
[me@linuxbox ~]$ !88
```

bash will expand !88 into the contents of the 88th line in the history list. There are other forms of history expansion that we will cover in the next section.

bash also provides the ability to search the history list incrementally. This means we can tell bash to search the history list as we enter characters, with each additional character further refining our search. To start incremental search, press CTRL-R followed by the text you are looking for. When you find it, you can either press ENTER to execute the command or press CTRL-J to copy the line from the history list to the current command line. To find the next occurrence of the text (moving "up" the history list), press CTRL-R again. To quit searching, press either CTRL-G or CTRL-C. Here we see it in action:

```
[me@linuxbox ~]$
```

First press CTRL-R.

```
(reverse-i-search)`':
```

The prompt changes to indicate that we are performing a reverse incremental search. It is "reverse" because we are searching from "now" to sometime in the past. Next, we start typing our search text. In this example, we're searching for */usr/bin*:

```
(reverse-i-search)`/usr/bin': ls -l /usr/bin > ls-output.txt
```

Immediately, the search returns our result. With our result, we can execute the command by pressing ENTER, or we can copy the command to our current command line for further editing by pressing CTRL-J. Let's copy it. Press CTRL-J.

```
[me@linuxbox ~]$ ls -l /usr/bin > ls-output.txt
```

Our shell prompt returns, and our command line is loaded and ready for action!

Table 8-5 lists some of the keystrokes used to manipulate the history list.

**Table 8-5:** History Commands

| Key | Action |
|---|---|
| CTRL-P | Move to the previous history entry. This is the same action as the up arrow. |
| CTRL-N | Move to the next history entry. This is the same action as the down arrow. |
| ALT-< | Move to the beginning (top) of the history list. |
| ALT-> | Move to the end (bottom) of the history list, i.e., the current command line. |
| CTRL-R | Reverse incremental search. This searches incrementally from the current command line up the history list. |
| ALT-P | Reverse search, nonincremental. With this key, type in the search string and press ENTER before the search is performed. |
| ALT-N | Forward search, nonincremental. |
| CTRL-O | Execute the current item in the history list and advance to the next one. This is handy if you are trying to re-execute a sequence of commands in the history list. |

## *History Expansion*

The shell offers a specialized type of expansion for items in the history list by using the ! character. We have already seen how the exclamation point can be followed by a number to insert an entry from the history list. There are a number of other expansion features, as described in Table 8-6.

**Table 8-6:** History Expansion Commands

| Sequence | Action |
|---|---|
| `!!` | Repeat the last command. It is probably easier to press the up arrow and ENTER. |
| `!`*`number`* | Repeat history list item *`number`*. |
| `!`*`string`* | Repeat last history list item starting with *`string`*. |
| `!?`*`string`* | Repeat last history list item containing *`string`*. |

I caution against using the `!`*`string`* and `!?`*`string`* forms unless you are absolutely sure of the contents of the history list items.

Many more elements are available in the history expansion mechanism, but this subject is already too arcane, and our heads may explode if we continue. The "HISTORY EXPANSION" section of the bash man page goes into all the gory details. Feel free to explore!

**SCRIPT**

In addition to the command history feature in `bash`, most Linux distributions include a program called `script` that can be used to record an entire shell session and store it in a file. The basic syntax of the command is as follows:

---

**`script`** *`file`*

---

where *`file`* is the name of the file used for storing the recording. If no file is specified, the file `typescript` is used. See the `script` man page for a complete list of the program's options and features.

## Summing Up

In this chapter, we covered *some* of the keyboard tricks that the shell provides to help hardcore typists reduce their workloads. As time goes by and we become more involved with the command line, we can refer back to this chapter to pick up more of these tricks. For now, consider them optional and potentially helpful.

# 9

# PERMISSIONS

Operating systems in the Unix tradition differ from those in the MS-DOS tradition in that they are not only multitasking systems but also multiuser systems.

What exactly does this mean? It means that more than one person can be using the computer at the same time. While a typical computer will likely have only one keyboard and monitor, it can still be used by more than one user. For example, if a computer is attached to a network or the Internet, remote users can log in via `ssh` (secure shell) and operate the computer. In fact, remote users can execute graphical applications and have the graphical output appear on a remote display. The X Window System supports this as part of its basic design.

The multiuser capability of Linux is not a recent "innovation" but rather a feature that is deeply embedded into the design of the operating system. Considering the environment in which Unix was created, this makes perfect sense. Years ago, before computers were "personal," they were large, expensive, and centralized. A typical university computer system, for example,

consisted of a large central computer located in one building and terminals that were located throughout the campus, each connected to the large central computer. The computer would support many users at the same time.

To make this practical, a method had to be devised to protect the users from each other. After all, the actions of one user could not be allowed to crash the computer, nor could one user interfere with the files belonging to another user.

In this chapter, we will look at this essential part of system security and introduce the following commands:

**id** Display user identity

**chmod** Change a file's mode

**umask** Set the default file permissions

**su** Run a shell as another user

**sudo** Execute a command as another user

**chown** Change a file's owner

**chgrp** Change a file's group ownership

**passwd** Change a user's password

## Owners, Group Members, and Everybody Else

When we were exploring the system in Chapter 3, we may have encountered a problem when trying to examine a file such as */etc/shadow*.

```
[me@linuxbox ~]$ file /etc/shadow
/etc/shadow: regular file, no read permission
[me@linuxbox ~]$ less /etc/shadow
/etc/shadow: Permission denied
```

The reason for this error message is that, as regular users, we do not have permission to read this file.

In the Unix security model, a user may *own* files and directories. When a user owns a file or directory, the user has control over its access. Users can, in turn, belong to a *group* consisting of one or more users who are given access to files and directories by their owners. In addition to granting access to a group, an owner may also grant some set of access rights to everybody, which in Unix terms is referred to as the *world*. To find out information about your identity, use the `id` command.

```
[me@linuxbox ~]$ id
uid=500(me) gid=500(me) groups=500(me)
```

Let's look at the output. When user accounts are created, users are assigned a number called a *user ID* (*uid*), which is then, for the sake of the

humans, mapped to a username. The user is assigned a *group ID* (*gid*) and may belong to additional groups. The preceding example is from a Fedora system. On other systems, such as Ubuntu, the output may look a little different.

```
[me@linuxbox ~]$ id
uid=1000(me) gid=1000(me) groups=4(adm),20(dialout),24(cdrom),25(floppy),
29(audio),30(dip),44(video),46(plugdev),108(lpadmin),114(admin),1000(me)
```

As we can see, the uid and gid numbers are different in Ubuntu. This is simply because Fedora starts its numbering of regular user accounts at 500, while Ubuntu starts at 1,000. We can also see that the Ubuntu user belongs to a lot more groups. This has to do with the way Ubuntu manages privileges for system devices and services.

So, where does this information come from? Like so many things in Linux, it comes from a couple of text files. User accounts are defined in the */etc/passwd* file, and groups are defined in the */etc/group* file. When user accounts and groups are created, these files are modified along with *etc/shadow*, which holds information about the user's password. For each user account, the */etc/passwd* file defines the user (login) name, uid, gid, account's real name, home directory, and login shell. If we examine the contents of */etc/passwd* and */etc/group*, we notice that besides the regular user accounts, there are accounts for the superuser (uid 0) and various other system users.

In the next chapter, when we cover processes, we will see that some of these other "users" are, in fact, quite busy.

While many Unix-like systems assign regular users to a common group such as `users`, modern Linux practice is to create a unique, single-member group with the same name as the user. This makes certain types of permission assignment easier.

## Reading, Writing, and Executing

Access rights to files and directories are defined in terms of read access, write access, and execution access. If we look at the output of the `ls` command, we can get some clue as to how this is implemented.

```
[me@linuxbox ~]$ > foo.txt
[me@linuxbox ~]$ ls -l foo.txt
-rw-rw-r-- 1 me    me   0 2018-03-06 14:52 foo.txt
```

The first 10 characters of the listing are the *file attributes*. The first of these characters is the *file type*. Table 9-1 describes the file types you are most likely to see (there are other, less common types too).

**Table 9-1:** File Types

| Attribute | File type |
|---|---|
| `-` | A regular file. |
| `d` | A directory. |
| `l` | A symbolic link. Notice that with symbolic links, the remaining file attributes are always `rwxrwxrwx` and are dummy values. The real file attributes are those of the file the symbolic link points to. |
| `c` | A *character special file*. This file type refers to a device that handles data as a stream of bytes, such as a terminal or /dev/null. |
| `b` | A *block special file*. This file type refers to a device that handles data in blocks, such as a hard drive or DVD drive. |

The remaining nine characters of the file attributes, called the *file mode*, represent the read, write, and execute permissions for the file's owner, the file's group owner, and everybody else.

| Owner | Group | World |
|---|---|---|
| `rwx` | `rwx` | `rwx` |

Table 9-2 documents the effect that `r`, `w`, and `x` mode attributes have when set on files and directories.

**Table 9-2:** Permission Attributes

| Attribute | Files | Directories |
|---|---|---|
| `r` | Allows a file to be opened and read. | Allows a directory's contents to be listed if the execute attribute is also set. |
| `w` | Allows a file to be written to or truncated; however, this attribute does not allow files to be renamed or deleted. The ability to delete or rename files is determined by directory attributes. | Allows files within a directory to be created, deleted, and renamed if the execute attribute is also set. |
| `x` | Allows a file to be treated as a program and executed. Program files written in scripting languages must also be set as readable to be executed. | Allows a directory to be entered, e.g., `cd` *`directory`*. |

Table 9-3 provides some examples of file attribute settings.

**Table 9-3:** Permission Attribute Examples

| File Attributes | Meaning |
|---|---|
| `-rwx------` | A regular file that is readable, writable, and executable by the file's owner. No one else has any access. |
| `-rw-------` | A regular file that is readable and writable by the file's owner. No one else has any access. |
| `-rw-r--r--` | A regular file that is readable and writable by the file's owner. Members of the file's owner group may read the file. The file is world-readable. |
| `-rwxr-xr-x` | A regular file that is readable, writable, and executable by the file's owner. The file may be read and executed by everybody else. |
| `-rw-rw----` | A regular file that is readable and writable by the file's owner and members of the file's group owner only. |
| `lrwxrwxrwx` | A symbolic link. All symbolic links have "dummy" permissions. The real permissions are kept with the actual file pointed to by the symbolic link. |
| `drwxrwx---` | A directory. The owner and the members of the owner group may enter the directory and create, rename, and remove files within the directory. |
| `drwxr-x---` | A directory. The owner may enter the directory and create, rename, and delete files within the directory. Members of the owner group may enter the directory but cannot create, delete, or rename files. |

## *chmod: Change File Mode*

To change the mode (permissions) of a file or directory, use the `chmod` command. Be aware that only the file's owner or the superuser can change the mode of a file or directory. `chmod` supports two distinct ways of specifying mode changes.

- Octal number representation
- Symbolic representation

We will cover octal number representation first. With octal notation, we use octal numbers to set the pattern of desired permissions. Because each digit in an octal number represents three binary digits, this maps nicely to the scheme used to store the file mode. Table 9-4 shows what we mean.

### WHAT THE HECK IS OCTAL?

*Octal* (base 8) and its cousin, *hexadecimal* (base 16), are number systems often used to express numbers on computers. We humans, owing to the fact that we (or at least most of us) were born with 10 fingers, count using a base 10 number system. Computers, on the other hand, were born with only one finger and thus do all their counting in *binary* (base 2). Their number system has only two numerals, 0 and 1. So, in binary, counting looks like this:

0, 1, 10, 11, 100, 101, 110, 111, 1000, 1001, 1010, 1011. . .

In octal, counting is done with the numerals zero through seven, like so:

0, 1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21. . .

Hexadecimal counting uses the numerals zero through nine plus the letters *A* through *F*.

0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, 10, 11, 12, 13. . .

While we can see the sense in binary (since computers have only one finger), what are octal and hexadecimal good for? The answer has to do with human convenience. Many times, small portions of data are represented on computers as *bit patterns*. Take, for example, an RGB color. On most computer displays, each pixel is composed of three color components: eight bits of red, eight bits of green, and eight bits of blue. A lovely medium blue would be a 24-digit number.

010000110110111111001101

How would you like to read and write those kinds of numbers all day? I didn't think so. Here's where another number system would help. Each digit in a hexadecimal number represents four digits in binary. In octal, each digit represents three binary digits. So, our 24-digit medium blue could be condensed to a six-digit hexadecimal number, 436FCD.

Because the digits in the hexadecimal number "line up" with the bits in the binary number, we can see that the red component of our color is 43, the green 6F, and the blue CD.

These days, hexadecimal notation (often spoken as *hex*) is more common than octal, but as we will soon see, octal's capability to express three bits of binary will be very useful . . .

**Table 9-4:** File Modes in Binary and Octal

| Octal | Binary | File mode |
|---|---|---|
| 0 | 000 | `---` |
| 1 | 001 | `--x` |
| 2 | 010 | `-w-` |
| 3 | 011 | `-wx` |
| 4 | 100 | `r--` |
| 5 | 101 | `r-x` |
| 6 | 110 | `rw-` |
| 7 | 111 | `rwx` |

By using three octal digits, we can set the file mode for the owner, group owner, and world.

```
[me@linuxbox ~]$ > foo.txt
[me@linuxbox ~]$ ls -l foo.txt
-rw-rw-r-- 1 me    me   0 2018-03-06 14:52 foo.txt
[me@linuxbox ~]$ chmod 600 foo.txt
[me@linuxbox ~]$ ls -l foo.txt
-rw------- 1 me    me   0 2018-03-06 14:52 foo.txt
```

By passing the argument `600`, we were able to set the permissions of the owner to read and write while removing all permissions from the group owner and world. Though remembering the octal to binary mapping may seem inconvenient, you will usually have to use only a few common ones: 7 (`rwx`), 6 (`rw-`), 5 (`r-x`), 4 (`r--`), and 0 (`---`).

`chmod` also supports a symbolic notation for specifying file modes. Symbolic notation is divided into three parts.

- Who the change will affect
- Which operation will be performed
- What permission will be set

To specify who is affected, a combination of the characters `u`, `g`, `o`, and `a` is used, as shown in Table 9-5.

**Table 9-5:** `chmod` Symbolic Notation

| Symbol | Meaning |
|---|---|
| u | Short for "user" but means the file or directory owner. |
| g | Group owner. |
| o | Short for "others" but means world. |
| a | Short for "all." This is a combination of u, g, and o. |

If no character is specified, "all" will be assumed. The operation may be a + indicating that a permission is to be added, a - indicating that a permission is to be taken away, or a = indicating that only the specified permissions are to be applied and that all others are to be removed.

Permissions are specified with the `r`, `w`, and `x` characters. Table 9-6 provides some examples of symbolic notation.

**Table 9-6:** `chmod` Symbolic Notation Examples

| Notation | Meaning |
|---|---|
| `u+x` | Add execute permission for the owner. |
| `u-x` | Remove execute permission from the owner. |
| `+x` | Add execute permission for the owner, group, and world. This is equivalent to `a+x`. |
| `o-rw` | Remove the read and write permissions from anyone besides the owner and group owner. |
| `go=rw` | Set the group owner and anyone besides the owner to have read and write permissions. If either the group owner or the world previously had execute permission, it is removed. |
| `u+x,go=rx` | Add execute permission for the owner and set the permissions for the group and others to read and execute. Multiple specifications may be separated by commas. |

Some people prefer to use octal notation, and some folks really like the symbolic. Symbolic notation does offer the advantage of allowing you to set a single attribute without disturbing any of the others.

Take a look at the `chmod` man page for more details and a list of options. A word of caution regarding the `--recursive` option: it acts on both files and directories, so it's not as useful as we would hope because we rarely want files and directories to have the same permissions.

### *Setting File Mode with the GUI*

Now that we have seen how the permissions on files and directories are set, we can better understand the permission dialogs in the GUI. In both Files (GNOME) and Dolphin (KDE), right-clicking a file or directory icon will expose a properties dialog. Figure 9-1 provides an example from GNOME. Here we can see the settings for the owner, group, and world.

*Figure 9-1: GNOME file permissions dialog*

## umask: Set Default Permissions

The `umask` command controls the default permissions given to a file when it is created. It uses octal notation to express a *mask* of bits to be removed from a file's mode attributes. Let's take a look.

```
[me@linuxbox ~]$ rm -f foo.txt
[me@linuxbox ~]$ umask
0002
[me@linuxbox ~]$ > foo.txt
[me@linuxbox ~]$ ls -l foo.txt
-rw-rw-r-- 1 me    me   0 2018-03-06 14:53 foo.txt
```

We first removed any old copy of *foo.txt* to make sure we were starting fresh. Next, we ran the `umask` command without an argument to see the current value. It responded with the value `0002` (the value `0022` is another common default value), which is the octal representation of our mask. We next create a new instance of the file *foo.txt* and observe its permissions.

We can see that both the owner and group get read and write permission, while everyone else gets only read permission. The reason that world does not have write permission is because of the value of the mask. Let's repeat our example, this time setting the mask ourselves.

```
[me@linuxbox ~]$ rm foo.txt
[me@linuxbox ~]$ umask 0000
[me@linuxbox ~]$ > foo.txt
[me@linuxbox ~]$ ls -l foo.txt
-rw-rw-rw- 1 me    me   0 2018-03-06 14:58 foo.txt
```

When we set the mask to 0000 (effectively turning it off), we see that the file is now world writable. To understand how this works, we have to look at octal numbers again. If we take the mask, expand it into binary, and then compare it to the attributes, we can see what happens.

| | |
|---|---|
| Original file mode | --- rw- rw- rw- |
| Mask | 000 000 000 010 |
| Result | --- rw- rw- r-- |

Ignore for the moment the leading zeros (we'll get to those in a minute) and observe that where the 1 appears in our mask, an attribute was removed—in this case, the world write permission. That's what the mask does. Everywhere a 1 appears in the binary value of the mask, an attribute is unset. If we look at a mask value of 0022, we can see what it does.

| | |
|---|---|
| Original file mode | --- rw- rw- rw- |
| Mask | 000 000 010 010 |
| Result | --- rw- r-- r-- |

Again, where a 1 appears in the binary value, the corresponding attribute is unset. Play with some values (try some sevens) to get used to how this works. When you're done, remember to clean up.

```
[me@linuxbox ~]$ rm foo.txt; umask 0002
```

Most of the time we won't have to change the mask; the default provided by your distribution will be fine. In some high-security situations, however, we will want to control it.

## Some Special Permissions

Though we usually see an octal permission mask expressed as a three-digit number, it is more technically correct to express it in four digits. Why? Because, in addition to read, write, and execute permissions, there are some other, less used, permissions settings.

The first of these is the *setuid bit* (octal 4000). When applied to an executable file, it changes the *effective user ID* from that of the real user (the user actually running the program) to that of the program's owner. Most often this is given to a few programs owned by the superuser. When an ordinary user runs a program that is *setuid root*, the program runs with the effective privileges of the superuser. This allows the program to access files and directories that an ordinary user would normally be prohibited from accessing. Clearly, because this raises security concerns, the number of setuid programs must be held to an absolute minimum.

The second less-used setting is the *setgid bit* (octal 2000), which, like the setuid bit, changes the *effective group ID* from the *real group ID* of the real user to that of the file owner. If the setgid bit is set on a directory, newly created files in the directory will be given the group ownership of the directory rather the group ownership of the file's creator. This is useful in a shared directory when members of a common group need access to all the files in the directory, regardless of the file owner's primary group.

The third is called the *sticky bit* (octal 1000). This is a holdover from ancient Unix, where it was possible to mark an executable file as "not swappable." On files, Linux ignores the sticky bit, but if applied to a directory, it prevents users from deleting or renaming files unless the user is either the owner of the directory, the owner of the file, or the superuser. This is often used to control access to a shared directory, such as */tmp*.

Here are some examples of using `chmod` with symbolic notation to set these special permissions. First, here's an example of assigning setuid to a program:

```
chmod u+s program
```

Next, here's an example of assigning setgid to a directory:

```
chmod g+s dir
```

Finally, here's an example of assigning the sticky bit to a directory:

```
chmod +t dir
```

When viewing the output from `ls`, you can determine the special permissions. Here are some examples. First, an example of a program that is setuid:

```
-rwsr-xr-x
```

Here's an example of a directory that has the setgid attribute:

```
drwxrwsr-x
```

Here's an example of a directory with the sticky bit set:

```
drwxrwxrwt
```

## Changing Identities

At various times, we may find it necessary to take on the identity of another user. Often, we want to gain superuser privileges to carry out some administrative task, but it is also possible to "become" another

regular user for such things as testing an account. There are three ways to take on an alternate identity.

1. Log out and log back in as the alternate user.
2. Use the `su` command.
3. Use the `sudo` command.

We will skip the first technique because we know how to do it and it lacks the convenience of the other two. From within our own shell session, the `su` command allows you to assume the identity of another user and either start a new shell session with that user's ID or issue a single command as that user. The `sudo` command allows an administrator to set up a configuration file called */etc/sudoers* and define specific commands that particular users are permitted to execute under an assumed identity. The choice of which command to use is largely determined by which Linux distribution you use. Your distribution probably includes both commands, but its configuration will favor either one or the other. We'll start with `su`.

### su: Run a Shell with Substitute User and Group IDs

The `su` command is used to start a shell as another user. The command syntax looks like this:

```
su [-[l]] [user]
```

If the `-l` option is included, the resulting shell session is a *login shell* for the specified user. This means the user's environment is loaded and the working directory is changed to the user's home directory. This is usually what we want. If the user is not specified, the superuser is assumed. Notice that (strangely) the `-l` may be abbreviated as `-`, which is how it is most often used. To start a shell for the superuser, we would do this:

```
[me@linuxbox ~]$ su -
Password:
[root@linuxbox ~]#
```

After entering the command, we are prompted for the superuser's password. If it is successfully entered, a new shell prompt appears indicating that this shell has superuser privileges (the trailing `#` rather than a `$`), and the current working directory is now the home directory for the superuser (normally */root*). Once in the new shell, we can carry out commands as the superuser. When finished, enter **`exit`** to return to the previous shell.

```
[root@linuxbox ~]# exit
[me@linuxbox ~]$
```

It is also possible to execute a single command rather than starting a new interactive command by using su this way.

```
su -c 'command'
```

Using this form, a single command line is passed to the new shell for execution. It is important to enclose the command in quotes, as we do not want expansion to occur in our shell but rather in the new shell.

```
[me@linuxbox ~]$ su -c 'ls -l /root/*'
Password:
-rw------- 1 root root     754 2007-08-11 03:19 /root/anaconda-ks.cfg

/root/Mail:
total 0
[me@linuxbox ~]$
```

### sudo: Execute a Command As Another User

The sudo command is like su in many ways but has some important additional capabilities. The administrator can configure sudo to allow an ordinary user to execute commands as a different user (usually the superuser) in a controlled way. In particular, a user may be restricted to one or more specific commands and no others. Another important difference is that the use of sudo does not require access to the superuser's password. Authenticating using sudo requires the user's own password. Let's say, for example, that sudo has been configured to allow us to run a fictitious backup program called backup_script, which requires superuser privileges. With sudo it would be done like this:

```
[me@linuxbox ~]$ sudo backup_script
Password:
System Backup Starting...
```

After entering the command, we are prompted for our password (not the superuser's), and once the authentication is complete, the specified command is carried out. One important difference between su and sudo is that sudo does not start a new shell, nor does it load another user's environment. This means that commands do not need to be quoted any differently than they would be without using sudo. Note that this behavior can be overridden by specifying various options. Note, too, that sudo can be used to start an interactive superuser session (much like su -) by specifying the -i option. See the sudo man page for details.

To see what privileges are granted by sudo, use the -l option to list them.

```
[me@linuxbox ~]$ sudo -l
User me may run the following commands on this host:
    (ALL) ALL
```

**UBUNTU AND SUDO**

One of the recurrent problems for regular users is how to perform certain tasks that require superuser privileges. These tasks include installing and updating software, editing system configuration files, and accessing devices. In the Windows world, this is often done by giving users administrative privileges. This allows users to perform these tasks. However, it also enables programs executed by the user to have the same capabilities. This is desirable in most cases, but it also permits *malware* (malicious software) such as viruses to have free rein of the computer.

In the Unix world, there has always been a larger division between regular users and administrators, owing to the multiuser heritage of Unix. The approach taken in Unix is to grant superuser privileges only when needed. To do this, the su and sudo commands are commonly used.

Up until a few of years ago, most Linux distributions relied on su for this purpose. su didn't require the configuration that sudo required, and having a root account is traditional in Unix. This introduced a problem. Users were tempted to operate as root unnecessarily. In fact, some users operated their systems as the root user exclusively since it does away with all those annoying "permission denied" messages. This is how you reduce the security of a Linux system to that of a Windows system. Not a good idea.

When Ubuntu was introduced, its creators took a different tack. By default, Ubuntu disables logins to the root account (by failing to set a password for the account) and instead uses sudo to grant superuser privileges. The initial user account is granted full access to superuser privileges via sudo and may grant similar powers to subsequent user accounts.

## *chown: Change File Owner and Group*

The chown command is used to change the owner and group owner of a file or directory. Superuser privileges are required to use this command. The syntax of chown looks like this:

```
chown [owner][:[group]] file...
```

chown can change the file owner and/or the file group owner depending on the first argument of the command. Table 9-7 provides some examples.

**Table 9-7:** chown Argument Examples

| Argument | Results |
|---|---|
| bob | Changes the ownership of the file from its current owner to user bob. |
| bob:users | Changes the ownership of the file from its current owner to user bob and changes the file group owner to group users. |

| Argument | Results |
|---|---|
| :admins | Changes the group owner to the group admins. The file owner is unchanged. |
| bob: | Changes the file owner from the current owner to user bob and changes the group owner to the login group of user bob. |

Let's say we have two users: janet, who has access to superuser privileges, and tony, who does not. User janet wants to copy a file from her home directory to the home directory of tony. Because janet wants tony to be able to edit the file, janet changes the ownership of the copied file from janet to tony.

```
[janet@linuxbox ~]$ sudo cp myfile.txt ~tony
Password:
[janet@linuxbox ~]$ sudo ls -l ~tony/myfile.txt
 -rw-r--r-- 1 root  root  root 2018-03-20 14:30 /home/tony/myfile.txt
[janet@linuxbox ~]$ sudo chown tony: ~tony/myfile.txt
[janet@linuxbox ~]$ sudo ls -l ~tony/myfile.txt
 -rw-r--r-- 1 tony  tony  tony 2018-03-20 14:30 /home/tony/myfile.txt
```

Here we see user janet copy the file from her directory to the home directory of user tony. Next, janet changes the ownership of the file from root (a result of using sudo) to tony. Using the trailing colon in the first argument, janet also changed the group ownership of the file to the login group of tony, which happens to be group tony.

Notice that after the first use of sudo, janet was not prompted for her password. This is because sudo, in most configurations, "trusts" you for several minutes until its timer runs out.

### *chgrp: Change Group Ownership*

In older versions of Unix, the chown command changed only file ownership, not group ownership. For that purpose, a separate command, chgrp, was used. It works much the same way as chown, except for being more limited.

## Exercising Our Privileges

Now that we have learned how this permissions thing works, it's time to show it off. We are going to demonstrate the solution to a common problem—setting up a shared directory. Let's imagine that we have two users named bill and karen. They both have music collections and want to set up a shared directory, where they will each store their music files as Ogg Vorbis or MP3. User bill has access to superuser privileges via sudo.

The first thing that needs to happen is a group needs to be created that will have both bill and karen as members. Using the graphical user management tool, bill creates a group called music and adds the users bill and karen to it, as shown in Figure 9-2.

*Figure 9-2: Creating a new group*

Next, `bill` creates the directory for the music files.

```
[bill@linuxbox ~]$ sudo mkdir /usr/local/share/Music
Password:
```

Because `bill` is manipulating files outside his home directory, superuser privileges are required. After the directory is created, it has the following ownerships and permissions:

```
[bill@linuxbox ~]$ ls -ld /usr/local/share/Music
drwxr-xr-x 2 root root 4096 2018-03-21 18:05 /usr/local/share/Music
```

As we can see, the directory is owned by `root` and has permission mode 755. To make this directory sharable, `bill` needs to change the group ownership and the group permissions to allow writing.

```
[bill@linuxbox ~]$ sudo chown :music /usr/local/share/Music
[bill@linuxbox ~]$ sudo chmod 775 /usr/local/share/Music
[bill@linuxbox ~]$ ls -ld /usr/local/share/Music
drwxrwxr-x 2 root music 4096 2018-03-21 18:05 /usr/local/share/Music
```

What does this all mean? It means that we now have a directory, */usr/local/share/Music*, that is owned by `root` and allows read and write access to group `music`. Group `music` has members `bill` and `karen`; thus, `bill` and `karen` can create files in directory */usr/local/share/Music*. Other users can list the contents of the directory but cannot create files there.

But we still have a problem. With the current permissions, files and directories created within the *Music* directory will have the normal permissions of the users `bill` and `karen`.

```
[bill@linuxbox ~]$ > /usr/local/share/Music/test_file
[bill@linuxbox ~]$ ls -l /usr/local/share/Music
-rw-r--r-- 1 bill   bill   0 2018-03-24 20:03 test_file
```

Actually there are two problems. First, the default `umask` on this system is 0022, which prevents group members from writing files belonging to other members of the group. This would not be a problem if the shared directory

contained only files, but because this directory will store music, and music is usually organized in a hierarchy of artists and albums, members of the group will need the ability to create files and directories inside directories created by other members. We need to change the `umask` used by `bill` and `karen` to 0002 instead.

Second, each file and directory created by one member will be set to the primary group of the user rather than the group `music`. This can be fixed by setting the setgid bit on the directory.

```
[bill@linuxbox ~]$ sudo chmod g+s /usr/local/share/Music
[bill@linuxbox ~]$ ls -ld /usr/local/share/Music
drwxrwsr-x 2 root music 4096 2018-03-24 20:03 /usr/local/share/Music
```

Now we test to see whether the new permissions fix the problem. `bill` sets his `umask` to 0002, removes the previous test file, and creates a new test file and directory.

```
[bill@linuxbox ~]$ umask 0002
[bill@linuxbox ~]$ rm /usr/local/share/Music/test_file
[bill@linuxbox ~]$ > /usr/local/share/Music/test_file
[bill@linuxbox ~]$ mkdir /usr/local/share/Music/test_dir
[bill@linuxbox ~]$ ls -l /usr/local/share/Music
drwxrwsr-x 2 bill   music 4096 2018-03-24 20:24 test_dir
-rw-rw-r-- 1 bill   music    0 2018-03-24 20:22 test_file
[bill@linuxbox ~]$
```

Both files and directories are now created with the correct permissions to allow all members of the group `music` to create files and directories inside the *Music* directory.

The one remaining issue is `umask`. The necessary setting lasts only until the end of session and must be reset. We'll look at making the change to `umask` permanent in Chapter 11.

## Changing Your Password

The last topic we'll cover in this chapter is setting passwords for yourself (and for other users if you have access to superuser privileges). To set or change a password, use the `passwd` command. The command syntax looks like this:

```
passwd [user]
```

To change your password, just enter the `passwd` command. You will be prompted for your old password and your new password.

```
[me@linuxbox ~]$ passwd
(current) UNIX password:
New UNIX password:
```

The passwd command will try to enforce use of "strong" passwords. This means it will refuse to accept passwords that are too short, are too similar to previous passwords, are dictionary words, or are too easily guessed.

```
[me@linuxbox ~]$ passwd
(current) UNIX password:
New UNIX password:
BAD PASSWORD: is too similar to the old one
New UNIX password:
BAD PASSWORD: it is WAY too short
New UNIX password:
BAD PASSWORD: it is based on a dictionary word
```

If you have superuser privileges, you can specify a username as an argument to the passwd command to set the password for another user. Other options are available to the superuser to allow account locking, password expiration, and so on. See the passwd man page for details.

## Summing Up

In this chapter, we saw how Unix-like systems such as Linux manage user permissions to allow the read, write, and execution access to files and directories. The basic ideas of this system of permissions date back to the early days of Unix and have stood up pretty well to the test of time. But the native permissions mechanism in Unix-like systems lacks the fine granularity of more modern systems.

# 10

# PROCESSES

Modern operating systems are usually *multitasking*, meaning they create the illusion of doing more than one thing at once by rapidly switching from one executing program to another. The kernel manages this through the use of *processes*. Processes are how Linux organizes the different programs waiting for their turn at the CPU.

Sometimes a computer will become sluggish or an application will stop responding. In this chapter, we will look at some of the tools available at the command line that let us examine what programs are doing and how to terminate processes that are misbehaving.

This chapter will introduce the following commands:

- **`ps`** Report a snapshot of current processes
- **`top`** Display tasks
- **`jobs`** List active jobs
- **`bg`** Place a job in the background

**fg** Place a job in the foreground

**kill** Send a signal to a process

**killall** Kill processes by name

**shutdown** Shut down or reboot the system

## How a Process Works

When a system starts up, the kernel initiates a few of its own activities as processes and launches a program called `init`. `init`, in turn, runs a series of shell scripts (located in */etc*) called *init scripts*, which start all the system services. Many of these services are implemented as *daemon programs*, programs that just sit in the background and do their thing without having any user interface. So, even if we are not logged in, the system is at least a little busy performing routine stuff.

The fact that a program can launch other programs is expressed in the process scheme as a *parent process* producing a *child process*.

The kernel maintains information about each process to help keep things organized. For example, each process is assigned a number called a *process ID* (*PID*). PIDs are assigned in ascending order, with `init` always getting PID 1. The kernel also keeps track of the memory assigned to each process, as well as the processes' readiness to resume execution. Like files, processes also have owners and user IDs, effective user IDs, and so on.

## Viewing Processes

The most commonly used command to view processes (there are several) is `ps`. The `ps` program has a lot of options, but in its simplest form it is used like this:

```
[me@linuxbox ~]$ ps
  PID TTY          TIME CMD
 5198 pts/1    00:00:00 bash
10129 pts/1    00:00:00 ps
```

The result in this example lists two processes, process 5198 and process 10129, which are `bash` and `ps`, respectively. As we can see, by default, `ps` doesn't show us very much, just the processes associated with the current terminal session. To see more, we need to add some options; however, before we do that, let's look at the other fields produced by `ps`. TTY is short for "teletype" and refers to the *controlling terminal* for the process. Unix is showing its age here. The `TIME` field is the amount of CPU time consumed by the process. As we can see, neither process makes the computer work very hard.

If we add an option, we can get a bigger picture of what the system is doing.

```
[me@linuxbox ~]$ ps x
  PID TTY      STAT   TIME COMMAND
```

```
 2799 ?        Ssl    0:00 /usr/libexec/bonobo-activation-server -ac
 2820 ?        Sl     0:01 /usr/libexec/evolution-data-server-1.10 --
15647 ?        Ss     0:00 /bin/sh /usr/bin/startkde
15751 ?        Ss     0:00 /usr/bin/ssh-agent /usr/bin/dbus-launch --
15754 ?        S      0:00 /usr/bin/dbus-launch --exit-with-session
15755 ?        Ss     0:01 /bin/dbus-daemon --fork --print-pid 4 -pr
15774 ?        Ss     0:02 /usr/bin/gpg-agent -s -daemon
15793 ?        S      0:00 start_kdeinit --new-startup +kcminit_start
15794 ?        Ss     0:00 kdeinit Running...
15797 ?        S      0:00 dcopserver -nosid
--snip--
```

Adding the `x` option (note that there is no leading dash) tells `ps` to show all of our processes regardless of what terminal (if any) they are controlled by. The presence of a `?` in the `TTY` column indicates no controlling terminal. Using this option, we see a list of every process that we own.

Because the system is running a lot of processes, `ps` produces a long list. It is often helpful to pipe the output from `ps` into `less` for easier viewing. Some option combinations also produce long lines of output, so maximizing the terminal emulator window might be a good idea, too.

A new column titled `STAT` has been added to the output. `STAT` is short for *state* and reveals the current status of the process, as shown in Table 10-1.

**Table 10-1:** Process States

| State | Meaning |
|---|---|
| `R` | Running. This means the process is running or ready to run. |
| `S` | Sleeping. The process is not running; rather, it is waiting for an event, such as a keystroke or network packet. |
| `D` | Uninterruptible sleep. The process is waiting for I/O such as a disk drive. |
| `T` | Stopped. The process has been instructed to stop. You'll learn more about this later in the chapter. |
| `Z` | A defunct or "zombie" process. This is a child process that has terminated but has not been cleaned up by its parent. |
| `<` | A high-priority process. It's possible to grant more importance to a process, giving it more time on the CPU. This property of a process is called *niceness*. A process with high priority is said to be less nice because it's taking more of the CPU's time, which leaves less for everybody else. |
| `N` | A low-priority process. A process with low priority (a nice process) will get processor time only after other processes with higher priority have been serviced. |

The process state may be followed by other characters. These indicate various exotic process characteristics. See the `ps` man page for more details.

Another popular set of options is `aux` (without a leading dash). This gives us even more information.

```
[me@linuxbox ~]$ ps aux
USER     PID %CPU %MEM    VSZ   RSS TTY      STAT START   TIME COMMAND
root       1  0.0  0.0   2136   644 ?        Ss   Mar05   0:31 init
root       2  0.0  0.0      0     0 ?        S<   Mar05   0:00 [kt]
root       3  0.0  0.0      0     0 ?        S<   Mar05   0:00 [mi]
root       4  0.0  0.0      0     0 ?        S<   Mar05   0:00 [ks]
root       5  0.0  0.0      0     0 ?        S<   Mar05   0:06 [wa]
root       6  0.0  0.0      0     0 ?        S<   Mar05   0:36 [ev]
root       7  0.0  0.0      0     0 ?        S<   Mar05   0:00 [kh]
--snip--
```

This set of options displays the processes belonging to every user. Using the options without the leading dash invokes the command with "BSD-style" behavior. The Linux version of ps can emulate the behavior of the ps program found in several different Unix implementations. With these options, we get the additional columns shown in Table 10-2.

**Table 10-2:** BSD Style ps Column Headers

| Header | Meaning |
|---|---|
| USER | User ID. This is the owner of the process. |
| %CPU | CPU usage in percent. |
| %MEM | Memory usage in percent. |
| VSZ | Virtual memory size. |
| RSS | Resident set size. This is the amount of physical memory (RAM) the process is using in kilobytes. |
| START | Time when the process started. For values over 24 hours, a date is used. |

### *Viewing Processes Dynamically with top*

While the ps command can reveal a lot about what the machine is doing, it provides only a snapshot of the machine's state at the moment the ps command is executed. To see a more dynamic view of the machine's activity, we use the top command.

```
[me@linuxbox ~]$ top
```

The top program displays a continuously updating (by default, every three seconds) display of the system processes listed in order of process activity. The name *top* comes from the fact that the top program is used to see the "top" processes on the system. The top display consists of two parts: a system summary at the top of the display, followed by a table of processes sorted by CPU activity.

```
top - 14:59:20 up  6:30,  2 users,  load average: 0.07, 0.02, 0.00
Tasks: 109 total,   1 running, 106 sleeping,   0 stopped,   2 zombie
Cpu(s):  0.7%us,  1.0%sy,  0.0%ni, 98.3%id,  0.0%wa,  0.0%hi,  0.0%si
Mem:    319496k total,   314860k used,     4636k free,    19392k buff
```

```
Swap:   875500k total,   149128k used,   726372k free,   114676k cach

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
 6244 me        39  19 31752 3124 2188 S  6.3  1.0  16:24.42 trackerd
11071 me        20   0  2304 1092  840 R  1.3  0.3   0:00.14 top
 6180 me        20   0  2700 1100  772 S  0.7  0.3   0:03.66 dbus-dae
 6321 me        20   0 20944 7248 6560 S  0.7  2.3   2:51.38 multiloa
 4955 root      20   0  104m 9668 5776 S  0.3  3.0   2:19.39 Xorg
    1 root      20   0  2976  528  476 S  0.0  0.2   0:03.14 init
    2 root      15  -5     0    0    0 S  0.0  0.0   0:00.00 kthreadd
    3 root      RT  -5     0    0    0 S  0.0  0.0   0:00.00 migratio
    4 root      15  -5     0    0    0 S  0.0  0.0   0:00.72 ksoftirq
    5 root      RT  -5     0    0    0 S  0.0  0.0   0:00.04 watchdog
    6 root      15  -5     0    0    0 S  0.0  0.0   0:00.42 events/0
    7 root      15  -5     0    0    0 S  0.0  0.0   0:00.06 khelper
   41 root      15  -5     0    0    0 S  0.0  0.0   0:01.08 kblockd/
   67 root      15  -5     0    0    0 S  0.0  0.0   0:00.00 kseriod
  114 root      20   0     0    0    0 S  0.0  0.0   0:01.62 pdflush
  116 root      15  -5     0    0    0 S  0.0  0.0   0:02.44 kswapd0
```

The system summary contains a lot of good stuff. Table 10-3 provides a rundown.

**Table 10-3:** `top` Information Fields

| Row | Field | Meaning |
|---|---|---|
| 1 | `top` | This is the name of the program. |
| | `14:59:20` | This is the current time of day. |
| | `up 6:30` | This is called *uptime*. It is the amount of time since the machine was last booted. In this example, the system has been up for six and a half hours. |
| | `2 users` | There are two users logged in. |
| | `load average:` | *Load average* refers to the number of processes that are waiting to run; that is, the number of processes that are in a runnable state and are sharing the CPU. Three values are shown, each for a different period of time. The first is the average for the last 60 seconds, the next the previous 5 minutes, and finally the previous 15 minutes. Values less than 1.0 indicate that the machine is not busy. |
| 2 | `Tasks:` | This summarizes the number of processes and their various process states. |
| 3 | `Cpu(s):` | This row describes the character of the activities that the CPU is performing. |
| | `0.7%us` | 0.7 percent of the CPU is being used for *user processes*. This means processes outside the kernel. |
| | `1.0%sy` | 1.0 percent of the CPU is being used for *system* (kernel) processes. |

(*continued*)

**Table 10-3:** top Information Fields (continued)

| Row | Field | Meaning |
|---|---|---|
| | 0.0%ni | 0.0 percent of the CPU is being used by "nice" (low-priority) processes. |
| | 98.3%id | 98.3 percent of the CPU is idle. |
| | 0.0%wa | 0.0 percent of the CPU is waiting for I/O. |
| 4 | Mem: | This shows how physical RAM is being used. |
| 5 | Swap: | This shows how swap space (virtual memory) is being used. |

The top program accepts a number of keyboard commands. The two most interesting are h, which displays the program's help screen, and q, which quits top.

Both major desktop environments provide graphical applications that display information similar to top (in much the same way that Task Manager in Windows works), but top is better than the graphical versions because it is faster and it consumes far fewer system resources. After all, our system monitor program shouldn't be the source of the system slowdown that we are trying to track.

## Controlling Processes

Now that we can see and monitor processes, let's gain some control over them. For our experiments, we're going to use a little program called xlogo as our guinea pig. The xlogo program is a sample program supplied with the X Window System (the underlying engine that makes the graphics on our display go), which simply displays a resizable window containing the X logo. First, we'll get to know our test subject.

```
[me@linuxbox ~]$ xlogo
```

After entering the command, a small window containing the logo should appear somewhere on the screen. On some systems, xlogo might print a warning message, but it can be safely ignored.

**NOTE** *If your system does not include the* xlogo *program, try using* gedit *or* kwrite *instead.*

We can verify that xlogo is running by resizing its window. If the logo is redrawn in the new size, the program is running.

Notice how our shell prompt has not returned? This is because the shell is waiting for the program to finish, just like all the other programs we have used so far. If we close the xlogo window (see Figure 10-1), the prompt returns.

*Figure 10-1: The* xlogo *program*

### Interrupting a Process

Let's observe what happens when we run `xlogo` again. First, enter the `xlogo` command and verify that the program is running. Next, return to the terminal window and press CTRL-C.

```
[me@linuxbox ~]$ xlogo
[me@linuxbox ~]$
```

In a terminal, pressing CTRL-C *interrupts* a program. This means we are politely asking the program to terminate. After we pressed CTRL-C, the `xlogo` window closed, and the shell prompt returned.

Many (but not all) command line programs can be interrupted by using this technique.

### Putting a Process in the Background

Let's say we wanted to get the shell prompt back without terminating the `xlogo` program. We can do this by placing the program in the background. Think of the terminal as having a *foreground* (with stuff visible on the surface like the shell prompt) and a *background* (with stuff hidden behind the surface). To launch a program so that it is immediately placed in the background, we follow the command with an ampersand (`&`) character.

```
[me@linuxbox ~]$ xlogo &
[1] 28236
[me@linuxbox ~]$
```

After entering the command, the `xlogo` window appeared, and the shell prompt returned, but some funny numbers were printed too. This message is part of a shell feature called *job control*. With this message, the shell is telling us that we have started job number 1 (`[1]`) and that it has PID 28236. If we run `ps`, we can see our process.

```
[me@linuxbox ~]$ ps
  PID TTY          TIME CMD
10603 pts/1    00:00:00 bash
28236 pts/1    00:00:00 xlogo
28239 pts/1    00:00:00 ps
```

The shell's job control facility also gives us a way to list the jobs that have been launched from our terminal. Using the `jobs` command, we can see this list:

```
[me@linuxbox ~]$ jobs
[1]+  Running                 xlogo &
```

The results show that we have one job, numbered 1; that it is running; and that the command was `xlogo &`.

### Returning a Process to the Foreground

A process in the background is immune from terminal keyboard input, including any attempt to interrupt it with CTRL-C. To return a process to the foreground, use the fg command in this way:

```
[me@linuxbox ~]$ jobs
[1]+  Running                 xlogo &
[me@linuxbox ~]$ fg %1
xlogo
```

The fg command followed by a percent sign and the job number (called a *jobspec*) does the trick. If we have only one background job, the jobspec is optional. To terminate xlogo, press CTRL-C.

### Stopping (Pausing) a Process

Sometimes we'll want to stop a process without terminating it. This is often done to allow a foreground process to be moved to the background. To stop a foreground process and place it in the background, press CTRL-Z. Let's try it. At the command prompt, type xlogo, press ENTER, and then press CTRL-Z.

```
[me@linuxbox ~]$ xlogo
[1]+  Stopped                 xlogo
[me@linuxbox ~]$
```

After stopping xlogo, we can verify that the program has stopped by attempting to resize the xlogo window. We will see that it appears quite dead. We can either continue the program's execution in the foreground, using the fg command, or resume the program's execution in the background with the bg command.

```
[me@linuxbox ~]$ bg %1
[1]+ xlogo &
[me@linuxbox ~]$
```

As with the fg command, the jobspec is optional if there is only one job.

Moving a process from the foreground to the background is handy if we launch a graphical program from the command line but forget to place it in the background by appending the trailing &.

Why would we want to launch a graphical program from the command line? There are two reasons.

- The program you want to run might not be listed on the window manager's menus (such as xlogo).
- By launching a program from the command line, you might be able to see error messages that would otherwise be invisible if the program

were launched graphically. Sometimes, a program will fail to start up when launched from the graphical menu. By launching it from the command line instead, we may see an error message that will reveal the problem. Also, some graphical programs have interesting and useful command line options.

## Signals

The `kill` command is used to "kill" processes. This allows us to terminate programs that need killing (that is, some kind of pausing or termination). Here's an example:

```
[me@linuxbox ~]$ xlogo &
[1] 28401
[me@linuxbox ~]$ kill 28401
[1]+  Terminated              xlogo
```

We first launch `xlogo` in the background. The shell prints the jobspec and the PID of the background process. Next, we use the `kill` command and specify the PID of the process we want to terminate. We could have also specified the process using a jobspec (for example, `%1`) instead of a PID.

While this is all very straightforward, there is more to it than that. The `kill` command doesn't exactly "kill" processes; rather, it sends them *signals*. Signals are one of several ways that the operating system communicates with programs. We have already seen signals in action with the use of CTRL-C and CTRL-Z. When the terminal receives one of these keystrokes, it sends a signal to the program in the foreground. In the case of CTRL-C, a signal called `INT` (interrupt) is sent; with CTRL-Z, a signal called `TSTP` (terminal stop) is sent. Programs, in turn, "listen" for signals and may act upon them as they are received. The fact that a program can listen and act upon signals allows a program to do things such as save work in progress when it is sent a termination signal.

### *Sending Signals to Processes with kill*

The `kill` command is used to send signals to programs. Its most common syntax looks like this:

```
kill -signal PID...
```

If no signal is specified on the command line, then the `TERM` (terminate) signal is sent by default. The `kill` command is most often used to send the signals listed in Table 10-4.

**Table 10-4:** Common Signals

| Number | Name | Meaning |
|---|---|---|
| 1 | HUP | Hang up. This is a vestige of the good old days when terminals were attached to remote computers with phone lines and modems. The signal is used to indicate to programs that the controlling terminal has "hung up." The effect of this signal can be demonstrated by closing a terminal session. The foreground program running on the terminal will be sent the signal and will terminate.<br>This signal is also used by many daemon programs to cause a reinitialization. This means that when a daemon is sent this signal, it will restart and reread its configuration file. The Apache web server is an example of a daemon that uses the HUP signal in this way. |
| 2 | INT | Interrupt. This performs the same function as CTRL-C sent from the terminal. It will usually terminate a program. |
| 9 | KILL | Kill. This signal is special. Whereas programs may choose to handle signals sent to them in different ways, including ignoring them all together, the KILL signal is never actually sent to the target program. Rather, the kernel immediately terminates the process. When a process is terminated in this manner, it is given no opportunity to "clean up" after itself or save its work. For this reason, the KILL signal should be used only as a last resort when other termination signals fail. |
| 15 | TERM | Terminate. This is the default signal sent by the kill command. If a program is still "alive" enough to receive signals, it will terminate. |
| 18 | CONT | Continue. This will restore a process after a STOP or TSTP signal. This signal is sent by the bg and fg commands. |
| 19 | STOP | Stop. This signal causes a process to pause without terminating. Like the KILL signal, it is not sent to the target process, and thus it cannot be ignored. |
| 20 | TSTP | Terminal stop. This is the signal sent by the terminal when CTRL-Z is pressed. Unlike the STOP signal, the TSTP signal is received by the program, but the program may choose to ignore it. |

Let's try the kill command.

```
[me@linuxbox ~]$ xlogo &
[1] 13546
[me@linuxbox ~]$ kill -1 13546
[1]+  Hangup                  xlogo
```

In this example, we start the `xlogo` program in the background and then send it a `HUP` signal with `kill`. The `xlogo` program terminates, and the shell indicates that the background process has received a hang-up signal. We may need to press ENTER a couple of times before the message appears. Note that signals may be specified either by number or by name, including the name prefixed with the letters *SIG*.

```
[me@linuxbox ~]$ xlogo &
[1] 13601
[me@linuxbox ~]$ kill -INT 13601
[1]+  Interrupt               xlogo
[me@linuxbox ~]$ xlogo &
[1] 13608
[me@linuxbox ~]$ kill -SIGINT 13608
[1]+  Interrupt               xlogo
```

Repeat the preceding example and try the other signals. Remember, we can also use jobspecs in place of PIDs.

Processes, like files, have owners, and you must be the owner of a process (or the superuser) to send it signals with `kill`.

In addition to the list of signals covered so far, which are most often used with `kill`, there are other signals frequently used by the system, as listed in Table 10-5.

**Table 10-5:** Other Common Signals

| Number | Name | Meaning |
|---|---|---|
| 3 | QUIT | Quit. |
| 11 | SEGV | Segmentation violation. This signal is sent if a program makes illegal use of memory; that is, if it tried to write somewhere it was not allowed to write. |
| 28 | WINCH | Window change. This is the signal sent by the system when a window changes size. Some programs, such as `top` and `less`, will respond to this signal by redrawing themselves to fit the new window dimensions. |

For the curious, you can display a complete list of signals with the following command:

```
[me@linuxbox ~]$ kill -l
```

## Sending Signals to Multiple Processes with killall

It's also possible to send signals to multiple processes matching a specified program or username by using the `killall` command. Here is the syntax:

```
killall [-u user] [-signal] name...
```

To demonstrate, we will start a couple of instances of the xlogo program and then terminate them.

```
[me@linuxbox ~]$ xlogo &
[1] 18801
[me@linuxbox ~]$ xlogo &
[2] 18802
[me@linuxbox ~]$ killall xlogo
[1]-  Terminated              xlogo
[2]+  Terminated              xlogo
```

Remember, as with kill, you must have superuser privileges to send signals to processes that do not belong to you.

## Shutting Down the System

The process of shutting down the system involves the orderly termination of all the processes on the system, as well as performing some vital housekeeping chores (such as syncing all of the mounted file systems) before the system powers off. Four commands can perform this function:

- halt
- poweroff
- reboot
- shutdown

The first three are pretty self-explanatory and are generally used without any command line options. Here's an example:

```
[me@linuxbox ~]$ sudo reboot
```

The shutdown command is a bit more interesting. With it, we can specify which of the actions to perform (halt, power down, or reboot) and provide a time delay to the shutdown event. Most often it is used like this to halt the system:

```
[me@linuxbox ~]$ sudo shutdown -h now
```

or like this to reboot the system:

```
[me@linuxbox ~]$ sudo shutdown -r now
```

The delay can be specified in a variety of ways. See the shutdown man page for details. Once the shutdown command is executed, a message is "broadcast" to all logged-in users warning them of the impending event.

## More Process-Related Commands

Because monitoring processes is an important system administration task, there are a lot of commands for it. Table 10-6 lists some to play with.

**Table 10-6:** Other Process-Related Commands

| Command | Description |
|---|---|
| `pstree` | Outputs a process list arranged in a tree-like pattern showing the parent-child relationships between processes. |
| `vmstat` | Outputs a snapshot of system resource usage including memory, swap, and disk I/O. To see a continuous display, follow the command with a time delay (in seconds) for updates. Here's an example: `vmstat 5`. Terminate the output with CTRL-C. |
| `xload` | A graphical program that draws a graph showing system load over time. |
| `tload` | Similar to the `xload` program but draws the graph in the terminal. Terminate the output with CTRL-C. |

## Summing Up

Most modern systems feature a mechanism for managing multiple processes. Linux provides a rich set of tools for this purpose. Given that Linux is the world's most deployed server operating system, this makes a lot of sense. Unlike some other systems, however, Linux relies primarily on command line tools for process management. Though there are graphical process tools for Linux, the command line tools are greatly preferred because of their speed and light footprint. While the GUI tools may look pretty, they often create a lot of system load themselves, which somewhat defeats the purpose.

# PART II

## CONFIGURATION AND THE ENVIRONMENT

# 11

# THE ENVIRONMENT

As we discussed earlier, the shell maintains a body of information during our shell session called the *environment*. Programs use the data stored in the environment to determine facts about the system's configuration. While most programs use *configuration files* to store program settings, some programs also look for values stored in the environment to adjust their behavior. Knowing this, we can use the environment to customize our shell experience.

In this chapter, we will work with the following commands:

**`printenv`** Print part or all of the environment

**`set`** Set shell options

**`export`** Export environment to subsequently executed programs

**`alias`** Create an alias for a command

## What Is Stored in the Environment?

The shell stores two basic types of data in the environment; though, with bash, the types are largely indistinguishable. They are *environment variables* and *shell variables*. Shell variables are bits of data placed there by bash, and environment variables are everything else. In addition to variables, the shell stores some programmatic data, namely, *aliases* and *shell functions*. We covered aliases in Chapter 5 and we will cover shell functions (which are related to shell scripting) in Part IV of this book.

### *Examining the Environment*

To see what is stored in the environment, we can use either the set builtin in bash or the printenv program. The set command will show both the shell and environment variables, while printenv will display only the latter. Because the list of environment contents will be fairly long, it is best to pipe the output of either command into less.

```
[me@linuxbox ~]$ printenv | less
```

Doing so, we should get something that looks like this:

```
USER=me
PAGER=less
LSCOLORS=Gxfxcxdxbxegedabagacad
XDG_CONFIG_DIRS=/etc/xdg/xdg-ubuntu:/usr/share/upstart/xdg:/etc/xdg
PATH=/home/me/bin:/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/
bin:/usr/games:/usr/local/games
DESKTOP_SESSION=ubuntu
QT_IM_MODULE=ibus
QT_QPA_PLATFORMTHEME=appmenu-qt5
JOB=dbus
PWD=/home/me
XMODIFIERS=@im=ibus
GNOME_KEYRING_PID=1850
LANG=en_US.UTF-8
GDM_LANG=en_US
MANDATORY_PATH=/usr/share/gconf/ubuntu.mandatory.path
MASTER_HOST=linuxbox
IM_CONFIG_PHASE=1
COMPIZ_CONFIG_PROFILE=ubuntu
GDMSESSION=ubuntu
SESSIONTYPE=gnome-session
XDG_SEAT=seat0
HOME=/home/me
SHLVL=2
LANGUAGE=en_US
```

```
GNOME_DESKTOP_SESSION_ID=this-is-deprecated
LESS=-R
LOGNAME=me
COMPIZ_BIN_PATH=/usr/bin/
LC_CTYPE=en_US.UTF-8
XDG_DATA_DIRS=/usr/share/ubuntu:/usr/share/gnome:/usr/local/share/:/usr/share/
QT4_IM_MODULE=xim
DBUS_SESSION_BUS_ADDRESS=unix:abstract=/tmp/dbus-IwaesmWaTO
LESSOPEN=| /usr/bin/lesspipe %s
INSTANCE=
```

What we see is a list of environment variables and their values. For example, we see a variable called USER, which contains the value me. The printenv command can also list the value of a specific variable.

```
[me@linuxbox ~]$ printenv USER
me
```

The set command, when used without options or arguments, will display both the shell and environment variables, as well as any defined shell functions. Unlike printenv, its output is courteously sorted in alphabetical order.

```
[me@linuxbox ~]$ set | less
```

It is also possible to view the contents of a variable using the echo command, like this:

```
[me@linuxbox ~]$ echo $HOME
/home/me
```

One element of the environment that neither set nor printenv displays is aliases. To see them, enter the alias command without arguments.

```
[me@linuxbox ~]$ alias
alias l.='ls -d .* --color=tty'
alias ll='ls -l --color=tty'
alias ls='ls --color=tty'
alias vi='vim'
alias which='alias | /usr/bin/which --tty-only --read-alias --show-dot --show-tilde'
```

### *Some Interesting Variables*

The environment contains quite a few variables, and though the environment will differ from the one presented here, we will likely see the variables listed in Table 11-1 in our environment.

**Table 11-1:** Environment Variables

| Variable | Contents |
|---|---|
| DISPLAY | The name of your display if you are running a graphical environment. Usually this is :0, meaning the first display generated by the X server. |
| EDITOR | The name of the program to be used for text editing. |
| SHELL | The name of your shell program. |
| HOME | The pathname of your home directory. |
| LANG | Defines the character set and collation order of your language. |
| OLDPWD | The previous working directory. |
| PAGER | The name of the program to be used for paging output. This is often set to */usr/bin/less*. |
| PATH | A colon-separated list of directories that are searched when you enter the name of a executable program. |
| PS1 | Stands for "prompt string 1." This defines the contents of the shell prompt. As we will later see, this can be extensively customized. |
| PWD | The current working directory. |
| TERM | The name of your terminal type. Unix-like systems support many terminal protocols; this variable sets the protocol to be used with your terminal emulator. |
| TZ | Specifies your time zone. Most Unix-like systems maintain the computer's internal clock in *Coordinated Universal Time* (UTC) and then display the local time by applying an offset specified by this variable. |
| USER | Your username. |

Don't worry if some of these values are missing. They vary by distribution.

## How Is the Environment Established?

When we log on to the system, the bash program starts and reads a series of configuration scripts called *startup files*, which define the default environment shared by all users. This is followed by more startup files in our home directory that define our personal environment. The exact sequence depends on the type of shell session being started. There are two kinds.

**A login shell session** This is one in which we are prompted for our username and password. This happens when we start a virtual console session, for example.

**A non-login shell session** This typically occurs when we launch a terminal session in the GUI.

Login shells read one or more startup files, as shown in Table 11-2.

**Table 11-2:** Startup Files for Login Shell Sessions

| File | Contents |
|---|---|
| */etc/profile* | A global configuration script that applies to all users. |
| *~/.bash_profile* | A user's personal startup file. It can be used to extend or override settings in the global configuration script. |
| *~/.bash_login* | If *~/.bash_profile* is not found, bash attempts to read this script. |
| *~/.profile* | If neither *~/.bash_profile* nor *~/.bash_login* is found, bash attempts to read this file. This is the default in Debian-based distributions, such as Ubuntu. |

Non-login shell sessions read the startup files listed in Table 11-3.

**Table 11-3:** Startup Files for Non-Login Shell Sessions

| File | Contents |
|---|---|
| */etc/bash.bashrc* | A global configuration script that applies to all users. |
| *~/.bashrc* | A user's personal startup file. It can be used to extend or override settings in the global configuration script. |

In addition to reading the startup files listed in Table 11-3, non-login shells inherit the environment from their parent process, usually a login shell.

Take a look and see which of these startup files are installed. Remember—because most of the filenames listed start with a period (meaning that they are hidden), we will need to use the `-a` option when using `ls`.

The *~/.bashrc* file is probably the most important startup file from the ordinary user's point of view, because it is almost always read. Non-login shells read it by default, and most startup files for login shells are written in such a way as to read the *~/.bashrc* file as well.

### *What's in a Startup File?*

If we take a look inside a typical *.bash_profile* (taken from a CentOS 6 system), it looks something like this:

```
# .bash_profile

# Get the aliases and functions
if [ -f ~/.bashrc ]; then
        . ~/.bashrc
fi

# User specific environment and startup programs

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

Lines that begin with a # are *comments* and are not read by the shell. These are there for human readability. The first interesting thing occurs on the fourth line, with the following code:

```
if [ -f ~/.bashrc ]; then
        . ~/.bashrc
fi
```

This is called an `if` *compound command*, which we will cover fully when we get to shell scripting in Part IV, but for now, here is a translation:

```
If the file "~/.bashrc" exists, then
        read the "~/.bashrc" file.
```

We can see that this bit of code is how a login shell gets the contents of *.bashrc*. The next thing in our startup file has to do with the `PATH` variable.

Ever wonder how the shell knows where to find commands when we enter them on the command line? For example, when we enter `ls`, the shell does not search the entire computer to find */bin/ls* (the full pathname of the `ls` command); rather, it searches a list of directories that are contained in the `PATH` variable.

The `PATH` variable is often (but not always, depending on the distribution) set by the */etc/profile* startup file with this code:

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

`PATH` is modified to add the directory *$HOME/bin* to the end of the list. This is an example of *parameter expansion*, which we touched on in Chapter 7. To demonstrate how this works, try the following:

```
[me@linuxbox ~]$ foo="This is some "
[me@linuxbox ~]$ echo $foo
This is some
[me@linuxbox ~]$ foo=$foo"text."
[me@linuxbox ~]$ echo $foo
This is some text.
```

Using this technique, we can append text to the end of a variable's contents.

By adding the string `$HOME/bin` to the end of the `PATH` variable's contents, the directory *$HOME/bin* is added to the list of directories searched when a command is entered. This means that when we want to create a directory within our home directory for storing our own private programs, the shell is ready to accommodate us. All we have to do is call it `bin`, and we're ready to go.

**NOTE** *Many distributions provide this* `PATH` *setting by default. Debian-based distributions, such as Ubuntu, test for the existence of the* ~/bin *directory at login and dynamically add it to the* `PATH` *variable if the directory is found.*

Lastly, we have this:

```
export PATH
```

The `export` command tells the shell to make the contents of `PATH` available to child processes of this shell.

## Modifying the Environment

Because we know where the startup files are and what they contain, we can modify them to customize our environment.

### *Which Files Should We Modify?*

As a general rule, to add directories to your `PATH` or define additional environment variables, place those changes in *.bash_profile* (or the equivalent, according to your distribution; for example, Ubuntu uses *.profile*). For everything else, place the changes in *.bashrc*.

**NOTE** *Unless you are the system administrator and need to change the defaults for all users of the system, restrict your modifications to the files in your home directory. It is certainly possible to change the files in /*etc *such as* profile*, and in many cases it would be sensible to do so, but for now, let's play it safe.*

### *Text Editors*

To edit (that is, modify) the shell's startup files, as well as most of the other configuration files on the system, we use a program called a *text editor*. A text editor is a program that is, in some ways, like a word processor in that it allows us to edit the words on the screen with a moving cursor. It differs from a word processor by only supporting pure text and often contains features designed for writing programs. Text editors are the central tool used by software developers to write code and by system administrators to manage the configuration files that control the system.

A lot of different text editors are available for Linux; most systems have several installed. Why so many different ones? Because programmers like writing them and because programmers use them extensively, they write editors to express their own desires as to how they should work.

Text editors fall into two basic categories: graphical and text-based. GNOME and KDE both include some popular graphical editors. GNOME ships with an editor called `gedit`, which is usually called "Text Editor" in the GNOME menu. KDE usually ships with three, which are (in order of increasing complexity) `kedit`, `kwrite`, and `kate`.

There are many text-based editors. The popular ones we'll encounter are `nano`, `vi`, and `emacs`. The `nano` editor is a simple, easy-to-use editor designed as a replacement for the `pico` editor supplied with the PINE email suite. The `vi` editor (which on most Linux systems has been replaced by a program

named vim, which is short for "vi improved") is the traditional editor for Unix-like systems. It will be the subject of Chapter 12. The emacs editor was originally written by Richard Stallman. It is a gigantic, all-purpose, does-everything programming environment. While readily available, it is seldom installed on most Linux systems by default.

### Using a Text Editor

Text editors can be invoked from the command line by typing the name of the editor followed by the name of the file you want to edit. If the file does not already exist, the editor will assume that we want to create a new file. Here is an example using gedit:

```
[me@linuxbox ~]$ gedit some_file
```

This command will start the gedit text editor and load the file named *some_file*, if it exists.

Graphical text editors are pretty self-explanatory, so we won't cover them here. Instead, we will concentrate on our first text-based text editor, nano. Let's fire up nano and edit the *.bashrc* file. But before we do that, let's practice some "safe computing." Whenever we edit an important configuration file, it is always a good idea to create a backup copy of the file first. This protects us in case we mess up the file while editing. To create a backup of the *.bashrc* file, do this:

```
[me@linuxbox ~]$ cp .bashrc .bashrc.bak
```

It doesn't matter what we call the backup file; just pick an understandable name. The extensions *.bak*, *.sav*, *.old*, and *.orig* are all popular ways of indicating a backup file. Oh, and remember that cp will *overwrite existing files* silently.

Now that we have a backup file, we'll start the editor.

```
[me@linuxbox ~]$ nano .bashrc
```

Once nano starts, we'll get a screen like this:

```
  GNU nano 2.0.3           File: .bashrc

# .bashrc

# Source global definitions
if [ -f /etc/bashrc ]; then
        . /etc/bashrc
fi

# User specific aliases and functions

                          [ Read 8 lines ]
^G Get Help^O WriteOut^R Read Fil^Y Prev Pag^K Cut Text^C Cur Pos
^X Exit    ^J Justify ^W Where Is^V Next Pag^U UnCut Te^T To Spell
```

**NOTE** *If your system does not have* `nano` *installed, you may use a graphical editor instead.*

The screen consists of a header at the top, the text of the file being edited in the middle, and a menu of commands at the bottom. Because `nano` was designed to replace the text editor supplied with an email client, it is rather short on editing features.

The first command you should learn in any text editor is how to exit the program. In the case of `nano`, you press CTRL-X to exit. This is indicated in the menu at the bottom of the screen. The notation `^X` means CTRL-X. This is a common notation for control characters used by many programs.

The second command we need to know is how to save our work. With `nano` it's CTRL-O. With this knowledge, we're ready to do some editing. Using the down arrow key and/or the PAGE DOWN key, move the cursor to the end of the file and then add the following lines to the *.bashrc* file:

```
umask 0002
export HISTCONTROL=ignoredups
export HISTSIZE=1000
alias l.='ls -d .* --color=auto'
alias ll='ls -l --color=auto'
```

**NOTE** *Your distribution may already include some of these, but duplicates won't hurt anything.*

Table 11-4 details the meaning of our additions.

**Table 11-4:** Additions to Our *.bashrc*

| Line | Meaning |
|---|---|
| `umask 0002` | Sets the `umask` to solve the problem with the shared directories we discussed in Chapter 9. |
| `export HISTCONTROL=ignoredups` | Causes the shell's history recording feature to ignore a command if the same command was just recorded. |
| `export HISTSIZE=1000` | Increases the size of the command history from the usual default of 500 lines to 1,000 lines. |
| `alias l.='ls -d .* --color=auto'` | Creates a new command called `l.`, which displays all directory entries that begin with a dot. |
| `alias ll='ls -l --color=auto'` | Creates a new command called `ll`, which displays a long-format directory listing. |

As we can see, many of our additions are not intuitively obvious, so it would be a good idea to add some comments to our *.bashrc* file to help

explain things to the humans. Using the editor, change our additions to look like this:

```
# Change umask to make directory sharing easier
umask 0002

# Ignore duplicates in command history and increase
# history size to 1000 lines
export HISTCONTROL=ignoredups
export HISTSIZE=1000

# Add some helpful aliases
alias l.='ls -d .* --color=auto'
alias ll='ls -l --color=auto'
```

Ah, much better! With our changes complete, press CTRL-O to save our modified *.bashrc* file, and press CTRL-X to exit nano.

**WHY COMMENTS ARE IMPORTANT**

Whenever you modify configuration files, it's a good idea to add some comments to document your changes. Sure, you'll probably remember what you changed tomorrow, but what about six months from now? Do yourself a favor and add some comments. While you're at it, it's not a bad idea to keep a log of what changes you make.

Shell scripts and bash startup files use a # symbol to begin a comment. Other configuration files may use other symbols. Most configuration files will have comments. Use them as a guide.

You will often see lines in configuration files that are *commented out* to prevent them from being used by the affected program. This is done to give the reader suggestions for possible configuration choices or examples of correct configuration syntax. For example, the *.bashrc* file of Ubuntu 18.04 contains these lines:

```
# some more ls aliases
#alias ll='ls -l'
#alias la='ls -A'
#alias l='ls -CF'
```

The last three lines are valid alias definitions that have been commented out. If you remove the leading # symbols from these three lines, a technique called *uncommenting*, you will activate the aliases. Conversely, if you add a # symbol to the beginning of a line, you can deactivate a configuration line while preserving the information it contains.

### *Activating Our Changes*

The changes we have made to our *.bashrc* will not take effect until we close our terminal session and start a new one because the *.bashrc* file is read only at the beginning of a session. However, we can force `bash` to reread the modified *.bashrc* file with the following command:

```
[me@linuxbox ~]$ source ~/.bashrc
```

After doing this, we should be able to see the effect of our changes. Try one of the new aliases.

```
[me@linuxbox ~]$ ll
```

## Summing Up

In this chapter, we learned an essential skill: editing configuration files with a text editor. Moving forward, as we read man pages for commands, take note of the environment variables that commands support. There may be a gem or two. In later chapters, we will learn about shell functions, a powerful feature that you can also include in the `bash` startup files to add to your arsenal of custom commands.

# 12

## A GENTLE INTRODUCTION TO VI

There is an old joke about a visitor to New York City asking a passerby for directions to the city's famous classical music venue.

> Visitor: Excuse me, how do I get to Carnegie Hall?
> Passerby: Practice, practice, practice!

Learning the Linux command line, like becoming an accomplished pianist, is not something that we pick up in an afternoon. It takes years of practice. In this chapter, we will introduce the `vi` (pronounced "vee eye") text editor, one of the core programs in the Unix tradition. `vi` is somewhat notorious for its difficult user interface, but when we see a master sit down at the keyboard and begin to "play," we will indeed be witness to some great art. We won't become masters in this chapter, but when we are done, we will know how to play the equivalent of "Chopsticks" in `vi`.

## Why We Should Learn vi

In this modern age of graphical editors and easy-to-use text-based editors such as nano, why should we learn vi? There are three good reasons.

- vi is almost always available. If we have a system with no graphical interface, such as a remote server or a local system with a broken X configuration, this can be a lifesaver. nano, while increasingly popular, is still not universal. POSIX, a standard for program compatibility on Unix systems, requires that vi be present.
- vi is lightweight and fast. For many tasks, it's easier to bring up vi than it is to find the graphical text editor in the menus and wait for its multiple megabytes to load. In addition, vi is designed for typing speed. As we will see, a skilled vi user never has to lift their fingers from the keyboard while editing.
- We don't want other Linux and Unix users to think we are cowards.

  Okay, maybe two good reasons.

## A Little Background

The first version of vi was written in 1976 by Bill Joy, a University of California at Berkeley student who later went on to cofound Sun Microsystems. vi derives its name from the word "visual," because it was intended to allow editing on a video terminal with a moving cursor. Previous to *visual editors*, there were *line editors* that operated on a single line of text at a time. To specify a change, we tell a line editor to go to a particular line and describe what change to make, such as adding or deleting text. With the advent of video terminals (rather than printer-based terminals like teletypes), visual editing became possible. vi actually incorporates a powerful line editor called ex, and we can use line editing commands while using vi.

Most Linux distributions don't include real vi; rather, they ship with an enhanced replacement called vim (which is short for "vi improved") written by Bram Moolenaar. vim is a substantial improvement over traditional Unix vi and is usually symbolically linked (or aliased) to the name *vi* on Linux systems. In the discussions that follow, we will assume that we have a program called *vi* that is really vim.

## Starting and Stopping vi

To start vi, we simply enter the following:

```
[me@linuxbox ~]$ vi
```

A screen like the following should appear.

```
~
~
~                        VIM - Vi Improved
~
~                         version 8.0.707
~                     by Bram Moolenaar et al.
~           Vim is open source and freely distributable
~
~                     Sponsor Vim development!
~          type  :help sponsor<Enter>    for information
~
~          type  :q<Enter>               to exit
~          type  :help<Enter>  or  <F1>  for on-line help
~          type  :help version8<Enter>   for version info
~
~                   Running in Vi compatible mode
~          type  :set nocp<Enter>        for Vim defaults
~          type  :help cp-default<Enter> for info on this
~
~
~
```

**COMPATIBILITY MODE**

In the example startup screen, we see the text "Running in Vi compatible mode." This means that `vim` will run in a mode that is closer to the normal behavior of `vi` rather than the enhanced behavior of `vim`. For the purposes of this chapter, we will want to run `vim` with its enhanced behavior. To do this, you have a few options. Try running `vim` instead of `vi`. If that works, consider adding `alias vi='vim'` to your *.bashrc* file. Alternatively, use this command to add a line to your `vim` configuration file:

```
echo "set nocp" >> ~/.vimrc
```

Different Linux distributions package `vim` in different ways. Some distributions install a minimal version of `vim` by default that supports only a limited set of `vim` features. While performing the lessons that follow, you may encounter missing features. If this is the case, install the full version of `vim`.

Just as we did with `nano` earlier, the first thing to learn is how to exit. To exit, we enter the following command (note that the colon character is part of the command):

```
:q
```

The shell prompt should return. If, for some reason, vi will not quit (usually because we made a change to a file that has not yet been saved), we can tell vi that we really mean it by adding an exclamation point to the command.

```
:q!
```

**TIP** *If you get "lost" in* vi*, try pressing the* ESC *key twice to find your way again.*

## Editing Modes

Let's start vi again, this time passing the name of a nonexistent file to it. This is how we can create a new file with vi:

```
[me@linuxbox ~]$ rm -f foo.txt
[me@linuxbox ~]$ vi foo.txt
```

If all goes well, we should get a screen like this:

```
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
~
"foo.txt" [New File]
```

The leading tilde characters (~) indicate that no text exists on that line. This shows that we have an empty file. Do not type anything yet!

The second most important thing to learn about vi (after learning how to exit) is that vi is a *modal editor*. When vi starts, it begins in *command mode*. In this mode, almost every key is a command, so if we were to start typing, vi would basically go crazy and make a big mess.

### Entering Insert Mode

To add some text to our file, we must first enter *insert mode*. To do this, we press the `i` key. Afterward, we should see the following at the bottom of the screen if `vim` is running in its usual enhanced mode (this will not appear in `vi` compatible mode):

```
-- INSERT --
```

Now we can enter some text. Try this:

```
The quick brown fox jumped over the lazy dog.
```

To exit insert mode and return to command mode, press the ESC key.

### Saving Our Work

To save the change we just made to our file, we must enter an `ex` command while in command mode. This is easily done by pressing the `:` key. After doing this, a colon character should appear at the bottom of the screen.

```
:
```

To write our modified file, we follow the colon with a `w` and then press ENTER.

```
:w
```

The file will be written to the hard drive, and we should get a confirmation message at the bottom of the screen, like this:

```
"foo.txt" [New] 1L, 46C written
```

**TIP** *If you read the `vim` documentation, you will notice that (confusingly) command mode is called normal mode and `ex` commands are called command mode. Beware.*

## Moving the Cursor Around

While in command mode, `vi` offers a large number of movement commands, some of which it shares with `less`. Table 12-1 lists a subset.

**Table 12-1:** Cursor Movement Keys

| Key | Moves the cursor |
|---|---|
| `l` or right arrow | Right one character. |
| `h` or left arrow | Left one character. |
| `j` or down arrow | Down one line. |

*(continued)*

**Table 12-1:** Cursor Movement Keys (continued)

| Key | Moves the cursor |
|---|---|
| k or up arrow | Up one line. |
| 0 (zero) | To the beginning of the current line. |
| ^ | To the first non-whitespace character on the current line. |
| $ | To the end of the current line. |
| w | To the beginning of the next word or punctuation character. |
| W | To the beginning of the next word, ignoring punctuation characters. |
| b | To the beginning of the previous word or punctuation character. |
| B | To the beginning of the previous word, ignoring punctuation characters. |
| CTRL-F or PAGE DOWN | Down one page. |
| CTRL-B or PAGE UP | Up one page. |
| *number*G | To line number. For example, 1G moves to the first line of the file. |
| G | To the last line of the file. |

Why are the h, j, k, and l keys used for cursor movement? When vi was originally written, not all video terminals had arrow keys, and skilled typists could use regular keyboard keys to move the cursor without ever having to lift their fingers from the keyboard.

Many commands in vi can be prefixed with a number, as with the G command listed in Table 12-1. By prefixing a command with a number, we may specify the number of times a command is to be carried out. For example, the command 5j causes vi to move the cursor down five lines.

## Basic Editing

Most editing consists of a few basic operations such as inserting text, deleting text, and moving text around by cutting and pasting. vi, of course, supports all of these operations in its own unique way. vi also provides a limited form of undo. If we press the u key while in command mode, vi will undo the last change that you made. This will come in handy as we try some of the basic editing commands.

### *Appending Text*

vi has several different ways of entering insert mode. We have already used the i command to insert text.

Let's go back to our *foo.txt* file for a moment.

```
The quick brown fox jumped over the lazy dog.
```

If we wanted to add some text to the end of this sentence, we would discover that the `i` command will not do it, because we can't move the cursor beyond the end of the line. `vi` provides a command to append text, the sensibly-named `a` command. If we move the cursor to the end of the line and type `a`, the cursor will move past the end of the line and `vi` will enter insert mode. This will allow us to add some more text.

```
The quick brown fox jumped over the lazy dog. It was cool.
```

Remember to press the ESC key to exit insert mode.

Because we will almost always want to append text to the end of a line, `vi` offers a shortcut to move to the end of the current line and start appending. It's the `A` command. Let's try it and add some more lines to our file.

First, we'll move the cursor to the beginning of the line using the `0` (zero) command. Now we type `A` and add the following lines of text:

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
Line 5
```

Again, press the ESC key to exit insert mode.

As we can see, the `A` command is more useful as it moves the cursor to the end of the line before starting insert mode.

### *Opening a Line*

Another way we can insert text is by "opening" a line. This inserts a blank line between two existing lines and enters insert mode. This has two variants, as described in Table 12-2.

**Table 12-2:** Line Opening Keys

| Command | Opens |
|---|---|
| o | The line below the current line |
| O | The line above the current line |

We can demonstrate this as follows: place the cursor on line 3 and then type `o`.

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3

Line 4
Line 5
```

A new line was opened below the third line, and we entered insert mode. Exit insert mode by pressing the ESC key. Press u to undo our change.

Type O to open the line above the cursor.

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2

Line 3
Line 4
Line 5
```

Exit insert mode by pressing ESC, and undo our change by typing u.

### Deleting Text

As we might expect, vi offers a variety of ways to delete text, all of which contain one of two keystrokes. First, the x command will delete a character at the cursor location. x may be preceded by a number specifying how many characters are to be deleted. The d command is more general purpose. Like x, it may be preceded by a number specifying the number of times the deletion is to be performed. In addition, d is always followed by a movement command that controls the size of the deletion. Table 12-3 provides some examples.

**Table 12-3:** Text Deletion Commands

| Command | Deletes |
|---|---|
| x | The current character |
| 3x | The current character and the next two characters |
| dd | The current line |
| 5dd | The current line and the next four lines |
| dW | From the current cursor position to the beginning of the next word |
| d$ | From the current cursor location to the end of the current line |
| d0 | From the current cursor location to the beginning of the line |
| d^ | From the current cursor location to the first non-whitespace character in the line |
| dG | From the current line to the end of the file |
| d20G | From the current line to the twentieth line of the file |

Place the cursor on the word *It* on the first line of our text. Press the x key repeatedly until the rest of the sentence is deleted. Next, press the u key repeatedly until the deletion is undone.

**NOTE** *Real vi supports only a single level of undo. vim supports multiple levels.*

Let's try the deletion again, this time using the d command. Again, move the cursor to the word *It* and type dW to delete the word.

```
The quick brown fox jumped over the lazy dog. was cool.
Line 2
Line 3
Line 4
Line 5
```

Type `d$` to delete from the cursor position to the end of the line.

```
The quick brown fox jumped over the lazy dog.
Line 2
Line 3
Line 4
Line 5
```

Type `dG` to delete from the current line to the end of the file.

```
~
~
~
~
~
```

Type `u` three times to undo the deletion.

### *Cutting, Copying, and Pasting Text*

The `d` command not only deletes text, it also "cuts" text. Each time we use the `d` command, the deletion is copied into a paste buffer (think clipboard) that we can later recall with the `p` command to paste the contents of the buffer either before or after the cursor.

The `y` command is used to "yank" (copy) text in much the same way the `d` command is used to cut text. Table 12-4 provides some examples of combining the `y` command with various movement commands.

**Table 12-4:** Yanking Commands

| Command | Copies |
|---|---|
| `yy` | The current line |
| `5yy` | The current line and the next four lines |
| `yW` | From the current cursor position to the beginning of the next word |
| `y$` | From the current cursor location to the end of the current line |
| `y0` | From the current cursor location to the beginning of the line |
| `y^` | From the current cursor location to the first non-whitespace character in the line |
| `yG` | From the current line to the end of the file |
| `y20G` | From the current line to the twentieth line of the file |

Let's try some copy-and-paste. Place the cursor on the first line of the text and type `yy` to copy the current line. Next, move the cursor to the last line (`G`) and type `p` to paste the line below the current line.

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
Line 5
The quick brown fox jumped over the lazy dog. It was cool.
```

Just as before, the `u` command will undo our change. With the cursor still positioned on the last line of the file, type `P` to paste the text above the current line.

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
The quick brown fox jumped over the lazy dog. It was cool.
Line 5
```

Try some of the other `y` commands in Table 12-4 and get to know the behavior of both the `p` and `P` commands. When you are done, return the file to its original state.

### *Joining Lines*

`vi` is rather strict about its idea of a line. Normally, it is not possible to move the cursor to the end of a line and delete the end-of-line character to join one line with the one below it. Because of this, `vi` provides a specific command, `J` (not to be confused with `j`, which is for cursor movement), to join lines together.

If we place the cursor on line 3 and type the `J` command, here's what happens:

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3 Line 4
Line 5
```

## Search-and-Replace

`vi` has the capability to move the cursor to locations based on searches. It can do this either on a single line or over an entire file. It can also perform text replacements with or without confirmation from the user.

### Searching Within a Line

The `f` command searches a line and moves the cursor to the next instance of a specified character. For example, the command `fa` would move the cursor to the next occurrence of the character *a* within the current line. After performing a character search within a line, the search may be repeated by typing a semicolon.

### Searching the Entire File

To move the cursor to the next occurrence of a word or phrase, the `/` command is used. This works the same way as we learned earlier in the `less` program. When you type the `/` command, a `/` will appear at the bottom of the screen. Next, type the word or phrase to be searched for, followed by the ENTER key. The cursor will move to the next location containing the search string. A search may be repeated using the previous search string with the `n` command. Here's an example:

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
Line 5
```

Place the cursor on the first line of the file. Type this and press ENTER:

```
/Line
```

The cursor will move to line 2. Next, type `n` and the cursor will move to line 3. Repeating the `n` command will move the cursor down the file until it runs out of matches. While we have so far used only words and phrases for our search patterns, `vi` allows the use of *regular expressions*, a powerful method of expressing complex text patterns. We will cover regular expressions fully in Chapter 19.

### Global Search-and-Replace

`vi` uses an `ex` command to perform search-and-replace operations (called *substitution* in `vi`) over a range of lines or the entire file. To change the word *Line* to *line* for the entire file, we would enter the following command:

```
:%s/Line/line/g
```

Let's break down this command into separate items and see what each one does (see Table 12-5).

**Table 12-5:** An Example of Global Search-and-Replace Syntax

| Item | Meaning |
|---|---|
| `:` | The colon character starts an ex command. |
| `%` | This specifies the range of lines for the operation. `%` is a shortcut meaning from the first line to the last line. Alternately, the range could have been specified `1,5` (since our file is five lines long) or `1,$`, which means "from line 1 to the last line in the file." If the range of lines is omitted, the operation is performed only on the current line. |
| `s` | This specifies the operation. In this case, it's substitution (search-and-replace). |
| `/Line/line/` | This specifies the search pattern and the replacement text. |
| `g` | This means "global" in the sense that the search-and-replace is performed on every instance of the search string in the line. If omitted, only the first instance of the search string on each line is replaced. |

After executing our search-and-replace command, our file looks like this:

```
The quick brown fox jumped over the lazy dog. It was cool.
line 2
line 3
line 4
line 5
```

We can also specify a substitution command with user confirmation. This is done by adding a `c` to the end of the command. Here's an example:

```
:%s/line/Line/gc
```

This command will change our file back to its previous form; however, before each substitution, `vi` stops and asks us to confirm the substitution with this message:

```
replace with Line (y/n/a/q/l/^E/^Y)?
```

Each of the characters within the parentheses is a possible choice, as described in Table 12-6.

**Table 12-6:** Replace Confirmation Keys

| Key | Action |
|---|---|
| `y` | Perform the substitution. |
| `n` | Skip this instance of the pattern. |
| `a` | Perform the substitution on this and all subsequent instances of the pattern. |
| `q` or `ESC` | Quit substituting. |

| Key | Action |
|---|---|
| l | Perform this substitution and then quit. This is short for "last." |
| CTRL-E, CTRL-Y | Scroll down and scroll up, respectively. This is useful for viewing the context of the proposed substitution. |

If you type y, the substitution will be performed. n will cause vi to skip this instance and move on to the next one.

## Editing Multiple Files

It's often useful to edit more than one file at a time. You might need to make changes to multiple files, or you might need to copy content from one file into another. With vi we can open multiple files for editing by specifying them on the command line.

```
vi file1 file2 file3 . . .
```

Let's exit our existing vi session and create a new file for editing. Type :wq to exit vi, saving our modified text. Next, we'll create an additional file in our home directory that we can play with. We'll create the file by capturing some output from the ls command.

```
[me@linuxbox ~]$ ls -l /usr/bin > ls-output.txt
```

Let's edit our old file and our new one with vi.

```
[me@linuxbox ~]$ vi foo.txt ls-output.txt
```

vi will start, and we will see the first file on the screen.

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
Line 5
```

### *Switching Between Files*

To switch from one file to the next, use this ex command:

```
:bn
```

To move back to the previous file, use the following:

```
:bp
```

While we can move from one file to another, vi enforces a policy that prevents us from switching files if the current file has unsaved changes. To force vi to switch files and abandon your changes, add an exclamation point (!) to the command.

In addition to the switching method already described, vim (and some versions of vi) provides some ex commands that make multiple files easier to manage. We can view a list of files being edited with the :buffers command. Doing so will display a list of the files at the bottom of the display.

```
:buffers
  1 %a   "foo.txt"                      line 1
  2      "ls-output.txt"                line 0
Press ENTER or type command to continue
```

To switch to another buffer (file), type :buffer followed by the number of the buffer you want to edit. For example, to switch from buffer 1 containing the file *foo.txt* to buffer 2 containing the file *ls-output.txt*, we would type this:

```
:buffer 2
```

Our screen now displays the second file. Another way we can change buffers is to use the :bn (short for buffer next) and :bp (short for buffer previous) commands mentioned earlier.

### Opening Additional Files for Editing

It's also possible to add files to our current editing session. The ex command :e (short for "edit") followed by a filename will open an additional file. Let's end our current editing session and return to the command line.

Start vi again with just one file.

```
[me@linuxbox ~]$ vi foo.txt
```

To add our second file, enter the following:

```
:e ls-output.txt
```

It should appear on the screen. The first file is still present, as we can verify.

```
:buffers
  1 #    "foo.txt"                      line 1
  2 %a   "ls-output.txt"                line 0
Press ENTER or type command to continue
```

### Copying Content from One File into Another

Often while editing multiple files, we will want to copy a portion of one file into another file that we are editing. This is easily done using the usual yank and paste commands we used earlier. We can demonstrate as follows. First, using our two files, switch to buffer 1 (*foo.txt*) by entering this:

```
:buffer 1
```

That command should give us this:

```
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
Line 5
```

Next, move the cursor to the first line, and type yy to yank (copy) the line. Switch to the second buffer by entering the following:

```
:buffer 2
```

The screen will now contain some file listings like this (only a portion is shown here):

```
total 343700
-rwxr-xr-x 1 root root       31316 2017-12-05 08:58 [
-rwxr-xr-x 1 root root        8240 2017-12-09 13:39 411toppm
-rwxr-xr-x 1 root root      111276 2018-01-31 13:36 a2p
-rwxr-xr-x 1 root root       25368 2017-10-06 20:16 a52dec
-rwxr-xr-x 1 root root       11532 2017-05-04 17:43 aafire
-rwxr-xr-x 1 root root        7292 2017-05-04 17:43 aainfo
```

Move the cursor to the first line and paste the line we copied from the preceding file by typing the p command.

```
total 343700
The quick brown fox jumped over the lazy dog. It was cool.
-rwxr-xr-x 1 root root       31316 2017-12-05 08:58 [
-rwxr-xr-x 1 root root        8240 2017-12-09 13:39 411toppm
-rwxr-xr-x 1 root root      111276 2018-01-31 13:36 a2p
-rwxr-xr-x 1 root root       25368 2016-10-06 20:16 a52dec
-rwxr-xr-x 1 root root       11532 2017-05-04 17:43 aafire
-rwxr-xr-x 1 root root        7292 2017-05-04 17:43 aainfo
```

### Inserting an Entire File into Another

It's also possible to insert an entire file into one we are editing. To see this in action, let's end our vi session and start a new one with just a single file.

```
[me@linuxbox ~]$ vi ls-output.txt
```

We will see our file listing again.

```
total 343700
-rwxr-xr-x 1 root root       31316 2017-12-05 08:58 [
-rwxr-xr-x 1 root root        8240 2017-12-09 13:39 411toppm
-rwxr-xr-x 1 root root      111276 2018-01-31 13:36 a2p
-rwxr-xr-x 1 root root       25368 2016-10-06 20:16 a52dec
-rwxr-xr-x 1 root root       11532 2017-05-04 17:43 aafire
-rwxr-xr-x 1 root root        7292 2017-05-04 17:43 aainfo
```

Move the cursor to the third line and then enter the following ex command:

```
:r foo.txt
```

The :r command (short for "read") inserts the specified file below the cursor position. Our screen should now look like this:

```
total 343700
-rwxr-xr-x 1 root root       31316 2017-12-05 08:58 [
-rwxr-xr-x 1 root root        8240 2017-12-09 13:39 411toppm
The quick brown fox jumped over the lazy dog. It was cool.
Line 2
Line 3
Line 4
Line 5
-rwxr-xr-x 1 root root      111276 2018-01-31 13:36 a2p
-rwxr-xr-x 1 root root       25368 2016-10-06 20:16 a52dec
-rwxr-xr-x 1 root root       11532 2017-05-04 17:43 aafire
-rwxr-xr-x 1 root root        7292 2017-05-04 17:43 aainfo
```

## Saving Our Work

Like everything else in vi, there are several different ways to save our edited files. We have already covered the ex command :w, but there are some others we may also find helpful.

In command mode, typing ZZ will save the current file and exit vi. Likewise, the ex command :wq will combine the :w and :q commands into one that will both save the file and exit.

The :w command may also specify an optional filename. This acts like Save As. For example, if we were editing *foo.txt* and wanted to save an alternate version called *foo1.txt*, we would enter the following:

```
:w foo1.txt
```

**NOTE** *While this command saves the file under a new name, it does not change the name of the file you are editing. As you continue to edit, you will still be editing* foo.txt, *not* foo1.txt.

## Summing Up

With this basic set of skills, we can now perform most of the text editing needed to maintain a typical Linux system. Learning to use `vim` on a regular basis will pay off in the long run. Since `vi`-style editors are so deeply embedded in Unix culture, we will see many other programs that have been influenced by its design. `less` is a good example of this influence.

# 13

# CUSTOMIZING THE PROMPT

In this chapter, we will look at a seemingly trivial detail—our shell prompt. This examination will reveal some of the inner workings of the shell and the terminal emulator program.

Like so many things in Linux, the shell prompt is highly configurable, and while we have pretty much taken it for granted, the prompt is a really useful device once we learn how to control it.

## Anatomy of a Prompt

Our default prompt looks something like this:

```
[me@linuxbox ~]$
```

Notice that it contains our username, our hostname, and our current working directory, but how did it get that way? Very simply, it turns out. The prompt is defined by an environment variable named `PS1` (short for "prompt string 1"). We can view the contents of `PS1` with the `echo` command.

```
[me@linuxbox ~]$ echo $PS1
[\u@\h \W]\$
```

**NOTE** *Don't worry if your results are not the same as this example. Every Linux distribution defines the prompt string a little differently, some quite exotically.*

From the results, we can see that PS1 contains a few of the characters we see in our prompt such as the brackets, the at-sign, and the dollar sign, but the rest are a mystery. The astute among us will recognize these as *backslash-escaped special characters* like those we saw in Chapter 7. Table 13-1 provides a partial list of the characters that the bash treats specially in the prompt string.

**Table 13-1:** Escape Codes Used in Shell Prompts

| Sequence | Value displayed |
|---|---|
| \a | ASCII bell. This makes the computer beep when it is encountered. |
| \d | Current date in day, month, date format. For example, "Mon May 26." |
| \h | Hostname of the local machine minus the trailing domain name. |
| \H | Full hostname. |
| \j | Number of jobs running in the current shell session. |
| \l | Name of the current terminal device. |
| \n | A newline character. |
| \r | A carriage return. |
| \s | Name of the shell program. |
| \t | Current time in 24-hour hours:minutes:seconds format. |
| \T | Current time in 12-hour format. |
| \@ | Current time in 12-hour AM/PM format. |
| \A | Current time in 24-hour hours:minutes format. |
| \u | Username of the current user. |
| \v | Version number of the shell. |
| \V | Version and release numbers of the shell. |
| \w | Name of the current working directory. |
| \W | Last part of the current working directory name. |
| \! | History number of the current command. |
| \# | Number of commands entered during this shell session. |
| \$ | This displays a $ character unless we have superuser privileges. In that case, it displays a # instead. |
| \[ | Signals the start of a series of one or more non-printing characters. This is used to embed non-printing control characters that manipulate the terminal emulator in some way, such as moving the cursor or changing text colors. |
| \] | Signals the end of a non-printing character sequence. |

## Trying Some Alternative Prompt Designs

With this list of special characters, we can change the prompt to see the effect. First, we'll back up the existing prompt string so we can restore it later. To do this, we will copy the existing string into another shell variable that we create ourselves.

```
[me@linuxbox ~]$ ps1_old="$PS1"
```

We create a new variable called `ps1_old` and assign the value of `PS1` to it. We can verify that the string has been copied by using the `echo` command.

```
[me@linuxbox ~]$ echo $ps1_old
[\u@\h \W]\$
```

We can restore the original prompt at any time during our terminal session by simply reversing the process.

```
[me@linuxbox ~]$ PS1="$ps1_old"
```

Now that we are ready to proceed, let's see what happens if we have an empty prompt string.

```
[me@linuxbox ~]$ PS1=
```

If we assign nothing to the prompt string, we get nothing. No prompt string at all! The prompt is still there but displays nothing, just as we asked it to do. Because this is kind of disconcerting to look at, we'll replace it with a minimal prompt.

```
PS1="\$ "
```

That's better. At least now we can see what we are doing. Notice the trailing space within the double quotes. This provides the space between the dollar sign and the cursor when the prompt is displayed.

Let's add a bell to our prompt.

```
$ PS1="\[\a\]\$ "
```

Now we should hear a beep each time the prompt is displayed, though some systems disable this "feature." This could get annoying, but it might be useful if we needed notification when an especially long-running command has been executed. Note that we included the `\[` and `\]` sequences. Since the ASCII bell (`\a`) does not "print," that is, it does not move the cursor, we need to tell `bash` so it can correctly determine the length of the prompt.

Next, let's try to make an informative prompt with some hostname and time-of-day information.

```
$ PS1="\A \h \$ "
17:33 linuxbox $
```

Adding time-of-day to our prompt will be useful if we need to keep track of when we perform certain tasks. Finally, we'll make a new prompt that is similar to our original.

```
17:37 linuxbox $ PS1="<\u@\h \W>\$ "
<me@linuxbox ~>$
```

Try the other sequences listed in Table 13-1 and see whether you can come up with a brilliant new prompt.

## Adding Color

Most terminal emulator programs respond to certain non-printing character sequences to control such things as character attributes (such as color, bold text, and the dreaded blinking text) and cursor position. We'll cover cursor position in a little bit, but first we'll look at color.

**TERMINAL CONFUSION**

Back in ancient times, when terminals were hooked to remote computers, there were many competing brands of terminals, and they all worked differently. They had different keyboards, and they all had different ways of interpreting control information. Unix and Unix-like systems have two rather complex subsystems to deal with the babel of terminal control (called `termcap` and `terminfo`). If you look in the deepest recesses of your terminal emulator settings, you might find a setting for the type of terminal emulation.

In an effort to make terminals speak some sort of common language, the American National Standards Institute (ANSI) developed a standard set of character sequences to control video terminals. Old-time DOS users will remember the *ANSI.SYS* file that was used to enable interpretation of these codes.

Character color is controlled by sending the terminal emulator an *ANSI escape code* embedded in the stream of characters to be displayed. The control code does not "print out" on the display; rather, it is interpreted by the terminal as an instruction. As we saw in Table 13-1, the \[ and \] sequences are used to encapsulate non-printing characters. An ANSI escape code begins with an octal 033 (the code generated by the ESC key), followed by an optional character attribute, followed by an instruction. For example, the code to set the text color to normal (attribute = 0), black text is as follows:

```
\033[0;30m
```

Table 13-2 lists the available text colors. Notice that the colors are divided into two groups, differentiated by the application of the bold character attribute (1), which creates the appearance of "light" colors.

**Table 13-2:** Escape Sequences Used to Set Text Colors

| Sequence | Text color | Sequence | Text color |
|---|---|---|---|
| `\033[0;30m` | Black | `\033[1;30m` | Dark gray |
| `\033[0;31m` | Red | `\033[1;31m` | Light red |
| `\033[0;32m` | Green | `\033[1;32m` | Light green |
| `\033[0;33m` | Brown | `\033[1;33m` | Yellow |
| `\033[0;34m` | Blue | `\033[1;34m` | Light blue |
| `\033[0;35m` | Purple | `\033[1;35m` | Light purple |
| `\033[0;36m` | Cyan | `\033[1;36m` | Light cyan |
| `\033[0;37m` | Light gray | `\033[1;37m` | White |

Let's try to make a red prompt (seen here as gray). We'll insert the escape code at the beginning.

```
<me@linuxbox ~>$ PS1="\[\033[0;31m\]<\u@\h \W>\$ "
<me@linuxbox ~>$
```

That works, but notice that all the text that we type after the prompt will also display in red. To fix this, we will add another escape code to the end of the prompt that tells the terminal emulator to return to the previous color.

```
<me@linuxbox ~>$ PS1="\[\033[0;31m\]<\u@\h \W>\$\[\033[0m\] "
<me@linuxbox ~>$
```

That's better!

It's also possible to set the text background color using the codes listed in Table 13-3. The background colors do not support the bold attribute.

**Table 13-3:** Escape Sequences Used to Set Background Color

| Sequence | Background color | Sequence | Background color |
|---|---|---|---|
| `\033[0;40m` | Black | `\033[0;44m` | Blue |
| `\033[0;41m` | Red | `\033[0;45m` | Purple |
| `\033[0;42m` | Green | `\033[0;46m` | Cyan |
| `\033[0;43m` | Brown | `\033[0;47m` | Light gray |

We can create a prompt with a red background by applying a simple change to the first escape code.

```
<me@linuxbox ~>$ PS1="\[\033[0;41m\]<\u@\h \W>\$\[\033[0m\] "
<me@linuxbox ~>$
```

Try the color codes and see what you can create!

**NOTE** *Besides the normal (0) and bold (1) character attributes, text may be given underscore (4), blinking (5), and inverse (7) attributes. In the interests of good taste, many terminal emulators refuse to honor the blinking attribute, however.*

## Moving the Cursor

Escape codes can be used to position the cursor. This is commonly used to provide a clock or some other kind of information at a different location on the screen, such as in an upper corner each time the prompt is drawn. Table 13-4 lists the escape codes that position the cursor.

**Table 13-4:** Cursor Movement Escape Sequences

| Escape code | Action |
|---|---|
| `\033[l;cH` | Move the cursor to line *l* and column *c* |
| `\033[nA` | Move the cursor up *n* lines |
| `\033[nB` | Move the cursor down *n* lines |
| `\033[nC` | Move the cursor forward *n* characters |
| `\033[nD` | Move the cursor backward *n* characters |
| `\033[2J` | Clear the screen and move the cursor to the upper-left corner (line 0, column 0) |
| `\033[K` | Clear from the cursor position to the end of the current line |
| `\033[s` | Store the current cursor position |
| `\033[u` | Recall the stored cursor position |

Using the codes in Table 13-4, we'll construct a prompt that draws a red bar at the top of the screen containing a clock (rendered in yellow text) each time the prompt is displayed. The code for the prompt is this formidable-looking string:

```
PS1="\[\033[s\033[0;0H\033[0;41m\033[K\033[1;33m\t\033[0m\033[u\]<\u@\h \W>\$ "
```

Table 13-5 outlines what each part of the string does.

**Table 13-5:** Breakdown of Complex Prompt String

| Sequence | Action |
|---|---|
| `\[` | Begin a non-printing character sequence. The purpose of this is to allow bash to properly calculate the size of the visible prompt. Without an accurate calculation, command line editing features cannot position the cursor correctly. |

| Sequence | Action |
|---|---|
| `\033[s` | Store the cursor position. This is needed to return to the prompt location after the bar and clock have been drawn at the top of the screen. Be aware that some terminal emulators do not recognize this code. |
| `\033[0;0H` | Move the cursor to the upper-left corner, which is line 0, column 0. |
| `\033[0;41m` | Set the background color to red. |
| `\033[K` | Clear from the current cursor location (the top-left corner) to the end of the line. Because the background color is now red, the line is cleared to that color, creating our bar. Note that clearing to the end of the line does not change the cursor position, which remains in the upper-left corner. |
| `\033[1;33m` | Set the text color to yellow. |
| `\t` | Display the current time. While this is a "printing" element, we still include it in the non-printing portion of the prompt since we don't want bash to include the clock when calculating the true size of the displayed prompt. |
| `\033[0m` | Turn off color. This affects both the text and the background. |
| `\033[u` | Restore the cursor position saved earlier. |
| `\]` | End the non-printing characters sequence. |
| `<\u@\h \W>\$` | Prompt string. |

## Saving the Prompt

Obviously, we don't want to be typing that monster all the time, so we'll want to store our prompt someplace. We can make the prompt permanent by adding it to our *.bashrc* file. To do so, add these two lines to the file:

```
PS1="\[\033[s\033[0;0H\033[0;41m\033[K\033[1;33m\t\033[0m\033[u\]<\u@\h \W>\$ "

export PS1
```

## Summing Up

Believe it or not, there is much more that can be done with prompts involving shell functions and scripts that we haven't covered here, but this is a good start. Not everyone will care enough to change the prompt since the default prompt is usually satisfactory. But for those of us who like to tinker, the shell provides the opportunity for many hours of casual fun.

# PART III

## COMMON TASKS AND ESSENTIAL TOOLS

# 14

# PACKAGE MANAGEMENT

If we spend any time in the Linux community, we hear many opinions as to which of the many Linux distributions is "best." Often, these discussions get really silly, focusing on such things as the prettiness of the desktop background (some people won't use Ubuntu because of its default color scheme!) and other trivial matters.

The most important determinant of distribution quality is the *packaging system* and the vitality of the distribution's support community. As we spend more time with Linux, we will see that its software landscape is extremely dynamic. Things are constantly changing. Most of the top-tier Linux distributions release new versions every six months and many individual program updates every day. To keep up with this blizzard of software, we need good tools for *package management*.

Package management is a method of installing and maintaining software on the system. Today, most people can satisfy all of their software needs by installing *packages* from their Linux distributor. This contrasts

with the early days of Linux, when one had to download and compile *source code* to install software. There isn't anything wrong with compiling source code; in fact, having access to source code is the great wonder of Linux. It gives us (and everybody else) the ability to examine and improve the system. It's just that having a precompiled package is faster and easier to deal with.

In this chapter, we will look at some of the command line tools used for package management. While all the major distributions provide powerful and sophisticated graphical programs for maintaining the system, it is important to learn about the command line programs, too. They can perform many tasks that are difficult (or impossible) to do with their graphical counterparts.

## Packaging Systems

Different distributions use different packaging systems, and as a general rule, a package intended for one distribution is not compatible with another distribution. Most distributions fall into one of two camps of packaging technologies: the Debian *.deb* camp and the Red Hat *.rpm* camp. There are some important exceptions such as Gentoo, Slackware, and Arch, but most others use one of these two basic systems, as shown in Table 14-1.

**Table 14-1:** Major Packaging System Families

| Packaging system | Distributions (partial listing) |
|---|---|
| Debian-style (.deb) | Debian, Ubuntu, Linux Mint, Raspbian |
| Red Hat–style (.rpm) | Fedora, CentOS, Red Hat Enterprise Linux, OpenSUSE |

## How a Package System Works

The method of software distribution found in the proprietary software industry usually entails buying a piece of installation media such as an "install disk" or visiting each vendor's website and downloading the product and then running an "installation wizard" to install a new application on the system.

Linux doesn't work that way. Virtually all software for a Linux system will be found on the Internet. Most of it will be provided by the distribution vendor in the form of *package files*, and the rest will be available in source code form that can be installed manually. We'll talk about how to install software by compiling source code in Chapter 23.

### *Package Files*

The basic unit of software in a packaging system is the *package file*. A package file is a compressed collection of files that comprise the software package. A package may consist of numerous programs and data files that support the programs. In addition to the files to be installed, the package file also

includes metadata about the package, such as a text description of the package and its contents. Additionally, many packages contain pre- and post-installation scripts that perform configuration tasks before and after the package installation.

Package files are created by a person known as a *package maintainer*, often (but not always) an employee of the distribution vendor. The package maintainer gets the software in source code form from the *upstream provider* (the author of the program), compiles it, and creates the package metadata and any necessary installation scripts. Often, the package maintainer will apply modifications to the original source code to improve the program's integration with the other parts of the Linux distribution.

### Repositories

While some software projects choose to perform their own packaging and distribution, most packages today are created by the distribution vendors and interested third parties. Packages are made available to the users of a distribution in central repositories that may contain many thousands of packages, each specially built and maintained for the distribution.

A distribution may maintain several different repositories for different stages of the software development life cycle. For example, there will usually be a "testing" repository that contains packages that have just been built and are intended for use by brave souls who are looking for bugs before the packages are released for general distribution. A distribution will often have a "development" repository where work-in-progress packages destined for inclusion in the distribution's next major release are kept.

A distribution may also have related third-party repositories. These are often needed to supply software that, for legal reasons such as patents or DRM anti-circumvention issues, cannot be included with the distribution. Perhaps the best known case is that of encrypted DVD support, which is not legal in the United States. The third-party repositories operate in countries where software patents and anti-circumvention laws do not apply. These repositories are usually wholly independent of the distribution they support, and to use them, one must know about them and manually include them in the configuration files for the package management system.

### Dependencies

Programs are seldom "stand alone"; rather, they rely on the presence of other software components to get their work done. Common activities, such as input/output, for example, are handled by routines shared by many programs. These routines are stored in *shared libraries*, which provide essential services to more than one program. If a package requires a shared resource such as a shared library, it is said to have a *dependency*. Modern package management systems all provide some method of *dependency resolution* to ensure that when a package is installed, all of its dependencies are installed, too.

### *High- and Low-Level Package Tools*

Package management systems usually consist of two types of tools.

- Low-level tools that handle tasks such as installing and removing package files
- High-level tools that perform metadata searching and dependency resolution

In this chapter, we will look at the tools supplied with Debian-style systems (such as Ubuntu and many others) and those used by Red Hat products. While all Red Hat–style distributions rely on the same low-level program (`rpm`), they use different high-level tools. For our discussion, we will cover the high-level program `yum`, used by Red Hat Enterprise Linux and CentOS. Other Red Hat–style distributions provide high-level tools with comparable features (see Table 14-2).

**Table 14-2:** Packaging System Tools

| Distributions | Low-level tools | High-level tools |
|---|---|---|
| Debian-style | `dpkg` | `apt-get, apt, aptitude` |
| Fedora, Red Hat Enterprise Linux, CentOS | `rpm` | `yum, dnf` |

## Common Package Management Tasks

Many operations can be performed with the command line package management tools. We will look at the most common. Be aware that the low-level tools also support the creation of package files, an activity outside the scope of this book.

In the discussion that follows, the term *`package_name`* refers to the actual name of a package rather than the term *`package_file`*, which is the name of the file that contains the package.

### *Finding a Package in a Repository*

Using the high-level tools to search repository metadata, a package can be located based on its name or description (see Table 14-3).

**Table 14-3:** Package Search Commands

| Style | Command(s) |
|---|---|
| Debian | `apt-get update`<br>`apt-cache search` *`search_string`* |
| Red Hat | `yum search` *`search_string`* |

For example, to search a `yum` repository for the `emacs` text editor, we can use this command:

```
yum search emacs
```

### Installing a Package from a Repository

High-level tools permit a package to be downloaded from a repository and installed with full dependency resolution (see Table 14-4).

**Table 14-4:** Package Installation Commands

| Style | Command(s) |
|---|---|
| Debian | `apt-get update`<br>`apt-get install` *`package_name`* |
| Red Hat | `yum install` *`package_name`* |

For example, to install the `emacs` text editor from an `apt` repository on a Debian system, we can use this command:

```
apt-get update; apt-get install emacs
```

### Installing a Package from a Package File

If a package file has been downloaded from a source other than a repository, it can be installed directly (though without dependency resolution) using a low-level tool (see Table 14-5).

**Table 14-5:** Low-Level Package Installation Commands

| Style | Command(s) |
|---|---|
| Debian | `dpkg -i` *`package_file`* |
| Red Hat | `rpm -i` *`package_file`* |

For example, if the *emacs-22.1-7.fc7-i386.rpm* package file had been downloaded from a non-repository site, it would be installed this way:

```
rpm -i emacs-22.1-7.fc7-i386.rpm
```

**NOTE** *Because this technique uses the low-level `rpm` program to perform the installation, no dependency resolution is performed. If `rpm` discovers a missing dependency, `rpm` will exit with an error.*

### Removing a Package

Packages can be uninstalled using either the high-level or low-level tools. Table 14-6 lists the high-level tools.

**Table 14-6:** Package Removal Commands

| Style | Command(s) |
|---|---|
| Debian | `apt-get remove` *`package_name`* |
| Red Hat | `yum erase` *`package_name`* |

For example, to uninstall the `emacs` package from a Debian-style system, we can use this command:

```
apt-get remove emacs
```

### Updating Packages from a Repository

The most common package management task is keeping the system up-to-date with the latest versions of packages. The high-level tools can perform this vital task in a single step (see Table 14-7).

**Table 14-7:** Package Update Commands

| Style | Command(s) |
|---|---|
| Debian | `apt-get update; apt-get upgrade` |
| Red Hat | `yum update` |

For example, to apply all available updates to the installed packages on a Debian-style system, we can use this command:

```
apt-get update; apt-get upgrade
```

### Upgrading a Package from a Package File

If an updated version of a package has been downloaded from a non-repository source, it can be installed, replacing the previous version (see Table 14-8).

**Table 14-8:** Low-Level Package Upgrade Commands

| Style | Command(s) |
|---|---|
| Debian | `dpkg -i` *`package_file`* |
| Red Hat | `rpm -U` *`package_file`* |

For example, to update an existing installation of `emacs` to the version contained in the package file *emacs-22.1-7.fc7-i386.rpm* on a Red Hat system, we can use this command:

```
rpm -U emacs-22.1-7.fc7-i386.rpm
```

**NOTE** *`dpkg` does not have a specific option for upgrading a package versus installing one as `rpm` does.*

### Listing Installed Packages

Table 14-9 lists the commands we can use to display a list of all the packages installed on the system.

**Table 14-9:** Package Listing Commands

| Style | Command(s) |
|---|---|
| Debian | `dpkg -l` |
| Red Hat | `rpm -qa` |

### Determining Whether a Package Is Installed

Table 14-10 lists the low-level tools we can use to display whether a specified package is installed.

**Table 14-10:** Package Status Commands

| Style | Command(s) |
|---|---|
| Debian | `dpkg -s` *`package_name`* |
| Red Hat | `rpm -q` *`package_name`* |

For example, to determine whether the `emacs` package is installed on a Debian-style system, we can use this:

```
dpkg -s emacs
```

### Displaying Information About an Installed Package

If the name of an installed package is known, we can use the commands in Table 14-11 to display a description of the package.

**Table 14-11:** Package Information Commands

| Style | Command(s) |
|---|---|
| Debian | `apt-cache show` *`package_name`* |
| Red Hat | `yum info` *`package_name`* |

For example, to see a description of the `emacs` package on a Debian-style system, we can use the following:

```
apt-cache show emacs
```

### *Finding Which Package Installed a File*

To determine what package is responsible for the installation of a particular file, we can use the commands in Table 14-12.

**Table 14-12:** Package File Identification Commands

| Style | Command(s) |
|---|---|
| Debian | `dpkg -S` *`file_name`* |
| Red Hat | `rpm -qf` *`file_name`* |

To see what package installed the `/usr/bin/vim` file on a Red Hat system, we can use the following:

```
rpm -qf /usr/bin/vim
```

## Summing Up

In the chapters that follow, we will explore many different programs covering a wide range of application areas. While most of these programs are commonly installed by default, we may need to install additional packages if the necessary programs are not already installed on our system. With our newfound knowledge (and appreciation) of package management, we should have no problem installing and managing the programs we need.

**THE LINUX SOFTWARE INSTALLATION MYTH**

People migrating from other platforms sometimes fall victim to the myth that software is somehow difficult to install under Linux and that the variety of packaging schemes used by different distributions is a hindrance. Well, it is a hindrance, but only to proprietary software vendors that want to distribute binary-only versions of their secret software.

The Linux software ecosystem is based on the idea of open source code. If a program developer releases source code for a program, it is likely that a person associated with a distribution will package the program and include it in their repository. This method ensures that the program is well integrated into

the distribution, and the user is given the convenience of "one-stop shopping" for software, rather than having to search for each program's website. Recently, major proprietary platform vendors have begun building application stores that mimic this idea.

Device drivers are handled in much the same way, except that instead of being separate items in a distribution's repository, they become part of the Linux kernel. Generally speaking, there is no such thing as a "driver disk" in Linux. Either the kernel supports a device or it doesn't, and the Linux kernel supports a lot of devices—many more, in fact, than Windows does. Of course, this is of no consolation if the particular device you need is not supported. When that happens, you need to look at the cause. A lack of driver support is usually caused by one of three things.

- **The device is too new.** Since many hardware vendors don't actively support Linux development, it falls upon a member of the Linux community to write the kernel driver code. This takes time.
- **The device is too exotic.** Not all distributions include every possible device driver. Each distribution builds its own kernels, and since kernels are configurable (which is what makes it possible to run Linux on everything from wristwatches to mainframes), they may have overlooked a particular device. By locating and downloading the source code for the driver, it is possible for you (yes, you) to compile and install the driver yourself. This process is not overly difficult, but it is rather involved. We'll talk about compiling software in a later chapter.
- **The hardware vendor is hiding something.** It has neither released source code for a Linux driver nor has it released the technical documentation for somebody to create one for them. This means the hardware vendor is trying to keep the programming interfaces to the device a secret. Because we don't want secret devices in our computers, it is best that you avoid such products.

# 15

# STORAGE MEDIA

In previous chapters, we looked at manipulating data at the file level. In this chapter, we will consider data at the device level.

Linux has amazing capabilities for handling storage devices, whether physical storage such as hard disks, network storage, or virtual storage devices such as RAID (Redundant Array of Independent Disks) and LVM (Logical Volume Manager).

However, because this is not a book about system administration, we will not try to cover this entire topic in depth. What we will try to do is introduce some of the concepts and key commands that are used to manage storage devices.

To carry out the exercises in this chapter, we will use a USB flash drive and a CD-RW disc (for systems equipped with a CD-ROM burner).

We will look at the following commands:

**mount** Mount a file system

**umount** Unmount a file system

**fsck** Check and repair a file system

**fdisk** Manipulate disk partition table

**mkfs** Create a file system

**dd** Convert and copy a file

**genisoimage (mkisofs)** Create an ISO 9660 image file

**wodim (cdrecord)** Write data to optical storage media

**md5sum** Calculate an MD5 checksum

## Mounting and Unmounting Storage Devices

Recent advances in the Linux desktop have made storage device management extremely easy for desktop users. For the most part, we attach a device to our system and it "just works." In the old days (say, 2004), this stuff had to be done manually. On non-desktop systems (i.e., servers) this is still a largely manual procedure since servers often have extreme storage needs and complex configuration requirements.

The first step in managing a storage device is attaching the device to the file system tree. This process, called *mounting*, allows the device to interact with the operating system. As we recall from Chapter 2, Unix-like operating systems (like Linux) maintain a single file system tree with devices attached at various points. This contrasts with other operating systems such as Windows that maintain separate file system trees for each device (for example `C:\`, `D:\`, etc.).

A file named */etc/fstab* (short for "file system table") lists the devices (typically hard disk partitions) that are to be mounted at boot time. Here is an example */etc/fstab* file from an early Fedora system:

```
LABEL=/12         /                    ext4    defaults        1 1
LABEL=/home       /home                ext4    defaults        1 2
LABEL=/boot       /boot                ext4    defaults        1 2
tmpfs             /dev/shm             tmpfs   defaults        0 0
devpts            /dev/pts             devpts  gid=5,mode=620  0 0
sysfs             /sys                 sysfs   defaults        0 0
proc              /proc                proc    defaults        0 0
LABEL=SWAP-sda3   swap                 swap    defaults        0 0
```

Most of the file systems listed in this example file are virtual and not applicable to our discussion. For our purposes, the interesting ones are the first three.

```
LABEL=/12         /                    ext4    defaults        1 1
LABEL=/home       /home                ext4    defaults        1 2
LABEL=/boot       /boot                ext4    defaults        1 2
```

These are the hard disk partitions. Each line of the file consists of six fields, as described in Table 15-1.

**Table 15-1:** */etc/fstab* Fields

| Field | Contents | Description |
|---|---|---|
| 1 | Device | Traditionally, this field contains the actual name of a device file associated with the physical device, such as */dev/sda1* (the first partition of the first detected hard disk). But with today's computers, which have many devices that are hot pluggable (like USB drives), many modern Linux distributions associate a device with a text label instead. This label (which is added to the storage media when it is formatted) can be either a simple text label or a randomly generated UUID (Universally Unique Identifier). This label is read by the operating system when the device is attached to the system. That way, no matter which device file is assigned to the actual physical device, it can still be correctly identified. |
| 2 | Mount point | The directory where the device is attached to the file system tree. |
| 3 | File system type | Linux allows many file system types to be mounted. Most native Linux file systems are Fourth Extended File System (`ext4`), but many others are supported, such as FAT16 (`msdos`), FAT32 (`vfat`), NTFS (`ntfs`), CD-ROM (`iso9660`), etc. |
| 4 | Options | File systems can be mounted with various options. It is possible, for example, to mount file systems as read-only or to prevent any programs from being executed from them (a useful security feature for removable media). |
| 5 | Frequency | A single number that specifies if and when a file system is to be backed up with the `dump` command. |
| 6 | Order | A single number that specifies in what order file systems should be checked with the `fsck` command. |

## *Viewing a List of Mounted File Systems*

The `mount` command is used to mount file systems. Entering the command without arguments will display a list of the file systems currently mounted.

```
[me@linuxbox ~]$ mount
/dev/sda2 on / type ext4 (rw)
proc on /proc type proc (rw)
sysfs on /sys type sysfs (rw)
devpts on /dev/pts type devpts (rw,gid=5,mode=620)
/dev/sda5 on /home type ext4 (rw)
/dev/sda1 on /boot type ext4 (rw)
tmpfs on /dev/shm type tmpfs (rw)
none on /proc/sys/fs/binfmt_misc type binfmt_misc (rw)
```

```
sunrpc on /var/lib/nfs/rpc_pipefs type rpc_pipefs (rw)
fusectl on /sys/fs/fuse/connections type fusectl (rw)
/dev/sdd1 on /media/disk type vfat (rw,nosuid,nodev,noatime,
uhelper=hal,uid=500,utf8,shortname=lower)
twin4:/musicbox on /misc/musicbox type nfs4 (rw,addr=192.168.1.4)
```

The format of the listing is as follows: *device on mount_point type filesystem_type (options)*. For example, the first line shows that device */dev/sda2* is mounted as the root file system, is of type ext4, and is both readable and writable (the option `rw`). This listing also has two interesting entries at the bottom of the list. The next-to-last entry shows a 2GB SD memory card in a card reader mounted at */media/disk*, and the last entry is a network drive mounted at */misc/musicbox*.

For our first experiment, we will work with a CD-ROM. First, let's look at a system before a CD-ROM is inserted.

```
[me@linuxbox ~]$ mount
/dev/mapper/VolGroup00-LogVol00 on / type ext4 (rw)
proc on /proc type proc (rw)
sysfs on /sys type sysfs (rw)
devpts on /dev/pts type devpts (rw,gid=5,mode=620)
/dev/sda1 on /boot type ext4 (rw)
tmpfs on /dev/shm type tmpfs (rw)
none on /proc/sys/fs/binfmt_misc type binfmt_misc (rw)
sunrpc on /var/lib/nfs/rpc_pipefs type rpc_pipefs (rw)
```

This listing is from a CentOS system, which is using LVM (Logical Volume Manager) to create its root file system. Like many modern Linux distributions, this system will attempt to automatically mount the CD-ROM after insertion. After we insert the disc, we see the following:

```
[me@linuxbox ~]$ mount
/dev/mapper/VolGroup00-LogVol00 on / type ext4 (rw)
proc on /proc type proc (rw)
sysfs on /sys type sysfs (rw)
devpts on /dev/pts type devpts (rw,gid=5,mode=620)
/dev/hda1 on /boot type ext4 (rw)
tmpfs on /dev/shm type tmpfs (rw)
none on /proc/sys/fs/binfmt_misc type binfmt_misc (rw)
sunrpc on /var/lib/nfs/rpc_pipefs type rpc_pipefs (rw)
/dev/sdc on /media/live-1.0.10-8 type iso9660 (ro,noexec,nosuid,nodev,uid=500)
```

After we insert the disc, we see the same listing as before with one additional entry. At the end of the listing we see that the CD-ROM (which is device */dev/sdc* on this system) has been mounted on */media/live-1.0.10-8* and is type `iso9660` (a CD-ROM). For the purposes of our experiment, we're interested in the name of the device. When you conduct this experiment yourself, the device name will most likely be different.

**WARNING** *In the examples that follow, it is vitally important that you pay close attention to the actual device names in use on your system and* ***do not use the names used in this text!*** *Also note that audio CDs are not the same as CD-ROMs. Audio CDs do not contain file systems and thus cannot be mounted in the usual sense.*

Now that we have the device name of the CD-ROM drive, let's unmount the disc and remount it at another location in the file system tree. To do this, we become the superuser (using the command appropriate for our system) and unmount the disc with the `umount` (notice the spelling) command.

```
[me@linuxbox ~]$ su -
Password:
[root@linuxbox ~]# umount /dev/sdc
```

The next step is to create a new *mount point* for the disk. A mount point is simply a directory somewhere on the file system tree. There's nothing special about it. It doesn't even have to be an empty directory, though if you mount a device on a non-empty directory, you will not be able to see the directory's previous contents until you unmount the device. For our purposes, we will create a new directory.

```
[root@linuxbox ~]# mkdir /mnt/cdrom
```

Finally, we mount the CD-ROM at the new mount point. The `-t` option is used to specify the file system type.

```
[root@linuxbox ~]# mount -t iso9660 /dev/sdc /mnt/cdrom
```

Afterward, we can examine the contents of the CD-ROM via the new mount point.

```
[root@linuxbox ~]# cd /mnt/cdrom
[root@linuxbox cdrom]# ls
```

Notice what happens when we try to unmount the CD-ROM.

```
[root@linuxbox cdrom]# umount /dev/sdc
umount: /mnt/cdrom: device is busy
```

Why is this? The reason is that we cannot unmount a device if the device is being used by someone or some process. In this case, we changed our working directory to the mount point for the CD-ROM, which causes the device to be busy. We can easily remedy the issue by changing the working directory to something other than the mount point.

```
[root@linuxbox cdrom]# cd
[root@linuxbox ~]# umount /dev/hdc
```

Now the device unmounts successfully.

**WHY UNMOUNTING IS IMPORTANT**

If you look at the output of the `free` command, which displays statistics about memory usage, you will see a statistic called *buffers*. Computer systems are designed to go as fast as possible. One of the impediments to system speed is slow devices. Printers are a good example. Even the fastest printer is extremely slow by computer standards. A computer would be very slow indeed if it had to stop and wait for a printer to finish printing a page. In the early days of PCs (before multitasking), this was a real problem. If you were working on a spreadsheet or text document, the computer would stop and become unavailable every time you printed. The computer would send the data to the printer as fast as the printer could accept it, but it was very slow because printers don't print very fast. This problem was solved by the advent of the *printer buffer*, a device containing some RAM memory that would sit between the computer and the printer. With the printer buffer in place, the computer would send the printer output to the buffer, and it would quickly be stored in the fast RAM so the computer could go back to work without waiting. Meanwhile, the printer buffer would slowly *spool* the data to the printer from the buffer's memory at the speed at which the printer could accept it.

This idea of buffering is used extensively in computers to make them faster. Don't let the need to occasionally read or write data to or from slow devices impede the speed of the system. Operating systems store data that has been read from and is to be written to storage devices in memory for as long as possible before actually having to interact with the slower device. On a Linux system, for example, you will notice that the system seems to fill up memory the longer it is used. This does not mean Linux is "using" all the memory; it means that Linux is taking advantage of all the available memory to do as much buffering as it can.

This buffering allows writing to storage devices to be done very quickly because writing to the physical device is being deferred to a future time. In the meantime, the data destined for the device is piling up in memory. From time to time, the operating system will write this data to the physical device.

Unmounting a device entails writing all the remaining data to the device so that it can be safely removed. If the device is removed without unmounting it first, the possibility exists that not all the data destined for the device has been transferred. In some cases, this data may include vital directory updates, which will lead to *file system corruption*, one of the worst things that can happen on a computer.

## Determining Device Names

It's sometimes difficult to determine the name of a device. In the old days, it wasn't very hard. A device was always in the same place, and it didn't change. Unix-like systems like it that way. When Unix was developed, "changing a disk drive" involved using a forklift to remove a washing

machine–sized device from the computer room. In recent years, the typical desktop hardware configuration has become quite dynamic, and Linux has evolved to become more flexible than its ancestors.

In the examples in the previous section, we took advantage of the modern Linux desktop's capability to "automagically" mount the device and then determine the name after the fact. But what if we are managing a server or some other environment where this does not occur? How can we figure it out?

First, let's look at how the system names devices. If we list the contents of the */dev* directory (where all devices live), we can see that there are lots and lots of devices.

```
[me@linuxbox ~]$ ls /dev
```

The contents of this listing reveal some patterns of device naming. Table 15-2 outlines a few of these patterns.

**Table 15-2:** Linux Storage Device Names

| Pattern | Device |
|---|---|
| */dev/fd** | Floppy disk drives. |
| */dev/hd** | IDE (PATA) disks on older systems. Typical motherboards contain two IDE connectors or *channels*, each with a cable with two attachment points for drives. The first drive on the cable is called the *master* device, and the second is called the slave device. The device names are ordered such that */dev/hda* refers to the master device on the first channel, */dev/hdb* is the slave device on the first channel; */dev/hdc* is the master device on the second channel, and so on. A trailing digit indicates the partition number on the device. For example, */dev/hda1* refers to the first partition on the first hard drive on the system, while */dev/hda* refers to the entire drive. |
| */dev/lp** | Printers. |
| */dev/sd** | SCSI disks. On modern Linux systems, the kernel treats all disk-like devices (including PATA/SATA hard disks, flash drives, and USB mass storage devices such as portable music players and digital cameras) as SCSI disks. The rest of the naming system is similar to the older */dev/hd** naming scheme previously described. |
| */dev/sr** | Optical drives (CD/DVD readers and burners). |

In addition, we often see symbolic links such as */dev/cdrom*, */dev/dvd*, and */dev/floppy*, which point to the actual device files, provided as a convenience.

If you are working on a system that does not automatically mount removable devices, you can use the following technique to determine how the removable device is named when it is attached. First, start a real-time view of the */var/log/messages* or */var/log/syslog* file (you may require superuser privileges for this).

```
[me@linuxbox ~]$ sudo tail -f /var/log/messages
```

The last few lines of the file will be displayed and then will pause. Next, plug in the removable device. In this example, we will use a 16MB flash drive. Almost immediately, the kernel will notice the device and probe it.

```
Jul 23 10:07:53 linuxbox kernel: usb 3-2: new full speed USB device using uhci_hcd and address 2
Jul 23 10:07:53 linuxbox kernel: usb 3-2: configuration #1 chosen from 1 choice
Jul 23 10:07:53 linuxbox kernel: scsi3 : SCSI emulation for USB Mass Storage devices
Jul 23 10:07:58 linuxbox kernel: scsi scan: INQUIRY result too short (5), using 36
Jul 23 10:07:58 linuxbox kernel: scsi 3:0:0:0: Direct-Access   Easy   Disk   .00 PQ: 0 ANSI: 2
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] 31263 512-byte hardware sectors (16 MB)
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] Write Protect is off
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] Assuming drive cache: write through
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] 31263 512-byte hardware sectors (16 MB)
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] Write Protect is off
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] Assuming drive cache: write through
Jul 23 10:07:59 linuxbox kernel:  sdb: sdb1
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] Attached SCSI removable disk
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: Attached scsi generic sg3 type 0
```

After the display pauses again, press CTRL-C to get the prompt back. The interesting parts of the output are the repeated references to `[sdb]`, which matches our expectation of a SCSI disk device name. Knowing this, these two lines become particularly illuminating:

```
Jul 23 10:07:59 linuxbox kernel:  sdb: sdb1
Jul 23 10:07:59 linuxbox kernel: sd 3:0:0:0: [sdb] Attached SCSI removable disk
```

This tells us the device name is */dev/sdb* for the entire device and */dev/sdb1* for the first partition on the device. As we have seen, working with Linux is full of interesting detective work!

**TIP** *Using the `tail -f /var/log/messages` technique is a great way to watch what the system is doing in near real-time.*

With our device name in hand, we can now mount the flash drive.

```
[me@linuxbox ~]$ sudo mkdir /mnt/flash
[me@linuxbox ~]$ sudo mount /dev/sdb1 /mnt/flash
[me@linuxbox ~]$ df
Filesystem           1K-blocks      Used Available Use% Mounted on
/dev/sda2             15115452   5186944   9775164  35% /
/dev/sda5             59631908  31777376  24776480  57% /home
/dev/sda1               147764     17277    122858  13% /boot
tmpfs                   776808         0    776808   0% /dev/shm
/dev/sdb1                15560         0     15560   0% /mnt/flash
```

The device name will remain the same as long as it remains physically attached to the computer and the computer is not rebooted.

## Creating New File Systems

Suppose that we want to reformat the flash drive with a Linux native file system, rather than the FAT32 system it has now. This involves two steps.

1. (optional) Create a new partition layout if the existing one is not to our liking.
2. Create a new, empty file system on the drive.

**WARNING** *In the following exercise, we are going to format a flash drive. Use a drive that contains nothing you care about because it will be erased! Again,* ***make absolutely sure you are specifying the correct device name for your system, not the one shown in the text. Failure to heed this warning could result in you formatting (i.e., erasing) the wrong drive!***

### *Manipulating Partitions with fdisk*

`fdisk` is one of a host of available programs (both command line and graphical) that allows us to interact directly with disk-like devices (such as hard disk drives and flash drives) at a very low level. With this tool we can edit, delete, and create partitions on the device. To work with our flash drive, we must first unmount it (if needed) and then invoke the `fdisk` program as follows:

```
[me@linuxbox ~]$ sudo umount /dev/sdb1
[me@linuxbox ~]$ sudo fdisk /dev/sdb
```

Notice that we must specify the device in terms of the entire device, not by partition number. After the program starts up, we will see the following prompt:

```
Command (m for help):
```

Entering an `m` will display the program menu.

```
Command action
   a   toggle a bootable flag
   b   edit bsd disklabel
   c   toggle the dos compatibility flag
   d   delete a partition
   l   list known partition types
   m   print this menu
   n   add a new partition
   o   create a new empty DOS partition table
   p   print the partition table
   q   quit without saving changes
   s   create a new empty Sun disklabel
   t   change a partition's system id
   u   change display/entry units
   v   verify the partition table
```

```
   w   write table to disk and exit
   x   extra functionality (experts only)


Command (m for help):
```

The first thing we want to do is examine the existing partition layout. We do this by entering p to print the partition table for the device.

```
Command (m for help): p

Disk /dev/sdb: 16 MB, 16006656 bytes
1 heads, 31 sectors/track, 1008 cylinders
Units = cylinders of 31 * 512 = 15872 bytes

   Device Boot      Start         End      Blocks   Id  System
/dev/sdb1               2        1008       15608+   b  W95 FAT32
```

In this example, we see a 16MB device with a single partition (1) that uses 1,006 of the available 1,008 cylinders on the device. The partition is identified as a Windows 95 FAT32 partition. Some programs will use this identifier to limit the kinds of operations that can be done to the disk, but most of the time it is not critical to change it. However, in the interest of this demonstration, we will change it to indicate a Linux partition. To do this, we must first find out what ID is used to identify a Linux partition. In the previous listing, we see that the ID b is used to specify the existing partition. To see a list of the available partition types, we refer to the program menu. There we can see the following choice:

```
   l   list known partition types
```

If we enter l at the prompt, a large list of possible types is displayed. Among them we see b for our existing partition type and 83 for Linux.

Going back to the menu, we see this choice to change a partition ID:

```
   t   change a partition's system id
```

We enter t at the prompt and enter the new ID.

```
Command (m for help): t
Selected partition 1
Hex code (type L to list codes): 83
Changed system type of partition 1 to 83 (Linux)
```

This completes all the changes we need to make. Up to this point, the device has been untouched (all the changes have been stored in memory, not on the physical device), so we will write the modified partition table to the device and exit. To do this, we enter w at the prompt.

```
Command (m for help): w
The partition table has been altered!

Calling ioctl() to re-read partition table.

WARNING: If you have created or modified any DOS 6.x
partitions, please see the fdisk manual page for additional
information.
Syncing disks.
[me@linuxbox ~]$
```

If we had decided to leave the device unaltered, we could have entered q at the prompt, which would have exited the program without writing the changes. We can safely ignore the ominous-sounding warning message.

### *Creating a New File System with mkfs*

With our partition editing done (lightweight though it might have been), it's time to create a new file system on our flash drive. To do this, we will use mkfs (short for "make file system"), which can create file systems in a variety of formats. To create an ext4 file system on the device, we use the -t option to specify the "ext4" system type, followed by the name of the device containing the partition we want to format.

```
[me@linuxbox ~]$ sudo mkfs -t ext4 /dev/sdb1
mke2fs 2.23.2 (12-Jul-2011)
Filesystem label=
OS type: Linux
Block size=1024 (log=0)
Fragment size=1024 (log=0)
3904 inodes, 15608 blocks
780 blocks (5.00%) reserved for the super user
First data block=1
Maximum filesystem blocks=15990784
2 block groups
8192 blocks per group, 8192 fragments per group
1952 inodes per group
Superblock backups stored on blocks:
    8193

Writing inode tables: done
Creating journal (1024 blocks): done
Writing superblocks and filesystem accounting information: done

This filesystem will be automatically checked every 34 mounts or
180 days, whichever comes first. Use tune2fs -c or -i to override.
[me@linuxbox ~]$
```

The program will display a lot of information when ext4 is the chosen file system type. To reformat the device to its original FAT32 file system, specify vfat as the file system type.

```
[me@linuxbox ~]$ sudo mkfs -t vfat /dev/sdb1
```

This process of partitioning and formatting can be used anytime additional storage devices are added to the system. While we worked with a tiny flash drive, the same process can be applied to internal hard disks and other removable storage devices like USB hard drives.

## Testing and Repairing File Systems

In our earlier discussion of the */etc/fstab* file, we saw some mysterious digits at the end of each line. Each time the system boots, it routinely checks the integrity of the file systems before mounting them. This is done by the `fsck` program (short for "file system check"). The last number in each *fstab* entry specifies the order in which the devices are to be checked. In our previous example, we see that the root file system is checked first, followed by the *home* and *boot* file systems. Devices with a zero as the last digit are not routinely checked.

In addition to checking the integrity of file systems, `fsck` can also repair corrupt file systems with varying degrees of success, depending on the amount of damage. On Unix-like file systems, recovered portions of files are placed in the *lost+found* directory, located in the root of each file system.

To check our flash drive (which should be unmounted first), we could do the following:

```
[me@linuxbox ~]$ sudo fsck /dev/sdb1
fsck 1.40.8 (13-Mar-2016)
e2fsck 1.40.8 (13-Mar-2016)
/dev/sdb1: clean, 11/3904 files, 1661/15608 blocks
```

These days, file system corruption is quite rare unless there is a hardware problem, such as a failing disk drive. On most systems, file system corruption detected at boot time will cause the system to stop and direct you to run `fsck` before continuing.

**WHAT THE FSCK?**

In Unix culture, the word *fsck* is often used in place of a popular word with which it shares three letters. This is especially appropriate, given that you will probably be uttering the aforementioned word if you find yourself in a situation where you are forced to run `fsck`.

## Moving Data Directly to and from Devices

While we usually think of data on our computers as being organized into files, it is also possible to think of the data in "raw" form. If we look at a disk drive, for example, we see that it consists of a large number of "blocks" of data that the operating system sees as directories and files. However, if we could treat a disk drive as simply a large collection of data blocks, we could perform useful tasks, such as cloning devices.

The `dd` program performs this task. It copies blocks of data from one place to another. It uses a unique syntax (for historical reasons) and is usually used this way:

```
dd if=input_file of=output_file [bs=block_size [count=blocks]]
```

**WARNING** *The `dd` command is very powerful. Though its name derives from "data definition," it is sometimes called "destroy disk" because users often mistype either the `if` or `of` specification.* ***Always double-check your input and output specifications before pressing*** *ENTER****!***

Let's say we had two USB flash drives of the same size and we wanted to exactly copy the first drive to the second. If we attached both drives to the computer and they are assigned to devices */dev/sdb* and */dev/sdc*, respectively, we could copy everything on the first drive to the second drive with the following:

```
dd if=/dev/sdb of=/dev/sdc
```

Alternately, if only the first device were attached to the computer, we could copy its contents to an ordinary file for later restoration or copying.

```
dd if=/dev/sdb of=flash_drive.img
```

### Creating CD-ROM Images

Writing a recordable CD-ROM (either a CD-R or CD-RW) consists of two steps.

1. Constructing an *ISO image file* that is the exact file system image of the CD-ROM
2. Writing the image file onto the CD-ROM media

### Creating an Image Copy of a CD-ROM

If we want to make an ISO image of an existing CD-ROM, we can use `dd` to read all the data blocks off the CD-ROM and copy them to a local file. Say we had an Ubuntu CD and we wanted to make an ISO file that we could

later use to make more copies. After inserting the CD and determining its device name (we'll assume */dev/cdrom*), we can make the ISO file like so:

```
dd if=/dev/cdrom of=ubuntu.iso
```

This technique works for data DVDs as well but will not work for audio CDs, as they do not use a file system for storage. For audio CDs, look at the `cdrdao` command.

### *Creating an Image from a Collection of Files*

To create an ISO image file containing the contents of a directory, we use the `genisoimage` program. To do this, we first create a directory containing all the files we want to include in the image and then execute the `genisoimage` command to create the image file. For example, if we had created a directory called *~/cd-rom-files* and filled it with files for our CD-ROM, we could create an image file named *cd-rom.iso* with the following command:

```
genisoimage -o cd-rom.iso -R -J ~/cd-rom-files
```

The `-R` option adds metadata for the *Rock Ridge extensions*, which allows the use of long filenames and POSIX-style file permissions. Likewise, the `-J` option enables the *Joliet extensions*, which permit long filenames for Windows.

**A PROGRAM BY ANY OTHER NAME . . .**

If you look at online tutorials for creating and burning optical media like CD-ROMs and DVDs, you will frequently encounter two programs called `mkisofs` and `cdrecord`. These programs were part of a popular package called `cdrtools` authored by Jörg Schilling. In the summer of 2006, Mr. Schilling made a license change to a portion of the `cdrtools` package, which, in the opinion of many in the Linux community, created a license incompatibility with the GNU GPL. As a result, a *fork* of the `cdrtools` project was started that now includes replacement programs for `cdrecord` and `mkisofs` named `wodim` and `genisoimage`, respectively.

## Writing CD-ROM Images

After we have an image file, we can burn it onto our optical media. Most of the commands we will discuss in the sections that follow can be applied to both recordable CD-ROM and DVD media.

### Mounting an ISO Image Directly

There is a trick that we can use to mount an ISO image while it is still on our hard disk and treat it as though it were already on optical media. By adding the `-o loop` option to `mount` (along with the required `-t iso9660` file system type), we can mount the image file as though it were a device and attach it to the file system tree.

```
mkdir /mnt/iso_image
mount -t iso9660 -o loop image.iso /mnt/iso_image
```

In this example, we created a mount point named */mnt/iso_image* and then mounted the image file *image.iso* at that mount point. After the image is mounted, it can be treated just as though it were a real CD-ROM or DVD. *Remember to unmount the image when it is no longer needed.*

### Blanking a Rewritable CD-ROM

Rewritable CD-RW media needs to be erased or *blanked* before it can be reused. To do this, we can use `wodim`, specifying the device name for the CD writer and the type of blanking to be performed. The `wodim` program offers several types. The most minimal (and fastest) is the "fast" type.

```
wodim dev=/dev/cdrw blank=fast
```

### Writing an Image

To write an image, we again use `wodim`, specifying the name of the optical media writer device and the name of the image file.

```
wodim dev=/dev/cdrw image.iso
```

In addition to the device name and image file, `wodim` supports a large set of options. Two common ones are `-v` for verbose output, and `-dao`, which writes the disc in *disc-at-once* mode. This mode should be used if you are preparing a disc for commercial reproduction. The default mode for `wodim` is *track-at-once*, which is useful for recording music tracks.

## Summing Up

In this chapter, we looked at the basic storage management tasks. There are, of course, many more. Linux supports a vast array of storage devices and file system schemes. It also offers many features for interoperability with other systems.

## Extra Credit

It's often useful to verify the integrity of an ISO image that we have downloaded. In most cases, a distributor of an ISO image will also supply a *checksum file*. A checksum is the result of an exotic mathematical calculation resulting in a number that represents the content of the target file. If the contents of the file change by even one bit, the resulting checksum will be much different. The most common method of checksum generation uses the `md5sum` program. When you use `md5sum`, it produces a unique hexadecimal number.

```
md5sum image.iso
34e354760f9bb7fbf85c96f6a3f94ece  image.iso
```

After you download an image, you should run `md5sum` against it and compare the results with the `md5sum` value supplied by the publisher.

In addition to checking the integrity of a downloaded file, we can use `md5sum` to verify newly written optical media. To do this, we first calculate the checksum of the image file and then calculate a checksum for the media. The trick to verifying the media is to limit the calculation to only the portion of the optical media that contains the image. We do this by determining the number of 2,048-byte blocks the image contains (optical media is always written in 2,048-byte blocks) and reading that many blocks from the media. On some types of media, this is not required. CD-R and CD-RW disks written in disc-at-once mode can be checked this way.

```
md5sum /dev/cdrom
34e354760f9bb7fbf85c96f6a3f94ece  /dev/cdrom
```

Many types of media, such as DVDs, require a precise calculation of the number of blocks. In the following example, we check the integrity of the image file *dvd-image.iso* and the disc in the DVD reader */dev/dvd*. Can you figure out how this works?

```
md5sum dvd-image.iso; dd if=/dev/dvd bs=2048 count=$(( $(stat -c "%s" dvd-image.iso) / 2048 ))
| md5sum
```

# 16

# NETWORKING

When it comes to networking, there is probably nothing that cannot be done with Linux. Linux is used to build all sorts of networking systems and appliances, including firewalls, routers, name servers, network-attached storage (NAS) boxes, and on and on.

Just as the subject of networking is vast, so are the number of commands that can be used to configure and control it. We will focus our attention on just a few of the most frequently used ones. The commands chosen for examination include those used to monitor networks and those used to transfer files. In addition, we are going to explore the `ssh` program that is used to perform remote logins. This chapter will cover the following commands:

**`ping`** Send an ICMP ECHO_REQUEST to network hosts

**`traceroute`** Print the route packets trace to a network host

**`ip`** Show/manipulate routing, devices, policy routing, and tunnels

**netstat** Print network connections, routing tables, interface statistics, masquerade connections, and multicast memberships

**ftp** Internet file transfer program

**wget** Non-interactive network downloader

**ssh** OpenSSH SSH client (remote login program)

We're going to assume a little background in networking. In this, the Internet age, everyone using a computer needs a basic understanding of networking concepts. To make full use of this chapter, we should be familiar with the following terms:

- Internet Protocol (IP) address
- Host and domain name
- Uniform Resource Identifier (URI)

**NOTE** *Some of the commands we will cover may (depending on your distribution) require the installation of additional packages from your distribution's repositories, and some may require superuser privileges to execute.*

## Examining and Monitoring a Network

Even if you're not the system administrator, it's often helpful to examine the performance and operation of a network.

### *ping*

The most basic network command is `ping`. The `ping` command sends a special network packet called an ICMP ECHO_REQUEST to a specified host. Most network devices receiving this packet will reply to it, allowing the network connection to be verified.

**NOTE** *It is possible to configure most network devices (including Linux hosts) to ignore these packets. This is usually done for security reasons to partially obscure a host from a potential attacker. It is also common for firewalls to be configured to block ICMP traffic.*

For example, to see whether we can reach *linuxcommand.org* (one of our favorite sites), we can use `ping` like this:

```
[me@linuxbox ~]$ ping linuxcommand.org
```

Once started, `ping` continues to send packets at a specified interval (the default is one second) until it is interrupted.

```
[me@linuxbox ~]$ ping linuxcommand.org
PING linuxcommand.org (66.35.250.210) 56(84) bytes of data.
64 bytes from vhost.sourceforge.net (66.35.250.210): icmp_seq=1 ttl=43 time=107 ms
64 bytes from vhost.sourceforge.net (66.35.250.210): icmp_seq=2 ttl=43 time=108 ms
64 bytes from vhost.sourceforge.net (66.35.250.210): icmp_seq=3 ttl=43 time=106 ms
```

```
64 bytes from vhost.sourceforge.net (66.35.250.210): icmp_seq=4 ttl=43 time=106 ms
64 bytes from vhost.sourceforge.net (66.35.250.210): icmp_seq=5 ttl=43 time=105 ms
64 bytes from vhost.sourceforge.net (66.35.250.210): icmp_seq=6 ttl=43 time=107 ms

--- linuxcommand.org ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 6010ms
rtt min/avg/max/mdev = 105.647/107.052/108.118/0.824 ms
```

After it is interrupted (in this case after the sixth packet) by pressing CTRL-C, ping prints performance statistics. A properly performing network will exhibit 0 percent packet loss. A successful "ping" will indicate that the elements of the network (its interface cards, cabling, routing, and gateways) are in generally good working order.

### traceroute

The traceroute program (some systems use the similar tracepath program instead) lists all the "hops" network traffic takes to get from the local system to a specified host. For example, to see the route taken to reach *slashdot.org*, we would do this:

```
[me@linuxbox ~]$ traceroute slashdot.org
```

The output looks like this:

```
traceroute to slashdot.org (216.34.181.45), 30 hops max, 40 byte packets
 1  ipcop.localdomain (192.168.1.1)  1.066 ms  1.366 ms  1.720 ms
 2  * * *
 3  ge-4-13-ur01.rockville.md.bad.comcast.net (68.87.130.9)  14.622 ms  14.885 ms  15.169 ms
 4  po-30-ur02.rockville.md.bad.comcast.net (68.87.129.154)  17.634 ms  17.626 ms  17.899 ms
 5  po-60-ur03.rockville.md.bad.comcast.net (68.87.129.158)  15.992 ms  15.983 ms  16.256 ms
 6  po-30-ar01.howardcounty.md.bad.comcast.net (68.87.136.5)  22.835 ms  14.233 ms  14.405 ms
 7  po-10-ar02.whitemarsh.md.bad.comcast.net (68.87.129.34)  16.154 ms  13.600 ms  18.867 ms
 8  te-0-3-0-1-cr01.philadelphia.pa.ibone.comcast.net (68.86.90.77)  21.951 ms  21.073 ms
21.557 ms
 9  pos-0-8-0-0-cr01.newyork.ny.ibone.comcast.net (68.86.85.10)  22.917 ms  21.884 ms
22.126 ms
10  204.70.144.1 (204.70.144.1)  43.110 ms  21.248 ms  21.264 ms
11  cr1-pos-0-7-3-1.newyork.savvis.net (204.70.195.93)  21.857 ms cr2-pos-0-0-3-1.newyork.
savvis.net (204.70.204.238)  19.556 ms cr1-pos-0-7-3-1.newyork.savvis.net (204.70.195.93)
19.634 ms
12  cr2-pos-0-7-3-0.chicago.savvis.net (204.70.192.109)  41.586 ms  42.843 ms cr2-
tengig-0-0-2-0.chicago.savvis.net (204.70.196.242)  43.115 ms
13  hr2-tengigabitethernet-12-1.elkgrovech3.savvis.net (204.70.195.122)  44.215 ms  41.833 ms
45.658 ms
14  csr1-ve241.elkgrovech3.savvis.net (216.64.194.42)  46.840 ms  43.372 ms  47.041 ms
15  64.27.160.194 (64.27.160.194)  56.137 ms  55.887 ms  52.810 ms
16  slashdot.org (216.34.181.45)  42.727 ms  42.016 ms  41.437 ms
```

In the output, we can see that connecting from our test system to *slashdot.org* requires traversing 16 routers. For routers that provided identifying information, we see their hostnames, IP addresses, and performance

data, which includes three samples of round-trip time from the local system to the router. For routers that do not provide identifying information (because of router configuration, network congestion, firewalls, etc.), we see asterisks as in the line for hop number 2. In cases where routing information is blocked, we can sometimes overcome this by adding either the `-T` or `-I` option to the `traceroute` command.

### ip

The `ip` program is a multipurpose network configuration tool that makes use of the full range of networking features available in modern Linux kernels. It replaces the earlier and now deprecated `ifconfig` program. With `ip`, we can examine a system's network interfaces and routing table.

```
[me@linuxbox ~]$ ip a
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group
default
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc pfifo_fast state UP
group default qlen 1000
    link/ether ac:22:0b:52:cf:84 brd ff:ff:ff:ff:ff:ff
    inet 192.168.1.14/24 brd 192.168.1.255 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::ae22:bff:fe52:cf84/64 scope link
       valid_lft forever preferred_lft forever
```

In the preceding example, we see that our test system has two network interfaces. The first, called `lo`, is the *loopback interface*, a virtual interface that the system uses to "talk to itself," and the second, called `eth0`, is the Ethernet interface.

When performing casual network diagnostics, the important things to look for are the presence of the word *UP* in the first line for each interface, indicating that the network interface is enabled, and the presence of a valid IP address in the `inet` field on the third line. For systems using Dynamic Host Configuration Protocol (DHCP), a valid IP address in this field will verify that the DHCP is working.

### netstat

The `netstat` program is used to examine various network settings and statistics. Through the use of its many options, we can look at a variety of features in our network setup. Using the `-ie` option, we can examine the network interfaces in our system.

```
[me@linuxbox ~]$ netstat -ie
eth0    Link encap:Ethernet  HWaddr 00:1d:09:9b:99:67
```

```
          inet addr:192.168.1.2 Bcast:192.168.1.255 Mask:255.255.255.0
          inet6 addr: fe80::21d:9ff:fe9b:9967/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:238488 errors:0 dropped:0 overruns:0 frame:0
          TX packets:403217 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:100
          RX bytes:153098921 (146.0 MB)  TX bytes:261035246 (248.9 MB)
          Memory:fdfc0000-fdfe0000

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:16436  Metric:1
          RX packets:2208 errors:0 dropped:0 overruns:0 frame:0
          TX packets:2208 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:111490 (108.8 KB)  TX bytes:111490 (108.8 KB)
```

Using the `-r` option will display the kernel's network routing table. This shows how the network is configured to send packets from network to network:

```
[me@linuxbox ~]$ netstat -r
Kernel IP routing table
Destination  Gateway     Genmask       Flags   MSS Window  irtt Iface
192.168.1.0  *           255.255.255.0 U       0   0       0    eth0
default      192.168.1.1 0.0.0.0       UG      0   0       0    eth0
```

In this simple example, we see a typical routing table for a client machine on a local area network (LAN) behind a firewall/router. The first line of the listing shows the destination `192.168.1.0`. IP addresses that end in zero refer to networks rather than individual hosts, so this destination means any host on the LAN. The next field, `Gateway`, is the name or IP address of the gateway (router) used to go from the current host to the destination network. An asterisk in this field indicates that no gateway is needed.

The last line contains the destination `default`. This means any traffic destined for a network that is not otherwise listed in the table. In our example, we see that the gateway is defined as a router with the address of `192.168.1.1`, which presumably knows what to do with the destination traffic.

Like `ip`, the `netstat` program has many options, and we have looked only at a couple. Check out the `ip` and `netstat` man pages for a complete list.

## Transporting Files over a Network

What good is a network unless we can move files across it? There are many programs that move data over networks. We will cover two of them now and several more in later sections.

## ftp

One of the true "classic" programs, `ftp` gets its name from the protocol it uses, the *File Transfer Protocol*. FTP was once the most widely used method of downloading files over the Internet. Most, if not all, web browsers support it, and you often see URIs starting with the protocol `ftp://`.

Before there were web browsers, there was the `ftp` program. `ftp` is used to communicate with *FTP servers*, machines that contain files that can be uploaded and downloaded over a network.

FTP (in its original form) is not secure because it sends account names and passwords in *cleartext*. This means they are not encrypted, and anyone *sniffing* the network can see them. Because of this, almost all FTP done over the Internet is done by *anonymous FTP servers*. An anonymous server allows anyone to log in using the login name "anonymous" and a meaningless password.

In the example that follows, we show a typical session with the `ftp` program downloading an Ubuntu iso image located in the */pub/cd_images/ubuntu-18.04* directory of the anonymous FTP server *fileserver*:

```
[me@linuxbox ~]$ ftp fileserver
Connected to fileserver.localdomain.
220 (vsFTPd 2.0.1)
Name (fileserver:me): anonymous
331 Please specify the password.
Password:
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> cd pub/cd_images/ubuntu-18.04
250 Directory successfully changed.
ftp> ls
200 PORT command successful. Consider using PASV.
150 Here comes the directory listing.
-rw-rw-r--    1 500      500      733079552 Apr 25 03:53 ubuntu-18.04-desktop-amd64.iso
226 Directory send OK.
ftp> lcd Desktop
Local directory now /home/me/Desktop
ftp> get ubuntu-18.04-desktop-amd64.iso
local: ubuntu-18.04-desktop-amd64.iso remote: ubuntu-18.04-desktop-amd64.iso
200 PORT command successful. Consider using PASV.
150 Opening BINARY mode data connection for ubuntu-18.04-desktop-amd64.iso (733079552 bytes).
226 File send OK.
733079552 bytes received in 68.56 secs (10441.5 kB/s)
ftp> bye
```

Table 16-1 provides an explanation of the commands entered during this session.

**Table 16-1:** Examples of Interactive ftp Commands

| Command | Meaning |
|---|---|
| `ftp fileserver` | Invoke the `ftp` program and have it connect to the FTP server *fileserver*. |
| `anonymous` | Login name. After the login prompt, a password prompt will appear. Some servers will accept a blank password; others will require a password in the form of an email address. In that case, try something like *user@example.com*. |
| `cd pub/cd_images/ubuntu-18.04` | Change to the directory on the remote system containing the desired file. Note that on most anonymous FTP servers, the files for public downloading are found somewhere under the *pub* directory. |
| `ls` | List the directory on the remote system. |
| `lcd Desktop` | Change the directory on the local system to *~/Desktop*. In the example, the `ftp` program was invoked when the working directory was ~. This command changes the working directory to *~/Desktop*. |
| `get ubuntu-18.04-desktop-amd64.iso` | Tell the remote system to transfer the file *ubuntu-18.04-desktop-amd64.iso* to the local system. Since the working directory on the local system was changed to *~/Desktop*, the file will be downloaded there. |
| `bye` | Log off the remote server and end the `ftp` program session. The commands `quit` and `exit` may also be used. |

Typing **`help`** at the `ftp>` prompt will display a list of the supported commands. Using `ftp` on a server where sufficient permissions have been granted, it is possible to perform many ordinary file management tasks. It's clumsy, but it does work.

## *lftp—a Better ftp*

`ftp` is not the only command-line FTP client. In fact, there are many. One of the better (and more popular) ones is `lftp` by Alexander Lukyanov. It works much like the traditional `ftp` program but has many additional convenience features including multiple-protocol support (including HTTP), automatic retry on failed downloads, background processes, tab completion of path names, and many more.

### wget

Another popular command-line program for file downloading is wget. It is useful for downloading content from both web and FTP sites. Single files, multiple files, and even entire sites can be downloaded. To download the first page of *linuxcommand.org*, we could do this:

```
[me@linuxbox ~]$ wget http://linuxcommand.org/index.php
--11:02:51--  http://linuxcommand.org/index.php
           => `index.php'
Resolving linuxcommand.org... 66.35.250.210
Connecting to linuxcommand.org|66.35.250.210|:80... connected.
HTTP request sent, awaiting response... 200 OK
Length: unspecified [text/html]

    [ <=>                                   ] 3,120         --.--K/s

11:02:51 (161.75 MB/s) - `index.php' saved [3120]
```

The program's many options allow wget to recursively download, download files in the background (allowing you to log off but continue downloading), and complete the download of a partially downloaded file. These features are well documented in its better-than-average man page.

## Secure Communication with Remote Hosts

For many years, Unix-like operating systems have had the capability to be administered remotely via a network. In the early days, before the general adoption of the Internet, there were a couple of popular programs used to log in to remote hosts. These were the rlogin and telnet programs. These programs, however, suffer from the same fatal flaw that the ftp program does; they transmit all their communications (including login names and passwords) in cleartext. This makes them wholly inappropriate for use in the Internet Age.

### ssh

To address this problem, a new protocol called Secure Shell (SSH) was developed. SSH solves the two basic problems of secure communication with a remote host.

- It authenticates that the remote host is who it says it is (thus preventing so-called man-in-the-middle attacks).
- It encrypts all of the communications between the local and remote hosts.

SSH consists of two parts. An SSH server runs on the remote host, listening for incoming connections, by default, on port 22, while an SSH client is used on the local system to communicate with the remote server.

Most Linux distributions ship an implementation of SSH called `OpenSSH` from the OpenBSD project. Some distributions include both the client and the server packages by default (for example, Red Hat), while others (such as Ubuntu) supply only the client. To enable a system to receive remote connections, it must have the `OpenSSH-server` package installed, configured, and running, and (if the system either is running or is behind a firewall) it must allow incoming network connections on TCP port 22.

**TIP** *If you don't have a remote system to connect to but want to try these examples, make sure the `OpenSSH-server` package is installed on your system and use `localhost` as the name of the remote host. That way, your machine will create network connections with itself.*

The SSH client program used to connect to remote SSH servers is called, appropriately enough, `ssh`. To connect to a remote host named `remote-sys`, we would use the `ssh` client program like so:

```
[me@linuxbox ~]$ ssh remote-sys
The authenticity of host 'remote-sys (192.168.1.4)' can't be established.
RSA key fingerprint is 41:ed:7a:df:23:19:bf:3c:a5:17:bc:61:b3:7f:d9:bb.
Are you sure you want to continue connecting (yes/no)?
```

The first time the connection is attempted, a message is displayed indicating that the authenticity of the remote host cannot be established. This is because the client program has never seen this remote host before. To accept the credentials of the remote host, enter **`yes`** when prompted. Once the connection is established, the user is prompted for a password.

```
Warning: Permanently added 'remote-sys,192.168.1.4' (RSA) to the list of known hosts.
me@remote-sys's password:
```

After the password is successfully entered, we receive the shell prompt from the remote system.

```
Last login: Sat Aug 25 13:00:48 2018
[me@remote-sys ~]$
```

The remote shell session continues until the user enters the `exit` command at the remote shell prompt, thereby closing the remote connection. At this point, the local shell session resumes, and the local shell prompt reappears.

It is also possible to connect to remote systems using a different username. For example, if the local user *me* had an account named *bob* on a remote system, user *me* could log in to the account *bob* on the remote system as follows:

```
[me@linuxbox ~]$ ssh bob@remote-sys
bob@remote-sys's password:
Last login: Sat Aug 25 13:03:21 2018
[bob@remote-sys ~]$
```

As stated earlier, ssh verifies the authenticity of the remote host. If the remote host does not successfully authenticate, the following message appears:

```
[me@linuxbox ~]$ ssh remote-sys
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@    WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!     @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now (man-in-the-middle attack)!
It is also possible that the RSA host key has just been changed.
The fingerprint for the RSA key sent by the remote host is
41:ed:7a:df:23:19:bf:3c:a5:17:bc:61:b3:7f:d9:bb.
Please contact your system administrator.
Add correct host key in /home/me/.ssh/known_hosts to get rid of this message.
Offending key in /home/me/.ssh/known_hosts:1
RSA host key for remote-sys has changed and you have requested strict
checking.
Host key verification failed.
```

This message is caused by one of two possible situations. First, an attacker may be attempting a man-in-the-middle attack. This is rare because everybody knows that ssh alerts the user to this. The more likely culprit is that the remote system has been changed somehow; for example, its operating system or SSH server has been reinstalled. In the interests of security and safety, however, the first possibility should not be dismissed out of hand. Always check with the administrator of the remote system when this message occurs.

After it has been determined that the message is because of a benign cause, it is safe to correct the problem on the client side. This is done by using a text editor (vim perhaps) to remove the obsolete key from the *~/.ssh/known_hosts* file. In the preceding example message, we see this:

```
Offending key in /home/me/.ssh/known_hosts:1
```

This means that the first line of the *known_hosts* file contains the offending key. Delete this line from the file, and the ssh program will be able to accept new authentication credentials from the remote system.

Besides opening a shell session on a remote system, ssh allows us to execute a single command on a remote system. For example, to execute the free command on a remote host named remote-sys and have the results displayed on the local system, use this:

```
[me@linuxbox ~]$ ssh remote-sys free
me@twin4's password:
             total       used       free     shared    buffers     cached
Mem:        775536     507184     268352          0     110068     154596
-/+ buffers/cache:     242520     533016
Swap:      1572856          0    1572856
[me@linuxbox ~]$
```

It's possible to use this technique in more interesting ways, such as the following example in which we perform an `ls` on the remote system and redirect the output to a file on the local system:

```
[me@linuxbox ~]$ ssh remote-sys 'ls *' > dirlist.txt
me@twin4's password:
[me@linuxbox ~]$
```

Notice the use of the single quotes in the preceding command. This is done because we do not want the pathname expansion performed on the local machine; rather, we want it to be performed on the remote system. Likewise, if we had wanted the output redirected to a file on the remote machine, we could have placed the redirection operator and the filename within the single quotes.

```
[me@linuxbox ~]$ ssh remote-sys 'ls * > dirlist.txt'
```

### TUNNELING WITH SSH

Part of what happens when you establish a connection with a remote host via SSH is that an *encrypted tunnel* is created between the local and remote systems. Normally, this tunnel is used to allow commands typed at the local system to be transmitted safely to the remote system and for the results to be transmitted safely back. In addition to this basic function, the SSH protocol allows most types of network traffic to be sent through the encrypted tunnel, creating a sort of *virtual private network* (*VPN*) between the local and remote systems.

Perhaps the most common use of this feature is to allow X Window system traffic to be transmitted. On a system running an X server (that is, a machine displaying a GUI), it is possible to launch and run an X client program (a graphical application) on a remote system and have its display appear on the local system. It's easy to do; here's an example. Let's say we are sitting at a Linux system called `linuxbox` that is running an X server and we want to run the `xload` program on a remote system named `remote-sys` to see the program's graphical output on our local system. We could do this:

```
[me@linuxbox ~]$ ssh -X remote-sys
me@remote-sys's password:
Last login: Mon Sep 10 13:23:11 2018
[me@remote-sys ~]$ xload
```

After the `xload` command is executed on the remote system, its window appears on the local system. On some systems, you may need to use the `-Y` option rather than the `-X` option to do this.

### scp and sftp

The OpenSSH package also includes two programs that can make use of an SSH-encrypted tunnel to copy files across the network. The first, scp (secure copy), is used much like the familiar cp program to copy files. The most notable difference is that the source or destination pathnames may be preceded with the name of a remote host, followed by a colon character. For example, if we wanted to copy a document named *document.txt* from our home directory on the remote system, *remote-sys*, to the current working directory on our local system, we could do this:

```
[me@linuxbox ~]$ scp remote-sys:document.txt .
me@remote-sys's password:
document.txt                              100% 5581     5.5KB/s   00:00
[me@linuxbox ~]$
```

As with ssh, you may apply a username to the beginning of the remote host's name if the desired remote host account name does not match that of the local system.

```
[me@linuxbox ~]$ scp bob@remote-sys:document.txt .
```

The second SSH file-copying program is sftp, which, as its name implies, is a secure replacement for the ftp program. sftp works much like the original ftp program that we used earlier; however, instead of transmitting everything in cleartext, it uses an SSH encrypted tunnel. sftp has an important advantage over conventional ftp in that it does not require an FTP server to be running on the remote host. It requires only the SSH server. This means that any remote machine that can connect with the SSH client can also be used as an FTP-like server. Here is a sample session.

```
[me@linuxbox ~]$ sftp remote-sys
Connecting to remote-sys...
me@remote-sys's password:
sftp> ls
ubuntu-8.04-desktop-i386.iso
sftp> lcd Desktop
sftp> get ubuntu-8.04-desktop-i386.iso
Fetching /home/me/ubuntu-8.04-desktop-i386.iso to ubuntu-8.04-desktop-i386.iso
/home/me/ubuntu-8.04-desktop-i386.iso 100%  699MB   7.4MB/s   01:35
sftp> bye
```

**TIP** *The SFTP protocol is supported by many of the graphical file managers found in Linux distributions. Using either GNOME or KDE, we can enter a URI beginning with* sftp:// *into the location bar and operate on files stored on a remote system running an SSH server.*

**AN SSH CLIENT FOR WINDOWS?**

Let's say you are sitting at a Windows machine but you need to log in to your Linux server and get some real work done; what do you do? Get an SSH client program for your Windows box, of course! There are a number of these. The most popular one is probably PuTTY by Simon Tatham and his team. The PuTTY program displays a terminal window and allows a Windows user to open an SSH (or telnet) session on a remote host. The program also provides analogs for the `scp` and `sftp` programs.

PuTTY is available at *www.chiark.greenend.org.uk/~sgtatham/putty/*.

## Summing Up

In this chapter, we surveyed the field of networking tools found on most Linux systems. Since Linux is so widely used in servers and networking appliances, there are many more that can be added by installing additional software. But even with the basic set of tools, it is possible to perform many useful network-related tasks.

# 17

# SEARCHING FOR FILES

As we have wandered around our Linux system, one thing has become abundantly clear: a typical Linux system has a lot of files! This raises the question, "How do we find things?" We already know that the Linux file system is well organized according to conventions passed down from one generation of Unix-like systems to the next, but the sheer number of files can present a daunting problem.

In this chapter, we will look at two tools that are used to find files on a system.

**`locate`** Find files by name

**`find`** Search for files in a directory hierarchy

We will also look at a command that is often used with file-search commands to process the resulting list of files.

**`xargs`** Build and execute command lines from standard input

In addition, we will introduce a couple of commands to assist us in our explorations.

**touch** Change file times

**stat** Display file or file system status

## locate—Find Files the Easy Way

The `locate` program performs a rapid database search of pathnames and then outputs every name that matches a given substring. Say, for example, we want to find all the programs with names that begin with *zip*. Because we are looking for programs, we can assume that the name of the directory containing the programs would end with *bin/*. Therefore, we could try to use `locate` this way to find our files:

```
[me@linuxbox ~]$ locate bin/zip
```

`locate` will search its database of pathnames and output any that contain the string *bin/zip*.

```
/usr/bin/zip
/usr/bin/zipcloak
/usr/bin/zipgrep
/usr/bin/zipinfo/usr/bin/zipnote
/usr/bin/zipsplit
```

If the search requirement is not so simple, we can combine `locate` with other tools such as `grep` to design more interesting searches.

```
[me@linuxbox ~]$ locate zip | grep bin
/bin/bunzip2
/bin/bzip2
/bin/bzip2recover
/bin/gunzip
/bin/gzip
/usr/bin/funzip
/usr/bin/gpg-zip
/usr/bin/preunzip
/usr/bin/prezip
/usr/bin/prezip-bin
/usr/bin/unzip
/usr/bin/unzipsfx
/usr/bin/zip
/usr/bin/zipcloak
/usr/bin/zipgrep
/usr/bin/zipinfo
/usr/bin/zipnote
/usr/bin/zipsplit
```

The locate program has been around for a number of years, and there are several variants in common use. The two most common ones found in modern Linux distributions are slocate and mlocate, though they are usually accessed by a symbolic link named locate. The different versions of locate have overlapping options sets. Some versions include regular expression matching (which we'll cover in Chapter 19) and wildcard support. Check the man page for locate to determine which version of locate is installed.

**WHERE DOES THE LOCATE DATABASE COME FROM?**

You might notice that, on some distributions, locate fails to work just after the system is installed, but if you try again the next day, it works fine. What gives? The locate database is created by another program named updatedb. Usually, it is run periodically as a *cron job*, that is, a task performed at regular intervals by the cron daemon. Most systems equipped with locate run updatedb once a day. Because the database is not updated continuously, you will notice that very recent files do not show up when using locate. To overcome this, it's possible to run the updatedb program manually by becoming the superuser and running updatedb at the prompt.

## find—Find Files the Hard Way

While the locate program can find a file based solely on its name, the find program searches a given directory (and its subdirectories) for files based on a variety of attributes. We're going to spend a lot of time with find because it has a lot of interesting features that we will see again and again when we start to cover programming concepts in later chapters.

In its simplest use, find is given one or more names of directories to search. For example, to produce a listing of our home directory, we can use this:

```
[me@linuxbox ~]$ find ~
```

On most active user accounts, this will produce a large list. Because the list is sent to standard output, we can pipe the list into other programs. Let's use wc to count the number of files.

```
[me@linuxbox ~]$ find ~ | wc -l
47068
```

Wow, we've been busy! The beauty of find is that it can be used to identify files that meet specific criteria. It does this through the (slightly strange) application of *options*, *tests*, and *actions*. We'll look at the tests first.

### *Tests*

Let's say we want a list of directories from our search. To do this, we could add the following test:

```
[me@linuxbox ~]$ find ~ -type d | wc -l
1695
```

Adding the test `-type d` limited the search to directories. Conversely, we could have limited the search to regular files with this test:

```
[me@linuxbox ~]$ find ~ -type f | wc -l
38737
```

Table 17-1 lists the common file type tests supported by `find`.

**Table 17-1:** `find` File Types

| File type | Description |
|---|---|
| `b` | Block special device file |
| `c` | Character special device file |
| `d` | Directory |
| `f` | Regular file |
| `l` | Symbolic link |

We can also search by file size and filename by adding some additional tests. Let's look for all the regular files that match the wildcard pattern `*.JPG` and are larger than one megabyte.

```
[me@linuxbox ~]$ find ~ -type f -name "*.JPG" -size +1M | wc -l
840
```

In this example, we add the `-name` test followed by the wildcard pattern. Notice how we enclose it in quotes to prevent pathname expansion by the shell. Next, we add the `-size` test followed by the string `+1M`. The leading plus sign indicates that we are looking for files larger than the specified number. A leading minus sign would change the meaning of the string to be smaller than the specified number. Using no sign means "match the value exactly." The trailing letter `M` indicates that the unit of measurement is megabytes. Table 17-2 lists the characters that can be used to specify units.

**Table 17-2:** `find` Size Units

| Character | Unit |
|---|---|
| `b` | 512-byte blocks. This is the default if no unit is specified. |
| `c` | Bytes. |
| `w` | 2-byte words. |

| Character | Unit |
|---|---|
| k | Kilobytes (units of 1,024 bytes). |
| M | Megabytes (units of 1,048,576 bytes). |
| G | Gigabytes (units of 1,073,741,824 bytes). |

find supports a large number of tests. Table 17-3 provides a rundown of the common ones. Note that in cases where a numeric argument is required, the same + and - notation discussed previously can be applied.

**Table 17-3:** find Tests

| Test | Description |
|---|---|
| -cmin *n* | Match files or directories whose content or attributes were last modified exactly *n* minutes ago. To specify less than *n* minutes ago, use -*n*, and to specify more than *n* minutes ago, use +*n*. |
| -cnewer *file* | Match files or directories whose contents or attributes were last modified more recently than those of *file*. |
| -ctime *n* | Match files or directories whose contents or attributes were last modified *n**24 hours ago. |
| -empty | Match empty files and directories. |
| -group *name* | Match file or directories belonging to belonging to group *name*. *name* may be expressed may be expressed either as a group name or as a numeric group ID. |
| -iname *pattern* | Like the -name test but case-insensitive. |
| -inum *n* | Match files with inode number *n*. This is helpful for finding all the hard links to a particular inode. |
| -mmin *n* | Match files or directories whose contents were last modified *n* minutes ago. |
| -mtime *n* | Match files or directories whose contents were last modified *n**24 hours ago. |
| -name *pattern* | Match files and directories with the specified wildcard *pattern*. |
| -newer *file* | Match files and directories whose contents were modified more recently than the specified *file*. This is useful when writing shell scripts that perform file backups. Each time you make a backup, update a file (such as a log) and then use find to determine which files have changed since the last update. |
| -nouser | Match file and directories that do not belong to a valid user. This can be used to find files belonging to deleted accounts or to detect activity by attackers. |
| -nogroup | Match files and directories that do not belong to a valid group. |
| -perm *mode* | Match files or directories that have permissions set to the specified *mode*. *mode* can be expressed by either octal or symbolic notation. |

*(continued)*

**Table 17-3:** `find` Tests (continued)

| Test | Description |
|---|---|
| `-samefile` *name* | Similar to the `-inum` test. Match files that share the same inode number as file *name*. |
| `-size` *n* | Match files of size *n*. |
| `-type` *c* | Match files of type *c*. |
| `-user` *name* | Match files or directories belonging to user *name*. The user may be expressed by a username or by a numeric user ID. |

This is not a complete list. The `find` man page has all the details.

### Operators

Even with all the tests that `find` provides, we might still need a better way to describe the *logical relationships* between the tests. For example, what if we needed to determine whether all the files and subdirectories in a directory had secure permissions? We would look for all the files with permissions that are not 0600 and the directories with permissions that are not 0700. Fortunately, `find` provides a way to combine tests using *logical operators* to create more complex logical relationships. To express the aforementioned test, we could do this:

```
[me@linuxbox ~]$ find ~ \( -type f -not -perm 0600 \) -or \( -type d -not -perm 0700 \)
```

Yikes! That sure looks weird. What is all this stuff? Actually, the operators are not that complicated once you get to know them. Table 17-4 describes the logical operators used with `find`.

**Table 17-4:** `find` Logical Operators

| Operator | Description |
|---|---|
| `-and` | Match if the tests on both sides of the operator are true. This can be shortened to `-a`. Note that when no operator is present, `-and` is implied by default. |
| `-or` | Match if a test on either side of the operator is true. This can be shortened to `-o`. |
| `-not` | Match if the test following the operator is false. This can be abbreviated with an exclamation point (!). |
| `( )` | Group tests and operators together to form larger expressions. This is used to control the precedence of the logical evaluations. By default, `find` evaluates from left to right. It is often necessary to override the default evaluation order to obtain the desired result. Even if not needed, it is helpful sometimes to include the grouping characters to improve the readability of the command. Note that since the parentheses have special meaning to the shell, they must be quoted when using them on the command line to allow them to be passed as arguments to `find`. Usually the backslash character is used to escape them. |

With this list of operators in hand, let's deconstruct our `find` command. When viewed from the uppermost level, we see that our tests are arranged as two groupings separated by an `-or` operator.

```
( expression 1 ) -or ( expression 2 )
```

This makes sense because we are searching for files with a certain set of permissions and for directories with a different set. If we are looking for both files and directories, why do we use `-or` instead of `-and`? As `find` scans through the files and directories, each one is evaluated to see whether it matches the specified tests. We want to know whether it is *either* a file with bad permissions *or* a directory with bad permissions. It can't be both at the same time. So if we expand the grouped expressions, we can see it this way:

```
( file with bad perms ) -or ( directory with bad perms )
```

Our next challenge is how to test for "bad permissions." How do we do that? Actually, we don't. What we will test for is "not good permissions" because we know what "good permissions" are. In the case of files, we define good as 0600, and for directories, we define it as 0700. The expression that will test files for "not good" permissions is as follows:

```
-type f -and -not -perms 0600
```

For directories it is as follows:

```
-type d -and -not -perms 0700
```

As noted in Table 17-4, the `-and` operator can be safely removed because it is implied by default. So if we put this all back together, we get our final command.

```
find ~ ( -type f -not -perms 0600 ) -or ( -type d -not -perms 0700 )
```

However, because the parentheses have special meaning to the shell, we must escape them to prevent the shell from trying to interpret them. Preceding each one with a backslash character does the trick.

There is another feature of logical operators that is important to understand. Let's say that we have two expressions separated by a logical operator.

```
expr1 -operator expr2
```

In all cases, *`expr1`* will always be performed; however, the operator will determine whether *`expr2`* is performed. Table 17-5 outlines how it works.

**Table 17-5:** `find` AND/OR Logic

| Results of `expr1` | Operator | `expr2` is . . . |
|---|---|---|
| True | `-and` | Always performed |
| False | `-and` | Never performed |
| True | `-or` | Never performed |
| False | `-or` | Always performed |

Why does this happen? It's done to improve performance. Take `-and`, for example. We know that the expression *`expr1`* `-and` *`expr2`* cannot be true if the result of *`expr1`* is false, so there is no point in performing *`expr2`*. Likewise, if we have the expression *`expr1`* `-or` *`expr2`* and the result of *`expr1`* is true, there is no point in performing *`expr2`*, as we already know that the expression *`expr1`* `-or` *`expr2`* is true.

OK, so it helps it go faster. Why is this important? It's important because we can rely on this behavior to control how actions are performed, as we will soon see.

## *Predefined Actions*

Let's get some work done! Having a list of results from our `find` command is useful, but what we really want to do is act on the items on the list. Fortunately, `find` allows actions to be performed based on the search results. There are a set of predefined actions and several ways to apply user-defined actions. First, let's look at a few of the predefined actions listed in Table 17-6.

**Table 17-6:** Predefined `find` Actions

| Action | Description |
|---|---|
| `-delete` | Delete the currently matching file. |
| `-ls` | Perform the equivalent of `ls -dils` on the matching file. Output is sent to standard output. |
| `-print` | Output the full pathname of the matching file to standard output. This is the default action if no other action is specified. |
| `-quit` | Quit once a match has been made. |

As with the tests, there are many more actions. See the `find` man page for full details.

In the first example, we did this:

```
find ~
```

This produced a list of every file and subdirectory contained within our home directory. It produced a list because the `-print` action is implied if

no other action is specified. Thus, our command could also be expressed as follows:

```
find ~ -print
```

We can use `find` to delete files that meet certain criteria. For example, to delete files that have the file extension *.bak* (which is often used to designate backup files), we could use this command:

```
find ~ -type f -name '*.bak' -delete
```

In this example, every file in the user's home directory (and its subdirectories) is searched for filenames ending in *.bak*. When they are found, they are deleted.

**WARNING** *It should go without saying that you should* use extreme caution *when using the* `-delete` *action. Always test the command first by substituting the* `-print` *action for* `-delete` *to confirm the search results.*

Before we go on, let's take another look at how the logical operators affect actions. Consider the following command:

```
find ~ -type f -name '*.bak' -print
```

As we have seen, this command will look for every regular file (`-type f`) whose name ends with *.bak* (`-name '*.bak'`) and will output the relative pathname of each matching file to standard output (`-print`). However, the reason the command performs the way it does is determined by the logical relationships between each of the tests and actions. Remember, there is, by default, an implied `-and` relationship between each test and action. We could also express the command this way to make the logical relationships easier to see:

```
find ~ -type f -and -name '*.bak' -and -print
```

With our command fully expressed, let's look at how the logical operators affect its execution:

| Test/Action | Is performed only if... |
|---|---|
| `-print` | `-type f` and `-name '*.bak'` are true |
| `-name '*.bak'` | `-type f` is true |
| `-type f` | Is always performed, since it is the first test/action in an `-and` relationship. |

Because the logical relationship between the tests and actions determines which of them are performed, we can see that the order of the tests

and actions is important. For instance, if we were to reorder the tests and actions so that the -print action was the first one, the command would behave much differently.

```
find ~ -print -and -type f -and -name '*.bak'
```

This version of the command will print each file (the -print action always evaluates to true) and then test for file type and the specified file extension.

### User-Defined Actions

In addition to the predefined actions, we can also invoke arbitrary commands. The traditional way of doing this is with the -exec action. This action works like this:

```
-exec command {} ;
```

Here, *command* is the name of a command, {} is a symbolic representation of the current pathname, and the semicolon is a required delimiter indicating the end of the command. Here's an example of using -exec to act like the -delete action discussed earlier:

```
-exec rm '{}' ';'
```

Again, because the brace and semicolon characters have special meaning to the shell, they must be quoted or escaped.

It's also possible to execute a user-defined action interactively. By using the -ok action in place of -exec, the user is prompted before execution of each specified command.

```
find ~ -type f -name 'foo*' -ok ls -l '{}' ';'
< ls ... /home/me/bin/foo > ? y
-rwxr-xr-x 1 me   me 224 2007-10-29 18:44 /home/me/bin/foo
< ls ... /home/me/foo.txt > ? y
-rw-r--r-- 1 me   me   0 2016-09-19 12:53 /home/me/foo.txt
```

In this example, we search for files with names starting with the string foo and execute the command ls -l each time one is found. Using the -ok action prompts the user before the ls command is executed.

### Improving Efficiency

When the -exec action is used, it launches a new instance of the specified command each time a matching file is found. There are times when we might prefer to combine all of the search results and launch a single instance of the command. For example, rather than executing the commands like this:

```
ls -l file1
ls -l file2
```

we may prefer to execute them this way:

```
ls -l file1 file2
```

This causes the command to be executed only one time rather than multiple times. There are two ways we can do this: the traditional way, using the external command `xargs`, and the alternate way, using a new feature in `find` itself. We'll talk about the alternate way first.

By changing the trailing semicolon character to a plus sign, we activate the capability of `find` to combine the results of the search into an argument list for a single execution of the desired command. Returning to our example, this will execute `ls` each time a matching file is found:

```
find ~ -type f -name 'foo*' -exec ls -l '{}' ';'
-rwxr-xr-x 1 me   me 224 2007-10-29 18:44 /home/me/bin/foo
-rw-r--r-- 1 me   me   0 2016-09-19 12:53 /home/me/foo.txt
```

By changing the command to the following:

```
find ~ -type f -name 'foo*' -exec ls -l '{}' +
-rwxr-xr-x 1 me   me 224 2007-10-29 18:44 /home/me/bin/foo
-rw-r--r-- 1 me   me   0 2016-09-19 12:53 /home/me/foo.txt
```

we get the same results, but the system has to execute the `ls` command only once.

### xargs

The `xargs` command performs an interesting function. It accepts input from standard input and converts it into an argument list for a specified command. With our example, we would use it like this:

```
find ~ -type f -name 'foo*' -print | xargs ls -l
-rwxr-xr-x 1 me   me 224 2007-10-29 18:44 /home/me/bin/foo
-rw-r--r-- 1 me   me   0 2016-09-19 12:53 /home/me/foo.txt
```

Here we see the output of the `find` command piped into `xargs`, which, in turn, constructs an argument list for the `ls` command and then executes it.

**NOTE** *While the number of arguments that can be placed into a command line is quite large, it's not unlimited. It is possible to create commands that are too long for the shell to accept. When a command line exceeds the maximum length supported by the system, `xargs` executes the specified command with the maximum number of arguments possible and then repeats this process until standard input is exhausted. To see the maximum size of the command line, execute `xargs` with the `--show-limits` option.*

**DEALING WITH FUNNY FILENAMES**

Unix-like systems allow embedded spaces (and even newlines!) in filenames. This causes problems for programs like xargs that construct argument lists for other programs. An embedded space will be treated as a delimiter, and the resulting command will interpret each space-separated word as a separate argument. To overcome this, find and xargs allow the optional use of a *null character* as an argument separator. A null character is defined in ASCII as the character represented by the number zero (as opposed to, for example, the space character, which is defined in ASCII as the character represented by the number 32). The find command provides the action -print0, which produces null-separated output, and the xargs command has the --null (or -0) option, which accepts null-separated input. Here's an example:

```
find ~ -iname '*.jpg' -print0 | xargs --null ls -l
```

Using this technique, we can ensure that all files, even those containing embedded spaces in their names, are handled correctly.

## A Return to the Playground

It's time to put find to some (almost) practical use. We'll create a playground and try some of what we have learned.

First, let's create a playground with lots of subdirectories and files.

```
[me@linuxbox ~]$ mkdir -p playground/dir-{001..100}
[me@linuxbox ~]$ touch playground/dir-{001..100}/file-{A..Z}
```

Marvel at the power of the command line! With these two lines, we created a playground directory containing 100 subdirectories each containing 26 empty files. Try that with the GUI!

The method we employed to accomplish this magic involved a familiar command (mkdir), an exotic shell expansion (braces), and a new command, touch. By combining mkdir with the -p option (which causes mkdir to create the parent directories of the specified paths) with brace expansion, we were able to create 100 subdirectories.

The touch command is usually used to set or update the access, change, and modify times of files. However, if a filename argument is that of a nonexistent file, an empty file is created.

In our playground, we created 100 instances of *file-A*. Let's find them.

```
[me@linuxbox ~]$ find playground -type f -name 'file-A'
```

Note that unlike ls, find does not produce results in sorted order. Its order is determined by the layout of the storage device. We can confirm that we actually have 100 instances of the file this way.

```
[me@linuxbox ~]$ find playground -type f -name 'file-A' | wc -l
100
```

Next, let's look at finding files based on their modification times. This will be helpful when creating backups or organizing files in chronological order. To do this, we will first create a reference file against which we will compare modification times.

```
[me@linuxbox ~]$ touch playground/timestamp
```

This creates an empty file named `timestamp` and sets its modification time to the current time. We can verify this by using another handy command, `stat`, which is a kind of souped-up version of `ls`. The `stat` command reveals all that the system understands about a file and its attributes.

```
[me@linuxbox ~]$ stat playground/timestamp
  File: `playground/timestamp'
  Size: 0          Blocks: 0       IO Block: 4096 regular empty file
Device: 803h/2051d Inode: 14265061 Links: 1
Access: (0644/-rw-r--r--)  Uid: ( 1001/ me)   Gid: ( 1001/ me)
Access: 2018-10-08 15:15:39.000000000 -0400
Modify: 2018-10-08 15:15:39.000000000 -0400
Change: 2018-10-08 15:15:39.000000000 -0400
```

If we use `touch` again and then examine the file with `stat`, we will see that the file's times have been updated.

```
[me@linuxbox ~]$ touch playground/timestamp
[me@linuxbox ~]$ stat playground/timestamp
  File: `playground/timestamp'
  Size: 0          Blocks: 0       IO Block: 4096 regular empty file
Device: 803h/2051d Inode: 14265061 Links: 1
Access: (0644/-rw-r--r--)  Uid: ( 1001/ me)   Gid: ( 1001/ me)
Access: 2018-10-08 15:23:33.000000000 -0400
Modify: 2018-10-08 15:23:33.000000000 -0400
Change: 2018-10-08 15:23:33.000000000 -0400
```

Next, let's use `find` to update some of our playground files.

```
[me@linuxbox ~]$ find playground -type f -name 'file-B' -exec touch '{}' ';'
```

This updates all playground files named *file-B*. We'll use `find` to identify the updated files by comparing all the files to the reference file `timestamp`.

```
[me@linuxbox ~]$ find playground -type f -newer playground/timestamp
```

The results contain all 100 instances of *file-B*. Since we performed a `touch` on all the files in the playground named *file-B* after we updated `timestamp`, they are now "newer" than `timestamp` and thus can be identified with the `-newer` test.

Finally, let's go back to the bad permissions test we performed earlier and apply it to *playground*.

```
[me@linuxbox ~]$ find playground \( -type f -not -perm 0600 \) -or \( -type d
-not -perm 0700 \)
```

This command lists all 100 directories and 2,600 files in *playground* (as well as `timestamp` and *playground* itself, for a total of 2,702) because none of them meets our definition of "good permissions." With our knowledge of operators and actions, we can add actions to this command to apply new permissions to the files and directories in our playground.

```
[me@linuxbox ~]$ find playground \( -type f -not -perm 0600 -exec chmod 0600
'{}' ';' \) -or \( -type d -not -perm 0700 -exec chmod 0700 '{}' ';' \)
```

On a day-to-day basis, we might find it easier to issue two commands, one for the directories and one for the files, rather than this one large compound command, but it's nice to know that we can do it this way. The important point here is to understand how the operators and actions can be used together to perform useful tasks.

### find Options

Finally, we have the options, which are used to control the scope of a `find` search. They may be included with other tests and actions when constructing `find` expressions. Table 17-7 lists the most commonly used `find` options.

**Table 17-7:** Commonly Used `find` Options

| Option | Description |
|---|---|
| `-depth` | Direct `find` to process a directory's files before the directory itself. This option is automatically applied when the `-delete` action is specified. |
| `-maxdepth` *`levels`* | Set the maximum number of levels that `find` will descend into a directory tree when performing tests and actions. |
| `-mindepth` *`levels`* | Set the minimum number of levels that `find` will descend into a directory tree before applying tests and actions. |
| `-mount` | Direct `find` not to traverse directories that are mounted on other file systems. |
| `-noleaf` | Direct `find` not to optimize its search based on the assumption that it is searching a Unix-like file system. This is needed when scanning DOS/Windows file systems and CD-ROMs. |

## Summing Up

It's easy to see that `locate` is as simple as `find` is complicated. They both have their uses. Take the time to explore the many features of `find`. It can, with regular use, improve your understanding of Linux file system operations.

# 18

## ARCHIVING AND BACKUP

One of the primary tasks of a computer system's administrator is keeping the system's data secure. One way this is done is by performing timely backups of the system's files. Even if you're not a system administrator, it is often useful to make copies of things and move large collections of files from place to place and from device to device.

In this chapter, we will look at several common programs that are used to manage collections of files. These are the file compression programs:

**gzip** Compress or expand files

**bzip2** A block sorting file compressor

These are the archiving programs:

**tar** Tape archiving utility

**zip** Package and compress files

This is the file synchronization program:

`rsync` Remote file and directory synchronization

## Compressing Files

Throughout the history of computing, there has been a struggle to get the most data into the smallest available space, whether that space be memory, storage devices, or network bandwidth. Many of the data services that we take for granted today, such as mobile phone service, high-definition television, or broadband Internet, owe their existence to effective *data compression* techniques.

Data compression is the process of removing *redundancy* from data. Let's consider an imaginary example. Suppose we had an entirely black picture file with the dimensions of 100 pixels by 100 pixels. In terms of data storage (assuming 24 bits, or 3 bytes per pixel), the image will occupy 30,000 bytes of storage.

$$100 \times 100 \times 3 = 30{,}000$$

An image that is all one color contains entirely redundant data. If we were clever, we could encode the data in such a way that we simply describe the fact that we have a block of 10,000 black pixels. So, instead of storing a block of data containing 30,000 zeros (black is usually represented in image files as zero), we could compress the data into the number 10,000, followed by a zero to represent our data. Such a data compression scheme is called *run-length encoding* and is one of the most rudimentary compression techniques. Today's techniques are much more advanced and complex, but the basic goal remains the same—get rid of redundant data. *Compression algorithms* (the mathematical techniques used to carry out the compression) fall into two general categories.

- *Lossless*. Lossless compression preserves all the data contained in the original. This means that when a file is restored from a compressed version, the restored file is exactly the same as the original, uncompressed version.
- *Lossy*. Lossy compression, on the other hand, removes data as the compression is performed to allow more compression to be applied. When a lossy file is restored, it does not match the original version; rather, it is a close approximation. Examples of lossy compression are JPEG (for images) and MP3 (for music).

In our discussion, we will look exclusively at lossless compression since most data on computers cannot tolerate any data loss.

### *gzip*

The `gzip` program is used to compress one or more files. When executed, it replaces the original file with a compressed version of the original. The

corresponding gunzip program is used to restore compressed files to their original, uncompressed form. Here is an example:

```
[me@linuxbox ~]$ ls -l /etc > foo.txt
[me@linuxbox ~]$ ls -l foo.*
-rw-r--r-- 1 me    me    15738 2018-10-14 07:15 foo.txt
[me@linuxbox ~]$ gzip foo.txt
[me@linuxbox ~]$ ls -l foo.*
-rw-r--r-- 1 me    me    3230 2018-10-14 07:15 foo.txt.gz
[me@linuxbox ~]$ gunzip foo.txt
[me@linuxbox ~]$ ls -l foo.*
-rw-r--r-- 1 me    me    15738 2018-10-14 07:15 foo.txt
```

In this example, we create a text file named *foo.txt* from a directory listing. Next, we run gzip, which replaces the original file with a compressed version named *foo.txt.gz*. In the directory listing of *foo.**, we see that the original file has been replaced with the compressed version and that the compressed version is about one-fifth the size of the original. We can also see that the compressed file has the same permissions and timestamp as the original.

Next, we run the gunzip program to uncompress the file. Afterward, we can see that the compressed version of the file has been replaced with the original, again with the permissions and timestamp preserved.

gzip has many options, as described in Table 18-1.

**Table 18-1:** gzip Options

| Option | Long option | Description |
|---|---|---|
| -c | --stdout<br>--to-stdout | Write output to standard output and keep the original files. |
| -d | --decompress<br>--uncompress | Decompress. This causes gzip to act like gunzip. |
| -f | --force | Force compression even if a compressed version of the original file already exists. |
| -h | --help | Display usage information. |
| -l | --list | List compression statistics for each file compressed. |
| -r | --recursive | If one or more arguments on the command line is a directory, recursively compress files contained within them. |
| -t | --test | Test the integrity of a compressed file. |
| -v | --verbose | Display verbose messages while compressing. |
| -*number* | | Set amount of compression. *number* is an integer in the range of 1 (fastest, least compression) to 9 (slowest, most compression). The values 1 and 9 may also be expressed as --fast and --best, respectively. The default value is 6. |

Let's return to our earlier example.

```
[me@linuxbox ~]$ gzip foo.txt
[me@linuxbox ~]$ gzip -tv foo.txt.gz
foo.txt.gz:  OK
[me@linuxbox ~]$ gzip -d foo.txt.gz
```

Here, we replaced *foo.txt* with a compressed version named *foo.txt.gz*. Next, we tested the integrity of the compressed version, using the `-t` and `-v` options. Finally, we decompressed the file to its original form.

`gzip` can also be used in interesting ways via standard input and output.

```
[me@linuxbox ~]$ ls -l /etc | gzip > foo.txt.gz
```

This command creates a compressed version of a directory listing.

The `gunzip` program, which uncompresses `gzip` files, assumes that filenames end in the extension *.gz*, so it's not necessary to specify it, as long as the specified name is not in conflict with an existing uncompressed file.

```
[me@linuxbox ~]$ gunzip foo.txt
```

If our goal were only to view the contents of a compressed text file, we could do this:

```
[me@linuxbox ~]$ gunzip -c foo.txt | less
```

Alternately, there is a program supplied with `gzip`, called `zcat`, that is equivalent to `gunzip` with the `-c` option. It can be used like the `cat` command on `gzip`-compressed files.

```
[me@linuxbox ~]$ zcat foo.txt.gz | less
```

**TIP** *There is a `zless` program, too. It performs the same function as the previous pipeline.*

## bzip2

The `bzip2` program, by Julian Seward, is similar to `gzip` but uses a different compression algorithm that achieves higher levels of compression at the cost of compression speed. In most regards, it works in the same fashion as `gzip`. A file compressed with `bzip2` is denoted with the extension *.bz2*.

```
[me@linuxbox ~]$ ls -l /etc > foo.txt
[me@linuxbox ~]$ ls -l foo.txt
-rw-r--r-- 1 me    me    15738 2018-10-17 13:51 foo.txt
[me@linuxbox ~]$ bzip2 foo.txt
[me@linuxbox ~]$ ls -l foo.txt.bz2
-rw-r--r-- 1 me    me     2792 2018-10-17 13:51 foo.txt.bz2
[me@linuxbox ~]$ bunzip2 foo.txt.bz2
```

As we can see, `bzip2` can be used the same way as `gzip`. All the options (except for `-r`) that we discussed for `gzip` are also supported in `bzip2`. Note, however, that the compression-level option (*-number*) has a somewhat different meaning to `bzip2`. `bzip2` comes with `bunzip2` and `bzcat` for decompressing files.

`bzip2` also comes with the `bzip2recover` program, which will try to recover damaged *.bz2* files.

**DON'T BE COMPRESSIVE COMPULSIVE**

I occasionally see people attempting to compress a file that has already been compressed with an effective compression algorithm by doing something like this:

```
$ gzip picture.jpg
```

Don't do it. You're probably just wasting time and space! If you apply compression to a file that is already compressed, you will usually end up with a larger file. This is because all compression techniques involve some overhead that is added to the file to describe the compression. If you try to compress a file that already contains no redundant information, the compression will most often not result in any savings to offset the additional overhead.

## Archiving Files

A common file-management task often used in conjunction with compression is *archiving*. Archiving is the process of gathering up many files and bundling them together into a single large file. Archiving is often done as part of system backups. It is also used when old data is moved from a system to some type of long-term storage.

### *tar*

In the Unix-like world of software, the `tar` program is the classic tool for archiving files. Its name, short for *tape archive*, reveals its roots as a tool for making backup tapes. While it is still used for that traditional task, it is equally adept on other storage devices. We often see filenames that end with the extension *.tar* or *.tgz*, which indicate a "plain" tar archive and a gzipped archive, respectively. A tar archive can consist of a group of separate files, one or more directory hierarchies, or a mixture of both. The command syntax works like this:

```
tar mode[options] pathname...
```

Here, *mode* is one of the operating modes listed in Table 18-2 (only a partial list is shown here; see the `tar` man page for a complete list).

**Table 18-2:** tar Modes

| Mode | Description |
|---|---|
| c | Create an archive from a list of files and/or directories. |
| x | Extract an archive. |
| r | Append specified pathnames to the end of an archive. |
| t | List the contents of an archive. |

tar uses a slightly odd way of expressing options, so we'll need some examples to show how it works. First, let's re-create our playground from the previous chapter.

```
[me@linuxbox ~]$ mkdir -p playground/dir-{001..100}
[me@linuxbox ~]$ touch playground/dir-{001..100}/file-{A..Z}
```

Next, let's create a tar archive of the entire playground.

```
[me@linuxbox ~]$ tar cf playground.tar playground
```

This command creates a tar archive named *playground.tar* that contains the entire playground directory hierarchy. We can see that the mode and the f option, which is used to specify the name of the tar archive, may be joined together and do not require a leading dash. Note, however, that the mode must always be specified first, before any other option.

To list the contents of the archive, we can do this:

```
[me@linuxbox ~]$ tar tf playground.tar
```

For a more detailed listing, we can add the v (verbose) option.

```
[me@linuxbox ~]$ tar tvf playground.tar
```

Now, let's extract the playground in a new location. We will do this by creating a new directory named *foo*, changing the directory, and extracting the tar archive.

```
[me@linuxbox ~]$ mkdir foo
[me@linuxbox ~]$ cd foo
[me@linuxbox foo]$ tar xf ../playground.tar
[me@linuxbox foo]$ ls
playground
```

If we examine the contents of *~/foo/playground*, we see that the archive was successfully installed, creating a precise reproduction of the original files. There is one caveat, however. Unless we are operating as the superuser, files and directories extracted from archives take on the ownership of the user performing the restoration, rather than the original owner.

Another interesting behavior of tar is the way it handles pathnames in archives. The default for pathnames is relative, rather than absolute. tar does this by simply removing any leading slash from the pathname when creating the archive. To demonstrate, we will re-create our archive, this time specifying an absolute pathname.

```
[me@linuxbox foo]$ cd
[me@linuxbox ~]$ tar cf playground2.tar ~/playground
```

Remember, *~/playground* will expand into */home/me/playground* when we press enter, so we will get an absolute pathname for our demonstration. Next, we will extract the archive as before and watch what happens.

```
[me@linuxbox ~]$ cd foo
[me@linuxbox foo]$ tar xf ../playground2.tar
[me@linuxbox foo]$ ls
home   playground
[me@linuxbox foo]$ ls home
me
[me@linuxbox foo]$ ls home/me
playground
```

Here we can see that when we extracted our second archive, it re-created the directory *home/me/playground* relative to our current working directory, *~/foo*, not relative to the root directory, as would have been the case with an absolute pathname. This might seem like an odd way for it to work, but it's actually more useful this way because it allows us to extract archives to any location rather than being forced to extract them to their original locations. Repeating the exercise with the inclusion of the verbose option (v) will give a clearer picture of what's going on.

Let's consider a hypothetical, yet practical, example of tar in action. Imagine we want to copy the home directory and its contents from one system to another and we have a large USB hard drive that we can use for the transfer. On our modern Linux system, the drive is "automagically" mounted in the */media* directory. Let's also imagine that the disk has a volume name of *BigDisk* when we attach it. To make the tar archive, we can do the following:

```
[me@linuxbox ~]$ sudo tar cf /media/BigDisk/home.tar /home
```

After the tar file is written, we unmount the drive and attach it to the second computer. Again, it is mounted at */media/BigDisk*. To extract the archive, we do this:

```
[me@linuxbox2 ~]$ cd /
[me@linuxbox2 /]$ sudo tar xf /media/BigDisk/home.tar
```

What's important to see here is that we must first change directory to / so that the extraction is relative to the root directory since all pathnames within the archive are relative.

When extracting an archive, it's possible to limit what is extracted from the archive. For example, if we wanted to extract a single file from an archive, it could be done like this:

```
tar xf archive.tar pathname
```

By adding the trailing *pathname* to the command, tar will restore only the specified file. Multiple pathnames may be specified. Note that the pathname must be the full, exact relative pathname as stored in the archive. When specifying pathnames, wildcards are not normally supported; however, the GNU version of tar (which is the version most often found in Linux distributions) supports them with the --wildcards option. Here is an example using our previous *playground.tar* file:

```
[me@linuxbox ~]$ cd foo
[me@linuxbox foo]$ tar xf ../playground2.tar --wildcards 'home/me/playground/dir-*/file-A'
```

This command will extract only files matching the specified pathname including the wildcard *dir-**.

tar is often used in conjunction with find to produce archives. In this example, we will use find to produce a set of files to include in an archive.

```
[me@linuxbox ~]$ find playground -name 'file-A' -exec tar rf playground.tar '{}' '+'
```

Here we use find to match all the files in *playground* named *file-A* and then, using the -exec action, we invoke tar in the append mode (r) to add the matching files to the archive *playground.tar*.

Using tar with find is a good way of creating *incremental backups* of a directory tree or an entire system. By using find to match files newer than a timestamp file, we could create an archive that contains only those files newer than the last archive, assuming that the timestamp file is updated right after each archive is created.

tar can also make use of both standard input and output. Here is a comprehensive example:

```
[me@linuxbox foo]$ cd
[me@linuxbox ~]$ find playground -name 'file-A' | tar cf - --files-from=- | gzip > playground.tgz
```

In this example, we used the find program to produce a list of matching files and piped them into tar. If the filename - is specified, it is taken to mean standard input or output, as needed. (By the way, this convention of using - to represent standard input/output is used by a number of other programs, too). The --files-from option (which may also be specified as -T) causes tar to read its list of pathnames from a file rather than the command line. Lastly, the archive produced by tar is piped into gzip to create the compressed archive *playground.tgz*. The *.tgz* extension is the conventional extension given to gzip-compressed tar files. The extension *.tar.gz* is also used sometimes.

While we used the gzip program externally to produce our compressed archive, modern versions of GNU tar support both gzip and bzip2 compression directly with the use of the z and j options, respectively. Using our previous example as a base, we can simplify it this way:

```
[me@linuxbox ~]$ find playground -name 'file-A' | tar czf playground.tgz -T -
```

If we had wanted to create a bzip2-compressed archive instead, we could have done this:

```
[me@linuxbox ~]$ find playground -name 'file-A' | tar cjf playground.tbz -T -
```

By simply changing the compression option from z to j (and changing the output file's extension to *.tbz* to indicate a bzip2-compressed file), we enabled bzip2 compression.

Another interesting use of standard input and output with the tar command involves transferring files between systems over a network. Imagine that we had two machines running a Unix-like system equipped with tar and ssh. In such a scenario, we could transfer a directory from a remote system (named remote-sys for this example) to our local system.

```
[me@linuxbox ~]$ mkdir remote-stuff
[me@linuxbox ~]$ cd remote-stuff
[me@linuxbox remote-stuff]$ ssh remote-sys 'tar cf - Documents' | tar xf -
me@remote-sys's password:
[me@linuxbox remote-stuff]$ ls
Documents
```

Here we were able to copy a directory named *Documents* from the remote system *remote-sys* to a directory within the directory named *remote-stuff* on the local system. How did we do this? First, we launched the tar program on the remote system using ssh. You will recall that ssh allows us to execute a program remotely on a networked computer and "see" the results on the local system—the standard output produced on the remote system is sent to the local system for viewing. We can take advantage of this by having tar create an archive (the c mode) and send it to standard output, rather than a file (the f option with the dash argument), thereby transporting the archive over the encrypted tunnel provided by ssh to the local system. On the local system, we execute tar and have it expand an archive (the x mode) supplied from standard input (again, the f option with the dash argument).

## zip

The zip program is both a compression tool and an archiver. The file format used by the program is familiar to Windows users, as it reads and writes *.zip* files. In Linux, however, gzip is the predominant compression program, with bzip2 being a close second.

In its most basic usage, zip is invoked like this:

```
zip options zipfile file...
```

For example, to make a zip archive of our playground, we would do this:

```
[me@linuxbox ~]$ zip -r playground.zip playground
```

Unless we include the -r option for recursion, only the *playground* directory (but none of its contents) is stored. Although the addition of the extension *.zip* is automatic, we will include the file extension for clarity.

During the creation of the zip archive, zip will normally display a series of messages like this:

```
 adding: playground/dir-020/file-Z (stored 0%)
 adding: playground/dir-020/file-Y (stored 0%)
 adding: playground/dir-020/file-X (stored 0%)
 adding: playground/dir-087/ (stored 0%)
 adding: playground/dir-087/file-S (stored 0%)
```

These messages show the status of each file added to the archive. zip will add files to the archive using one of two storage methods: either it will "store" a file without compression, as shown here, or it will "deflate" the file that performs compression. The numeric value displayed after the storage method indicates the amount of compression achieved. Since our playground contains only empty files, no compression is performed on its contents.

Extracting the contents of a zip file is straightforward when using the unzip program.

```
[me@linuxbox ~]$ cd foo
[me@linuxbox foo]$ unzip ../playground.zip
```

One thing to note about zip (as opposed to tar) is that if an existing archive is specified, it is updated rather than replaced. This means the existing archive is preserved, but new files are added, and matching files are replaced.

We can list and extract files selectively from a zip archive by specifying them to unzip.

```
[me@linuxbox ~]$ unzip -l playground.zip playground/dir-087/file-Z
Archive:  ../playground.zip
  Length     Date   Time    Name
 --------    ----   ----    ----
        0  10-05-18 09:25   playground/dir-087/file-Z
 --------                   -------
        0                   1 file
[me@linuxbox ~]$ cd foo
[me@linuxbox foo]$ unzip ../playground.zip playground/dir-087/file-Z
Archive:  ../playground.zip
replace playground/dir-087/file-Z? [y]es, [n]o, [A]ll, [N]one, [r]ename: y
 extracting: playground/dir-087/file-Z
```

Using the -l option causes unzip to merely list the contents of the archive without extracting the file. If no files are specified, unzip will list all files in

the archive. The -v option can be added to increase the verbosity of the listing. Note that when the archive extraction conflicts with an existing file, the user is prompted before the file is replaced.

Like tar, zip can make use of standard input and output, though its implementation is somewhat less useful. It is possible to pipe a list of filenames to zip via the -@ option.

```
[me@linuxbox foo]$ cd
[me@linuxbox ~]$ find playground -name "file-A" | zip -@ file-A.zip
```

Here we use find to generate a list of files matching the test -name "file-A" and then pipe the list into zip, which creates the archive *file-A.zip* containing the selected files.

zip also supports writing its output to standard output, but its use is limited because few programs can make use of the output. Unfortunately, the unzip program does not accept standard input. This prevents zip and unzip from being used together to perform network file copying like tar.

zip can, however, accept standard input, so it can be used to compress the output of other programs.

```
[me@linuxbox ~]$ ls -l /etc/ | zip ls-etc.zip -
 adding: - (deflated 80%)
```

In this example, we pipe the output of ls into zip. Like tar, zip interprets the trailing dash as "use standard input for the input file."

The unzip program allows its output to be sent to standard output when the -p (for pipe) option is specified.

```
[me@linuxbox ~]$ unzip -p ls-etc.zip | less
```

We touched on some of the basic things that zip/unzip can do. They both have a lot of options that add to their flexibility, though some are platform specific to other systems. The man pages for both zip and unzip are pretty good and contain useful examples; however, the main use of these programs is for exchanging files with Windows systems, rather than performing compression and archiving on Linux, where tar and gzip are greatly preferred.

## Synchronizing Files and Directories

A common strategy for maintaining a backup copy of a system involves keeping one or more directories synchronized with another directory (or directories) located on either the local system (usually a removable storage device of some kind) or a remote system. We might, for example, have a local copy of a website under development and synchronize it from time to time with the "live" copy on a remote web server.

In the Unix-like world, the preferred tool for this task is rsync. This program can synchronize both local and remote directories by using the

*rsync remote-update protocol*, which allows rsync to quickly detect the differences between two directories and perform the minimum amount of copying required to bring them into sync. This makes rsync very fast and economical to use, compared to other kinds of copy programs.

rsync is invoked like this:

```
rsync options source destination
```

where *source* and *destination* are one of the following:

- A local file or directory
- A remote file or directory in the form of *[user@]host:path*
- A remote rsync server specified with a URI of *rsync://[user@]host[:port]/path*

Note that either the source or the destination must be a local file. Remote-to-remote copying is not supported.

Let's try rsync on some local files. First, let's clean out our *foo* directory.

```
[me@linuxbox ~]$ rm -rf foo/*
```

Next, we'll synchronize the *playground* directory with a corresponding copy in *foo*.

```
[me@linuxbox ~]$ rsync -av playground foo
```

We've included both the -a option (for archiving—causes recursion and preservation of file attributes) and the -v option (verbose output) to make a *mirror* of the *playground* directory within *foo*. While the command runs, we will see a list of the files and directories being copied. At the end, we will see a summary message like this indicating the amount of copying performed:

```
sent 135759 bytes  received 57870 bytes  387258.00 bytes/sec
total size is 3230  speedup is 0.02
```

If we run the command again, we will see a different result.

```
[me@linuxbox ~]$ rsync -av playground foo
building file list ... done

 sent 22635 bytes  received 20 bytes  45310.00 bytes/sec
total size is 3230  speedup is 0.14
```

Notice that there was no listing of files. This is because rsync detected that there were no differences between *~/playground* and *~/foo/playground*,

and therefore it didn't need to copy anything. If we modify a file in *playground* and run rsync again:

```
[me@linuxbox ~]$ touch playground/dir-099/file-Z
[me@linuxbox ~]$ rsync -av playground foo
building file list ... done
playground/dir-099/file-Z
sent 22685 bytes  received 42 bytes  45454.00 bytes/sec
total size is 3230  speedup is 0.14
```

we see that rsync detected the change and copied only the updated file.

There is a subtle but useful feature we can use when we specify an rsync source. Let's consider two directories.

```
[me@linuxbox ~]$ ls
source        destination
```

Directory *source* contains one file named *file1*, and directory *destination* is empty. If we perform a copy of *source* to *destination* like so:

```
[me@linuxbox ~]$ rsync source destination
```

then rsync copies the directory *source* into *destination*.

```
[me@linuxbox ~]$ ls destination
source
```

However, if we append a trailing / to the source directory name, rsync will copy only the contents of the source directory and not the directory itself.

```
[me@linuxbox ~]$ rsync source/ destination
[me@linuxbox ~]$ ls destination
file1
```

This is handy if we want only the contents of a directory copied without creating another level of directories within the destination. We can think of it as being like *source/** in its outcome, but this method will copy all of the source directory's content including the hidden files.

As a practical example, let's consider the imaginary external hard drive that we used earlier with tar. If we attach the drive to our system and, once again, it is mounted at */media/BigDisk*, we can perform a useful system backup by first creating a directory named */backup* on the external drive and then using rsync to copy the most important stuff from our system to the external drive.

```
[me@linuxbox ~]$ mkdir /media/BigDisk/backup
[me@linuxbox ~]$ sudo rsync -av --delete /etc /home /usr/local /media/BigDisk/backup
```

In this example, we copied the */etc*, */home*, and */usr/local* directories from our system to our imaginary storage device. We included the `--delete` option to remove files that may have existed on the backup device that no longer existed on the source device (this is irrelevant the first time we make a backup but will be useful on subsequent copies). Repeating the procedure of attaching the external drive and running this `rsync` command would be a useful (though not ideal) way of keeping a small system backed up. Of course, an alias would be helpful here, too. We could create an alias and add it to our *.bashrc* file to provide this feature.

```
alias backup='sudo rsync -av --delete /etc /home /usr/local /media/BigDisk/backup'
```

Now all we have to do is attach our external drive and run the `backup` command to do the job.

### Using rsync over a Network

One of the real beauties of `rsync` is that it can be used to copy files over a network. After all, the `r` in `rsync` stands for "remote." Remote copying can be done in one of two ways. The first way is with another system that has `rsync` installed, along with a remote shell program such as `ssh`. Let's say we had another system on our local network with a lot of available hard drive space and we wanted to perform our backup operation using the remote system instead of an external drive. Assuming that it already had a directory named */backup* where we could deliver our files, we could do this:

```
[me@linuxbox ~]$ sudo rsync -av --delete --rsh=ssh /etc /home /usr/local remote-sys:/backup
```

We made two changes to our command to facilitate the network copy. First, we added the `--rsh=ssh` option, which instructs `rsync` to use the `ssh` program as its remote shell. In this way, we were able to use an `ssh`-encrypted tunnel to securely transfer the data from the local system to the remote host. Second, we specified the remote host by prefixing its name (in this case the remote host is named *remote-sys*) to the destination pathname.

The second way that `rsync` can be used to synchronize files over a network is by using an *rsync server*. `rsync` can be configured to run as a daemon and listen to incoming requests for synchronization. This is often done to allow mirroring of a remote system. For example, Red Hat Software maintains a large repository of software packages under development for its Fedora distribution. It is useful for software testers to mirror this collection during the testing phase of the distribution release cycle. Since files in the repository change frequently (often more than once a day), it is desirable to maintain a local mirror by periodic synchronization, rather than

by bulk copying of the repository. One of these repositories is kept at Duke University; we could mirror it using our local copy of rsync and their rsync server like this:

```
[me@linuxbox ~]$ mkdir fedora-devel
[me@linuxbox ~]$ rsync -av -delete rsync://archive.linux.duke.edu/fedora/
linux/development/rawhide/Everything/x86_64/os/ fedora-devel
```

In this example, we use the URI of the remote rsync server, which consists of a protocol (*rsync://*), followed by the remote hostname (*archive.linux.duke.edu*), followed by the pathname of the repository.

## Summing Up

We've looked at the common compression and archiving programs used on Linux and other Unix-like operating systems. For archiving files, the tar/gzip combination is the preferred method on Unix-like systems, while zip/unzip is used for interoperability with Windows systems. Finally, we looked at the rsync program (a personal favorite), which is very handy for efficient synchronization of files and directories across systems.

# 19

## REGULAR EXPRESSIONS

In the next few chapters, we are going to look at tools used to manipulate text. As we have seen, text data plays an important role on all Unix-like systems, such as Linux. But before we can fully appreciate all the features offered by these tools, first we have to examine a technology that is frequently associated with the most sophisticated uses of these tools—*regular expressions.*

As we have navigated the many features and facilities offered by the command line, we have encountered some truly arcane features, such as shell expansion and quoting, keyboard shortcuts, and command history, not to mention the `vi` editor. Regular expressions continue this "tradition" and may be (arguably) the most arcane feature of them all. This is not to suggest that the time it takes to learn about them is not worth the effort. Quite the contrary. A good understanding will enable us to perform amazing feats, though their full value may not be immediately apparent.

## What Are Regular Expressions?

Simply put, regular expressions are symbolic notations used to identify patterns in text. In some ways, they resemble the shell's wildcard method of matching file and pathnames but on a much grander scale. Regular expressions are supported by many command line tools and by most programming languages to facilitate the solution of text manipulation problems. However, to further confuse things, not all regular expressions are the same; they vary slightly from tool to tool and from programming language to language. For our discussion, we will limit ourselves to regular expressions as described in the POSIX standard (which will cover most of the command line tools), as opposed to many programming languages (most notably Perl), which use slightly larger and richer sets of notations.

## grep

The main program we will use to work with regular expressions is our old pal `grep`. The name *grep* is actually derived from the phrase "global regular expression print," so we can see that `grep` has something to do with regular expressions. In essence, `grep` searches text files for text matching a specified regular expression and outputs any line containing a match to standard output.

So far, we have used `grep` with fixed strings, like so:

```
[me@linuxbox ~]$ ls /usr/bin | grep zip
```

This will list all the files in the */usr/bin* directory whose names contain the substring *zip*.

The `grep` program accepts options and arguments this way, where *regex* is a regular expression:

```
grep [options] regex [file...]
```

Table 19-1 describes the commonly used `grep` options.

**Table 19-1:** grep Options

| Option | Long option | Description |
|---|---|---|
| `-i` | `--ignore-case` | Ignore case. Do not distinguish between uppercase and lowercase characters. |
| `-v` | `--invert-match` | Invert match. Normally, `grep` prints lines that contain a match. This option causes `grep` to print every line that does not contain a match. |
| `-c` | `--count` | Print the number of matches (or non-matches if the -v option is also specified) instead of the lines themselves. |
| `-l` | `--files-with-matches` | Print the name of each file that contains a match instead of the lines themselves. |

| Option | Long option | Description |
|---|---|---|
| -L | --files-without-match | Like the -l option, but print only the names of files that do not contain matches. |
| -n | --line-number | Prefix each matching line with the number of the line within the file. |
| -h | --no-filename | For multifile searches, suppress the output of filenames. |

To more fully explore grep, let's create some text files to search.

```
[me@linuxbox ~]$ ls /bin > dirlist-bin.txt
[me@linuxbox ~]$ ls /usr/bin > dirlist-usr-bin.txt
[me@linuxbox ~]$ ls /sbin > dirlist-sbin.txt
[me@linuxbox ~]$ ls /usr/sbin > dirlist-usr-sbin.txt
[me@linuxbox ~]$ ls dirlist*.txt
dirlist-bin.txt   dirlist-sbin.txt     dirlist-usr-sbin.txt
dirlist-usr-bin.txt
```

We can perform a simple search of our list of files like this:

```
[me@linuxbox ~]$ grep bzip dirlist*.txt
dirlist-bin.txt:bzip2
dirlist-bin.txt:bzip2recover
```

In this example, grep searches all the listed files for the string *bzip* and finds two matches, both in the file *dirlist-bin.txt*. If we were interested only in the list of files that contained matches rather than the matches themselves, we could specify the -l option.

```
[me@linuxbox ~]$ grep -l bzip dirlist*.txt
dirlist-bin.txt
```

Conversely, if we wanted to see only a list of the files that did not contain a match, we could do this:

```
[me@linuxbox ~]$ grep -L bzip dirlist*.txt
dirlist-sbin.txt
dirlist-usr-bin.txt
dirlist-usr-sbin.txt
```

## Metacharacters and Literals

While it might not seem apparent, our grep searches have been using regular expressions all along, albeit very simple ones. The regular expression bzip is taken to mean that a match will occur only if the line in the file contains at least four characters and that somewhere in the line the characters *b*, *z*, *i*, and *p* are found in that order, with no other characters in between. The characters in the string *bzip* are all *literal characters*, in that they match

themselves. In addition to literals, regular expressions may also include *metacharacters* that are used to specify more complex matches. Regular expression metacharacters consist of the following:

```
^ $ . [ ] { } - ? * + ( ) | \
```

All other characters are considered literals, though the backslash character is used in a few cases to create *metasequences*, as well as allowing the metacharacters to be escaped and treated as literals instead of being interpreted as metacharacters.

**NOTE** *As we can see, many of the regular expression metacharacters are also characters that have meaning to the shell when expansion is performed. When we pass regular expressions containing metacharacters on the command line, it is vital that they be enclosed in quotes to prevent the shell from attempting to expand them.*

## The Any Character

The first metacharacter we will look at is the dot (`.`) or period character, which is used to match any character. If we include it in a regular expression, it will match any character in that character position. Here's an example:

```
[me@linuxbox ~]$ grep -h '.zip' dirlist*.txt
bunzip2
bzip2
bzip2recover
gunzip
gzip
funzip
gpg-zip
preunzip
prezip
prezip-bin
unzip
unzipsfx
```

We searched for any line in our files that matches the regular expression *.zip*. There are a couple of interesting things to note about the results. Notice that the `zip` program was not found. This is because the inclusion of the dot metacharacter in our regular expression increased the length of the required match to four characters, and because the name *zip* contains only three, it does not match. Also, if any files in our lists had contained the file extension *.zip*, they would have been matched as well, because the period character in the file extension would be matched by the "any character," too.

## Anchors

The caret (`^`) and dollar sign (`$`) are treated as *anchors* in regular expressions. This means they cause the match to occur only if the regular expression is found at the beginning of the line (`^`) or at the end of the line (`$`).

```
[me@linuxbox ~]$ grep -h '^zip' dirlist*.txt
zip
zipcloak
zipgrep
zipinfo
zipnote
zipsplit
[me@linuxbox ~]$ grep -h 'zip$' dirlist*.txt
gunzip
gzip
funzip
gpg-zip
preunzip
prezip
unzip
zip
[me@linuxbox ~]$ grep -h '^zip$' dirlist*.txt
zip
```

Here we searched the list of files for the string *zip* located at the beginning of the line, at the end of the line, and on a line where it is at both the beginning and the end of the line (i.e., by itself on the line). Note that the regular expression ^$ (a beginning and an end with nothing in between) will match blank lines.

### A CROSSWORD PUZZLE HELPER

Even with our limited knowledge of regular expressions at this point, we can do something useful.

My wife loves crossword puzzles, and she will sometimes ask me for help with a particular question. Something like, "What's a five-letter word whose third letter is *j* and last letter is *r* that means . . . ?" This kind of question got me thinking.

Did you know that your Linux system contains a dictionary? It does. Take a look in the */usr/share/dict* directory, and you might find one or several. The dictionary files located there are just long lists of words, one per line, arranged in alphabetical order. On my system, the *words* file contains just over 98,500 words. To find possible answers to the crossword puzzle question above, we could do this:

```
[me@linuxbox ~]$ grep -i '^..j.r$' /usr/share/dict/words
Major
major
```

Using this regular expression, we can find all the words in our dictionary file that are five letters long and have a *j* in the third position and an *r* in the last position.

## Bracket Expressions and Character Classes

In addition to matching any character at a given position in our regular expression, we can also match a single character from a specified set of characters by using *bracket expressions*. With bracket expressions, we can specify a set of characters (including characters that would otherwise be interpreted as metacharacters) to be matched. In this example, using a two-character set, we match any line that contains the string *bzip* or *gzip*:

```
[me@linuxbox ~]$ grep -h '[bg]zip' dirlist*.txt
bzip2
bzip2recover
gzip
```

A set may contain any number of characters, and metacharacters lose their special meaning when placed within brackets. However, there are two cases in which metacharacters are used within bracket expressions and have different meanings. The first is the caret (^), which is used to indicate negation; the second is the dash (-), which is used to indicate a character range.

### Negation

If the first character in a bracket expression is a caret (^), the remaining characters are taken to be a set of characters that must not be present at the given character position. We do this by modifying our previous example, as follows:

```
[me@linuxbox ~]$ grep -h '[^bg]zip' dirlist*.txt
bunzip2
gunzip
funzip
gpg-zip
preunzip
prezip
prezip-bin
unzip
unzipsfx
```

With negation activated, we get a list of files that contain the string *zip* preceded by any character except *b* or *g*. Notice that the file *zip* was not found. A negated character set still requires a character at the given position, but the character must not be a member of the negated set.

The caret character invokes negation only if it is the first character within a bracket expression; otherwise, it loses its special meaning and becomes an ordinary character in the set.

### Traditional Character Ranges

If we wanted to construct a regular expression that would find every file in our lists beginning with an uppercase letter, we could do this:

```
[me@linuxbox ~]$ grep -h '^[ABCDEFGHIJKLMNOPQRSTUVWXZY]' dirlist*.txt
```

It's just a matter of putting all 26 uppercase letters in a bracket expression. But the idea of all that typing is deeply troubling, so here is another way.

```
[me@linuxbox ~]$ grep -h '^[A-Z]' dirlist*.txt
MAKEDEV
ControlPanel
GET
HEAD
POST
X
X11
Xorg
MAKEFLOPPIES
NetworkManager
NetworkManagerDispatcher
```

By using a three-character range, we can abbreviate the 26 letters. Any range of characters can be expressed this way including multiple ranges, such as this expression that matches all filenames starting with letters and numbers:

```
[me@linuxbox ~]$ grep -h '^[A-Za-z0-9]' dirlist*.txt
```

In character ranges, we see that the dash character is treated specially, so how do we actually include a dash character in a bracket expression? By making it the first character in the expression. Consider these two examples:

```
[me@linuxbox ~]$ grep -h '[A-Z]' dirlist*.txt
```

This will match every filename containing an uppercase letter. The following will match every filename containing a dash or an uppercase *A* or an uppercase *Z*:

```
[me@linuxbox ~]$ grep -h '[-AZ]' dirlist*.txt
```

## POSIX Character Classes

The traditional character ranges are an easily understood and effective way to handle the problem of quickly specifying sets of characters. Unfortunately, they don't always work. While we have not encountered any problems with our use of `grep` so far, we might run into problems using other programs.

In Chapter 4, we looked at how wildcards are used to perform pathname expansion. In that discussion, we said that character ranges could be used in a manner almost identical to the way they are used in regular expressions, but here's the problem:

```
[me@linuxbox ~]$ ls /usr/sbin/[ABCDEFGHIJKLMNOPQRSTUVWXYZ]*
/usr/sbin/ModemManager
/usr/sbin/NetworkManager
```

(Depending on the Linux distribution, we will get a different list of files, possibly an empty list. This example is from Ubuntu.) This command produces the expected result—a list of only the files whose names begin with an uppercase letter, but with the following command we get an entirely different result (only a partial listing of the results is shown):

```
[me@linuxbox ~]$ ls /usr/sbin/[A-Z]*
/usr/sbin/biosdecode
/usr/sbin/chat
/usr/sbin/chgpasswd
/usr/sbin/chpasswd
/usr/sbin/chroot
/usr/sbin/cleanup-info
/usr/sbin/complain
/usr/sbin/console-kit-daemon
```

Why is that? It's a long story, but here's the short version:

Back when Unix was first developed, it knew only about ASCII characters, and this feature reflects that fact. In ASCII, the first 32 characters (numbers 0–31) are control codes (things such as tabs, backspaces, and carriage returns). The next 32 (32–63) contain printable characters, including most punctuation characters and the numerals 0–9. The next 32 (numbers 64–95) contain the uppercase letters and a few more punctuation symbols. The final 31 (numbers 96–127) contain the lowercase letters and yet more punctuation symbols. Based on this arrangement, systems using ASCII used a *collation order* that looks like this:

```
ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz
```

This differs from proper dictionary order, which is like this:

```
aAbBcCdDeEfFgGhHiIjJkKlLmMnNoOpPqQrRsStTuUvVwWxXyYzZ
```

As the popularity of Unix spread beyond the United States, there grew a need to support characters not found in US English. The ASCII table was expanded to use a full eight bits, adding characters 128–255, which accommodated many more languages. To support this capability, the POSIX standards introduced a concept called a *locale*, which could be adjusted to select the character set needed for a particular location. We can see the language setting of our system using the following command.

```
[me@linuxbox ~]$ echo $LANG
en_US.UTF-8
```

With this setting, POSIX-compliant applications will use a dictionary collation order rather than ASCII order. This explains the behavior of the previous commands. A character range of `[A-Z]` when interpreted in dictionary order includes all of the alphabetic characters except the lowercase *a*, hence our results.

To partially work around this problem, the POSIX standard includes a number of character classes that provide useful ranges of characters, as described in Table 19-2.

**Table 19-2:** POSIX Character Classes

| Character class | Description |
|---|---|
| `[:alnum:]` | The alphanumeric characters. In ASCII, equivalent to: `[A-Za-z0-9]` |
| `[:word:]` | The same as `[:alnum:]`, with the addition of the underscore (_) character. |
| `[:alpha:]` | The alphabetic characters. In ASCII, equivalent to: `[A-Za-z]` |
| `[:blank:]` | Includes the space and tab characters. |
| `[:cntrl:]` | The ASCII control codes. Includes the ASCII characters 0 through 31 and 127. |
| `[:digit:]` | The numerals 0 through 9. |
| `[:graph:]` | The visible characters. In ASCII, it includes characters 33 through 126. |
| `[:lower:]` | The lowercase letters. |
| `[:punct:]` | The punctuation characters. In ASCII, equivalent to: `[-!"#$%&'()*+,./:;<=>?@[\\\]_`{\|}~]` |
| `[:print:]` | The printable characters. All the characters in `[:graph:]` plus the space character. |
| `[:space:]` | The whitespace characters including space, tab, carriage return, newline, vertical tab, and form feed. In ASCII, equivalent to: `[ \t\r\n\v\f]` |
| `[:upper:]` | The uppercase characters. |
| `[:xdigit:]` | Characters used to express hexadecimal numbers. In ASCII, equivalent to: `[0-9A-Fa-f]` |

Even with the character classes, there is still no convenient way to express partial ranges, such as `[A-M]`.

Using character classes, we can repeat our directory listing and see an improved result.

```
[me@linuxbox ~]$ ls /usr/sbin/[[:upper:]]*
/usr/sbin/MAKEFLOPPIES
/usr/sbin/NetworkManagerDispatcher
/usr/sbin/NetworkManager
```

Remember, however, that this is not an example of a regular expression; rather, it is the shell performing pathname expansion. We show it here because POSIX character classes can be used for both.

**REVERTING TO TRADITIONAL COLLATION ORDER**

You can opt to have your system use the traditional (ASCII) collation order by changing the value of the `LANG` environment variable. As we saw earlier, the `LANG` variable contains the name of the language and character set used in your locale. This value was originally determined when you selected an installation language as your Linux version was installed.

To see the locale settings, use the `locale` command.

```
[me@linuxbox ~]$ locale
LANG=en_US.UTF-8
LC_CTYPE="en_US.UTF-8"
LC_NUMERIC="en_US.UTF-8"
LC_TIME="en_US.UTF-8"
LC_COLLATE="en_US.UTF-8"
LC_MONETARY="en_US.UTF-8"
LC_MESSAGES="en_US.UTF-8"
LC_PAPER="en_US.UTF-8"
LC_NAME="en_US.UTF-8"
LC_ADDRESS="en_US.UTF-8"
LC_TELEPHONE="en_US.UTF-8"
LC_MEASUREMENT="en_US.UTF-8"
LC_IDENTIFICATION="en_US.UTF-8"
LC_ALL=
```

To change the locale to use the traditional Unix behaviors, set the `LANG` variable to `POSIX`.

```
[me@linuxbox ~]$ export LANG=POSIX
```

Note that this change converts the system to use US English (more specifically, ASCII) for its character set, so be sure if this is really what you want.

You can make this change permanent by adding this line to your *.bashrc* file:

```
export LANG=POSIX
```

## POSIX Basic vs. Extended Regular Expressions

Just when we thought this couldn't get any more confusing, we discover that POSIX also splits regular expression implementations into two kinds: *basic regular expressions* (*BRE*) and *extended regular expressions* (*ERE*). The features we have covered so far are supported by any application that is POSIX compliant and implements BRE. Our `grep` program is one such program.

What's the difference between BRE and ERE? It's a matter of metacharacters. With BRE, the following metacharacters are recognized:

```
^ $ . [ ] *
```

All other characters are considered literals. With ERE, the following metacharacters (and their associated functions) are added:

```
( ) { } ? + |
```

However (and this is the fun part), the (, ), {, and } characters are treated as metacharacters in BRE *if* they are escaped with a backslash, whereas with ERE, preceding any metacharacter with a backslash causes it to be treated as a literal. Any weirdness that comes along will be covered in the discussions that follow.

Because the features we are going to discuss next are part of ERE, we are going to need to use a different grep. Traditionally, this has been performed by the egrep program, but the GNU version of grep also supports extended regular expressions when the -E option is used.

**POSIX**

During the 1980s, Unix became a very popular commercial operating system, but by 1988, the Unix world was in turmoil. Many computer manufacturers had licensed the Unix source code from its creators, AT&T, and were supplying various versions of the operating system with their systems. However, in their efforts to create product differentiation, each manufacturer added proprietary changes and extensions. This started to limit the compatibility of the software. As always with proprietary vendors, each was trying to play a winning game of "lock in" with their customers. This dark time in the history of Unix is known today as the *Balkanization*.

Enter the Institute of Electrical and Electronics Engineers (IEEE). In the mid-1980s, the IEEE began developing a set of standards that would define how Unix (and Unix-like) systems would perform. These standards, formally known as IEEE 1003, define the application programming interfaces (APIs), shell, and utilities that are to be found on a standard Unix-like system. The name POSIX, which stands for *Portable Operating System Interface* (with the *X* added to the end for extra snappiness), was suggested by Richard Stallman (yes, *that* Richard Stallman) and was adopted by the IEEE.

## Alternation

The first of the extended regular expression features we will discuss is called *alternation*, which is the facility that allows a match to occur from among a set of expressions. Just as a bracket expression allows a single character to match from a set of specified characters, alternation allows matches from a set of strings or other regular expressions.

To demonstrate, we'll use grep in conjunction with echo. First, let's try a plain old string match.

```
[me@linuxbox ~]$ echo "AAA" | grep AAA
AAA
[me@linuxbox ~]$ echo "BBB" | grep AAA
[me@linuxbox ~]$
```

This is a pretty straightforward example, in which we pipe the output of echo into grep and see the results. When a match occurs, we see it printed out; when no match occurs, we see no results.

Now we'll add alternation, signified by the vertical-bar metacharacter.

```
[me@linuxbox ~]$ echo "AAA" | grep -E 'AAA|BBB'
AAA
[me@linuxbox ~]$ echo "BBB" | grep -E 'AAA|BBB'
BBB
[me@linuxbox ~]$ echo "CCC" | grep -E 'AAA|BBB'
[me@linuxbox ~]$
```

Here we see the regular expression 'AAA|BBB', which means "match either the string AAA or the string BBB." Notice that since this is an extended feature, we added the -E option to grep (though we could have just used the egrep program instead), and we enclosed the regular expression in quotes to prevent the shell from interpreting the vertical-bar metacharacter as a pipe operator. Alternation is not limited to two choices.

```
[me@linuxbox ~]$ echo "AAA" | grep -E 'AAA|BBB|CCC'
AAA
```

To combine alternation with other regular expression elements, we can use () to separate the alternation.

```
[me@linuxbox ~]$ grep -Eh '^(bz|gz|zip)' dirlist*.txt
```

This expression will match the filenames in our lists that start with either *bz*, *gz*, or *zip*. Had we left off the parentheses, the meaning of this regular expression changes to match any filename that begins with *bz* or contains *gz* or contains *zip*:

```
[me@linuxbox ~]$ grep -Eh '^bz|gz|zip' dirlist*.txt
```

## Quantifiers

Extended regular expressions support several ways to specify the number of times an element is matched, as described in the sections that follow.

### ?—Match an Element Zero or One Time

This quantifier means, in effect, "make the preceding element optional." Let's say we wanted to check a phone number for validity and we considered

a phone number to be valid if it matched either of these two forms, where *n* is a numeral:

- *(nnn) nnn-nnnn*
- *nnn nnn-nnnn*

We could construct a regular expression like this:

```
^\(?[0-9][0-9][0-9]\)? [0-9][0-9][0-9]-[0-9][0-9][0-9][0-9]$
```

In this expression, we follow the parentheses characters with question marks to indicate that they are to be matched zero or one time. Again, because the parentheses are normally metacharacters (in ERE), we precede them with backslashes to cause them to be treated as literals instead.

Let's try it.

```
[me@linuxbox ~]$ echo "(555) 123-4567" | grep -E '^\(?[0-9][0-9][0-9]
\)? [0-9][0-9][0-9]-[0-9][0-9][0-9][0-9]$'
(555) 123-4567
[me@linuxbox ~]$ echo "555 123-4567" | grep -E '^\(?[0-9][0-9][0-9]\)
? [0-9][0-9][0-9]-[0-9][0-9][0-9][0-9]$'
555 123-4567
[me@linuxbox ~]$ echo "AAA 123-4567" | grep -E '^\(?[0-9][0-9][0-9]\)
? [0-9][0-9][0-9]-[0-9][0-9][0-9][0-9]$'
[me@linuxbox ~]$
```

Here we see that the expression matches both forms of the phone number but does not match one containing non-numeric characters. This expression is not perfect as it still allows mismatched parentheses around the area code, but it will perform the first stage of a verification.

### *—Match an Element Zero or More Times

Like the ? metacharacter, the * is used to denote an optional item; however, unlike the ?, the item may occur any number of times, not just once. Let's say we wanted to see whether a string was a sentence; that is, it starts with an uppercase letter, then contains any number of uppercase and lowercase letters and spaces, and ends with a period. To match this (crude) definition of a sentence, we could use a regular expression like this:

```
[[:upper:]][[:upper:][:lower:] ]*\.
```

The expression consists of three items: a bracket expression containing the `[:upper:]` character class, a bracket expression containing both the `[:upper:]` and `[:lower:]` character classes and a space, and a period escaped with a backslash. The second element is trailed with an * metacharacter so that after the leading uppercase letter in our sentence, any number of uppercase and lowercase letters and spaces may follow it and still match.

```
[me@linuxbox ~]$ echo "This works." | grep -E '[[:upper:]][[:upper:][:lower:] ]*\.'
This works.
[me@linuxbox ~]$ echo "This Works." | grep -E '[[:upper:]][[:upper:][:lower:] ]*\.'
This Works.
[me@linuxbox ~]$ echo "this does not" | grep -E '[[:upper:]][[:upper:][:lower:] ]*\.'
[me@linuxbox ~]$
```

The expression matches the first two tests, but not the third, since it lacks the required leading uppercase character and trailing period.

### +—Match an Element One or More Times

The + metacharacter works much like the *, except it requires at least one instance of the preceding element to cause a match. Here is a regular expression that will match only the lines consisting of groups of one or more alphabetic characters separated by single spaces:

```
^([[:alpha:]]+ ?)+$
```

Let's try it.

```
[me@linuxbox ~]$ echo "This that" | grep -E '^([[:alpha:]]+ ?)+$'
This that
[me@linuxbox ~]$ echo "a b c" | grep -E '^([[:alpha:]]+ ?)+$'
a b c
[me@linuxbox ~]$ echo "a b 9" | grep -E '^([[:alpha:]]+ ?)+$'
[me@linuxbox ~]$ echo "abc  d" | grep -E '^([[:alpha:]]+ ?)+$'
[me@linuxbox ~]$
```

We see that this expression does not match the line `a b 9` because it contains a nonalphabetic character; nor does it match `abc  d` because more than one space character separates the characters *c* and *d*.

### { }—Match an Element a Specific Number of Times

The { and } metacharacters are used to express minimum and maximum numbers of required matches. They may be specified in four possible ways, as outlined in Table 19-3.

**Table 19-3:** Specifying the Number of Matches

| Specifier | Meaning |
|---|---|
| {*n*} | Match the preceding element if it occurs exactly *n* times. |
| {*n*,*m*} | Match the preceding element if it occurs at least *n* times but no more than *m* times. |
| {*n*,} | Match the preceding element if it occurs *n* or more times. |
| {,*m*} | Match the preceding element if it occurs no more than *m* times. |

Going back to our earlier example with the phone numbers, we can use this method of specifying repetitions to simplify our original regular expression from the following:

```
^\(?[0-9][0-9][0-9]\)?  [0-9][0-9][0-9]-[0-9][0-9][0-9][0-9]$
```

to the following:

```
^\(?[0-9]{3}\)?  [0-9]{3}-[0-9]{4}$
```

Let's try it.

```
[me@linuxbox ~]$ echo "(555) 123-4567" | grep -E '^\(?[0-9]{3}\)? [0-9]{3}-[0-9]{4}$'
(555) 123-4567
[me@linuxbox ~]$ echo "555 123-4567" | grep -E '^\(?[0-9]{3}\)? [0-9]{3}-[0-9]{4}$'
555 123-4567
[me@linuxbox ~]$ echo "5555 123-4567" | grep -E '^\(?[0-9]{3}\)? [0-9]{3}-[0-9]{4}$'
[me@linuxbox ~]$
```

As we can see, our revised expression can successfully validate numbers both with and without the parentheses, while rejecting those numbers that are not properly formatted.

## Putting Regular Expressions to Work

Let's look at some of the commands we already know and see how they can be used with regular expressions.

### *Validating a Phone List with grep*

In our earlier example, we looked at single phone numbers and checked them for proper formatting. A more realistic scenario would be checking a list of numbers instead, so let's make a list. We'll do this by reciting a magical incantation to the command line. It will be magic because we have not covered most of the commands involved, but worry not. We will get there in future chapters. Here is the incantation.

```
[me@linuxbox ~]$ for i in {1..10}; do echo "(${RANDOM:0:3}) ${RANDOM:0:3}-$
{RANDOM:0:4}" >> phonelist.txt; done
```

This command will produce a file named *phonelist.txt* containing 10 phone numbers. Each time the command is repeated, another 10 numbers are added to the list. We can also change the value 10 near the beginning of the command to produce more or fewer phone numbers. If we examine the contents of the file, however, we see we have a problem.

```
[me@linuxbox ~]$ cat phonelist.txt
(232) 298-2265
```

```
(624) 381-1078
(540) 126-1980
(874) 163-2885
(286) 254-2860
(292) 108-518
(129) 44-1379
(458) 273-1642
(686) 299-8268
(198) 307-2440
```

Some of the numbers are malformed, which is perfect for our purposes because we will use grep to validate them.

One useful method of validation would be to scan the file for invalid numbers and display the resulting list.

```
[me@linuxbox ~]$ grep -Ev '^\([0-9]{3}\) [0-9]{3}-[0-9]{4}$' phonelist.txt
(292) 108-518
(129) 44-1379
[me@linuxbox ~]$
```

Here we use the -v option to produce an inverse match so that we will output only the lines in the list that do not match the specified expression. The expression itself includes the anchor metacharacters at each end to ensure that the number has no extra characters at either end. This expression also requires that the parentheses be present in a valid number, unlike our earlier phone number example.

### Finding Ugly Filenames with find

The find command supports a test based on a regular expression. There is an important consideration to keep in mind when using regular expressions in find versus grep. Whereas grep will print a line when the line *contains* a string that matches an expression, find requires that the pathname *exactly match* the regular expression. In the following example, we will use find with a regular expression to find every pathname that contains any character that is not a member of the following set:

```
[-_./0-9a-zA-Z]
```

Such a scan would reveal pathnames that contain embedded spaces and other potentially offensive characters.

```
[me@linuxbox ~]$ find . -regex '.*[^-_./0-9a-zA-Z].*'
```

Because of the requirement for an exact match of the entire pathname, we use .* at both ends of the expression to match zero or more instances of any character. In the middle of the expression, we use a negated bracket expression containing our set of acceptable pathname characters.

### Searching for Files with locate

The `locate` program supports both basic (the `--regexp` option) and extended (the `--regex` option) regular expressions. With it, we can perform many of the same operations that we performed earlier with our `dirlist` files.

```
[me@linuxbox ~]$ locate --regex 'bin/(bz|gz|zip)'
/bin/bzcat
/bin/bzcmp
/bin/bzdiff
/bin/bzegrep
/bin/bzexe
/bin/bzfgrep
/bin/bzgrep
/bin/bzip2
/bin/bzip2recover
/bin/bzless
/bin/bzmore
/bin/gzexe
/bin/gzip
/usr/bin/zip
/usr/bin/zipcloak
/usr/bin/zipgrep
/usr/bin/zipinfo
/usr/bin/zipnote
/usr/bin/zipsplit
```

Using alternation, we perform a search for pathnames that contain either *bin/bz*, *bin/gz*, or */bin/zip*.

### Searching for Text with less and vim

`less` and `vim` both share the same method of searching for text. Pressing the `/` key followed by a regular expression will perform a search. If we use `less` to view our *phonelist.txt* file, like so:

```
[me@linuxbox ~]$ less phonelist.txt
```

and then search for our validation expression, like this:

```
(232) 298-2265
(624) 381-1078
(540) 126-1980
(874) 163-2885
(286) 254-2860
(292) 108-518
(129) 44-1379
(458) 273-1642
(686) 299-8268
(198) 307-2440
~
~
```

```
~
/^\([0-9]{3}\) [0-9]{3}-[0-9]{4}$
```

less will highlight the strings that match, leaving the invalid ones easy to spot.

```
(232) 298-2265
(624) 381-1078
(540) 126-1980
(874) 163-2885
(286) 254-2860
(292) 108-518
(129) 44-1379
(458) 273-1642
(686) 299-8268
(198) 307-2440
~
~
~
(END)
```

vim, on the other hand, supports basic regular expressions, so our search expression would look like this:

```
/([0-9]\{3\}) [0-9]\{3\}-[0-9]\{4\}
```

We can see that the expression is mostly the same; however, many of the characters that are considered metacharacters in extended expressions are considered literals in basic expressions. They are treated only as metacharacters when escaped with a backslash. Depending on the particular configuration of vim on our system, the matching will be highlighted. If not, try this command mode command to activate search highlighting:

```
:hlsearch
```

**NOTE** *Depending on your distribution, vim may or may not support text search highlighting. Ubuntu, in particular, supplies a stripped-down version of vim by default. On such systems, you may want to use your package manager to install a more complete version of vim.*

## Summing Up

In this chapter, we saw a few of the many uses of regular expressions. We can find even more if we use regular expressions to search for additional applications that use them. We can do that by searching the man pages.

```
[me@linuxbox ~]$ cd /usr/share/man/man1
[me@linuxbox man1]$ zgrep -El 'regex|regular expression' *.gz
```

The `zgrep` program provides a front end for `grep`, allowing it to read compressed files. In our example, we search the compressed section 1 man page files in their usual location. The result of this command is a list of files containing either the string *regex* or the string *regular expression*. As we can see, regular expressions show up in a lot of programs.

There is one feature found in basic regular expressions that we did not cover. Called *back references*, this feature will be discussed in the next chapter.

# 20

## TEXT PROCESSING

All Unix-like operating systems rely heavily on text files for data storage. So it makes sense that there are many tools for manipulating text. In this chapter, we will look at programs that are used to "slice and dice" text. In the next chapter, we will look at more text processing, focusing on programs that are used to format text for printing and other kinds of human consumption.

This chapter will revisit some old friends and introduce us to some new ones:

- **`cat`** Concatenate files and print on the standard output
- **`sort`** Sort lines of text files
- **`uniq`** Report or omit repeated lines
- **`cut`** Remove sections from each line of files
- **`paste`** Merge lines of files

**join** Join lines of two files on a common field

**comm** Compare two sorted files line by line

**diff** Compare files line by line

**patch** Apply a diff file to an original

**tr** Translate or delete characters

**sed** Stream editor for filtering and transforming text

**aspell** Interactive spellchecker

## Applications of Text

So far, we have learned a couple of text editors (`nano` and `vim`), looked at a bunch of configuration files, and have witnessed the output of dozens of commands, all in text. But what else is text used for? For many things, it turns out.

### *Documents*

Many people write documents using plain text formats. While it is easy to see how a small text file could be useful for keeping simple notes, it is also possible to write large documents in text format. One popular approach is to write a large document in a text format and then embed a *markup language* to describe the formatting of the finished document. Many scientific papers are written using this method, as Unix-based text processing systems were among the first systems that supported the advanced typographical layout needed by writers in technical disciplines.

### *Web Pages*

The world's most popular type of electronic document is probably the web page. Web pages are text documents that use either *Hypertext Markup Language* (*HTML*) or *Extensible Markup Language* (*XML*) as markup languages to describe the document's visual format.

### *Email*

Email is an intrinsically text-based medium. Even non-text attachments are converted into a text representation for transmission. We can see this for ourselves by downloading an email message and then viewing it in `less`. We will see that the message begins with a *header* that describes the source of the message and the processing it received during its journey, followed by the *body* of the message with its content.

### *Printer Output*

On Unix-like systems, output destined for a printer is sent as plain text or, if the page contains graphics, is converted into a text format *page description language* known as *PostScript*, which is then sent to a program that generates the graphic dots to be printed.

### *Program Source Code*

Many of the command line programs found on Unix-like systems were created to support system administration and software development, and text processing programs are no exception. Many of them are designed to solve software development problems. The reason text processing is important to software developers is that all software starts out as text. *Source code*, the part of the program the programmer actually writes, is always in text format.

## Revisiting Some Old Friends

Back in Chapter 6 we learned about some commands that are able to accept standard input in addition to command line arguments. We touched on them only briefly then, but now we will take a closer look at how they can be used to perform text processing.

### *cat*

The `cat` program has a number of interesting options. Many of them are used to help better visualize text content. One example is the `-A` option, which is used to display non-printing characters in the text. There are times when we want to know whether control characters are embedded in our otherwise visible text. The most common of these are tab characters (as opposed to spaces) and carriage returns, often present as end-of-line characters in MS-DOS-style text files. Another common situation is a file containing lines of text with trailing spaces.

Let's create a test file using `cat` as a primitive word processor. To do this, we'll just enter the command `cat` (along with specifying a file for redirected output) and type our text, followed by ENTER to properly end the line and then CTRL-D to indicate to `cat` that we have reached end of file. In this example, we enter a leading tab character and follow the line with some trailing spaces:

```
[me@linuxbox ~]$ cat > foo.txt
    The quick brown fox jumped over the lazy dog.
[me@linuxbox ~]$
```

Next, we use `cat` with the `-A` option to display the text.

```
[me@linuxbox ~]$ cat -A foo.txt
^IThe quick brown fox jumped over the lazy dog.   $
[me@linuxbox ~]$
```

As we can see in the results, the tab character in our text is represented by `^I`. This is a common notation that means CTRL-I, which, as it turns out, is the same as a tab character. We also see that a `$` appears at the true end of the line, indicating that our text contains trailing spaces.

**MS-DOS TEXT VS. UNIX TEXT**

One of the reasons you may want to use cat to look for non-printing characters in text is to spot hidden carriage returns. Where do hidden carriage returns come from? DOS and Windows! Unix and DOS don't define the end of a line the same way in text files. Unix ends a line with a linefeed character (ASCII 10), while MS-DOS and its derivatives use the sequence carriage return (ASCII 13) and linefeed to terminate each line of text.

There are several ways to convert files from DOS to Unix format. On many Linux systems, there are programs called dos2unix and unix2dos, which can convert text files to and from DOS format. However, if you don't have dos2unix on your system, don't worry. The process of converting text from DOS to Unix format is simple; it involves the removal of the offending carriage returns. That is easily accomplished by a couple of the programs discussed later in this chapter.

cat also has options that are used to modify text. The two most prominent are -n, which numbers lines, and -s, which suppresses the output of multiple blank lines. We can demonstrate thusly:

```
[me@linuxbox ~]$ cat > foo.txt
The quick brown fox


jumped over the lazy dog.
[me@linuxbox ~]$ cat -ns foo.txt
     1      The quick brown fox
     2
     3      jumped over the lazy dog.
[me@linuxbox ~]$
```

In this example, we create a new version of our *foo.txt* test file, which contains two lines of text separated by two blank lines. After processing by cat with the -ns options, the extra blank line is removed, and the remaining lines are numbered. While this is not much of a process to perform on text, it is a process.

### sort

The sort program sorts the contents of standard input, or one or more files specified on the command line, and sends the results to standard output. Using the same technique that we used with cat, we can demonstrate processing of standard input directly from the keyboard as follows:

```
[me@linuxbox ~]$ sort > foo.txt
c
b
a
```

```
[me@linuxbox ~]$ cat foo.txt
a
b
c
```

After entering the command, we enter the letters *c*, *b*, and *a*, and then we press CTRL-D to indicate end of file. We then view the resulting file and see that the lines now appear in sorted order.

Because `sort` can accept multiple files on the command line as arguments, it is possible to *merge* multiple files into a single sorted whole. For example, if we had three text files and wanted to combine them into a single sorted file, we could do something like this:

```
sort file1.txt file2.txt file3.txt > final_sorted_list.txt
```

`sort` has several interesting options. Table 20-1 provides a partial list.

**Table 20-1:** Common `sort` Options

| Option | Long option | Description |
|---|---|---|
| `-b` | `--ignore-leading-blanks` | By default, sorting is performed on the entire line, starting with the first character in the line. This option causes `sort` to ignore leading spaces in lines and calculates sorting based on the first non-whitespace character on the line. |
| `-f` | `--ignore-case` | Make sorting case-insensitive. |
| `-n` | `--numeric-sort` | Perform sorting based on the numeric evaluation of a string. Using this option allows sorting to be performed on numeric values rather than alphabetic values. |
| `-r` | `--reverse` | Sort in reverse order. Results are in descending rather than ascending order. |
| `-k` | `--key=`*`field1`*`[,`*`field2`*`]` | Sort based on a key field located from *`field1`* to *`field2`* rather than the entire line. See the following discussion. |
| `-m` | `--merge` | Treat each argument as the name of a presorted file. Merge multiple files into a single sorted result without performing any additional sorting. |
| `-o` | `--output=`*`file`* | Send sorted output to *`file`* rather than standard output. |
| `-t` | `--field-separator=`*`char`* | Define the field-separator character. By default fields are separated by spaces or tabs. |

Although most of these options are pretty self-explanatory, some are not. First, let's look at the `-n` option, used for numeric sorting. With this option, it is possible to sort values based on numeric values rather than lexographically. We can demonstrate this by sorting the results of the `du` command to

determine the largest users of disk space. Normally, the du command lists the results of a summary in pathname order.

```
[me@linuxbox ~]$ du -s /usr/share/* | head
252         /usr/share/aclocal
96          /usr/share/acpi-support
8           /usr/share/adduser
196         /usr/share/alacarte
344         /usr/share/alsa
8           /usr/share/alsa-base
12488       /usr/share/anthy
8           /usr/share/apmdq
21440       /usr/share/app-install
48          /usr/share/application-registry
```

In this example, we pipe the results into head to limit the results to the first 10 lines. We can produce a numerically sorted list to show the 10 largest consumers of space this way.

```
[me@linuxbox ~]$ du -s /usr/share/* | sort -nr | head
509940    /usr/share/locale-langpack
242660    /usr/share/doc
197560    /usr/share/fonts
179144    /usr/share/gnome
146764    /usr/share/myspell
144304    /usr/share/gimp
135880    /usr/share/dict
76508     /usr/share/icons
68072     /usr/share/apps
62844     /usr/share/foomatic
```

By using the n and r options, we produce a reverse numerical sort, with the largest values appearing first in the results. This sort works because the numerical values occur at the beginning of each line. But what if we want to sort a list based on some value found within the line? For example, here are the results of ls -l:

```
[me@linuxbox ~]$ ls -l /usr/bin | head
total 152948
-rwxr-xr-x 1 root   root      34824 2016-04-04 02:42 [
-rwxr-xr-x 1 root   root     101556 2007-11-27 06:08 a2p
-rwxr-xr-x 1 root   root      13036 2016-02-27 08:22 aconnect
-rwxr-xr-x 1 root   root      10552 2007-08-15 10:34 acpi
-rwxr-xr-x 1 root   root       3800 2016-04-14 03:51 acpi_fakekey
-rwxr-xr-x 1 root   root       7536 2016-04-19 00:19 acpi_listen
-rwxr-xr-x 1 root   root       3576 2016-04-29 07:57 addpart
-rwxr-xr-x 1 root   root      20808 2016-01-03 18:02 addr2line
-rwxr-xr-x 1 root   root     489704 2016-10-09 17:02 adept_batch
```

Ignoring, for the moment, that ls can sort its results by size, we could use sort to sort this list by file size, as well.

```
[me@linuxbox ~]$ ls -l /usr/bin | sort -nrk 5 | head
-rwxr-xr-x 1 root   root    8234216 2016-04-07 17:42 inkscape
-rwxr-xr-x 1 root   root    8222692 2016-04-07 17:42 inkview
-rwxr-xr-x 1 root   root    3746508 2016-03-07 23:45 gimp-2.4
-rwxr-xr-x 1 root   root    3654020 2016-08-26 16:16 quanta
-rwxr-xr-x 1 root   root    2928760 2016-09-10 14:31 gdbtui
-rwxr-xr-x 1 root   root    2928756 2016-09-10 14:31 gdb
-rwxr-xr-x 1 root   root    2602236 2016-10-10 12:56 net
-rwxr-xr-x 1 root   root    2304684 2016-10-10 12:56 rpcclient
-rwxr-xr-x 1 root   root    2241832 2016-04-04 05:56 aptitude
-rwxr-xr-x 1 root   root    2202476 2016-10-10 12:56 smbcacls
```

Many uses of `sort` involve the processing of *tabular data*, such as the results of the previous `ls` command. If we apply database terminology to the previous table, we would say that each row is a *record* and that each record consists of multiple *fields*, such as the file attributes, link count, filename, file size, and so on. `sort` is able to process individual fields. In database terms, we are able to specify one or more *key fields* to use as *sort keys*. In the previous example, we specify the `n` and `r` options to perform a reverse numerical sort and specify `-k 5` to make `sort` use the fifth field as the key for sorting.

The `k` option is interesting and has many features, but first we need to talk about how `sort` defines fields. Let's consider the following simple text file consisting of a single line containing the author's name:

```
William Shotts
```

By default, `sort` sees this line as having two fields. The first field contains these characters: `"William"`. The second field contains these characters: `"Shotts"`.

This means that whitespace characters (spaces and tabs) are used as delimiters between fields and that the delimiters are included in the field when sorting is performed.

Looking again at a line from our `ls` output, as follows, we can see that a line contains eight fields and that the fifth field is the file size:

```
-rwxr-xr-x 1 root   root    8234216 2016-04-07 17:42 inkscape
```

For our next series of experiments, let's consider the following file containing the history of three popular Linux distributions released from 2006 to 2008. Each line in the file has three fields: the distribution name, version number, and date of release in MM/DD/YYYY format.

```
SUSE      10.2        12/07/2006
Fedora    10          11/25/2008
SUSE      11.0        06/19/2008
Ubuntu    8.04        04/24/2008
Fedora    8           11/08/2007
SUSE      10.3        10/04/2007
Ubuntu    6.10        10/26/2006
```

```
Fedora    7           05/31/2007
Ubuntu    7.10        10/18/2007
Ubuntu    7.04        04/19/2007
SUSE      10.1        05/11/2006
Fedora    6           10/24/2006
Fedora    9           05/13/2008
Ubuntu    6.06        06/01/2006
Ubuntu    8.10        10/30/2008
Fedora    5           03/20/2006
```

Using a text editor (perhaps `vim`), we'll enter this data and name the resulting file *distros.txt*.

Next, we'll try sorting the file and observe these results:

```
[me@linuxbox ~]$ sort distros.txt
Fedora    10          11/25/2008
Fedora    5           03/20/2006
Fedora    6           10/24/2006
Fedora    7           05/31/2007
Fedora    8           11/08/2007
Fedora    9           05/13/2008
SUSE      10.1        05/11/2006
SUSE      10.2        12/07/2006
SUSE      10.3        10/04/2007
SUSE      11.0        06/19/2008
Ubuntu    6.06        06/01/2006
Ubuntu    6.10        10/26/2006
Ubuntu    7.04        04/19/2007
Ubuntu    7.10        10/18/2007
Ubuntu    8.04        04/24/2008
Ubuntu    8.10        10/30/2008
```

Well, it mostly worked. The problem occurs in the sorting of the Fedora version numbers. Because 1 comes before 5 in the character set, version 10 ends up at the top while version 9 falls to the bottom.

To fix this problem, we are going to have to sort on multiple keys. We want to perform an alphabetic sort on the first field and then a numeric sort on the second field. `sort` allows multiple instances of the `-k` option so that multiple sort keys can be specified. In fact, a key may include a range of fields. If no range is specified (as has been the case with our previous examples), `sort` uses a key that begins with the specified field and extends to the end of the line. Here is the syntax for our multikey sort:

```
[me@linuxbox ~]$ sort --key=1,1 --key=2n distros.txt
Fedora    5           03/20/2006
Fedora    6           10/24/2006
Fedora    7           05/31/2007
Fedora    8           11/08/2007
Fedora    9           05/13/2008
Fedora    10          11/25/2008
SUSE      10.1        05/11/2006
SUSE      10.2        12/07/2006
```

```
SUSE      10.3        10/04/2007
SUSE      11.0        06/19/2008
Ubuntu    6.06        06/01/2006
Ubuntu    6.10        10/26/2006
Ubuntu    7.04        04/19/2007
Ubuntu    7.10        10/18/2007
Ubuntu    8.04        04/24/2008
Ubuntu    8.10        10/30/2008
```

Though we used the long form of the option for clarity, `-k 1,1 -k 2n` would be exactly equivalent. In the first instance of the key option, we specified a range of fields to include in the first key. Because we wanted to limit the sort to just the first field, we specified `1,1`, which means "start at field 1 and end at field 1." In the second instance, we specified `2n`, which means field 2 is the sort key and that the sort should be numeric. An option letter may be included at the end of a key specifier to indicate the type of sort to be performed. These option letters are the same as the global options for the `sort` program: `b` (ignore leading blanks), `n` (numeric sort), `r` (reverse sort), and so on.

The third field in our list contains a date in an inconvenient format for sorting. On computers, dates are usually formatted in YYYY-MM-DD order to make chronological sorting easy, but ours are in the American format of MM/DD/YYYY. How can we sort this list in chronological order?

Fortunately, `sort` provides a way. The key option allows specification of *offsets* within fields, so we can define keys within fields.

```
[me@linuxbox ~]$ sort -k 3.7nbr -k 3.1nbr -k 3.4nbr distros.txt
Fedora    10          11/25/2008
Ubuntu    8.10        10/30/2008
SUSE      11.0        06/19/2008
Fedora    9           05/13/2008
Ubuntu    8.04        04/24/2008
Fedora    8           11/08/2007
Ubuntu    7.10        10/18/2007
SUSE      10.3        10/04/2007
Fedora    7           05/31/2007
Ubuntu    7.04        04/19/2007
SUSE      10.2        12/07/2006
Ubuntu    6.10        10/26/2006
Fedora    6           10/24/2006
Ubuntu    6.06        06/01/2006
SUSE      10.1        05/11/2006
Fedora    5           03/20/2006
```

By specifying `-k 3.7`, we instruct `sort` to use a sort key that begins at the seventh character within the third field, which corresponds to the start of the year. Likewise, we specify `-k 3.1` and `-k 3.4` to isolate the month and day portions of the date. We also add the `n` and `r` options to achieve a reverse numeric sort. The `b` option is included to suppress the leading spaces (whose numbers vary from line to line, thereby affecting the outcome of the sort) in the date field.

Some files don't use tabs and spaces as field delimiters; for example, here's the */etc/passwd* file:

```
[me@linuxbox ~]$ head /etc/passwd
root:x:0:0:root:/root:/bin/bash
daemon:x:1:1:daemon:/usr/sbin:/bin/sh
bin:x:2:2:bin:/bin:/bin/sh
sys:x:3:3:sys:/dev:/bin/sh
sync:x:4:65534:sync:/bin:/bin/sync
games:x:5:60:games:/usr/games:/bin/sh
man:x:6:12:man:/var/cache/man:/bin/sh
lp:x:7:7:lp:/var/spool/lpd:/bin/sh
mail:x:8:8:mail:/var/mail:/bin/sh
news:x:9:9:news:/var/spool/news:/bin/sh
```

The fields in this file are delimited with colons (`:`), so how would we sort this file using a key field? `sort` provides the `-t` option to define the field separator character. To sort the *passwd* file on the seventh field (the account's default shell), we could do this:

```
[me@linuxbox ~]$ sort -t ':' -k 7 /etc/passwd | head
me:x:1001:1001:Myself,,,:/home/me:/bin/bash
root:x:0:0:root:/root:/bin/bash
dhcp:x:101:102::/nonexistent:/bin/false
gdm:x:106:114:Gnome Display Manager:/var/lib/gdm:/bin/false
hplip:x:104:7:HPLIP system user,,,:/var/run/hplip:/bin/false
klog:x:103:104::/home/klog:/bin/false
messagebus:x:108:119::/var/run/dbus:/bin/false
polkituser:x:110:122:PolicyKit,,,:/var/run/PolicyKit:/bin/false
pulse:x:107:116:PulseAudio daemon,,,:/var/run/pulse:/bin/false
```

By specifying the colon character as the field separator, we can sort on the seventh field.

### uniq

Compared to `sort`, the `uniq` program is lightweight. `uniq` performs a seemingly trivial task. When given a sorted file (or standard input), it removes any duplicate lines and sends the results to standard output. It is often used in conjunction with `sort` to clean the output of duplicates.

**TIP** *While `uniq` is a traditional Unix tool often used with `sort`, the GNU version of `sort` supports a `-u` option, which removes duplicates from the sorted output.*

Let's make a text file to try this, as shown here:

```
[me@linuxbox ~]$ cat > foo.txt
a
b
c
```

```
a
b
c
```

Remember to type CTRL-D to terminate standard input. Now, if we run uniq on our text file, we get this:

```
[me@linuxbox ~]$ uniq foo.txt
a
b
c
a
b
c
```

The results are no different from our original file; the duplicates were not removed. For uniq to do its job, the input must be sorted first.

```
[me@linuxbox ~]$ sort foo.txt | uniq
a
b
c
```

This is because uniq only removes duplicate lines that are adjacent to each other.

uniq has several options. Table 20-2 lists the common ones.

**Table 20-2:** Common uniq Options

| Option | Long option | Description |
|---|---|---|
| -c | --count | Output a list of duplicate lines preceded by the number of times the line occurs. |
| -d | --repeated | Output only repeated lines, rather than unique lines. |
| -f *n* | --skip-fields=*n* | Ignore *n* leading fields in each line. Fields are separated by whitespace as they are in sort; however, unlike sort, uniq has no option for setting an alternate field separator. |
| -i | --ignore-case | Ignore case during the line comparisons. |
| -s *n* | --skip-chars=*n* | Skip (ignore) the leading *n* characters of each line. |
| -u | --unique | Output only unique lines. Lines with duplicates are ignored. |

Here we see uniq used to report the number of duplicates found in our text file, using the -c option:

```
[me@linuxbox ~]$ sort foo.txt | uniq -c
      2 a
      2 b
      2 c
```

## Slicing and Dicing

The next three programs we will discuss are used to peel columns of text out of files and recombine them in useful ways.

### *cut—Remove Sections from Each Line of Files*

The cut program is used to extract a section of text from a line and output the extracted section to standard output. It can accept multiple file arguments or input from standard input.

Specifying the section of the line to be extracted is somewhat awkward and is specified using the options listed in Table 20-3.

**Table 20-3:** cut Selection Options

| Option | Long option | Description |
|---|---|---|
| -c *list* | --characters=*list* | Extract the portion of the line defined by *list*. The list may consist of one or more comma-separated numerical ranges. |
| -f *list* | --fields=*list* | Extract one or more fields from the line as defined by *list*. The list may contain one or more fields or field ranges separated by commas. |
| -d *delim* | --delimiter=*delim* | When -f is specified, use *delim* as the field delimiting character. By default, fields must be separated by a single tab character. |
| | --complement | Extract the entire line of text, except for those portions specified by -c and/or -f. |

As we can see, the way cut extracts text is rather inflexible. cut is best used to extract text from files that are produced by other programs, rather than text directly typed by humans. We'll take a look at our *distros.txt* file to see whether it is "clean" enough to be a good specimen for our cut examples. If we use cat with the -A option, we can see whether the file meets our requirements of tab-separated fields.

```
[me@linuxbox ~]$ cat -A distros.txt
SUSE^I10.2^I12/07/2006$
Fedora^I10^I11/25/2008$
SUSE^I11.0^I06/19/2008$
Ubuntu^I8.04^I04/24/2008$
Fedora^I8^I11/08/2007$
SUSE^I10.3^I10/04/2007$
Ubuntu^I6.10^I10/26/2006$
Fedora^I7^I05/31/2007$
Ubuntu^I7.10^I10/18/2007$
Ubuntu^I7.04^I04/19/2007$
SUSE^I10.1^I05/11/2006$
Fedora^I6^I10/24/2006$
Fedora^I9^I05/13/2008$
```

```
Ubuntu^I6.06^I06/01/2006$
Ubuntu^I8.10^I10/30/2008$
Fedora^I5^I03/20/2006$
```

It looks good. There are no embedded spaces, just single tab characters between the fields. Because the file uses tabs rather than spaces, we'll use the `-f` option to extract a field.

```
[me@linuxbox ~]$ cut -f 3 distros.txt
12/07/2006
11/25/2008
06/19/2008
04/24/2008
11/08/2007
10/04/2007
10/26/2006
05/31/2007
10/18/2007
04/19/2007
05/11/2006
10/24/2006
05/13/2008
06/01/2006
10/30/2008
03/20/2006
```

Because our *distros* file is tab-delimited, it is best to use `cut` to extract fields rather than characters. This is because when a file is tab-delimited, it is unlikely that each line will contain the same number of characters, which makes calculating character positions within the line difficult or impossible. In our previous example, however, we now have extracted a field that luckily contains data of identical length, so we can show how character extraction works by extracting the year from each line.

```
[me@linuxbox ~]$ cut -f 3 distros.txt | cut -c 7-10
2006
2008
2008
2008
2007
2007
2006
2007
2007
2007
2006
2006
2008
2006
2008
2006
```

By running cut a second time on our list, we are able to extract character positions 7 through 10, which corresponds to the year in our date field. The 7-10 notation is an example of a range. The cut man page contains a complete description of how ranges can be specified.

When working with fields, it is possible to specify a different field delimiter rather than the tab character. Here we will extract the first field from the */etc/passwd* file:

```
[me@linuxbox ~]$ cut -d ':' -f 1 /etc/passwd | head
root
daemon
bin
sys
sync
games
man
lp
mail
news
```

Using the -d option, we are able to specify the colon character as the field delimiter.

**EXPANDING TABS**

Our *distros.txt* file is ideally formatted for extracting fields using cut. But what if we wanted a file that could be fully manipulated with cut by characters, rather than fields? This would require us to replace the tab characters within the file with the corresponding number of spaces. Fortunately, the GNU Coreutils package includes a tool for that. Named expand, this program accepts either one or more file arguments or standard input and outputs the modified text to standard output.

If we process our *distros.txt* file with expand, we can use cut -c to extract any range of characters from the file. For example, we could use the following command to extract the year of release from our list by expanding the file and using cut to extract every character from the 23rd position to the end of the line:

```
[me@linuxbox ~]$ expand distros.txt | cut -c 23-
```

Coreutils also provides the unexpand program to substitute tabs for spaces.

## *paste—Merge Lines of Files*

The paste command does the opposite of cut. Rather than extracting a column of text from a file, it adds one or more columns of text to a file. It does this by reading multiple files and combining the fields found in each file into a single stream on standard output. Like cut, paste accepts

multiple file arguments and/or standard input. To demonstrate how paste operates, we will perform some surgery on our *distros.txt* file to produce a chronological list of releases.

From our earlier work with sort, we will first produce a list of distros sorted by date and store the result in a file called *distros-by-date.txt*.

```
[me@linuxbox ~]$ sort -k 3.7nbr -k 3.1nbr -k 3.4nbr distros.txt > distros-by-date.txt
```

Next, we will use cut to extract the first two fields from the file (the distro name and version) and store that result in a file named *distro-versions.txt*.

```
[me@linuxbox ~]$ cut -f 1,2 distros-by-date.txt > distros-versions.txt
[me@linuxbox ~]$ head distros-versions.txt
Fedora    10
Ubuntu    8.10
SUSE      11.0
Fedora    9
Ubuntu    8.04
Fedora    8
Ubuntu    7.10
SUSE      10.3
Fedora    7
Ubuntu    7.04
```

The final piece of preparation is to extract the release dates and store them in a file named *distro-dates.txt*.

```
[me@linuxbox ~]$ cut -f 3 distros-by-date.txt > distros-dates.txt
[me@linuxbox ~]$ head distros-dates.txt
11/25/2008
10/30/2008
06/19/2008
05/13/2008
04/24/2008
11/08/2007
10/18/2007
10/04/2007
05/31/2007
04/19/2007
```

We now have the parts we need. To complete the process, use paste to put the column of dates ahead of the distro names and versions, thus creating a chronological list. This is done simply by using paste and ordering its arguments in the desired arrangement.

```
[me@linuxbox ~]$ paste distros-dates.txt distros-versions.txt
11/25/2008    Fedora      10
10/30/2008    Ubuntu      8.10
06/19/2008    SUSE        11.0
05/13/2008    Fedora      9
04/24/2008    Ubuntu      8.04
11/08/2007    Fedora      8
```

```
10/18/2007    Ubuntu      7.10
10/04/2007    SUSE        10.3
05/31/2007    Fedora      7
04/19/2007    Ubuntu      7.04
12/07/2006    SUSE        10.2
10/26/2006    Ubuntu      6.10
10/24/2006    Fedora      6
06/01/2006    Ubuntu      6.06
05/11/2006    SUSE        10.1
03/20/2006    Fedora      5
```

## *join—Join Lines of Two Files on a Common Field*

In some ways, `join` is like `paste` in that it adds columns to a file, but it uses a unique way to do it. A *join* is an operation usually associated with *relational databases* where data from multiple tables with a shared key field is combined to form a desired result. The `join` program performs the same operation. It joins data from multiple files based on a shared key field.

To see how a join operation is used in a relational database, let's imagine a small database consisting of two tables, each containing a single record. The first table, called CUSTOMERS, has three fields: a customer number (CUSTNUM), the customer's first name (FNAME), and the customer's last name (LNAME):

```
CUSTNUM  FNAME LNAME
======== ===== ======
4681934  John  Smith
```

The second table is called ORDERS and contains four fields: an order number (ORDERNUM), the customer number (CUSTNUM), the quantity (QUAN), and the item ordered (ITEM).

```
ORDERNUM       CUSTNUM     QUAN  ITEM
========       =======     ====  ====
3014953305     4681934     1     Blue Widget
```

Note that both tables share the field CUSTNUM. This is important because it allows a relationship between the tables.

Performing a join operation would allow us to combine the fields in the two tables to achieve a useful result, such as preparing an invoice. Using the matching values in the CUSTNUM fields of both tables, a join operation could produce the following:

```
FNAME  LNAME  QUAN   ITEM
=====  =====  ====   ====
John   Smith  1      Blue Widget
```

To demonstrate the `join` program, we'll need to make a couple of files with a shared key. To do this, we will use our *distros-by-date.txt* file. From this

file, we will construct two additional files. One contains the release dates (which will be our shared key for this demonstration) and the release names, as shown here:

```
[me@linuxbox ~]$ cut -f 1,1 distros-by-date.txt > distros-names.txt
[me@linuxbox ~]$ paste distros-dates.txt distros-names.txt > distros-key-names.txt
[me@linuxbox ~]$ head distros-key-names.txt
11/25/2008      Fedora
10/30/2008      Ubuntu
06/19/2008      SUSE
05/13/2008      Fedora
04/24/2008      Ubuntu
11/08/2007      Fedora
10/18/2007      Ubuntu
10/04/2007      SUSE
05/31/2007      Fedora
04/19/2007      Ubuntu
```

The second file contains the release dates and the version numbers, as shown here.

```
[me@linuxbox ~]$ cut -f 2,2 distros-by-date.txt > distros-vernums.txt
[me@linuxbox ~]$ paste distros-dates.txt distros-vernums.txt > distros-key-vernums.txt
[me@linuxbox ~]$ head distros-key-vernums.txt
11/25/2008      10
10/30/2008      8.10
06/19/2008      11.0
05/13/2008      9
04/24/2008      8.04
11/08/2007      8
10/18/2007      7.10
10/04/2007      10.3
05/31/2007      7
04/19/2007      7.04
```

We now have two files with a shared key (the "release date" field). It is important to point out that the files must be sorted on the key field for `join` to work properly.

```
[me@linuxbox ~]$ join distros-key-names.txt distros-key-vernums.txt | head
11/25/2008 Fedora 10
10/30/2008 Ubuntu 8.10
06/19/2008 SUSE 11.0
05/13/2008 Fedora 9
04/24/2008 Ubuntu 8.04
11/08/2007 Fedora 8
10/18/2007 Ubuntu 7.10
10/04/2007 SUSE 10.3
05/31/2007 Fedora 7
04/19/2007 Ubuntu 7.04
```

Note also that, by default, `join` uses whitespace as the input field delimiter and a single space as the output field delimiter. This behavior can be modified by specifying options. See the `join` man page for details.

## Comparing Text

It is often useful to compare versions of text files. For system administrators and software developers, this is particularly important. A system administrator may, for example, need to compare an existing configuration file to a previous version to diagnose a system problem. Likewise, a programmer frequently needs to see what changes have been made to programs over time.

### *comm—Compare Two Sorted Files Line by Line*

The `comm` program compares two text files and displays the lines that are unique to each one and the lines they have in common. To demonstrate, we will create two nearly identical text files using `cat`.

```
[me@linuxbox ~]$ cat > file1.txt
a
b
c
d
[me@linuxbox ~]$ cat > file2.txt
b
c
d
e
```

Next, we will compare the two files using `comm`.

```
[me@linuxbox ~]$ comm file1.txt file2.txt
a
                b
                c
                d
        e
```

As we can see, `comm` produces three columns of output. The first column contains lines unique to the first file argument, the second column contains the lines unique to the second file argument, and the third column contains the lines shared by both files. `comm` supports options in the form `-n`, where *n* is either 1, 2, or 3. When used, these options specify which columns to suppress. For example, if we wanted to output only the lines shared by both files, we would suppress the output of the first and second columns.

```
[me@linuxbox ~]$ comm -12 file1.txt file2.txt
b
c
d
```

## diff—Compare Files Line by Line

Like the `comm` program, `diff` is used to detect the differences between files. However, `diff` is a much more complex tool, supporting many output formats and the ability to process large collections of text files at once. `diff` is often used by software developers to examine changes between different versions of program source code and thus has the ability to recursively examine directories of source code, often referred to as *source trees*. One common use for `diff` is the creation of *diff files* or patches that are used by programs such as `patch` (which we'll discuss shortly) to convert one version of a file (or files) to another version.

If we use `diff` to look at our previous example files:

```
[me@linuxbox ~]$ diff file1.txt file2.txt
1d0
< a
4a4
> e
```

we see its default style of output: a terse description of the differences between the two files. In the default format, each group of changes is preceded by a *change command* in the form of *range operation range* to describe the positions and types of changes required to convert the first file to the second file, as outlined in Table 20-4.

**Table 20-4:** `diff` Change Commands

| Change | Description |
|---|---|
| *r1ar2* | Append the lines at the position *r2* in the second file to the position *r1* in the first file. |
| *r1cr2* | Change (replace) the lines at position *r1* with the lines at the position *r2* in the second file. |
| *r1dr2* | Delete the lines in the first file at position *r1*, which would have appeared at range *r2* in the second file |

In this format, a range is a comma-separated list of the starting line and the ending line. While this format is the default (mostly for POSIX compliance and backward compatibility with traditional Unix versions of `diff`), it is not as widely used as other, optional formats. Two of the more popular formats are the *context format* and the *unified format*.

When viewed using the context format (the `-c` option), we will see this:

```
[me@linuxbox ~]$ diff -c file1.txt file2.txt
*** file1.txt    2008-12-23 06:40:13.000000000 -0500
--- file2.txt    2008-12-23 06:40:34.000000000 -0500
***************
*** 1,4 ****
- a
  b
```

```
  c
  d
--- 1,4 ----
  b
  c
  d
+ e
```

The output begins with the names of the two files and their timestamps. The first file is marked with asterisks, and the second file is marked with dashes. Throughout the remainder of the listing, these markers will signify their respective files. Next, we see groups of changes, including the default number of surrounding context lines. In the first group, we see this:

```
*** 1,4 ***
```

which indicates lines 1 through 4 in the first file. Later we see this:

```
--- 1,4 ---
```

which indicates lines 1 through 4 in the second file. Within a change group, lines begin with one of the four indicators described in Table 20-5.

**Table 20-5:** `diff` Context Format Change Indicators

| Indicator | Meaning |
|---|---|
| `blank` | A line shown for context. It does not indicate a difference between the two files. |
| `-` | A line deleted. This line will appear in the first file but not in the second file. |
| `+` | A line added. This line will appear in the second file but not in the first file. |
| `!` | A line changed. The two versions of the line will be displayed, each in its respective section of the change group. |

The unified format is similar to the context format but is more concise. It is specified with the `-u` option.

```
[me@linuxbox ~]$ diff -u file1.txt file2.txt
--- file1.txt    2008-12-23 06:40:13.000000000 -0500
+++ file2.txt    2008-12-23 06:40:34.000000000 -0500
@@ -1,4 +1,4 @@
-a
 b
 c
 d
+e
```

The most notable difference between the context and unified formats is the elimination of the duplicated lines of context, making the results of the unified format shorter than those of the context format. In our previous example, we see file timestamps like those of the context format, followed by the string `@@ -1,4 +1,4 @@`. This indicates the lines in the first file and the lines in the second file described in the change group. Following this are the lines themselves, with the default three lines of context. Each line starts with one of the three possible characters described in Table 20-6.

**Table 20-6:** `diff` Unified Format Change Indicators

| Character | Meaning |
|---|---|
| `blank` | This line is shared by both files. |
| - | This line was removed from the first file. |
| + | This line was added to the first file. |

## *patch—Apply a diff to an Original*

The `patch` program is used to apply changes to text files. It accepts output from `diff` and is generally used to convert older-version files into newer versions. Let's consider a famous example. The Linux kernel is developed by a large, loosely organized team of contributors who submit a constant stream of small changes to the source code. The Linux kernel consists of several million lines of code, while the changes that are made by one contributor at one time are quite small. It makes no sense for a contributor to send each developer an entire kernel source tree each time a small change is made. Instead, a diff file is submitted. The diff file contains the change from the previous version of the kernel to the new version with the contributor's changes. The receiver then uses the `patch` program to apply the change to their own source tree. Using `diff/patch` offers two significant advantages.

- The diff file is small, compared to the full size of the source tree.
- The diff file concisely shows the change being made, allowing reviewers of the patch to quickly evaluate it.

Of course, `diff/patch` will work on any text file, not just source code. It would be equally applicable to configuration files or any other text.

To prepare a diff file for use with `patch`, the GNU documentation suggests using `diff` as follows:

```
diff -Naur old_file new_file > diff_file
```

where *`old_file`* and *`new_file`* are either single files or directories containing files. The `r` option supports recursion of a directory tree.

Once the diff file has been created, we can apply it to patch the old file into the new file.

```
patch < diff_file
```

We'll demonstrate with our test file.

```
[me@linuxbox ~]$ diff -Naur file1.txt file2.txt > patchfile.txt
[me@linuxbox ~]$ patch < patchfile.txt
patching file file1.txt
[me@linuxbox ~]$ cat file1.txt
b
c
d
e
```

In this example, we created a diff file named *patchfile.txt* and then used the `patch` program to apply the patch. Note that we did not have to specify a target file to `patch`, as the diff file (in unified format) already contains the filenames in the header. Once the patch is applied, we can see that *file1.txt* now matches *file2.txt*.

`patch` has a large number of options, and there are additional utility programs that can be used to analyze and edit patches.

## Editing on the Fly

Our experience with text editors has been largely interactive, meaning that we manually move a cursor around and then type our changes. However, there are *non-interactive* ways to edit text as well. It's possible, for example, to apply a set of changes to multiple files with a single command.

### *tr—Transliterate or Delete Characters*

The `tr` program is used to *transliterate* characters. We can think of this as a sort of character-based search-and-replace operation. Transliteration is the process of changing characters from one alphabet to another. For example, converting characters from lowercase to uppercase is transliteration. We can perform such a conversion with `tr` as follows:

```
[me@linuxbox ~]$ echo "lowercase letters" | tr a-z A-Z
LOWERCASE LETTERS
```

As we can see, `tr` operates on standard input and outputs its results on standard output. `tr` accepts two arguments: a set of characters to convert from and a corresponding set of characters to convert to. Character sets may be expressed in one of three ways.

- An enumerated list. For example, `ABCDEFGHIJKLMNOPQRSTUVWXYZ`.
- A character range. For example, `A-Z`. Note that this method is sometimes subject to the same issues as other commands because of the locale collation order and thus should be used with caution.
- POSIX character classes. For example, `[:upper:]`.

In most cases, both character sets should be of equal length; however, it is possible for the first set to be larger than the second, particularly if we want to convert multiple characters to a single character.

```
[me@linuxbox ~]$ echo "lowercase letters" | tr [:lower:] A
AAAAAAAAA AAAAAAA
```

In addition to transliteration, `tr` allows characters to simply be deleted from the input stream. Earlier in this chapter, we discussed the problem of converting MS-DOS text files to Unix-style text. To perform this conversion, carriage return characters need to be removed from the end of each line. This can be performed with `tr` as follows:

```
tr -d '\r' < dos_file > unix_file
```

where *`dos_file`* is the file to be converted and *`unix_file`* is the result. This form of the command uses the escape sequence `\r` to represent the carriage return character. To see a complete list of the sequences and character classes `tr` supports, try the following:

```
[me@linuxbox ~]$ tr --help
```

`tr` can perform another trick, too. Using the `-s` option, `tr` can "squeeze" (delete) repeated instances of a character.

```
[me@linuxbox ~]$ echo "aaabbbccc" | tr -s ab
abccc
```

Here we have a string containing repeated characters. By specifying the set `ab` to `tr`, we eliminate the repeated instances of the letters in the set, while leaving the character that is missing from the set (`c`) unchanged. Note that the repeating characters must be adjoining. If they are not, the squeezing will have no effect.

```
[me@linuxbox ~]$ echo "abcabcabc" | tr -s ab
abcabcabc
```

**ROT13: THE NOT-SO-SECRET DECODER RING**

One amusing use of `tr` is to perform *ROT13 encoding* of text. ROT13 is a trivial type of encryption based on a simple substitution cipher. Calling ROT13 *encryption* is being generous; *text obfuscation* is more accurate. It is used sometimes on text to obscure potentially offensive content. The method simply moves each character 13 places up the alphabet. Because this is halfway up the possible 26 characters, performing the algorithm a second time on the text restores it to its original form. Use the following to perform this encoding with `tr`:

```
echo "secret text" | tr a-zA-Z n-za-mN-ZA-M
frperg grkg
```

Performing the same procedure a second time results in the following translation:

```
echo "frperg grkg" | tr a-zA-Z n-za-mN-ZA-M
secret text
```

A number of email programs and Usenet news readers support ROT13 encoding. Wikipedia contains a good article on the subject at *http://en.wikipedia.org/wiki/ROT13*.

## sed—Stream Editor for Filtering and Transforming Text

The name `sed` is short for *stream editor*. It performs text editing on a stream of text, either a set of specified files or standard input. `sed` is a powerful and somewhat complex program (there are entire books about it), so we will not cover it completely here.

In general, the way `sed` works is that it is given either a single editing command (on the command line) or the name of a script file containing multiple commands, and it then performs these commands upon each line in the stream of text. Here is a simple example of `sed` in action:

```
[me@linuxbox ~]$ echo "front" | sed 's/front/back/'
back
```

In this example, we produce a one-word stream of text using `echo` and pipe it into `sed`. `sed`, in turn, carries out the instruction `s/front/back/` upon the text in the stream and produces the output `back` as a result. We can also recognize this command as resembling the "substitution" (search-and-replace) command in `vi`.

Commands in `sed` begin with a single letter. In the previous example, the substitution command is represented by the letter `s` and is followed by the search-and-replace strings, separated by the slash character as a delimiter. The choice of the delimiter character is arbitrary. By convention, the slash

character is often used, but sed will accept any character that immediately follows the command as the delimiter. We could perform the same command this way:

```
[me@linuxbox ~]$ echo "front" | sed 's_front_back_'
back
```

By using the underscore character immediately after the command, it becomes the delimiter. The ability to set the delimiter can be used to make commands more readable, as we shall see.

Most commands in sed may be preceded by an *address*, which specifies which line(s) of the input stream will be edited. If the address is omitted, then the editing command is carried out on every line in the input stream. The simplest form of address is a line number. We can add one to our example.

```
[me@linuxbox ~]$ echo "front" | sed '1s/front/back/'
back
```

Adding the address 1 to our command causes our substitution to be performed on the first line of our one-line input stream. If we specify another number, we see that the editing is not carried out since our input stream does not have a line 2.

```
[me@linuxbox ~]$ echo "front" | sed '2s/front/back/'
front
```

Addresses may be expressed in many ways. Table 20-7 lists the most common.

**Table 20-7:** sed Address Notation

| Address | Description |
|---|---|
| *n* | A line number where *n* is a positive integer. |
| $ | The last line. |
| */regexp/* | Lines matching a POSIX basic regular expression. Note that the regular expression is delimited by slash characters. Optionally, the regular expression may be delimited by an alternate character, by specifying the expression with *\cregexpc*, where *c* is the alternate character. |
| *addr1,addr2* | A range of lines from *addr1* to *addr2*, inclusive. Addresses may be any of the single address forms listed earlier. |
| *first~step* | Match the line represented by the number *first* and then each subsequent line at *step* intervals. For example, 1~2 refers to each odd numbered line, and 5~5 refers to the fifth line and every fifth line thereafter. |
| *addr1,+n* | Match *addr1* and the following *n* lines. |
| *addr!* | Match all lines except *addr*, which may be any of the forms listed earlier. |

We'll demonstrate different kinds of addresses using the *distros.txt* file from earlier in this chapter. First, here's a range of line numbers:

```
[me@linuxbox ~]$ sed -n '1,5p' distros.txt
SUSE            10.2    12/07/2006
Fedora          10      11/25/2008
SUSE            11.0    06/19/2008
Ubuntu          8.04    04/24/2008
Fedora          8       11/08/2007
```

In this example, we print a range of lines, starting with line 1 and continuing to line 5. To do this, we use the `p` command, which simply causes a matched line to be printed. For this to be effective, however, we must include the option `-n` (the "no auto-print" option) to cause `sed` not to print every line by default.

Next, we'll try a regular expression.

```
[me@linuxbox ~]$ sed -n '/SUSE/p' distros.txt
SUSE            10.2    12/07/2006
SUSE            11.0    06/19/2008
SUSE            10.3    10/04/2007
SUSE            10.1    05/11/2006
```

By including the slash-delimited regular expression `/SUSE/`, we are able to isolate the lines containing it in much the same manner as `grep`.

Finally, we'll try negation by adding an exclamation point (`!`) to the address.

```
[me@linuxbox ~]$ sed -n '/SUSE/!p' distros.txt
Fedora          10      11/25/2008
Ubuntu          8.04    04/24/2008
Fedora          8       11/08/2007
Ubuntu          6.10    10/26/2006
Fedora          7       05/31/2007
Ubuntu          7.10    10/18/2007
Ubuntu          7.04    04/19/2007
Fedora          6       10/24/2006
Fedora          9       05/13/2008
Ubuntu          6.06    06/01/2006
Ubuntu          8.10    10/30/2008
Fedora          5       03/20/2006
```

Here we see the expected result: all the lines in the file except the ones matched by the regular expression.

So far, we've looked at two of the `sed` editing commands, `s` and `p`. Table 20-8 provides a more complete list of the basic editing commands.

**Table 20-8:** sed Basic Editing Commands

| Command | Description |
|---|---|
| = | Output the current line number. |
| a | Append text after the current line. |
| d | Delete the current line. |
| i | Insert text in front of the current line. |
| p | Print the current line. By default, sed prints every line and only edits lines that match a specified address within the file. The default behavior can be overridden by specifying the -n option. |
| q | Exit sed without processing any more lines. If the -n option is not specified, output the current line. |
| Q | Exit sed without processing any more lines. |
| s/*regexp*/*replacement*/ | Substitute the contents of *replacement* wherever *regexp* is found. *replacement* may include the special character &, which is equivalent to the text matched by *regexp*. In addition, *replacement* may include the sequences \1 through \9, which are the contents of the corresponding subexpressions in *regexp*. For more about this, see the following discussion of back references. After the trailing slash following *replacement*, an optional flag may be specified to modify the s command's behavior. |
| y/*set1*/*set2* | Perform transliteration by converting characters from *set1* to the corresponding characters in *set2*. Note that unlike tr, sed requires that both sets be of the same length. |

The s command is by far the most commonly used editing command. We will demonstrate just some of its power by performing an edit on our *distros.txt* file. We discussed earlier how the date field in *distros.txt* was not in a "computer-friendly" format. While the date is formatted MM/DD/YYYY, it would be better (for ease of sorting) if the format were YYYY-MM-DD. Performing this change on the file by hand would be both time-consuming and error-prone, but with sed, this change can be performed in one step.

```
[me@linuxbox ~]$ sed 's/\([0-9]\{2\}\)\/\([0-9]\{2\}\)\/\([0-9]\{4\}\
)$/\3-\1-\2/' distros.txt
SUSE            10.2      2006-12-07
Fedora          10        2008-11-25
SUSE            11.0      2008-06-19
Ubuntu          8.04      2008-04-24
Fedora          8         2007-11-08
SUSE            10.3      2007-10-04
Ubuntu          6.10      2006-10-26
Fedora          7         2007-05-31
```

```
Ubuntu          7.10      2007-10-18
Ubuntu          7.04      2007-04-19
SUSE            10.1      2006-05-11
Fedora          6         2006-10-24
Fedora          9         2008-05-13
Ubuntu          6.06      2006-06-01
Ubuntu          8.10      2008-10-30
Fedora          5         2006-03-20
```

Wow! Now that is an ugly-looking command. But it works. In just one step, we have changed the date format in our file. It is also a perfect example of why regular expressions are sometimes jokingly referred to as a *write-only* medium. We can write them, but we sometimes cannot read them. Before we are tempted to run away in terror from this command, let's look at how it was constructed. First, we know that the command will have this basic structure:

```
sed 's/regexp/replacement/' distros.txt
```

Our next step is to figure out a regular expression that will isolate the date. Because it is in MM/DD/YYYY format and appears at the end of the line, we can use an expression like this:

```
[0-9]{2}/[0-9]{2}/[0-9]{4}$
```

This matches two digits, a slash, two digits, a slash, four digits, and the end of line. So that takes care of *regexp*, but what about *replacement*? To handle that, we must introduce a new regular expression feature that appears in some applications that use BRE. This feature is called *back references* and works like this: if the sequence *\n* appears in *replacement* where *n* is a number from 1 to 9, the sequence will refer to the corresponding subexpression in the preceding regular expression. To create the subexpressions, we simply enclose them in parentheses like so:

```
([0-9]{2})/([0-9]{2})/([0-9]{4})$
```

We now have three subexpressions. The first contains the month, the second contains the day of the month, and the third contains the year. Now we can construct *replacement* as follows:

```
\3-\1-\2
```

This gives us the year, a dash, the month, a dash, and the day.

Now, our command looks like this:

```
sed 's/([0-9]{2})/([0-9]{2})/([0-9]{4})$/\3-\1-\2/' distros.txt
```

We have two remaining problems. The first is that the extra slashes in our regular expression will confuse `sed` when it tries to interpret the `s`

command. The second is that because sed, by default, accepts only basic regular expressions, several of the characters in our regular expression will be taken as literals, rather than as metacharacters. We can solve both these problems with a liberal application of backslashes to escape the offending characters.

```
sed 's/\([0-9]\{2\}\)\/\([0-9]\{2\}\)\/\([0-9]\{4\}\)$/\3-\1-\2/' distros.txt
```

And there you have it!

Another feature of the s command is the use of optional flags that may follow the replacement string. The most important of these is the g flag, which instructs sed to apply the search-and-replace globally to a line, not just to the first instance, which is the default. Here is an example:

```
[me@linuxbox ~]$ echo "aaabbbccc" | sed 's/b/B/'
aaaBbbccc
```

We see that the replacement was performed, but only to the first instance of the letter *b*, while the remaining instances were left unchanged. By adding the g flag, we are able to change all the instances.

```
[me@linuxbox ~]$ echo "aaabbbccc" | sed 's/b/B/g'
aaaBBBccc
```

So far, we have only given sed single commands via the command line. It is also possible to construct more complex commands in a script file using the -f option. To demonstrate, we will use sed with our *distros.txt* file to build a report. Our report will feature a title at the top, our modified dates, and all the distribution names converted to uppercase. To do this, we will need to write a script, so we'll fire up our text editor and enter the following:

```
# sed script to produce Linux distributions report

1 i\
\
Linux Distributions Report\

s/\([0-9]\{2\}\)\/\([0-9]\{2\}\)\/\([0-9]\{4\}\)$/\3-\1-\2/
y/abcdefghijklmnopqrstuvwxyz/ABCDEFGHIJKLMNOPQRSTUVWXYZ/
```

We will save our sed script as *distros.sed* and run it like this:

```
[me@linuxbox ~]$ sed -f distros.sed distros.txt

Linux Distributions Report

SUSE            10.2      2006-12-07
FEDORA          10        2008-11-25
SUSE            11.0      2008-06-19
UBUNTU          8.04      2008-04-24
FEDORA          8         2007-11-08
```

```
SUSE            10.3      2007-10-04
UBUNTU          6.10      2006-10-26
FEDORA          7         2007-05-31
UBUNTU          7.10      2007-10-18
UBUNTU          7.04      2007-04-19
SUSE            10.1      2006-05-11
FEDORA          6         2006-10-24
FEDORA          9         2008-05-13
UBUNTU          6.06      2006-06-01
UBUNTU          8.10      2008-10-30
FEDORA          5         2006-03-20
```

As we can see, our script produces the desired results, but how does it do it? Let's take another look at our script. We'll use `cat` to number the lines.

```
[me@linuxbox ~]$ cat -n distros.sed
   1 # sed script to produce Linux distributions report
   2
   3 1 i\
   4 \
   5 Linux Distributions Report\
   6
   7 s/\([0-9]\{2\}\)\/\([0-9]\{2\}\)\/\([0-9]\{4\}\)$/\3-\1-\2/
   8 y/abcdefghijklmnopqrstuvwxyz/ABCDEFGHIJKLMNOPQRSTUVWXYZ/
```

Line 1 of our script is a *comment*. Like many configuration files and programming languages on Linux systems, comments begin with the `#` character and are followed by human-readable text. Comments can be placed anywhere in the script (though not within commands themselves) and are helpful to any humans who might need to identify and/or maintain the script.

Line 2 is a blank line. Like comments, blank lines may be added to improve readability.

Many `sed` commands support line addresses. These are used to specify which lines of the input are to be acted upon. Line addresses may be expressed as single line numbers, line number ranges, and the special line number `$`, which indicates the last line of input.

Lines 3, 4, 5, and 6 contain text to be inserted at the address 1, the first line of the input. The `i` command is followed by the sequence of a backslash and then a carriage return to produce an escaped carriage return, or what is called a *line-continuation character*. This sequence, which can be used in many circumstances including shell scripts, allows a carriage return to be embedded in a stream of text without signaling the interpreter (in this case `sed`) that the end of the line has been reached. The `i` and the `a` (which appends text, rather than inserting it) and `c` (which replaces text) commands allow multiple lines of text as long as each line, except the last, ends with a line-continuation character. The sixth line of our script is actually the end of our inserted text and ends with a plain carriage return rather than a line-continuation character, signaling the end of the `i` command.

**NOTE** *A line-continuation character is formed by a backslash followed immediately by a carriage return. No intermediary spaces are permitted.*

Line 7 is our search-and-replace command. Since it is not preceded by an address, each line in the input stream is subject to its action.

Line 8 performs transliteration of the lowercase letters into uppercase letters. Note that unlike `tr`, the `y` command in `sed` does not support character ranges (for example, `[a-z]`), nor does it support POSIX. Again, because the `y` command is not preceded by an address, it applies to every line in the input stream.

**PEOPLE WHO LIKE SED ALSO LIKE...**

`sed` is a capable program, able to perform fairly complex editing tasks to streams of text. It is most often used for simple, one-line tasks rather than long scripts. Many users prefer other tools for larger tasks. The most popular of these are `awk` and `perl`. These go beyond mere tools like the programs covered here and extend into the realm of complete programming languages. `perl`, in particular, is often used instead of shell scripts for many system management and administration tasks, as well as being a popular medium for web development. `awk` is a little more specialized. Its specific strength is its ability to manipulate tabular data. It resembles `sed` in that `awk` programs normally process text files line by line, using a scheme similar to the `sed` concept of an address followed by an action. While both `awk` and `perl` are outside the scope of this book, they are good skills for the Linux command line user to learn.

## *aspell—Interactive Spellchecker*

The last tool we will look at is `aspell`, an interactive spelling checker. The `aspell` program is the successor to an earlier program named `ispell` and can be used, for the most part, as a drop-in replacement. While the `aspell` program is mostly used by other programs that require spellchecking capability, it can also be used effectively as a stand-alone tool from the command line. It has the ability to intelligently check various types of text files, including HTML documents, C or C++ programs, email messages, and other kinds of specialized texts.

To spellcheck a text file containing simple prose, it could be used like this:

```
aspell check textfile
```

where *`textfile`* is the name of the file to check. As a practical example, let's create a simple text file named *foo.txt* containing some deliberate spelling errors.

```
[me@linuxbox ~]$ cat > foo.txt
The quick brown fox jimped over the laxy dog.
```

Next we'll check the file using aspell.

```
[me@linuxbox ~]$ aspell check foo.txt
```

As aspell is interactive in the check mode, we will see a screen like this.

```
The quick brown fox jimped over the laxy dog.

1) jumped                          6) wimped
2) gimped                          7) camped
3) comped                          8) humped
4) limped                          9) impede
5) pimped                          0) umped
i) Ignore                          I) Ignore all
r) Replace                         R) Replace all
a) Add                             l) Add Lower
b) Abort                           x) Exit

?
```

At the top of the display, we see our text with a suspiciously spelled word highlighted. In the middle, we see 10 spelling suggestions numbered 0 through 9, followed by a list of other possible actions. Finally, at the bottom, we see a prompt ready to accept our choice.

If we press the 1 key, aspell replaces the offending word with the word *jumped* and moves on to the next misspelled word, which is *laxy*. If we select the replacement *lazy*, aspell replaces it and terminates. Once aspell has finished, we can examine our file and see that the misspellings have been corrected.

```
[me@linuxbox ~]$ cat foo.txt
The quick brown fox jumped over the lazy dog.
```

Unless told otherwise via the command line option --dont-backup, aspell creates a backup file containing the original text by appending the extension *.bak* to the filename.

Showing off our sed editing prowess, we'll put our spelling mistakes back in so we can reuse our file.

```
[me@linuxbox ~]$ sed -i 's/lazy/laxy/; s/jumped/jimped/' foo.txt
```

The sed option -i tells sed to edit the file "in-place," meaning that rather than sending the edited output to standard output, it will rewrite the file with the changes applied. We also see the ability to place more than one editing command on the line by separating them with a semicolon.

Next, we'll look at how aspell can handle different kinds of text files. Using a text editor such as vim (the adventurous may want to try sed), we will add some HTML markup to our file.

```
<html>
      <head>
            <title>Mispelled HTML file</title>
      </head>
      <body>
            <p>The quick brown fox jimped over the laxy dog.</p>
      </body>
</html>
```

Now, if we try to spellcheck our modified file, we run into a problem. If we do it this way:

```
[me@linuxbox ~]$ aspell check foo.txt
```

we'll get this:

```
<html>
        <head>
                <title>Mispelled HTML file</title>
        </head>
        <body>
                <p>The quick brown fox jimped over the laxy dog.</p>
        </body>
</html>
                                                                    
1) HTML                                 4) Hamel
2) ht ml                                5) Hamil
3) ht-ml                                6) hotel
i) Ignore                               I) Ignore all
r) Replace                              R) Replace all
a) Add                                  l) Add Lower
b) Abort                                x) Exit
                                                                    
?
```

aspell will see the contents of the HTML tags as misspelled. This problem can be overcome by including the -H (HTML) checking-mode option, like this:

```
[me@linuxbox ~]$ aspell -H check foo.txt
```

which will result in this:

```
<html>
        <head>
                <title>Mispelled HTML file</title>
        </head>
```

```
        <body>
                <p>The quick brown fox jimped over the laxy dog.</p>
        </body>
</html>
```

```
1) Mi spelled                          6) Misapplied
2) Mi-spelled                          7) Miscalled
3) Misspelled                          8) Respelled
4) Dispelled                           9) Misspell
5) Spelled                             0) Misled
i) Ignore                              I) Ignore all
r) Replace                             R) Replace all
a) Add                                 l) Add Lower
b) Abort                               x) Exit
?
```

The HTML is ignored, and only the non-markup portions of the file are checked. In this mode, the contents of HTML tags are ignored and not checked for spelling. However, the contents of `ALT` tags, which benefit from checking, are checked in this mode.

**NOTE** *By default, `aspell` will ignore URLs and email addresses in text. This behavior can be overridden with command line options. It is also possible to specify which markup tags are checked and skipped. See the `aspell` man page for details.*

## Summing Up

In this chapter, we looked at a few of the many command line tools that operate on text. In the next chapter, we will look at several more. Admittedly, it may not seem immediately obvious how or why you might use some of these tools on a day-to-day basis, though we have tried to show some practical examples of their use. We will find in later chapters that these tools form the basis of a tool set that is used to solve a host of practical problems. This will be particularly true when we get into shell scripting, where these tools will really show their worth.

## Extra Credit

There are a few more interesting text-manipulation commands worth investigating. Among these are `split` (split files into pieces), `csplit` (split files into pieces based on context), and `sdiff` (side-by-side merge of file differences).

# 21

## FORMATTING OUTPUT

In this chapter, we continue our look at text-related tools, focusing on programs that are used to format text output, rather than changing the text itself. These tools are often used to prepare text for eventual printing, a subject that we will cover in the next chapter. We will cover the following programs in this chapter:

- **`nl`** Number lines
- **`fold`** Wrap each line to a specified length
- **`fmt`** A simple text formatter
- **`pr`** Prepare text for printing
- **`printf`** Format and print data
- **`groff`** A document formatting system

## Simple Formatting Tools

We'll look at some of the simple formatting tools first. These are mostly single-purpose programs and a bit unsophisticated in what they do, but they can be used for small tasks and as parts of pipelines and scripts.

### *nl—Number Lines*

The `nl` program is a rather arcane tool used to perform a simple task. It numbers lines. In its simplest use, it resembles `cat -n`.

```
[me@linuxbox ~]$ nl distros.txt | head
     1    SUSE           10.2     12/07/2006
     2    Fedora         10       11/25/2008
     3    SUSE           11.0     06/19/2008
     4    Ubuntu         8.04     04/24/2008
     5    Fedora         8        11/08/2007
     6    SUSE           10.3     10/04/2007
     7    Ubuntu         6.10     10/26/2006
     8    Fedora         7        05/31/2007
     9    Ubuntu         7.10     10/18/2007
    10    Ubuntu         7.04     04/19/2007
```

Like `cat`, `nl` can accept either multiple files as command line arguments or standard input. However, `nl` has a number of options and supports a primitive form of markup to allow more complex kinds of numbering.

`nl` supports a concept called *logical pages* when numbering. This allows `nl` to reset (start over) the numerical sequence when numbering. Using options, it is possible to set the starting number to a specific value and, to a limited extent, its format. A logical page is further broken down into a header, body, and footer. Within each of these sections, line numbering may be reset and/or be assigned a different style. If `nl` is given multiple files, it treats them as a single stream of text. Sections in the text stream are indicated by the presence of some rather odd-looking markup added to the text, as described in Table 21-1.

**Table 21-1:** `nl` Markup

| Markup | Meaning |
|---|---|
| `\:\:\:` | Start of logical page header |
| `\:\:` | Start of logical page body |
| `\:` | Start of logical page footer |

Each of the markup elements listed in Table 21-1 must appear alone on its own line. After processing a markup element, `nl` deletes it from the text stream.

Table 21-2 lists the common options for `nl`.

**Table 21-2:** Common `nl` Options

| Option | Meaning |
|---|---|
| `-b` *`style`* | Set body numbering to *`style`*, where *`style`* is one of the following:<br>`a` = Number all lines.<br>`t` = Number only non-blank lines. This is the default.<br>`n` = None.<br>*`pregexp`* = Number only lines matching basic regular expression *`regexp`*. |
| `-f` *`style`* | Set footer numbering to *`style`*. The default is `n` (none). |
| `-h` *`style`* | Set header numbering to *`style`*. The default is `n` (none). |
| `-i` *`number`* | Set page numbering increment to *`number`*. The default is 1. |
| `-n` *`format`* | Sets numbering format to *`format`*, where *`format`* is one of the following:<br>`ln` = Left justified, without leading zeros.<br>`rn` = Right justified, without leading zeros. This is the default.<br>`rz` = Right justified, with leading zeros. |
| `-p` | Do not reset page numbering at the beginning of each logical page. |
| `-s` *`string`* | Add *`string`* to the end of each line number to create a separator. The default is a single tab character. |
| `-v` *`number`* | Set the first line number of each logical page to *`number`*. The default is 1. |
| `-w` *`width`* | Set the width of the line number field to *`width`*. The default is 6. |

Admittedly, we probably won't be numbering lines that often, but we can use `nl` to look at how we can combine multiple tools to perform more complex tasks. We will build on our work in the previous chapter to produce a Linux distributions report. Since we will be using `nl`, it will be useful to include its header/body/footer markup. To do this, we will add it to the `sed` script from the previous chapter. Using our text editor, we will change the script as follows and save it as *distros-nl.sed*:

```
# sed script to produce Linux distributions report

1 i\
\\:\\:\\:\
\
Linux Distributions Report\
\
Name        Ver.  Released\
----        ----  --------\
\\:\\:
s/\([0-9]\{2\}\)\/\([0-9]\{2\}\)\/\([0-9]\{4\}\)$/\3-\1-\2/
$ a\
\\:\
\
End Of Report
```

The script now inserts the `nl` logical page markup and adds a footer at the end of the report. Note that we had to double up the backslashes in our markup because they are normally interpreted as an escape character by `sed`.

Next, we'll produce our enhanced report by combining sort, sed, and nl.

```
[me@linuxbox ~]$ sort -k 1,1 -k 2n distros.txt | sed -f distros-nl.sed | nl


       Linux Distributions Report

       Name     Ver.    Released
       ----     ----    --------

     1  Fedora  5       2006-03-20
     2  Fedora  6       2006-10-24
     3  Fedora  7       2007-05-31
     4  Fedora  8       2007-11-08
     5  Fedora  9       2008-05-13
     6  Fedora  10      2008-11-25
     7  SUSE    10.1    2006-05-11
     8  SUSE    10.2    2006-12-07
     9  SUSE    10.3    2007-10-04
    10  SUSE    11.0    2008-06-19
    11  Ubuntu  6.06    2006-06-01
    12  Ubuntu  6.10    2006-10-26
    13  Ubuntu  7.04    2007-04-19
    14  Ubuntu  7.10    2007-10-18
    15  Ubuntu  8.04    2008-04-24
    16  Ubuntu  8.10    2008-10-30



       End Of Report
```

Our report is the result of our pipeline of commands. First, we sort the list by distribution name and version (fields 1 and 2), and then we process the results with sed, adding the report header (including the logical page markup for nl) and footer. Finally, we process the result with nl, which, by default, only numbers the lines of the text stream that belong to the body section of the logical page.

We can repeat the command and experiment with different options for nl. Some interesting ones are the following:

```
nl -n rz
```

and the following:

```
nl -w 3 -s ' '
```

## fold—Wrap Each Line to a Specified Length

*Folding* is the process of breaking lines of text at a specified width. Like our other commands, fold accepts either one or more text files or standard input. If we send fold a simple stream of text, we can see how it works.

```
[me@linuxbox ~]$ echo "The quick brown fox jumped over the lazy dog." | fold -w 12
The quick br
own fox jump
ed over the
lazy dog.
```

Here we see fold in action. The text sent by the echo command is broken into segments specified by the -w option. In this example, we specify a line width of 12 characters. If no width is specified, the default is 80 characters. Notice how the lines are broken regardless of word boundaries. The addition of the -s option will cause fold to break the line at the last available space before the line width is reached.

```
[me@linuxbox ~]$ echo "The quick brown fox jumped over the lazy dog." | fold -w 12 -s
The quick
brown fox
jumped over
the lazy
dog.
```

### *fmt—A Simple Text Formatter*

The fmt program also folds text, plus a lot more. It accepts either files or standard input and performs paragraph formatting on the text stream. Basically, it fills and joins lines in text while preserving blank lines and indentation.

To demonstrate, we'll need some text. Let's lift some from the fmt info page.

```
   `fmt' reads from the specified FILE arguments (or standard input if none
are given), and writes to standard output.

   By default, blank lines, spaces between words, and indentation are
preserved in the output; successive input lines with different
indentation are not joined; tabs are expanded on input and introduced on
output.

   `fmt' prefers breaking lines at the end of a sentence, and tries to avoid
line breaks after the first word of a sentence or before the last word of a
sentence.  A "sentence break" is defined as either the end of a paragraph
or a word ending in any of `.?!', followed by two spaces or end of line,
ignoring any intervening parentheses or quotes.  Like TeX, `fmt' reads entire
"paragraphs" before choosing line breaks; the algorithm is a variant of that
given by Donald E. Knuth and Michael F. Plass in "Breaking Paragraphs Into
Lines", `Software--Practice & Experience' 11, 11 (November 1981), 1119-1184.
```

We'll copy this text into our text editor and save the file as *fmt-info.txt*. Now, let's say we wanted to reformat this text to fit a 50-character-wide column. We could do this by processing the file with fmt and the -w option.

```
[me@linuxbox ~]$ fmt -w 50 fmt-info.txt | head
   `fmt' reads from the specified FILE arguments
   (or standard input if
none are given), and writes to standard output.

   By default, blank lines, spaces between words,
   and indentation are
preserved in the output; successive input lines
with different indentation are not joined; tabs
are expanded on input and introduced on output.
```

Well, that's an awkward result. Perhaps we should actually read this text since it explains what's going on.

> By default, blank lines, spaces between words, and indentation are preserved in the output; successive input lines with different indentation are not joined; tabs are expanded on input and introduced on output.

So, `fmt` is preserving the indentation of the first line. Fortunately, `fmt` provides an option to correct this.

```
[me@linuxbox ~]$ fmt -cw 50 fmt-info.txt
   `fmt' reads from the specified FILE arguments
(or standard input if none are given), and writes
to standard output.

   By default, blank lines, spaces between words,
and indentation are preserved in the output;
successive input lines with different indentation
are not joined; tabs are expanded on input and
introduced on output.

   `fmt' prefers breaking lines at the end of a
sentence, and tries to avoid line breaks after
the first word of a sentence or before the
last word of a sentence.  A "sentence break"
is defined as either the end of a paragraph
or a word ending in any of `.?!', followed
by two spaces or end of line, ignoring any
intervening parentheses or quotes.  Like TeX,
`fmt' reads entire "paragraphs" before choosing
line breaks; the algorithm is a variant of
that given by Donald E. Knuth and Michael F.
Plass in "Breaking Paragraphs Into Lines",
`Software--Practice & Experience' 11, 11
(November 1981), 1119-1184.
```

That's much better. By adding the `-c` option, we now have the desired result.

`fmt` has some interesting options, as described in Table 21-3.

**Table 21-3:** `fmt` Options

| Option | Description |
|---|---|
| `-c` | Operate in *crown margin* mode. This preserves the indentation of the first two lines of a paragraph. Subsequent lines are aligned with the indentation of the second line. |
| `-p string` | Format only those lines beginning with the prefix *`string`*. After formatting, the contents of *`string`* are prefixed to each reformatted line. This option can be used to format text in source code comments. For example, any programming language or configuration file that uses a # character to delineate a comment could be formatted by specifying `-p '# '` so that only the comments will be formatted. See the example that follows. |
| `-s` | Split-only mode. In this mode, lines will only be split to fit the specified column width. Short lines will not be joined to fill lines. This mode is useful when formatting text such as code where joining is not desired. |
| `-u` | Perform uniform spacing. This will apply traditional "typewriter-style" formatting to the text. This means a single space between words and two spaces between sentences. This mode is useful for removing *justification*, that is, text that has been padded with spaces to force alignment on both the left and right margins. |
| `-w width` | Format text to fit within a column *`width`* characters wide. The default is 75 characters. Note: `fmt` actually formats lines slightly shorter than the specified width to allow for line balancing. |

The `-p` option is particularly interesting. With it, we can format selected portions of a file, provided that the lines to be formatted all begin with the same sequence of characters. Many programming languages use the pound sign (#) to indicate the beginning of a comment and thus can be formatted using this option. Let's create a file that simulates a program that uses comments.

```
[me@linuxbox ~]$ cat > fmt-code.txt
# This file contains code with comments.

# This line is a comment.
# Followed by another comment line.
# And another.

This, on the other hand, is a line of code.
And another line of code.
And another.
```

Our sample file contains comments that begin with the string `# ` (a # followed by a space) and lines of "code" that do not. Now, using `fmt`, we can format the comments and leave the code untouched.

```
[me@linuxbox ~]$ fmt -w 50 -p '# ' fmt-code.txt
# This file contains code with comments.
```

```
# This line is a comment. Followed by another
# comment line. And another.

This, on the other hand, is a line of code.
And another line of code.
And another.
```

Notice that the adjoining comment lines are joined, while the blank lines and the lines that do not begin with the specified prefix are preserved.

## pr—Format Text for Printing

The pr program is used to *paginate* text. When printing text, it is often desirable to separate the pages of output with several lines of whitespace to provide a top margin and a bottom margin for each page. Further, this whitespace can be used to insert a header and footer on each page.

We'll demonstrate pr by formatting our *distros.txt* file into a series of short pages (only the first two pages are shown).

```
[me@linuxbox ~]$ pr -l 15 -w 65 distros.txt



2016-12-11 18:27                distros.txt                Page 1



SUSE            10.2      12/07/2006
Fedora          10        11/25/2008
SUSE            11.0      06/19/2008
Ubuntu          8.04      04/24/2008
Fedora          8         11/08/2007



2016-12-11 18:27                distros.txt                Page 2



SUSE            10.3      10/04/2007
Ubuntu          6.10      10/26/2006
Fedora          7         05/31/2007
Ubuntu          7.10      10/18/2007
Ubuntu          7.04      04/19/2007
```

In this example, we employ the -l option (for page length) and the -w option (page width) to define a "page" that is 65 columns wide and 15 lines long. pr paginates the contents of the *distros.txt* file, separates each page with several lines of whitespace, and creates a default header containing

the file modification time, filename, and page number. The pr program provides many options to control page layout, which we'll see in Chapter 22.

## printf—Format and Print Data

Unlike the other commands in this chapter, the printf command is not used for pipelines (it does not accept standard input) nor does it find frequent application directly on the command line (it's mostly used in scripts). So why is it important? Because it is so widely used.

printf (from the phrase *print formatted*) was originally developed for the C programming language and has been implemented in many programming languages including the shell. In fact, in bash, printf is a builtin.

printf works like this:

```
printf "format" arguments
```

The command is given a string containing a format description, which is then applied to a list of arguments. The formatted result is sent to standard output. Here is a trivial example:

```
[me@linuxbox ~]$ printf "I formatted the string: %s\n" foo
I formatted the string: foo
```

The format string may contain literal text (like "I formatted the string:"), escape sequences (such as \n, a newline character), and sequences beginning with the % character, which are called *conversion specifications*. In the preceding example, the conversion specification %s is used to format the string "foo" and place it in the command's output. Here it is again:

```
[me@linuxbox ~]$ printf "I formatted '%s' as a string.\n" foo
I formatted 'foo' as a string.
```

As we can see, the %s conversion specification is replaced by the string "foo" in the command's output. The s conversion is used to format string data. There are other specifiers for other kinds of data. Table 21-4 lists the commonly used data types.

**Table 21-4:** Common printf Data Type Specifiers

| Specifier | Description |
|---|---|
| d | Format a number as a signed decimal integer. |
| f | Format and output a floating-point number. |
| o | Format an integer as an octal number. |
| s | Format a string. |
| x | Format an integer as a hexadecimal number using lowercase a to f where needed. |
| X | Same as x but use uppercase letters. |
| % | Print a literal % symbol (i.e., specify %%). |

We'll demonstrate the effect each of the conversion specifiers on the string 380.

```
[me@linuxbox ~]$ printf "%d, %f, %o, %s, %x, %X\n" 380 380 380 380 380 380
380, 380.000000, 574, 380, 17c, 17C
```

Because we specified six conversion specifiers, we must also supply six arguments for printf to process. The six results show the effect of each specifier.

Several optional components may be added to the conversion specifier to adjust its output. A complete conversion specification may consist of the following:

```
%[flags][width][.precision]conversion_specification
```

Multiple optional components, when used, must appear in the order specified earlier to be properly interpreted. Table 21-5 describes each.

**Table 21-5:** printf Conversion Specification Components

| Component | Description |
|---|---|
| *flags* | There are five different flags: |
| | #: Use the *alternate format* for output. This varies by data type. For o (octal number) conversion, the output is prefixed with 0. For x and X (hexadecimal number) conversions, the output is prefixed with 0x or 0X, respectively. |
| | 0 (zero): Pad the output with zeros. This means that the field will be filled with leading zeros, as in 000380. |
| | - (dash): Left-align the output. By default, printf right-aligns output. |
| | ' ' (space): Produce a leading space for positive numbers. |
| | + (plus sign): Sign positive numbers. By default, printf only signs negative numbers. |
| *width* | A number specifying the minimum field width. |
| *.precision* | For floating-point numbers, specify the number of digits of precision to be output after the decimal point. For string conversion, *precision* specifies the number of characters to output. |

Table 21-6 lists some examples of different formats in action.

**Table 21-6:** printf Conversion Specification Examples

| Argument | Format | Result | Notes |
|---|---|---|---|
| 380 | "%d" | 380 | Simple formatting of an integer. |
| 380 | "%#x" | 0x17c | Integer formatted as a hexadecimal number using the "alternate format" flag. |

| Argument | Format | Result | Notes |
|---|---|---|---|
| 380 | "%05d" | 00380 | Integer formatted with leading zeros (padding) and a minimum field width of five characters. |
| 380 | "%05.5f" | 380.00000 | Number formatted as a floating-point number with padding and five decimal places of precision. Since the specified minimum field width (5) is less than the actual width of the formatted number, the padding has no effect. |
| 380 | "%010.5f" | 0380.00000 | By increasing the minimum field width to 10, the padding is now visible. |
| 380 | "%+d" | +380 | The + flag signs a positive number. |
| 380 | "%-d" | 380 | The - flag left-aligns the formatting. |
| abcdefghijk | "%5s" | abcedfghijk | A string formatted with a minimum field width. |
| abcdefghijk | "%.5s" | abcde | By applying precision to a string, it is truncated. |

Again, printf is used mostly in scripts where it is employed to format tabular data, rather than on the command line directly. But we can still show how it can be used to solve various formatting problems. First, let's output some fields separated by tab characters.

```
[me@linuxbox ~]$ printf "%s\t%s\t%s\n" str1 str2 str3
str1    str2    str3
```

By inserting \t (the escape sequence for a tab), we achieve the desired effect. Next, here are some numbers with neat formatting:

```
[me@linuxbox ~]$ printf "Line: %05d %15.3f Result: %+15d\n" 1071 3.14156295
32589
Line: 01071           3.142 Result:          +32589
```

This shows the effect of minimum field width on the spacing of the fields. Or how about formatting a tiny web page?

```
[me@linuxbox ~]$ printf "<html>\n\t<head>\n\t\t<title>%s</title>\n\t</head>\n\
t<body>\n\t\t<p>%s</p>\n\t</body>\n</html>\n" "Page Title" "Page Content"
<html>
        <head>
                <title>Page Title</title>
        </head>
        <body>
                <p>Page Content</p>
        </body>
</html>
```

## Document Formatting Systems

So far, we have examined the simple text-formatting tools. These are good for small, simple tasks, but what about larger jobs? One of the reasons that Unix became a popular operating system among technical and scientific users (aside from providing a powerful multitasking, multiuser environment for all kinds of software development) is that it offered tools that could be used to produce many types of documents, particularly scientific and academic publications. In fact, as the GNU documentation describes, document preparation was instrumental to the development of Unix.

> The first version of UNIX was developed on a PDP-7 which was sitting around Bell Labs. In 1971 the developers wanted to get a PDP-11 for further work on the operating system. In order to justify the cost for this system, they proposed that they would implement a document formatting system for the AT&T patents division. This first formatting program was a reimplementation of McIllroy's *roff*, written by J. F. Ossanna.

Two main families of document formatters dominate the field: those descended from the original `roff` program, including `nroff` and `troff`, and those based on Donald Knuth's TEX (pronounced "tek") typesetting system. And yes, the dropped *E* in the middle is part of its name.

The name *roff* is derived from the term *run off* as in, "I'll run off a copy for you." The `nroff` program is used to format documents for output to devices that use monospaced fonts, such as character terminals and typewriter-style printers. At the time of its introduction, this included nearly all printing devices attached to computers. The later `troff` program formats documents for output on *typesetters*, devices used to produce "camera-ready" type for commercial printing. Most computer printers today are able to simulate the output of typesetters. The `roff` family also includes some other programs that are used to prepare portions of documents. These include `eqn` (for mathematical equations) and `tbl` (for tables).

The TEX system (in stable form) first appeared in 1989 and has, to some degree, displaced `troff` as the tool of choice for typesetter output. We won't be covering TEX here, both because of its complexity (there are entire books about it) and because it is not installed by default on most modern Linux systems.

**TIP** *For those interested in installing TEX, check out the `texlive` package, which can be found in most distribution repositories, and the `LyX` graphical content editor.*

### groff

`groff` is a suite of programs containing the GNU implementation of `troff`. It also includes a script that is used to emulate `nroff` and the rest of the `roff` family as well.

While roff and its descendants are used to make formatted documents, they do it in a way that is rather foreign to modern users. Most documents today are produced using word processors that are able to perform both the composition and the layout of a document in a single step. Prior to the advent of the graphical word processor, documents were often produced in a two-step process involving the use of a text editor to perform composition, and a processor, such as troff, to apply the formatting. Instructions for the formatting program were embedded into the composed text through the use of a markup language. The modern analog for such a process is the web page, which is composed using a text editor of some kind and then rendered by a web browser using HTML as the markup language to describe the final page layout.

We're not going to cover groff in its entirety, as many elements of its markup language deal with rather arcane details of typography. Instead, we will concentrate on one of its *macro packages* that remains in wide use. These macro packages condense many of its low-level commands into a smaller set of high-level commands that make using groff much easier.

For a moment, let's consider the humble man page. It lives in the */usr/share/man* directory as a gzip-compressed text file. If we were to examine its uncompressed contents, we would see the following (the man page for ls in section 1 is shown):

```
[me@linuxbox ~]$ zcat /usr/share/man/man1/ls.1.gz | head

.\" DO NOT MODIFY THIS FILE!  It was generated by help2man 1.47.3.
.TH LS "1" "January 2018" "GNU coreutils 8.28" "User Commands"
.SH NAME
ls \- list directory contents
.SH SYNOPSIS
.B ls
[\fI\,OPTION\/\fR]... [\fI\,FILE\/\fR]...
.SH DESCRIPTION
.\" Add any additional description here
.PP
```

Compared to the man page in its normal presentation, we can begin to see a correlation between the markup language and its results.

```
[me@linuxbox ~]$ man ls | head
LS(1)                     User Commands                     LS(1)


NAME
       ls - list directory contents

SYNOPSIS
       ls [OPTION]... [FILE]...
```

The reason this is of interest is that man pages are rendered by `groff`, using the `mandoc` macro package. In fact, we can simulate the `man` command with the following pipeline:

```
[me@linuxbox ~]$ zcat /usr/share/man/man1/ls.1.gz | groff -mandoc -T ascii |
head
LS(1)                    User Commands                    LS(1)



NAME
       ls - list directory contents

SYNOPSIS
       ls [OPTION]... [FILE]...
```

Here we use the `groff` program with the options set to specify the `mandoc` macro package and the output driver for ASCII. `groff` can produce output in several formats. If no format is specified, PostScript is output by default.

```
[me@linuxbox ~]$ zcat /usr/share/man/man1/ls.1.gz | groff -mandoc | head
%!PS-Adobe-3.0
%%Creator: groff version 1.18.1
%%CreationDate: Thu Feb  5 13:44:37 2009
%%DocumentNeededResources: font Times-Roman
%%+ font Times-Bold
%%+ font Times-Italic
%%DocumentSuppliedResources: procset grops 1.18 1
%%Pages: 4
%%PageOrder: Ascend
%%Orientation: Portrait
```

We briefly mentioned PostScript in the previous chapter and will again in the next chapter. PostScript is a *page description language* that is used to describe the contents of a printed page to a typesetter-like device. If we take the output of our command and store it to a file (assuming that we are using a graphical desktop with a *Desktop* directory), an icon for the output file should appear on the desktop.

```
[me@linuxbox ~]$ zcat /usr/share/man/man1/ls.1.gz | groff -mandoc > ~/Desktop/ls.ps
```

By double-clicking the icon, a page viewer should start up and reveal the file in its rendered form, as shown in Figure 21-1.

What we see is a nicely typeset man page for `ls`! In fact, it's possible to convert the PostScript file into a *Portable Document Format* (*PDF*) file with this command:

```
[me@linuxbox ~]$ ps2pdf ~/Desktop/ls.ps ~/Desktop/ls.pdf
```

The `ps2pdf` program is part of the `ghostscript` package, which is installed on most Linux systems that support printing.

*Figure 21-1: Viewing PostScript output with a page viewer in GNOME*

**TIP** *Linux systems often include many command line programs for file format conversion. They are often named using the convention of* format2format. *Try using the command* `ls /usr/bin/*[[:alpha:]]2[[:alpha:]]*` *to identify them. Also try searching for programs named* formattoformat.

For our last exercise with `groff`, we will revisit our old friend *distros.txt*. This time, we will use the `tbl` program, which is used to format tables to typeset our list of Linux distributions. To do this, we are going to use our earlier `sed` script to add markup to a text stream that we will feed to `groff`.

First, we need to modify our `sed` script to add the necessary markup elements (called *requests* in `groff`) that `tbl` requires. Using a text editor, we will change *distros.sed* to the following:

```
# sed script to produce Linux distributions report

1 i\
.TS\
center box;\
cb s s\
cb cb cb\
l n c.\
Linux Distributions Report\
=\
```

```
Name    Version    Released\
_
s/\([0-9]\{2\}\)\/\([0-9]\{2\}\)\/\([0-9]\{4\}\)$/\3-\1-\2/
$ a\
.TE
```

Note that for the script to work properly, care must been taken to see that the words *Name Version Released* are separated by tabs, not spaces. We'll save the resulting file as *distros-tbl.sed*. `tbl` uses the `.TS` and `.TE` requests to start and end the table. The rows following the `.TS` request define global properties of the table, which, for our example, are centered horizontally on the page and surrounded by a box. The remaining lines of the definition describe the layout of each table row. Now, if we run our report-generating pipeline again with the new `sed` script, we'll get the following:

```
[me@linuxbox ~]$ sort -k 1,1 -k 2n distros.txt | sed -f distros-tbl.sed | groff -t -T ascii
                 +-----------------------------+
                 | Linux Distributions Report  |
                 +-----------------------------+
                 | Name    Version    Released |
                 +-----------------------------+
                 |Fedora     5       2006-03-20 |
                 |Fedora     6       2006-10-24 |
                 |Fedora     7       2007-05-31 |
                 |Fedora     8       2007-11-08 |
                 |Fedora     9       2008-05-13 |
                 |Fedora    10       2008-11-25 |
                 |SUSE      10.1     2006-05-11 |
                 |SUSE      10.2     2006-12-07 |
                 |SUSE      10.3     2007-10-04 |
                 |SUSE      11.0     2008-06-19 |
                 |Ubuntu     6.06    2006-06-01 |
                 |Ubuntu     6.10    2006-10-26 |
                 |Ubuntu     7.04    2007-04-19 |
                 |Ubuntu     7.10    2007-10-18 |
                 |Ubuntu     8.04    2008-04-24 |
                 |Ubuntu     8.10    2008-10-30 |
                 +-----------------------------+
```

Adding the `-t` option to `groff` instructs it to preprocess the text stream with `tbl`. Likewise, the `-T` option is used to output to ASCII rather than the default output medium, PostScript.

The format of the output is the best we can expect if we are limited to the capabilities of a terminal screen or typewriter-style printer. If we specify PostScript output and graphically view the output, we get a much more satisfying result, as shown in Figure 21-2.

```
[me@linuxbox ~]$ sort -k 1,1 -k 2n distros.txt | sed -f distros-tbl.sed |
groff -t > ~/Desktop/distros.ps
```

Linux Distributions Report

| Name | Version | Released |
|---|---|---|
| Fedora | 5 | 2006-03-20 |
| Fedora | 6 | 2006-10-24 |
| Fedora | 7 | 2007-05-31 |
| Fedora | 8 | 2007-11-08 |
| Fedora | 9 | 2008-05-13 |
| Fedora | 10 | 2008-11-25 |
| SUSE | 10.1 | 2006-05-11 |
| SUSE | 10.2 | 2006-12-07 |
| SUSE | 10.3 | 2007-10-04 |
| SUSE | 11.0 | 2008-06-19 |
| Ubuntu | 6.06 | 2006-06-01 |
| Ubuntu | 6.10 | 2006-10-26 |
| Ubuntu | 7.04 | 2007-04-19 |
| Ubuntu | 7.10 | 2007-10-18 |
| Ubuntu | 8.04 | 2008-04-24 |
| Ubuntu | 8.10 | 2008-10-30 |

*Figure 21-2: Viewing the finished table*

## Summing Up

Given that text is so central to the character of Unix-like operating systems, it makes sense that there would be many tools that are used to manipulate and format text. As we have seen, there are! The simple formatting tools like `fmt` and `pr` will find many uses in scripts that produce short documents, while `groff` (and friends) can be used to write books. We may never write a technical paper using command line tools (though there are some people who do!), but it's good to know that we could.

# 22

# PRINTING

After spending the last couple of chapters manipulating text, it's time to put that text on paper. In this chapter, we'll look at the command line tools that are used to print files and control printer operation. We won't be looking at how to configure printing because that varies from distribution to distribution and is usually set up automatically during installation. Note that we will need a working printer configuration to perform the exercises in this chapter.

We will discuss the following commands:

**`pr`** Convert text files for printing

**`lpr`** Print files

**`a2ps`** Format files for printing on a PostScript printer

**`lpstat`** Show printer status information

**`lpq`** Show printer queue status

**`lprm`** Cancel print jobs

## A Brief History of Printing

To fully understand the printing features found in Unix-like operating systems, we must first learn some history. Printing on Unix-like systems goes way back to the beginning of the operating system. In those days, printers and how they were used were much different from today.

### *Printing in the Dim Times*

Like computers, printers in the pre-PC era tended to be large, expensive, and centralized. The typical computer user of 1980 worked at a terminal connected to a computer some distance away. The printer was located near the computer and was under the watchful eyes of the computer's operators.

When printers were expensive and centralized, as they often were in the early days of Unix, it was common practice for many users to share a printer. To identify print jobs belonging to a particular user, a *banner page* displaying the name of the user was often printed at the beginning of each print job. The computer support staff would then load up a cart containing the day's print jobs and deliver them to the individual users.

### *Character-Based Printers*

The printer technology of the 1980s was very different from today in two respects. First, printers of that period were almost always *impact printers*. Impact printers use a mechanical mechanism that strikes a ribbon against the paper to form character impressions on the page. Two of the popular technologies of that time were *daisy-wheel* printing and *dot-matrix* printing.

The second, and more important, characteristic of early printers was that printers used a fixed set of characters that were intrinsic to the device. For example, a daisy-wheel printer could print only the characters actually molded into the petals of the daisy wheel. This made the printers much like high-speed typewriters. As with most typewriters, they printed using monospaced (fixed-width) fonts. This means that each character has the same width. Printing was done at fixed positions on the page, and the printable area of a page contained a fixed number of characters. Most printers printed 10 characters per inch (CPI) horizontally and 6 lines per inch (LPI) vertically. Using this scheme, a US-letter sheet of paper is 85 characters wide and 66 lines high. Taking into account a small margin on each side, 80 characters was considered the maximum width of a print line. This explains why terminal displays (and our terminal emulators) are normally 80 characters wide. Using a monospaced font and an 80-character-wide terminal provides a what-you-see-is-what-you-get (WYSIWYG, pronounced "whizzy-wig") view of printed output.

Data is sent to a typewriter-like printer in a simple stream of bytes containing the characters to be printed. For example, to print an *a*, the ASCII character code 97 is sent. In addition, the low-numbered ASCII control codes provided a means of moving the printer's carriage and paper, using codes for carriage return, line feed, form feed, and so on. Using the control codes, it's possible to achieve some limited font effects,

such as boldface, by having the printer print a character, backspace, and print the character again to get a darker print impression on the page. We can actually witness this if we use `nroff` to render a man page and examine the output using `cat -A`.

```
[me@linuxbox ~]$ zcat /usr/share/man/man1/ls.1.gz | nroff -man | cat -A | head
LS(1)                       User Commands                      LS(1)
$
$
$
N^HNA^HAM^HME^HE$
       ls - list directory contents$
$
S^HSY^HYN^HNO^HOP^HPS^HSI^HIS^HS$
       l^Hls^Hs [_^HO_^HP_^HT_^HI_^HO_^HN]... [_^HF_^HI_^HL_^HE]...$
```

The `^H` (CTRL-H) characters are the backspaces used to create the boldface effect. Likewise, we can also see a backspace/underscore sequence used to produce underlining.

### Graphical Printers

The development of GUIs led to major changes in printer technology. As computers moved to more picture-based displays, printing moved from character-based to graphical techniques. This was facilitated by the advent of the low-cost laser printer, which, instead of printing fixed characters, could print tiny dots anywhere in the printable area of the page. This made printing proportional fonts (like those used by typesetters), and even photographs and high-quality diagrams, possible.

However, moving from a character-based scheme to a graphical scheme presented a formidable technical challenge. Here's why: the number of bytes needed to fill a page using a character-based printer can be calculated this way (assuming 60 lines per page each containing 80 characters):

$$60 \times 80 = 4{,}800 \text{ bytes}$$

In comparison, a 300 dot per inch (DPI) laser printer (assuming an 8- by 10-inch print area per page) requires this many bytes:

$$(8 \times 300) \times (10 \times 300) \ / \ 8 = 900{,}000 \text{ bytes}$$

Many of the slow PC networks simply could not handle the nearly 1MB of data required to print a full page on a laser printer, so it was clear that a clever invention was needed.

That invention turned out to be the *page description language* (PDL). A page description language is a programming language that describes the contents of a page. Basically it says, "Go to this position, draw the character *a* in 10-point Helvetica, go to this position . . ." until everything on the page is described. The first major PDL was *PostScript* from Adobe Systems, which is still in wide use today. The PostScript language is a complete programming language tailored for typography and other kinds of graphics and imaging. It includes built-in support for 35 standard, high-quality fonts, plus the ability to

accept additional font definitions at runtime. At first, support for PostScript was built into the printers themselves. This solved the data transmission problem. While the typical PostScript program was very verbose in comparison to the simple byte stream of character-based printers, it was much smaller than the number of bytes required to represent the entire printed page.

A *PostScript printer* accepted a PostScript program as input. The printer contained its own processor and memory (oftentimes making the printer a more powerful computer than the computer to which it was attached) and executed a special program called a *PostScript interpreter*, which read the incoming PostScript program and *rendered* the results into the printer's internal memory, thus forming the pattern of bits (dots) that would be transferred to the paper. The generic name for this process of rendering something into a large bit pattern (called a *bitmap*) is *raster image processor* (*RIP*).

As the years went by, both computers and networks became much faster. This allowed the RIP to move from the printer to the host computer, which, in turn, permitted high-quality printers to be much less expensive.

Many printers today still accept character-based streams, but many low-cost printers do not. They rely on the host computer's RIP to provide a stream of bits to print as dots. There are still some PostScript printers, too.

## Printing with Linux

Modern Linux systems employ two software suites to perform and manage printing. The first, the Common Unix Printing System (CUPS), provides print drivers and print-job management, and the second, Ghostscript, a PostScript interpreter, acts as a RIP.

CUPS manages printers by creating and maintaining *print queues*. As we discussed in the earlier history lesson, Unix printing was originally designed to manage a centralized printer shared by multiple users. Since printers are slow by nature, compared to the computers that are feeding them, printing systems need a way to schedule multiple print jobs and keep things organized. CUPS also has the ability to recognize different types of data (within reason) and can convert files to a printable form.

## Preparing Files for Printing

As command line users, we are mostly interested in printing text, though it is certainly possible to print other data formats as well.

### *pr—Convert Text Files for Printing*

We looked at `pr` a little in the previous chapter. Now we will examine some of its many options used in conjunction with printing. In our history of printing, we saw how character-based printers use monospaced fonts, resulting in fixed numbers of characters per line and lines per page. `pr` is used to adjust text to fit on a specific page size, with optional page headers and margins. Table 22-1 summarizes its most commonly used options.

**Table 22-1:** Common pr Options

| Option | Description |
|---|---|
| +*first*[:*last*] | Output a range of pages starting with *first* and, optionally, ending with *last*. |
| -*columns* | Organize the content of the page into the number of columns specified by *columns*. |
| -a | By default, multicolumn output is listed vertically. By adding the -a (across) option, content is listed horizontally. |
| -d | Double-space output. |
| -D *format* | Format the date displayed in page headers using *format*. See the man page for the date command for a description of the format string. |
| -f | Use form feeds rather than carriage returns to separate pages. |
| -h *header* | In the center portion of the page header, use *header* rather than the name of the file being processed. |
| -l *length* | Set page length to *length*. The default is 66 (US letter at 6 lines per inch). |
| -n | Number lines. |
| -o *offset* | Create a left margin *offset* characters wide. |
| -w *width* | Set the page width to *width*. The default is 72. |

pr is often used in pipelines as a filter. In this example, we will produce a directory listing of */usr/bin* and format it into paginated, three-column output using pr:

```
[me@linuxbox ~]$  ls /usr/bin | pr -3 -w 65 | head


2016-02-18 14:00                                          Page 1
[                           apturl                bsd-write
411toppm                    ar                    bsh
a2p                         arecord               btcflash
a2ps                        arecordmidi           bug-buddy
a2ps-lpr-wrapper            ark                   buildhash
```

## Sending a Print Job to a Printer

The CUPS printing suite supports two methods of printing historically used on Unix-like systems. One method, called Berkeley or LPD (used in the Berkeley Software Distribution version of Unix), uses the lpr program, while the other method, called SysV (from the System V version of Unix), uses the lp program. Both programs do roughly the same thing. Choosing one over the other is a matter of personal taste.

## lpr—Print Files (Berkeley Style)

The `lpr` program can be used to send files to the printer. It may also be used in pipelines, as it accepts standard input. For example, to print the results of our previous multicolumn directory listing, we could do this:

```
[me@linuxbox ~]$ ls /usr/bin | pr -3 | lpr
```

The report would be sent to the system's default printer. To send the file to a different printer, the `-P` option can be used like this:

```
lpr -P printer_name
```

Here, *`printer_name`* is the name of the desired printer. To see a list of printers known to the system, use this:

```
[me@linuxbox ~]$ lpstat -a
```

**TIP** *Many Linux distributions allow you to define a "printer" that outputs files to PDF, rather than printing on the physical printer. This is handy for experimenting with printing commands. Check your printer configuration program to see whether it supports this configuration. On some distributions, you may need to install additional packages (such as `cups-pdf`) to enable this capability.*

Table 22-2 describes some of the common options for `lpr`.

**Table 22-2:** Common `lpr` Options

| Option | Description |
|---|---|
| `-#` *`number`* | Set number of copies to *`number`*. |
| `-p` | Print each page with a shaded header with the date, time, job name, and page number. This so-called pretty-print option can be used when printing text files. |
| `-P` *`printer`* | Specify the name of the printer used for output. If no printer is specified, the system's default printer is used. |
| `-r` | Delete files after printing. This would be useful for programs that produce temporary printer-output files. |

## lp—Print Files (System V Style)

Like `lpr`, `lp` accepts either files or standard input for printing. It differs from `lpr` in that it supports a different (and slightly more sophisticated) option set. Table 22-3 describes the common options.

**Table 22-3:** Common `lp` Options

| Option | Description |
|---|---|
| `-d` *`printer`* | Set the destination (printer) to *`printer`*. If no `d` option is specified, the system default printer is used. |
| `-n` *`number`* | Set the number of copies to *`number`*. |
| `-o landscape` | Set output to landscape orientation. |
| `-o fitplot` | Scale the file to fit the page. This is useful when printing images, such as JPEG files. |
| `-o scaling=`*`number`* | Scale file to *`number`*. The value of 100 fills the page. Values less than 100 are reduced, while values greater than 100 cause the file to be printed across multiple pages. |
| `-o cpi=`*`number`* | Set the output characters per inch to *`number`*. The default is 10. |
| `-o lpi=`*`number`* | Set the output lines per inch to *`number`*. The default is 6. |
| `-o page-bottom=`*`points`*<br>`-o page-left=`*`points`*<br>`-o page-right=`*`points`*<br>`-o page-top=`*`points`* | Set the page margins. Values are expressed in *`points`*, a unit of typographic measurement. There are 72 points to an inch. |
| `-P` *`pages`* | Specify the list of pages. *`pages`* may be expressed as a comma-separated list and/or a range, for example, `1,3,5,7-10`. |

We'll produce our directory listing again, this time printing 12 CPI and 8 LPI with a left margin of one-half inch. Note that we have to adjust the `pr` options to account for the new page size.

```
[me@linuxbox ~]$ ls /usr/bin | pr -4 -w 90 -l 88 | lp -o page-left=36 -o cpi=12 -o lpi=8
```

This pipeline produces a four-column listing using smaller type than the default. The increased number of characters per inch allows us to fit more columns on the page.

### *Another Option: a2ps*

The `a2ps` program (available in most distribution repositories) is interesting. As we can surmise from its name, it's a format conversion program, but it's also much more. Its name originally meant "ASCII to PostScript," and it was used to prepare text files for printing on PostScript printers. Over the years, however, the capabilities of the program have grown, and now its name means "Anything to PostScript." While its name suggests a format-conversion program, it is actually a printing program. It sends its default output to the system's default printer rather than standard output. The program's default behavior is that of a "pretty printer," meaning that it improves the appearance of output. We can use the program to create a PostScript file on our desktop.

```
[me@linuxbox ~]$ ls /usr/bin | pr -3 -t | a2ps -o ~/Desktop/ls.ps -L 66
[stdin (plain): 11 pages on 6 sheets]
[Total: 11 pages on 6 sheets] saved into the file `/home/me/Desktop/ls.ps'
```

Here we filter the stream with `pr`, using the `-t` option (omit headers and footers), and then with `a2ps`, specifying an output file (`-o` option) and 66 lines per page (`-L` option) to match the output pagination of `pr`. If we view the resulting file with a suitable file viewer, we will see the output in Figure 22-1.

*Figure 22-1: Viewing a2ps output*

As we can see, the default output layout is "two-up" format. This causes the contents of two pages to be printed on each sheet of paper. `a2ps` applies nice page headers and footers, too.

`a2ps` has a lot of options. Table 22-4 provides a summary.

**Table 22-4:** `a2ps` Options

| Option | Description |
|---|---|
| `--center-title=`*`text`* | Set center page title to *`text`*. |
| `--columns=`*`number`* | Arrange pages into *`number`* columns. The default is 2. |
| `--footer=`*`text`* | Set page footer to *`text`*. |
| `--guess` | Report the types of files given as arguments. Since `a2ps` tries to convert and format all types of data, this option can be useful for predicting what `a2ps` will do when given a particular file. |
| `--left-footer=`*`text`* | Set the left-page footer to *`text`*. |
| `--left-title=`*`text`* | Set the left-page title to *`text`*. |

| Option | Description |
|---|---|
| `--line-numbers=interval` | Number lines of output every *interval* lines. |
| `--list=defaults` | Display default settings. |
| `--pages=range` | Print pages in range. |
| `--right-footer=text` | Set the right-page footer to *text*. |
| `--right-title=text` | Set the right-page title to *text*. |
| `--rows=number` | Arrange pages into *number* rows. The default is 1. |
| `-B` | No page headers. |
| `-b text` | Set the page header to *text*. |
| `-f size` | Use *size* point font. |
| `-l number` | Set characters per line to *number*. This and the `-L` option (see the next entry) can be used to make files paginated with other programs, such as `pr`, fit correctly on the page. |
| `-L number` | Set lines per page to *number*. |
| `-M name` | Use a media *name*, such as `A4`. |
| `-n number` | Output *number* copies of each page. |
| `-o file` | Send output to *file*. If *file* is specified as `-`, use standard output. |
| `-P printer` | Use *printer*. If a printer is not specified, the system default printer is used. |
| `-R` | Portrait orientation. |
| `-r` | Landscape orientation. |
| `-T number` | Set tab stops to every *number* characters. |
| `-u text` | Underlay (watermark) pages with *text*. |

This is just a summary. `a2ps` has several more options.

**NOTE** *There is another output formatter that is useful for converting text into PostScript. Called `enscript`, it can perform many of the same kinds of formatting and printing tricks, but unlike `a2ps`, it accepts only text input.*

## Monitoring and Controlling Print Jobs

As Unix printing systems are designed to handle multiple print jobs from multiple users, CUPS is designed to do the same. Each printer is given a *print queue*, where jobs are parked until they can be *spooled* to the printer. CUPS supplies several command line programs that are used to manage printer status and print queues. Like the `lpr` and `lp` programs, these management programs are modeled after the corresponding programs from the Berkeley and System V printing systems.

## lpstat—Display Print System Status

The `lpstat` program is useful for determining the names and availability of printers on the system. For example, if we had a system with both a physical printer (named *printer*) and a PDF virtual printer (named *PDF*), we could check their status like this:

```
[me@linuxbox ~]$ lpstat -a
PDF accepting requests since Mon 08 Dec 2017 03:05:59 PM EST
printer accepting requests since Tue 24 Feb 2018 08:43:22 AM EST
```

Further, we could determine a more detailed description of the print system configuration this way:

```
[me@linuxbox ~]$ lpstat -s
system default destination: printer
device for PDF: cups-pdf:/
device for printer: ipp://print-server:631/printers/printer
```

In this example, we see that *printer* is the system's default printer and that it is a network printer using Internet Printing Protocol (*ipp://*) attached to a system named *print-server*.

Table 22-5 describes some of the commonly useful options.

**Table 22-5:** Common `lpstat` Options

| Option | Description |
|---|---|
| `-a [printer...]` | Display the state of the printer queue for *`printer`*. Note that this is the status of the printer queue's ability to accept jobs, not the status of the physical printers. If no printers are specified, all print queues are shown. |
| `-d` | Display the name of the system's default printer. |
| `-p [printer...]` | Display the status of the specified *`printer`*. If no printers are specified, all printers are shown. |
| `-r` | Display the status of the print server. |
| `-s` | Display a status summary. |
| `-t` | Display a complete status report. |

## lpq—Display Printer Queue Status

To see the status of a printer queue, the `lpq` program is used. This allows us to view the status of the queue and the print jobs it contains. Here is an example of an empty queue for a system default printer named *printer*:

```
[me@linuxbox ~]$ lpq
printer is ready
no entries
```

If we do not specify a printer (using the -P option), the system's default printer is shown. If we send a job to the printer and then look at the queue, we will see it listed.

```
[me@linuxbox ~]$ ls *.txt | pr -3 | lp
request id is printer-603 (1 file(s))
[me@linuxbox ~]$ lpq
printer is ready and printing
Rank    Owner   Job     File(s)                         Total Size
active  me      603     (stdin)                         1024 bytes
```

### lprm/cancel—Cancel Print Jobs

CUPS supplies two programs used to terminate print jobs and remove them from the print queue. One is Berkeley style (lprm), and the other is System V (cancel). They differ slightly in the options they support but do basically the same thing. Using our earlier print job as an example, we could stop the job and remove it this way:

```
[me@linuxbox ~]$ cancel 603
[me@linuxbox ~]$ lpq
printer is ready
no entries
```

Each command has options for removing all the jobs belonging to a particular user, particular printer, and multiple job numbers. Their respective man pages have all the details.

## Summing Up

In this chapter, we saw how the printers of the past influenced the design of the printing systems on Unix-like machines. We also explored how much control is available on the command line to control not only the scheduling and execution of print jobs, but also the various output options.

# 23

## COMPILING PROGRAMS

In this chapter, we will look at how to build programs by compiling source code. The availability of source code is the essential freedom that makes Linux possible. The entire ecosystem of Linux development relies on free exchange between developers. For many desktop users, compiling is a lost art. It used to be quite common, but today, distribution providers maintain huge repositories of precompiled binaries, ready to download and use. At press time, the Debian repository (one of the largest of any of the distributions) contains more than 68,000 packages.

So why compile software? There are two reasons.

- **Availability**. Despite the number of precompiled programs in distribution repositories, some distributions may not include all the desired applications. In this case, the only way to get the desired program is to compile it from source.
- **Timeliness**. While some distributions specialize in cutting-edge versions of programs, many do not. This means that to have the latest version of a program, compiling is necessary.

Compiling software from source code can become quite complex and technical and well beyond the reach of many users. However, many compiling tasks are easy and involve only a few steps. It all depends on the package. We will look at a very simple case to provide an overview of the process and as a starting point for those who want to undertake further study.

We will introduce one new command.

`make` Utility to maintain programs

## What Is Compiling?

Simply put, compiling is the process of translating *source code* (the human-readable description of a program written by a programmer) into the native language of the computer's processor.

The computer's processor (or *CPU*) works at an elemental level, executing programs in what is called *machine language*. This is a numeric code that describes extremely small operations, such as "add this byte," "point to this location in memory," or "copy this byte." Each of these instructions is expressed in binary (ones and zeros). The earliest computer programs were written using this numeric code, which may explain why programmers who wrote it were said to smoke a lot, drink gallons of coffee, and wear thick glasses.

This problem was overcome by the advent of *assembly language*, which replaced the numeric codes with (slightly) easier-to-use character *mnemonics* such as CPY (for copy) and MOV (for move). Programs written in assembly language are processed into machine language by a program called an *assembler*. Assembly language is still used today for certain specialized programming tasks, such as *device drivers* and *embedded systems*.

We next come to what are called *high-level programming languages*, which allow the programmer to be less concerned with the details of what the processor is doing and more with solving the problem at hand. The early ones (developed during the 1950s) include *FORTRAN* (designed for scientific and technical tasks) and *COBOL* (designed for business applications). Both are still in limited use today.

While there are many popular programming languages, two predominate. Most programs written for modern systems are written in either C or C++. In the examples to follow, we will be compiling a C program.

Programs written in high-level programming languages are converted into machine language by processing them with another program, called a *compiler*. Some compilers translate high-level instructions into assembly language and then use an assembler to perform the final stage of translation into machine language.

A process often used in conjunction with compiling is called *linking*. There are many common tasks performed by programs. Take, for instance, opening a file. Many programs perform this task, but it would be wasteful to have each program implement its own routine to open files. It makes more sense to have a single piece of programming that knows how to open files and to allow all programs that need it to share it. Providing support for common tasks is accomplished by what are called *libraries*. They contain multiple *routines*, each performing some common task that multiple programs can share. If we look in the */lib* and */usr/lib* directories, we can see where many of them live. A program called a *linker* is used to form the connections between the output of the compiler and the libraries that the compiled program requires. The final result of this process is the *executable program file*, ready for use.

### Are All Programs Compiled?

No. As we have seen, there are programs such as shell scripts that do not require compiling. They are executed directly. These are written in what are known as *scripting* or *interpreted* languages. These languages have grown in popularity in recent years and include Perl, Python, PHP, Ruby, and many others.

Scripted languages are executed by a special program called an *interpreter*. An interpreter inputs the program file and reads and executes each instruction contained within it. In general, interpreted programs execute much more slowly than compiled programs. This is because each source code instruction in an interpreted program is translated every time it is carried out, whereas with a compiled program, a source code instruction is translated only once, and this translation is permanently recorded in the final executable file.

Why are interpreted languages so popular? For many programming chores, the results are "fast enough," but the real advantage is that it is generally faster and easier to develop interpreted programs than compiled programs. Programs are usually developed in a repeating cycle of code, compile, test. As a program grows in size, the compilation phase of the cycle can become quite long. Interpreted languages remove the compilation step and thus speed up program development.

## Compiling a C Program

Let's compile something. Before we do that, however, we're going to need some tools like the compiler, the linker, and `make`. The C compiler used almost universally in the Linux environment is called `gcc` (GNU C Compiler),

originally written by Richard Stallman. Most distributions do not install gcc by default. We can check to see whether the compiler is present like this:

```
[me@linuxbox ~]$ which gcc
/usr/bin/gcc
```

The results in this example indicate that the compiler is installed.

**TIP** *Your distribution may have a meta-package (a collection of packages) for software development. If so, consider installing it if you intend to compile programs on your system. If your system does not provide a meta-package, try installing the* gcc *and* make *packages. On many distributions, this is sufficient to carry out the following exercise.*

## Obtaining the Source Code

For our compiling exercise, we are going to compile a program from the GNU Project called diction. This handy little program checks text files for writing quality and style. As programs go, it is fairly small and easy to build.

Following convention, we're first going to create a directory for our source code named *src* and then download the source code into it using ftp.

```
[me@linuxbox ~]$ mkdir src
[me@linuxbox ~]$ cd src
[me@linuxbox src]$ ftp ftp.gnu.org
Connected to ftp.gnu.org.
220 GNU FTP server ready.
Name (ftp.gnu.org:me): anonymous
230 Login successful.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> cd gnu/diction
250 Directory successfully changed.
ftp> ls
200 PORT command successful. Consider using PASV.
150 Here comes the directory listing.
-rw-r--r--    1 1003  65534   68940 Aug 28  1998 diction-0.7.tar.gz
-rw-r--r--    1 1003  65534   90957 Mar 04  2002 diction-1.02.tar.gz
-rw-r--r--    1 1003  65534  141062 Sep 17  2007 diction-1.11.tar.gz
226 Directory send OK.
ftp> get diction-1.11.tar.gz
local: diction-1.11.tar.gz remote: diction-1.11.tar.gz
200 PORT command successful. Consider using PASV.
150 Opening BINARY mode data connection for diction-1.11.tar.gz (141062
bytes).
226 File send OK.
141062 bytes received in 0.16 secs (847.4 kB/s)
ftp> bye
221 Goodbye.
[me@linuxbox src]$ ls
diction-1.11.tar.gz
```

While we used ftp in the previous example, which is traditional, there are other ways of downloading source code. For example, the GNU Project also supports downloading using HTTPS. We can download the diction source code using the wget program.

```
[me@linuxbox src]$ wget https://ftp.gnu.org/gnu/diction/diction-1.11.tar.gz
--2018-07-25 09:42:20--  https://ftp.gnu.org/gnu/diction/diction-1.11.tar.gz
Resolving ftp.gnu.org (ftp.gnu.org)... 208.118.235.20, 2001:4830:134:3::b
Connecting to ftp.gnu.org (ftp.gnu.org)|208.118.235.20|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 141062 (138K) [application/x-gzip]
Saving to: 'diction-1.11.tar.gz'
diction-1.11.tar.gz 100%[===================>] 137.76K
--.-KB/s in 0.09s

2018-07-25 09:42:20 (1.43 MB/s) - 'diction-1.11.tar.gz.1' saved [141062/141062]
```

**NOTE** *Because we are the "maintainer" of this source code while we compile it, we will keep it in ~/*src*. Source code installed by your distribution will be installed in /*usr/src*, while source code we maintain that's intended for use by multiple users is usually installed in /*usr/local/src*.*

As we can see, source code is usually supplied in the form of a compressed tar file. Sometimes called a *tarball*, this file contains the *source tree*, or hierarchy of directories and files that comprise the source code. After arriving at the FTP site, we examine the list of tar files available and select the newest version for download. Using the get command within ftp, we copy the file from the FTP server to the local machine.

Once the tar file is downloaded, it must be unpacked. This is done with the tar program.

```
[me@linuxbox src]$ tar xzf diction-1.11.tar.gz
[me@linuxbox src]$ ls
diction-1.11        diction-1.11.tar.gz
```

**TIP** *The diction program, like all GNU Project software, follows certain standards for source code packaging. Most other source code available in the Linux ecosystem also follows this standard. One element of the standard is that when the source code tar file is unpacked, a directory will be created that contains the source tree, and this directory will be named* project-x.xx*, thus containing both the project's name and its version number. This scheme allows easy installation of multiple versions of the same program. However, it is often a good idea to examine the layout of the tree before unpacking it. Some projects will not create the directory but instead will deliver the files directly into the current directory. This will make a mess in our otherwise well-organized* src *directory. To avoid this, use the following command to examine the contents of the tar file:*

```
tar tzvf tarfile | head
```

### *Examining the Source Tree*

Unpacking the tar file results in the creation of a new directory, named *diction-1.11*. This directory contains the source tree. Let's look inside.

```
[me@linuxbox src]$ cd diction-1.11
[me@linuxbox diction-1.11]$ ls
config.guess  diction.c        getopt.c      nl
config.h.in   diction.pot      getopt.h      nl.po
config.sub    diction.spec     getopt_int.h  README
configure     diction.spec.in  INSTALL       sentence.c
configure.in  diction.texi.in  install-sh    sentence.h
COPYING       en               Makefile.in   style.1.in
de            en_GB            misc.c        style.c
de.po         en_GB.po         misc.h        test
diction.1.in  getopt1.c        NEWS
```

In it, we see a number of files. Programs belonging to the GNU Project, and many others, will supply the documentation files *README*, *INSTALL*, *NEWS*, and *COPYING*. These files contain the description of the program, information on how to build and install it, and its licensing terms. It is always a good idea to carefully read the *README* and *INSTALL* files before attempting to build the program.

The other interesting files in this directory are the ones ending with *.c* and *.h*.

```
[me@linuxbox diction-1.11]$ ls *.c
diction.c  getopt1.c  getopt.c  misc.c  sentence.c  style.c
[me@linuxbox diction-1.11]$ ls *.h
getopt.h  getopt_int.h  misc.h  sentence.h
```

The *.c* files contain the two C programs supplied by the package (`style` and `diction`), divided into modules. It is common practice for large programs to be broken into smaller, easier-to-manage pieces. The source code files are ordinary text and can be examined with `less`.

```
[me@linuxbox diction-1.11]$ less diction.c
```

The *.h* files are known as *header files*. These, too, are ordinary text. Header files contain descriptions of the routines included in a source code file or library. For the compiler to connect the modules, it must receive a description of all the modules needed to complete the entire program. Near the beginning of the *diction.c* file, we see this line:

```
#include "getopt.h"
```

This instructs the compiler to read the file *getopt.h* as it reads the source code in *diction.c* to "know" what's in *getopt.c*. The *getopt.c* file supplies routines that are shared by both the `style` and `diction` programs.

Before the include statement for *getopt.h*, we see some other include statements such as these:

```
#include <regex.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <unistd.h>
```

These also refer to header files, but they refer to header files that live outside the current source tree. They are supplied by the system to support the compilation of every program. If we look in */usr/include*, we can see them.

```
[me@linuxbox diction-1.11]$ ls /usr/include
```

The header files in this directory were installed when we installed the compiler.

### Building the Program

Most programs build with a simple, two-command sequence.

```
./configure
make
```

The `configure` program is a shell script that is supplied with the source tree. Its job is to analyze the *build environment*. Most source code is designed to be *portable*. That is, it is designed to build on more than one kind of Unix-like system. But to do that, the source code may need to undergo slight adjustments during the build to accommodate differences between systems. `configure` also checks to see that necessary external tools and components are installed.

Let's run `configure`. Because `configure` is not located where the shell normally expects programs to be located, we must explicitly tell the shell its location by prefixing the command with `./` to indicate that the program is located in the current working directory.

```
[me@linuxbox diction-1.11]$ ./configure
```

`configure` will output a lot of messages as it tests and configures the build. When it finishes, it will look something like this:

```
checking libintl.h presence... yes
checking for libintl.h... yes
checking for library containing gettext... none required
configure: creating ./config.status
config.status: creating Makefile
config.status: creating diction.1
config.status: creating diction.texi
config.status: creating diction.spec
```

```
config.status: creating style.1
config.status: creating test/rundiction
config.status: creating config.h
[me@linuxbox diction-1.11]$
```

What's important here is that there are no error messages. If there were, the configuration failed, and the program will not build until the errors are corrected.

We see `configure` created several *new* files in our source directory. The most important one is the *makefile*. The makefile is a configuration file that instructs the `make` program exactly how to build the program. Without it, `make` will refuse to run. The makefile is an ordinary text file, so we can view it.

```
[me@linuxbox diction-1.11]$ less Makefile
```

The `make` program takes as input a makefile (which is normally named *Makefile*), which describes the relationships and dependencies among the components that comprise the finished program.

The first part of the makefile defines variables that are substituted in later sections of the makefile. For example we see the following line:

```
CC=             gcc
```

This defines the C compiler to be `gcc`. Later in the makefile, we see one instance where it gets used.

```
diction:        diction.o sentence.o misc.o getopt.o getopt1.o
                $(CC) -o $@ $(LDFLAGS) diction.o sentence.o misc.o \
                getopt.o getopt1.o $(LIBS)
```

A substitution is performed here, and the value `$(CC)` is replaced by `gcc` at runtime.

Most of the makefile consists of lines that define a *target*—in this case, the executable file *diction* and the files on which it is dependent. The remaining lines describe the commands needed to create the target from its components. We see in this example that the executable file *diction* (one of the end products) depends on the existence of *diction.o*, *sentence.o*, *misc.o*, *getopt.o*, and *getopt1.o*. Later, in the makefile, we see definitions of each of these as targets.

```
diction.o:      diction.c config.h getopt.h misc.h sentence.h
getopt.o:       getopt.c getopt.h getopt_int.h
getopt1.o:      getopt1.c getopt.h getopt_int.h
misc.o:         misc.c config.h misc.h
sentence.o:     sentence.c config.h misc.h sentence.h
style.o:        style.c config.h getopt.h misc.h sentence.h
```

However, we don't see any command specified for them. This is handled by a general target, earlier in the file, that describes the command used to compile any *.c* file into an *.o* file.

```
.c.o:
                $(CC) -c $(CPPFLAGS) $(CFLAGS) $<
```

This all seems very complicated. Why not simply list all the steps to compile the parts and be done with it? The answer to this will become clear in a moment. In the meantime, let's run make and build our programs.

```
[me@linuxbox diction-1.11]$ make
```

The make program will run, using the contents of *Makefile* to guide its actions. It will produce a lot of messages.

When it finishes, we will see that all the targets are now present in our directory.

```
[me@linuxbox diction-1.11]$ ls
config.guess   de.po            en            install-sh   sentence.c
config.h       diction          en_GB         Makefile     sentence.h
config.h.in    diction.1        en_GB.mo      Makefile.in  sentence.o
config.log     diction.1.in     en_GB.po      misc.c       style
config.status  diction.c        getopt1.c     misc.h       style.1
config.sub     diction.o        getopt1.o     misc.o       style.1.in
configure      diction.pot      getopt.c      NEWS         style.c
configure.in   diction.spec     getopt.h      nl           style.o
COPYING        diction.spec.in  getopt_int.h  nl.mo        test
de             diction.texi     getopt.o      nl.po
de.mo          diction.texi.in  INSTALL       README
```

Among the files, we see diction and style, the programs that we set out to build. Congratulations are in order! We just compiled our first programs from source code!

But just out of curiosity, let's run make again.

```
[me@linuxbox diction-1.11]$ make
make: Nothing to be done for `all'.
```

It only produces this strange message. What's going on? Why didn't it build the program again? Ah, this is the magic of make. Rather than simply building everything again, make only builds what needs building. With all of the targets present, make determined that there was nothing to do. We can demonstrate this by deleting one of the targets and running make again to see what it does. Let's get rid of one of the intermediate targets.

```
[me@linuxbox diction-1.11]$ rm getopt.o
[me@linuxbox diction-1.11]$ make
```

We see that make rebuilds it and relinks the diction and style programs because they depend on the missing module. This behavior also points out another important feature of make: it keeps targets up-to-date. make insists

that targets be newer than their dependencies. This makes perfect sense because a programmer will often update a bit of source code and then use make to build a new version of the finished product. make ensures that everything that needs building based on the updated code is built. If we use the touch program to "update" one of the source code files, we can see this happen:

```
[me@linuxbox diction-1.11]$ ls -l diction getopt.c
-rwxr-xr-x 1 me      me      37164 2009-03-05 06:14 diction
-rw-r--r-- 1 me      me      33125 2007-03-30 17:45 getopt.c
[me@linuxbox diction-1.11]$ touch getopt.c
[me@linuxbox diction-1.11]$ ls -l diction getopt.c
-rwxr-xr-x 1 me      me      37164 2009-03-05 06:14 diction
-rw-r--r-- 1 me      me      33125 2009-03-05 06:23 getopt.c
[me@linuxbox diction-1.11]$ make
```

After make runs, we see that it has restored the target to being newer than the dependency.

```
[me@linuxbox diction-1.11]$ ls -l diction getopt.c
-rwxr-xr-x 1 me      me      37164 2009-03-05 06:24 diction
-rw-r--r-- 1 me      me      33125 2009-03-05 06:23 getopt.c
```

The ability of make to intelligently build only what needs building is a great benefit to programmers. While the time savings may not be apparent with our small project, it is very significant with larger projects. Remember, the Linux kernel (a program that undergoes continuous modification and improvement) contains several *million* lines of code.

### Installing the Program

Well-packaged source code will often include a special make target called install. This target will install the final product in a system directory for use. Usually, this directory is */usr/local/bin*, the traditional location for locally built software. However, this directory is not normally writable by ordinary users, so we must become the superuser to perform the installation.

```
[me@linuxbox diction-1.11]$ sudo make install
```

After we perform the installation, we can check that the program is ready to go.

```
[me@linuxbox diction-1.11]$ which diction
/usr/local/bin/diction
[me@linuxbox diction-1.11]$ man diction
```

There we have it!

## Summing Up

In this chapter, we saw how three simple commands—`./configure`, `make`, and `make install`—can be used to build many source code packages. We also saw the important role that `make` plays in the maintenance of programs. The `make` program can be used for any task that needs to maintain a target/dependency relationship, not just for compiling source code.

# PART IV

## WRITING SHELL SCRIPTS

# 24

# WRITING YOUR FIRST SCRIPT

In the preceding chapters, we assembled an arsenal of command line tools. While these tools can solve many kinds of computing problems, we are still limited to manually using them one by one on the command line. Wouldn't it be great if we could get the shell to do more of the work? We can! By joining our tools together into programs of our own design, the shell can carry out complex sequences of tasks all by itself. We can enable it to do this by writing *shell scripts*.

## What Are Shell Scripts?

In the simplest terms, a shell script is a file containing a series of commands. The shell reads this file and carries out the commands as though they have been entered directly on the command line.

The shell is somewhat unique, in that it is both a powerful command line interface to the system and a scripting language interpreter. As we will

see, most of the things that can be done on the command line can be done in scripts, and most of the things that can be done in scripts can be done on the command line.

We have covered many shell features, but we have focused on those features most often used directly on the command line. The shell also provides a set of features usually (but not always) used when writing programs.

## How to Write a Shell Script

To successfully create and run a shell script, we need to do three things.

1. **Write a script**. Shell scripts are ordinary text files. So, we need a text editor to write them. The best text editors will provide *syntax highlighting*, allowing us to see a color-coded view of the elements of the script. Syntax highlighting will help us spot certain kinds of common errors. `vim`, `gedit`, `kate`, and many other editors are good candidates for writing scripts.
2. **Make the script executable**. The system is rather fussy about not letting any old text file be treated as a program, and for good reason! We need to set the script file's permissions to allow execution.
3. **Put the script somewhere the shell can find it**. The shell automatically searches certain directories for executable files when no explicit pathname is specified. For maximum convenience, we will place our scripts in these directories.

### *Script File Format*

In keeping with programming tradition, we'll create a "Hello World" program to demonstrate an extremely simple script. Let's fire up our text editors and enter the following script:

```
#!/bin/bash

# This is our first script.

echo 'Hello World!'
```

The last line of our script is pretty familiar; it's just an `echo` command with a string argument. The second line is also familiar. It looks like a comment that we have seen used in many of the configuration files we have examined and edited. One thing about comments in shell scripts is that they may also appear at the ends of lines provided they are preceded by at least one whitespace character, like so:

```
echo 'Hello World!' # This is a comment too
```

Everything from the # symbol onward on the line is ignored.

Like many things, this works on the command line, too.

```
[me@linuxbox ~]$ echo 'Hello World!' # This is a comment too
Hello World!
```

Though comments are of little use on the command line, they will work.

The first line of our script is a little mysterious. It looks as if it should be a comment since it starts with #, but it looks too purposeful to be just that. The #! character sequence is, in fact, a special construct called a *shebang*. The shebang is used to tell the kernel the name of the interpreter that should be used to execute the script that follows. Every shell script should include this as its first line.

Let's save our script file as *hello_world*.

### Executable Permissions

The next thing we have to do is make our script executable. This is easily done using chmod.

```
[me@linuxbox ~]$ ls -l hello_world
-rw-r--r-- 1 me      me      63 2018-03-07 10:10 hello_world
[me@linuxbox ~]$ chmod 755 hello_world
[me@linuxbox ~]$ ls -l hello_world
-rwxr-xr-x 1 me      me      63 2018-03-07 10:10 hello_world
```

There are two common permission settings for scripts: 755 for scripts that everyone can execute and 700 for scripts that only the owner can execute. Note that scripts must be readable to be executed.

### Script File Location

With the permissions set, we can now execute our script.

```
[me@linuxbox ~]$ ./hello_world
Hello World!
```

For the script to run, we must precede the script name with an explicit path. If we don't, we get this:

```
[me@linuxbox ~]$ hello_world
bash: hello_world: command not found
```

Why is this? What makes our script different from other programs? As it turns out, nothing. Our script is fine. Its location is the problem. In Chapter 11, we discussed the PATH environment variable and its effect on how the system searches for executable programs. To recap, the system searches a list of directories each time it needs to find an executable program, if no explicit path is specified. This is how the system knows to execute */bin/ls* when we type ls at the command line. The */bin* directory is one of the directories that the system automatically searches. The list of directories is held within an environment variable named PATH. The PATH

variable contains a colon-separated list of directories to be searched. We can view the contents of PATH.

```
[me@linuxbox ~]$ echo $PATH
/home/me/bin:/usr/local/sbin:/usr/local/bin:/usr/sbin:/usr/bin:/sbin:/bin:/usr/games
```

Here we see our list of directories. If our script were located in any of the directories in the list, our problem would be solved. Notice the first directory in the list, */home/me/bin*. Most Linux distributions configure the PATH variable to contain a *bin* directory in the user's home directory to allow users to execute their own programs. So, if we create the *bin* directory and place our script within it, it should start to work like other programs.

```
[me@linuxbox ~]$ mkdir bin
[me@linuxbox ~]$ mv hello_world bin
[me@linuxbox ~]$ hello_world
Hello World!
```

And so it does.

If the PATH variable does not contain the directory, we can easily add it by including this line in our *.bashrc* file:

```
export PATH=~/bin:"$PATH"
```

After this change is made, it will take effect in each new terminal session. To apply the change to the current terminal session, we must have the shell reread the *.bashrc* file. This can be done by "sourcing" it.

```
[me@linuxbox ~]$ . .bashrc
```

The dot (.) command is a synonym for the source command, a shell builtin that reads a specified file of shell commands and treats it like input from the keyboard.

**NOTE** *Ubuntu (and most other Debian-based distributions) automatically adds the ~/*bin *directory to the* PATH *variable if the ~/*bin *directory exists when the user's* .bashrc *file is executed. So, on Ubuntu systems, if we create the ~/*bin *directory and then log out and log in again, everything works.*

## Good Locations for Scripts

The *~/bin* directory is a good place to put scripts intended for personal use. If we write a script that everyone on a system is allowed to use, the traditional location is */usr/local/bin*. Scripts intended for use by the system administrator are often located in */usr/local/sbin*. In most cases, locally supplied software, whether scripts or compiled programs, should be placed in the */usr/local* hierarchy and not in */bin* or */usr/bin*. These directories are specified by the Linux Filesystem Hierarchy Standard to contain only files supplied and maintained by the Linux distributor.

## More Formatting Tricks

One of the key goals of serious script writing is ease of maintenance; that is, the ease with which a script may be modified by its author or others to adapt it to changing needs. Making a script easy to read and understand is one way to facilitate easy maintenance.

### *Long Option Names*

Many of the commands we have studied feature both short and long option names. For instance, the `ls` command has many options that can be expressed in either short or long form. For example, the following:

```
[me@linuxbox ~]$ ls -ad
```

is equivalent to this:

```
[me@linuxbox ~]$ ls --all --directory
```

In the interests of reduced typing, short options are preferred when entering options on the command line, but when writing scripts, long options can provide improved readability.

### *Indentation and Line Continuation*

When employing long commands, readability can be enhanced by spreading the command over several lines. In Chapter 17, we looked at a particularly long example of the `find` command.

```
[me@linuxbox ~]$ find playground \( -type f -not -perm 0600 -exec
chmod 0600 '{}' ';' \) -or \( -type d -not -perm 0700 -exec chmod
0700 '{}' ';' \)
```

Obviously, this command is a little hard to figure out at first glance. In a script, this command might be easier to understand if written this way:

```
find playground \
     \( \
          -type f \
          -not -perm 0600 \
          -exec chmod 0600 '{}' ';' \
     \) \
     -or \
     \( \
          -type d \
          -not -perm 0700 \
          -exec chmod 0700 '{}' ';' \
     \)
```

By using line continuations (backslash-linefeed sequences) and indentation, the logic of this complex command is more clearly described to the reader. This technique works on the command line, though it is seldom used,

as it is awkward to type and edit. One difference between a script and a command line is that the script may employ tab characters to achieve indentation, whereas the command line cannot since tabs are used to activate completion.

### CONFIGURING VIM FOR SCRIPT WRITING

The `vim` text editor has many, many configuration settings. There are several common options that can facilitate script writing.

The following turns on syntax highlighting:

```
:syntax on
```

With this setting, different elements of shell syntax will be displayed in different colors when viewing a script. This is helpful for identifying certain kinds of programming errors. It looks cool, too. Note that for this feature to work, you must have a complete version of `vim` installed, and the file you are editing must have a shebang indicating the file is a shell script. If you have difficulty with the previous command, try **`:set syntax=sh`** instead.

This turns on the option to highlight search results:

```
:set hlsearch
```

Say we search for the word *echo*. With this option on, each instance of the word will be highlighted.

The following sets the number of columns occupied by a tab character:

```
:set tabstop=4
```

The default is eight columns. Setting the value to 4 (which is a common practice) allows long lines to fit more easily on the screen.

The following turns on the "auto indent" feature:

```
:set autoindent
```

This causes `vim` to indent a new line the same amount as the line just typed. This speeds up typing on many kinds of programming constructs. To stop indentation, press CTRL-D.

These changes can be made permanent by adding these commands (without the leading colon characters) to your *~/.vimrc* file.

## Summing Up

In this first chapter of scripting, we looked at how scripts are written and made to easily execute on our system. We also saw how we can use various formatting techniques to improve the readability (and thus the maintainability) of our scripts. In future chapters, ease of maintenance will come up again and again as a central principle in good script writing.

# 25

## STARTING A PROJECT

Starting with this chapter, we will begin to build a program. The purpose of this project is to see how various shell features are used to create programs and, more importantly, create *good* programs.

The program we will write is a *report generator*. It will present various statistics about our system and its status and will produce this report in HTML format so we can view it with a web browser such as Firefox or Chrome.

Programs are usually built up in a series of stages, with each stage adding features and capabilities. The first stage of our program will produce a minimal HTML document that contains no system information. That will come later.

## First Stage: Minimal Document

The first thing we need to know is the format of a well-formed HTML document. It looks like this:

```
<html>
      <head>
            <title>Page Title</title>
      </head>
      <body>
            Page body.
      </body>
</html>
```

If we enter this into our text editor and save the file as *foo.html*, we can use the following URL in Firefox to view the file: *file:///home/username/foo.html*.

The first stage of our program will be able to output this HTML file to standard output. We can write a program to do this pretty easily. Let's start our text editor and create a new file named *~/bin/sys_info_page*.

```
[me@linuxbox ~]$ vim ~/bin/sys_info_page
```

Enter the following program:

```
#!/bin/bash

# Program to output a system information page

echo "<html>"
echo "     <head>"
echo "          <title>Page Title</title>"
echo "     </head>"
echo "     <body>"
echo "          Page body."
echo "     </body>"
echo "</html>"
```

Our first attempt at this problem contains a shebang, a comment (always a good idea), and a sequence of `echo` commands, one for each line of output. After saving the file, we'll make it executable and attempt to run it.

```
[me@linuxbox ~]$ chmod 755 ~/bin/sys_info_page
[me@linuxbox ~]$ sys_info_page
```

When the program runs, we should see the text of the HTML document displayed on the screen, because the `echo` commands in the script send their output to standard output. We'll run the program again and redirect the output of the program to the file *sys_info_page.html* so that we can view the result with a web browser.

```
[me@linuxbox ~]$ sys_info_page > sys_info_page.html
[me@linuxbox ~]$ firefox sys_info_page.html
```

So far, so good.

When writing programs, it's always a good idea to strive for simplicity and clarity. Maintenance is easier when a program is easy to read and understand, not to mention that it can make the program easier to write by reducing the amount of typing. Our current version of the program works fine, but it could be simpler. We could actually combine all the `echo` commands into one, which will certainly make it easier to add more lines to the program's output. So, let's change our program to this:

```
#!/bin/bash

# Program to output a system information page

echo "<html>
     <head>
          <title>Page Title</title>
     </head>
     <body>
          Page body.
     </body>
</html>"
```

A quoted string may include newlines and, therefore, contain multiple lines of text. The shell will keep reading the text until it encounters the closing quotation mark. It works this way on the command line, too:

```
[me@linuxbox ~]$ echo "<html>
>         <head>
>                 <title>Page Title</title>
>         </head>
>         <body>
>                 Page body.
>         </body>
> </html>"
```

The leading > character is the shell prompt contained in the `PS2` shell variable. It appears whenever we type a multiline statement into the shell. This feature is a little obscure right now, but later, when we cover multiline programming statements, it will turn out to be quite handy.

## Second Stage: Adding a Little Data

Now that our program can generate a minimal document, let's put some data in the report. To do this, we will make the following changes:

```
#!/bin/bash

# Program to output a system information page

echo "<html>
        <head>
```

```
                <title>System Information Report</title>
        </head>
        <body>
                <h1>System Information Report</h1>
        </body>
</html>"
```

We added a page title and a heading to the body of the report.

## Variables and Constants

There is an issue with our script, however. Notice how the string `System Information Report` is repeated? With our tiny script it's not a problem, but let's imagine that our script was really long and we had multiple instances of this string. If we wanted to change the title to something else, we would have to change it in multiple places, which could be a lot of work. What if we could arrange the script so that the string appeared only once and not multiple times? That would make future maintenance of the script much easier. Here's how we could do that:

```
#!/bin/bash

# Program to output a system information page

title="System Information Report"

echo "<html>
        <head>
                <title>$title</title>
        </head>
        <body>
                <h1>$title</h1>
        </body>
</html>"
```

By creating a *variable* named `title` and assigning it the value `System Information Report`, we can take advantage of parameter expansion and place the string in multiple locations.

So, how do we create a variable? Simple, we just use it. When the shell encounters a variable, it automatically creates it. This differs from many programming languages in which variables must be explicitly *declared* or defined before use. The shell is very lax about this, which can lead to some problems. For example, consider this scenario played out on the command line:

```
[me@linuxbox ~]$ foo="yes"
[me@linuxbox ~]$ echo $foo
yes
[me@linuxbox ~]$ echo $fool

[me@linuxbox ~]$
```

We first assign the value yes to the variable foo, and then we display its value with echo. Next we display the value of the variable name misspelled as fool and get a blank result. This is because the shell happily created the variable fool when it encountered it and gave it the default value of nothing, or empty. From this, we learn that we must pay close attention to our spelling! It's also important to understand what really happened in this example. From our previous look at how the shell performs expansions, we know that the following command:

```
[me@linuxbox ~]$ echo $foo
```

undergoes parameter expansion and results in the following:

```
[me@linuxbox ~]$ echo yes
```

By contrast, the following command:

```
[me@linuxbox ~]$ echo $fool
```

expands into this:

```
[me@linuxbox ~]$ echo
```

The empty variable expands into nothing! This can play havoc with commands that require arguments. Here's an example:

```
[me@linuxbox ~]$ foo=foo.txt
[me@linuxbox ~]$ foo1=foo1.txt
[me@linuxbox ~]$ cp $foo $fool
cp: missing destination file operand after `foo.txt'
Try `cp --help' for more information.
```

We assign values to two variables, foo and foo1. We then perform a cp but misspell the name of the second argument. After expansion, the cp command is sent only one argument, though it requires two.

There are some rules about variable names:

- Variable names may consist of alphanumeric characters (letters and numbers) and underscore characters.
- The first character of a variable name must be either a letter or an underscore.
- Spaces and punctuation symbols are not allowed.

The word *variable* implies a value that changes, and in many applications, variables are used this way. However, the variable in our application, title, is used as a *constant*. A constant is just like a variable in that it has a name and contains a value. The difference is that the value of a constant does not change. In an application that performs geometric calculations, we might define PI as a constant and assign it the value of 3.1415, instead of using the

number literally throughout our program. The shell makes no distinction between variables and constants; they are mostly for the programmer's convenience. A common convention is to use uppercase letters to designate constants and lowercase letters for true variables. We will modify our script to comply with this convention:

```
#!/bin/bash

# Program to output a system information page

TITLE="System Information Report For $HOSTNAME"

echo "<html>
        <head>
                <title>$TITLE</title>
        </head>
        <body>
                <h1>$TITLE</h1>
        </body>
</html>"
```

We also took the opportunity to jazz up our title by adding the value of the shell variable `HOSTNAME`. This is the network name of the machine.

**NOTE** *The shell actually does provide a way to enforce the immutability of constants, through the use of the `declare` built-in command with the `-r` (read-only) option. Had we assigned `TITLE` this way:*

```
declare -r TITLE="Page Title"
```

*the shell would prevent any subsequent assignment to `TITLE`. This feature is rarely used, but it exists for very formal scripts.*

## Assigning Values to Variables and Constants

Here is where our knowledge of expansion really starts to pay off. As we have seen, variables are assigned values this way:

```
variable=value
```

where *`variable`* is the name of the variable and *`value`* is a string. Unlike some other programming languages, the shell does not care about the type of data assigned to a variable; it treats them all as strings. You can force the shell to restrict the assignment to integers by using the `declare` command with the `-i` option, but, like setting variables as read-only, this is rarely done.

Note that in an assignment, there must be no spaces between the variable name, the equal sign, and the value. So, what can the value consist of? It can have anything that we can expand into a string.

```
a=z                     # Assign the string "z" to variable a.
b="a string"            # Embedded spaces must be within quotes.
```

```
c="a string and $b"     # Other expansions such as variables can be
                        # expanded into the assignment.
d="$(ls -l foo.txt)"    # Results of a command.
e=$((5 * 7))            # Arithmetic expansion.
f="\t\ta string\n"      # Escape sequences such as tabs and newlines.
```

Multiple variable assignments may be done on a single line.

```
a=5 b="a string"
```

During expansion, variable names may be surrounded by optional braces, {}. This is useful in cases where a variable name becomes ambiguous because of its surrounding context. Here, we try to change the name of a file from *myfile* to *myfile1*, using a variable:

```
[me@linuxbox ~]$ filename="myfile"
[me@linuxbox ~]$ touch "$filename"
[me@linuxbox ~]$ mv "$filename" "$filename1"
mv: missing destination file operand after `myfile'
Try `mv --help' for more information.
```

This attempt fails because the shell interprets the second argument of the `mv` command as a new (and empty) variable. The problem can be overcome this way:

```
[me@linuxbox ~]$ mv "$filename" "${filename}1"
```

By adding the surrounding braces, the shell no longer interprets the trailing `1` as part of the variable name.

**NOTE** *It's good practice is to enclose variables and command substitutions in double quotes to limit the effects of word-splitting by the shell. Quoting is especially important when a variable might contain a filename.*

We'll take this opportunity to add some data to our report: namely, the date and time the report was created and the username of the creator.

```
#!/bin/bash

# Program to output a system information page

TITLE="System Information Report For $HOSTNAME"
CURRENT_TIME="$(date +"%x %r %Z")"
TIMESTAMP="Generated $CURRENT_TIME, by $USER"

echo "<html>
        <head>
                <title>$TITLE</title>
        </head>
        <body>
                <h1>$TITLE</h1>
```

```
                <p>$TIMESTAMP</p>
        </body>
</html>"
```

## Here Documents

We've looked at two different methods of outputting our text, both using the `echo` command. There is a third way called a *here document* or *here script*. A here document is an additional form of I/O redirection in which we embed a body of text into our script and feed it into the standard input of a command. It works like this:

```
command << token
text
token
```

where *command* is the name of command that accepts standard input and *token* is a string used to indicate the end of the embedded text. Here we'll modify our script to use a here document:

```
#!/bin/bash

# Program to output a system information page

TITLE="System Information Report For $HOSTNAME"
CURRENT_TIME="$(date +"%x %r %Z")"
TIMESTAMP="Generated $CURRENT_TIME, by $USER"

cat << _EOF_
<html>
        <head>
                <title>$TITLE</title>
        </head>
        <body>
                <h1>$TITLE</h1>
                <p>$TIMESTAMP</p>
        </body>
</html>
_EOF_
```

Instead of using `echo`, our script now uses `cat` and a here document. The string `_EOF_` (meaning *end of file*, a common convention) was selected as the token and marks the end of the embedded text. Note that the token must appear alone and that there must not be trailing spaces on the line.

So, what's the advantage of using a here document? It's mostly the same as `echo`, except that, by default, single and double quotes within here documents lose their special meaning to the shell. Here is a command line example:

```
[me@linuxbox ~]$ foo="some text"
[me@linuxbox ~]$ cat << _EOF_
```

```
> $foo
> "$foo"
> '$foo'
> \$foo
> _EOF_
some text
"some text"
'some text'
$foo
```

As we can see, the shell pays no attention to the quotation marks. It treats them as ordinary characters. This allows us to embed quotes freely within a here document. This could turn out to be handy for our report program.

Here documents can be used with any command that accepts standard input. In this example, we use a here document to pass a series of commands to the `ftp` program to retrieve a file from a remote FTP server:

```
#!/bin/bash

# Script to retrieve a file via FTP

FTP_SERVER=ftp.nl.debian.org FTP_PATH=/debian/dists/stretch/main/installer-
amd64/current/images/cdrom REMOTE_FILE=debian-cd_info.tar.gz

ftp -n << _EOF_
open $FTP_SERVER
user anonymous me@linuxbox
cd $FTP_PATH
hash
get $REMOTE_FILE
bye
_EOF_
ls -l "$REMOTE_FILE"
```

If we change the redirection operator from `<<` to `<<-`, the shell will ignore leading tab characters (but not spaces) in the here document. This allows a here document to be indented, which can improve readability.

```
#!/bin/bash

# Script to retrieve a file via FTP

FTP_SERVER=ftp.nl.debian.org
FTP_PATH=/debian/dists/stretch/main/installer-amd64/current/images/cdrom
REMOTE_FILE=debian-cd_info.tar.gz

ftp -n <<- _EOF_
      open $FTP_SERVER
      user anonymous me@linuxbox
      cd $FTP_PATH
      hash
      get $REMOTE_FILE
```

```
    bye
    _EOF_

ls -l "$REMOTE_FILE"
```

This feature can be somewhat problematic because many text editors (and programmers themselves) will prefer to use spaces instead of tabs to achieve indentation in their scripts.

## Summing Up

In this chapter, we started a project that will carry us through the process of building a successful script. We introduced the concept of variables and constants and how they can be employed. They are the first of many applications we will find for parameter expansion. We also looked at how to produce output from our script and various methods for embedding blocks of text.

# 26

## TOP-DOWN DESIGN

As programs get larger and more complex, they become more difficult to design, code, and maintain. As with any large project, it is often a good idea to break large, complex tasks into a series of small, simple tasks. Let's imagine we are trying to describe a common, everyday task, going to the market to buy food, to a person from Mars. We might describe the overall process as the following series of steps:

1. Get in car.
2. Drive to market.
3. Park car.
4. Enter market.
5. Purchase food.

6. Return to car.
7. Drive home.
8. Park car.
9. Enter house.

However, a person from Mars is likely to need more detail. We could further break down the subtask "Park car" into this series of steps:

1. Find parking space.
2. Drive car into space.
3. Turn off motor.
4. Set parking brake.
5. Exit car.
6. Lock car.

The "Turn off motor" subtask could further be broken down into steps including "Turn off ignition," "Remove ignition key," and so on, until every step of the entire process of going to the market has been fully defined.

This process of identifying the top-level steps and developing increasingly detailed views of those steps is called *top-down design*. This technique allows us to break large complex tasks into many small, simple tasks. Top-down design is a common method of designing programs and one that is well suited to shell programming in particular.

In this chapter, we will use top-down design to further develop our report-generator script.

## Shell Functions

Our script currently performs the following steps to generate the HTML document:

1. Open page.
2. Open page header.
3. Set page title.
4. Close page header.
5. Open page body.
6. Output page heading.
7. Output timestamp.
8. Close page body.
9. Close page.

For our next stage of development, we will add some tasks between steps 7 and 8. These will include the following:

- **System uptime and load.** This is the amount of time since the last shutdown or reboot and the average number of tasks currently running on the processor over several time intervals.
- **Disk space.** This is the overall use of space on the system's storage devices.
- **Home space.** This is the amount of storage space being used by each user.

If we had a command for each of these tasks, we could add them to our script simply through command substitution.

```
#!/bin/bash

# Program to output a system information page

TITLE="System Information Report For $HOSTNAME"
CURRENT_TIME="$(date +"%x %r %Z")"
TIMESTAMP="Generated $CURRENT_TIME, by $USER"

cat << _EOF_
<html>
        <head>
                <title>$TITLE</title>
        </head>
        <body>
                <h1>$TITLE</h1>
                <p>$TIMESTAMP</p>
                $(report_uptime)
                $(report_disk_space)
                $(report_home_space)
        </body>
</html>
_EOF_
```

We could create these additional commands in two ways. We could write three separate scripts and place them in a directory listed in our `PATH`, or we could embed the scripts within our program as *shell functions*. As we have mentioned, shell functions are "mini-scripts" that are located inside other scripts and can act as autonomous programs. Shell functions have two syntactic forms. First, here is the more formal form:

```
function name {
      commands
      return
}
```

Here is the simpler (and generally preferred) form:

```
name () {
      commands
      return
}
```

where *name* is the name of the function and *commands* is a series of commands contained within the function. Both forms are equivalent and may be used interchangeably. The following is a script that demonstrates the use of a shell function:

```
 1    #!/bin/bash
 2
 3    # Shell function demo
 4
 5    function step2 {
 6        echo "Step 2"
 7        return
 8    }
 9
10    # Main program starts here
11
12    echo "Step 1"
13    step2
14    echo "Step 3"
```

As the shell reads the script, it passes over lines 1 through 11 because those lines consist of comments and the function definition. Execution begins at line 12, with an `echo` command. Line 13 *calls* the shell function `step2`, and the shell executes the function just as it would any other command. Program control then moves to line 6, and the second `echo` command is executed. Line 7 is executed next. Its `return` command terminates the function and returns control to the program at the line following the function call (line 14), and the final `echo` command is executed. Note that for function calls to be recognized as shell functions and not interpreted as the names of external programs, shell function definitions must appear in the script before they are called.

We'll add minimal shell function definitions to our script, shown here:

```
#!/bin/bash

# Program to output a system information page

TITLE="System Information Report For $HOSTNAME"
CURRENT_TIME="$(date +"%x %r %Z")"
TIMESTAMP="Generated $CURRENT_TIME, by $USER"

report_uptime () {
      return
}
```

```
report_disk_space () {
      return
}

report_home_space () {
      return
}

cat << _EOF_
<html>
      <head>
            <title>$TITLE</title>
      </head>
      <body>
            <h1>$TITLE</h1>
            <p>$TIMESTAMP</p>
            $(report_uptime)
            $(report_disk_space)
            $(report_home_space)
      </body>
</html>
_EOF_
```

Shell function names follow the same rules as variables. A function must contain at least one command. The `return` command (which is optional) satisfies the requirement.

## Local Variables

In the scripts we have written so far, all the variables (including constants) have been *global variables*. Global variables maintain their existence throughout the program. This is fine for many things, but it can sometimes complicate the use of shell functions. Inside shell functions, it is often desirable to have *local variables*. Local variables are accessible only within the shell function in which they are defined and cease to exist once the shell function terminates.

Having local variables allows the programmer to use variables with names that may already exist, either in the script globally or in other shell functions, without having to worry about potential name conflicts.

Here is an example script that demonstrates how local variables are defined and used:

```
#!/bin/bash

# local-vars: script to demonstrate local variables

foo=0   # global variable foo

funct_1 () {

      local foo      # variable foo local to funct_1
```

```
      foo=1
      echo "funct_1: foo = $foo"
}

funct_2 () {

      local foo      # variable foo local to funct_2

      foo=2
      echo "funct_2: foo = $foo"
}

echo "global:  foo = $foo"
funct_1
echo "global:  foo = $foo"
funct_2
echo "global:  foo = $foo"
```

As we can see, local variables are defined by preceding the variable name with the word `local`. This creates a variable that is local to the shell function in which it is defined. Once outside the shell function, the variable no longer exists. When we run this script, we see these results:

```
[me@linuxbox ~]$ local-vars
global:  foo = 0
funct_1: foo = 1
global:  foo = 0
funct_2: foo = 2
global:  foo = 0
```

We see that the assignment of values to the local variable `foo` within both shell functions has no effect on the value of `foo` defined outside the functions.

This feature allows shell functions to be written so that they remain independent of each other and of the script in which they appear. This is valuable because it helps prevent one part of a program from interfering with another. It also allows shell functions to be written so that they can be portable. That is, they may be cut and pasted from script to script, as needed.

## Keep Scripts Running

While developing our program, it is useful to keep the program in a runnable state. By doing this, and testing frequently, we can detect errors early in the development process. This will make debugging problems much easier. For example, if we run the program, make a small change, then run the program again and find a problem, it's likely that the most recent change is the source of the problem. By adding the empty functions, called *stubs* in programmer-speak, we can verify the logical flow of our program at an early stage. When constructing a stub, it's a good idea to include something that provides feedback to the programmer, which

shows the logical flow is being carried out. If we look at the output of our script now:

```
[me@linuxbox ~]$ sys_info_page
<html>
      <head>
            <title>System Information Report For twin2</title>
      </head>
      <body>
            <h1>System Information Report For linuxbox</h1>
            <p>Generated 03/19/2018 04:02:10 PM EDT, by me</p>



       </body>
</html>
```

we see that there are some blank lines in our output after the timestamp, but we can't be sure of the cause. If we change the functions to include some feedback:

```
report_uptime () {
        echo "Function report_uptime executed."
        return
}

report_disk_space () {
        echo "Function report_disk_space executed."
        return
}

report_home_space () {
        echo "Function report_home_space executed."
        return
}
```

and run the script again:

```
[me@linuxbox ~]$ sys_info_page
<html>
      <head>
            <title>System Information Report For linuxbox</title>
       </head>
      <body>
            <h1>System Information Report For linuxbox</h1>
            <p>Generated 03/20/2018 05:17:26 AM EDT, by me</p>
            Function report_uptime executed.
            Function report_disk_space executed.
            Function report_home_space executed.
      </body>
</html>
```

we now see that, in fact, our three functions are being executed.

With our function framework in place and working, it's time to flesh out some of the function code. First, here's the report_uptime function:

```
report_uptime () {
      cat <<- _EOF_
              <h2>System Uptime</h2>
              <pre>$(uptime)</pre>
              _EOF_
      return
}
```

It's pretty straightforward. We use a here document to output a section header and the output of the uptime command, surrounded by <pre> tags to preserve the formatting of the command. The report_disk_space function is similar.

```
report_disk_space () {
      cat <<- _EOF_
            <h2>Disk Space Utilization</h2>
            <pre>$(df -h)</pre>
            _EOF_
      return
}
```

This function uses the df -h command to determine the amount of disk space. Lastly, we'll build the report_home_space function.

```
report_home_space () {
      cat <<- _EOF_
            <h2>Home Space Utilization</h2>
            <pre>$(du -sh /home/*)</pre>
            _EOF_
      return
}
```

We use the du command with the -sh options to perform this task. This, however, is not a complete solution to the problem. While it will work on some systems (Ubuntu, for example), it will not work on others. The reason is that many systems set the permissions of home directories to prevent them from being world-readable, which is a reasonable security measure. On these systems, the report_home_space function, as written, will work only if our script is run with superuser privileges. A better solution would be to have the script adjust its behavior according to the privileges of the user. We will take this up in the next chapter.

**SHELL FUNCTIONS IN YOUR .BASHRC FILE**

Shell functions make excellent replacements for aliases and are actually the preferred method of creating small commands for personal use. Aliases are limited in the kind of commands and shell features they support, whereas shell functions allow anything that can be scripted. For example, if we liked the `report_disk_space` shell function that we developed for our script, we could create a similar function named `ds` for our *.bashrc* file:

```
ds () {
      echo "Disk Space Utilization For $HOSTNAME"
      df -h
}
```

## Summing Up

In this chapter, we introduced a common method of program design called top-down design, and we saw how shell functions are used to build the stepwise refinement that it requires. We also saw how local variables can be used to make shell functions independent from one another and from the program in which they are placed. This makes it possible for shell functions to be written in a portable manner and to be *reusable* by allowing them to be placed in multiple programs; this is a great time saver.

# 27

## FLOW CONTROL: BRANCHING WITH IF

In the previous chapter, we were presented with a problem. How can we make our report-generator script adapt to the privileges of the user running the script? The solution to this problem will require us to find a way to "change directions" within our script, based on the results of a test. In programming terms, we need the program to *branch*.

Let's consider a simple example of logic expressed in *pseudocode*, a simulation of a computer language intended for human consumption.

```
X = 5
If X = 5, then:
    Say "X equals 5."
Otherwise:
    Say "X is not equal to 5."
```

This is an example of a branch. Based on the condition "Does X = 5?" do one thing, "Say X equals 5," and otherwise do another thing, "Say X is not equal to 5."

## if Statements

Using the shell, we can code the previous logic as follows:

```
x=5

if [ "$x" -eq 5 ]; then
      echo "x equals 5."
else
      echo "x does not equal 5."
fi
```

Or we can enter it directly at the command line (slightly shortened).

```
[me@linuxbox ~]$ x=5
[me@linuxbox ~]$ if [ "$x" -eq 5 ]; then echo "equals 5"; else echo "does not equal 5";
fi
equals 5
[me@linuxbox ~]$ x=0
[me@linuxbox ~]$ if [ "$x" -eq 5 ]; then echo "equals 5"; else echo "does not equal 5";
fi
does not equal 5
```

In this example, we execute the command twice: once, with the value of `x` set to 5, which results in the string "equals 5" being output, and the second time with the value of `x` set to 0, which results in the string "does not equal 5" being output.

The `if` statement has the following syntax:

```
if commands; then
      commands
[elif commands; then
      commands...]
[else
      commands]
fi
```

where *`commands`* is a list of commands. This is a little confusing at first glance. But before we can clear this up, we have to look at how the shell evaluates the success or failure of a command.

## Exit Status

Commands (including the scripts and shell functions we write) issue a value to the system when they terminate, called an *exit status*. This value, which is an integer in the range of 0 to 255, indicates the success or failure of the

command's execution. By convention, a value of zero indicates success and any other value indicates failure. The shell provides a parameter that we can use to examine the exit status. Here we see it in action:

```
[me@linuxbox ~]$ ls -d /usr/bin
/usr/bin
[me@linuxbox ~]$ echo $?
0
[me@linuxbox ~]$ ls -d /bin/usr
ls: cannot access /bin/usr: No such file or directory
[me@linuxbox ~]$ echo $?
2
```

In this example, we execute the `ls` command twice. The first time, the command executes successfully. If we display the value of the parameter `$?`, we see that it is zero. We execute the `ls` command a second time (specifying a nonexistent directory), producing an error, and examine the parameter `$?` again. This time it contains a 2, indicating that the command encountered an error. Some commands use different exit status values to provide diagnostics for errors, while many commands simply exit with a value of 1 when they fail. Man pages often include a section entitled "Exit Status," describing what codes are used. However, a zero always indicates success.

The shell provides two extremely simple builtin commands that do nothing except terminate with either a 0 or 1 exit status. The `true` command always executes successfully, and the `false` command always executes unsuccessfully.

```
[me@linuxbox ~]$ true
[me@linuxbox ~]$ echo $?
0
[me@linuxbox ~]$ false
[me@linuxbox ~]$ echo $?
1
```

We can use these commands to see how the `if` statement works. What the `if` statement really does is evaluate the success or failure of commands.

```
[me@linuxbox ~]$ if true; then echo "It's true."; fi
It's true.
[me@linuxbox ~]$ if false; then echo "It's true."; fi
[me@linuxbox ~]$
```

The command `echo "It's true."` is executed when the command following `if` executes successfully and is not executed when the command following `if` does not execute successfully. If a list of commands follows `if`, the last command in the list is evaluated.

```
[me@linuxbox ~]$ if false; true; then echo "It's true."; fi
It's true.
[me@linuxbox ~]$ if true; false; then echo "It's true."; fi
[me@linuxbox ~]$
```

## Using test

By far, the command used most frequently with `if` is `test`. The `test` command performs a variety of checks and comparisons. It has two equivalent forms. The first, shown here:

```
test expression
```

And the second, more popular form, here:

```
[ expression ]
```

where *expression* is an expression that is evaluated as either true or false. The `test` command returns an exit status of 0 when the expression is true and a status of 1 when the expression is false.

It is interesting to note that both `test` and `[` are actually commands. In `bash` they are builtins, but they also exist as programs in */usr/bin* for use with other shells. The expression is actually just its arguments with the `[` command requiring that the `]` character be provided as its final argument.

The `test` and `[` commands support a wide range of useful expressions and tests.

### *File Expressions*

Table 27-1 lists the expressions used to evaluate the status of files.

**Table 27-1:** `test` File Expressions

| Expression | Is true if: |
|---|---|
| *file1* `-ef` *file2* | *file1* and *file2* have the same inode numbers (the two filenames refer to the same file by hard linking). |
| *file1* `-nt` *file2* | *file1* is newer than *file2*. |
| *file1* `-ot` *file2* | *file1* is older than *file2*. |
| `-b` *file* | *file* exists and is a block-special (device) file. |
| `-c` *file* | *file* exists and is a character-special (device) file. |
| `-d` *file* | *file* exists and is a directory. |
| `-e` *file* | *file* exists. |
| `-f` *file* | *file* exists and is a regular file. |
| `-g` *file* | *file* exists and is set-group-ID. |
| `-G` *file* | *file* exists and is owned by the effective group ID. |
| `-k` *file* | *file* exists and has its "sticky bit" set. |
| `-L` *file* | *file* exists and is a symbolic link. |
| `-O` *file* | *file* exists and is owned by the effective user ID. |
| `-p` *file* | *file* exists and is a named pipe. |
| `-r` *file* | *file* exists and is readable (has readable permission for the effective user). |

| Expression | Is true if: |
|---|---|
| -s *file* | *file* exists and has a length greater than zero. |
| -S *file* | *file* exists and is a network socket. |
| -t *fd* | *fd* is a file descriptor directed to/from the terminal. This can be used to determine whether standard input/output/error is being redirected. |
| -u *file* | *file* exists and is setuid. |
| -w *file* | *file* exists and is writable (has write permission for the effective user). |
| -x *file* | *file* exists and is executable (has execute/search permission for the effective user). |

Here we have a script that demonstrates some of the file expressions:

```
#!/bin/bash

# test-file: Evaluate the status of a file

FILE=~/.bashrc

if [ -e "$FILE" ]; then
      if [ -f "$FILE" ]; then
            echo "$FILE is a regular file."
      fi
      if [ -d "$FILE" ]; then
            echo "$FILE is a directory."
      fi
      if [ -r "$FILE" ]; then
            echo "$FILE is readable."
      fi
      if [ -w "$FILE" ]; then
            echo "$FILE is writable."
      fi
      if [ -x "$FILE" ]; then
            echo "$FILE is executable/searchable."
      fi
else
      echo "$FILE does not exist"
      exit 1
fi

exit
```

The script evaluates the file assigned to the constant `FILE` and displays its results as the evaluation is performed. There are two interesting things to note about this script. First, notice how the parameter `$FILE` is quoted within the expressions. This is not required to syntactically complete the expression; rather, it is a defense against the parameter being empty or containing only whitespace. If the parameter expansion of `$FILE` were to

result in an empty value, it would cause an error (the operators would be interpreted as non-null strings rather than operators). Using the quotes around the parameter ensures that the operator is always followed by a string, even if the string is empty. Second, notice the presence of the `exit` command near the end of the script. The `exit` command accepts a single, optional argument, which becomes the script's exit status. When no argument is passed, the exit status defaults to the exit status of the last command executed. Using `exit` in this way allows the script to indicate failure if `$FILE` expands to the name of a nonexistent file. The `exit` command appearing on the last line of the script is there as a formality. When a script "runs off the end" (reaches end of file), it terminates with an exit status of the last command executed.

Similarly, shell functions can return an exit status by including an integer argument to the `return` command. If we were to convert the previous script to a shell function to include it in a larger program, we could replace the `exit` commands with `return` statements and get the desired behavior.

```
test_file () {

      # test-file: Evaluate the status of a file

      FILE=~/.bashrc

      if [ -e "$FILE" ]; then
            if [ -f "$FILE" ]; then
                  echo "$FILE is a regular file."
            fi
            if [ -d "$FILE" ]; then
                  echo "$FILE is a directory."
            fi
            if [ -r "$FILE" ]; then
                  echo "$FILE is readable."
            fi
            if [ -w "$FILE" ]; then
                  echo "$FILE is writable."
            fi
            if [ -x "$FILE" ]; then
                  echo "$FILE is executable/searchable."
            fi
      else
            echo "$FILE does not exist"
            return 1
      fi

}
```

## *String Expressions*

Table 27-2 lists the expressions used to evaluate strings.

**Table 27-2:** test String Expressions

| Expression | Is true if: |
|---|---|
| *string* | *string* is not null. |
| -n *string* | The length of *string* is greater than zero. |
| -z *string* | The length of *string* is zero. |
| *string1* = *string2*<br>*string1* == *string2* | *string1* and *string2* are equal. Single or double equal signs may be used. The use of double equal signs is greatly preferred, but it is not POSIX compliant. |
| *string1* != *string2* | *string1* and *string2* are not equal. |
| *string1* > *string2* | *string1* sorts after *string2*. |
| *string1* < *string2* | *string1* sorts before *string2*. |

**WARNING** *The > and < expression operators must be quoted (or escaped with a backslash) when used with* test*. If they are not, they will be interpreted by the shell as redirection operators, with potentially destructive results. Also note that while the* bash *documentation states that the sorting order conforms to the collation order of the current locale, it does not. ASCII (POSIX) order is used in versions of* bash *up to and including 4.0. This problem was fixed in version 4.1.*

Here is a script that incorporates string expressions:

```
#!/bin/bash

# test-string: evaluate the value of a string

ANSWER=maybe

if [ -z "$ANSWER" ]; then
      echo "There is no answer." >&2
      exit 1
fi

if [ "$ANSWER" = "yes" ]; then
      echo "The answer is YES."
elif [ "$ANSWER" = "no" ]; then
      echo "The answer is NO."
elif [ "$ANSWER" = "maybe" ]; then
      echo "The answer is MAYBE."
else
      echo "The answer is UNKNOWN."
fi
```

In this script, we evaluate the constant ANSWER. We first determine whether the string is empty. If it is, we terminate the script and set the exit status to 1. Notice the redirection that is applied to the echo command. This redirects the error message "There is no answer." to standard error, which is the proper thing to do with error messages. If the string is not empty, we evaluate the

value of the string to see whether it is equal to either "yes," "no," or "maybe." We do this by using `elif`, which is short for "else if." By using `elif`, we are able to construct a more complex logical test.

### Integer Expressions

To compare values as integers rather than as strings, we can use the expressions listed in Table 27-3.

**Table 27-3:** test Integer Expressions

| Expression | Is true if: |
|---|---|
| *integer1* -eq *integer2* | *integer1* is equal to *integer2*. |
| *integer1* -ne *integer2* | *integer1* is not equal to *integer2*. |
| *integer1* -le *integer2* | *integer1* is less than or equal to *integer2*. |
| *integer1* -lt *integer2* | *integer1* is less than *integer2*. |
| *integer1* -ge *integer2* | *integer1* is greater than or equal to *integer2*. |
| *integer1* -gt *integer2* | *integer1* is greater than *integer2*. |

Here is a script that demonstrates them:

```
#!/bin/bash

# test-integer: evaluate the value of an integer.

INT=-5

if [ -z "$INT" ]; then
      echo "INT is empty." >&2
      exit 1
fi

if [ "$INT" -eq 0 ]; then
      echo "INT is zero."
else
      if [ "$INT" -lt 0 ]; then
            echo "INT is negative."
      else
            echo "INT is positive."
      fi
      if [ $((INT % 2)) -eq 0 ]; then
            echo "INT is even."
      else
            echo "INT is odd."
      fi
fi
```

The interesting part of the script is how it determines whether an integer is even or odd. By performing a modulo 2 operation on the number, which divides the number by 2 and returns the remainder, it can tell whether the number is odd or even.

## A More Modern Version of test

Modern versions of bash include a compound command that acts as an enhanced replacement for test. It uses the following syntax:

```
[[ expression ]]
```

where, like test, *expression* is an expression that evaluates to either a true or false result. The [[ ]] command is similar to test (it supports all of its expressions) but adds an important new string expression.

```
string1 =~ regex
```

This returns true if *string1* is matched by the extended regular expression *regex*. This opens up a lot of possibilities for performing such tasks as data validation. In our earlier example of the integer expressions, the script would fail if the constant INT contained anything except an integer. The script needs a way to verify that the constant contains an integer. Using [[ ]] with the =~ string expression operator, we could improve the script this way:

```
#!/bin/bash

# test-integer2: evaluate the value of an integer.

INT=-5

if [[ "$INT" =~ ^-?[0-9]+$ ]]; then
      if [ "$INT" -eq 0 ]; then
            echo "INT is zero."
      else
            if [ "$INT" -lt 0 ]; then
                  echo "INT is negative."
            else
                  echo "INT is positive."
            fi
            if [ $((INT % 2)) -eq 0 ]; then
                  echo "INT is even."
            else
                  echo "INT is odd."
            fi
      fi
else
      echo "INT is not an integer." >&2
      exit 1
fi
```

By applying the regular expression, we are able to limit the value of INT to only strings that begin with an optional minus sign, followed by one or more numerals. This expression also eliminates the possibility of empty values.

Another added feature of [[ ]] is that the == operator supports pattern matching the same way pathname expansion does. Here's an example:

```
[me@linuxbox ~]$ FILE=foo.bar
[me@linuxbox ~]$ if [[ $FILE == foo.* ]]; then
> echo "$FILE matches pattern 'foo.*'"
> fi
foo.bar matches pattern 'foo.*'
```

This makes [[ ]] useful for evaluating file and pathnames.

## (( ))—Designed for Integers

In addition to the [[ ]] compound command, bash also provides the (( )) compound command, which is useful for operating on integers. It supports a full set of arithmetic evaluations, a subject we will cover fully in Chapter 34.

(( )) is used to perform arithmetic truth tests. An *arithmetic truth test* results in true if the result of the arithmetic evaluation is non-zero.

```
[me@linuxbox ~]$ if ((1)); then echo "It is true."; fi
It is true.
[me@linuxbox ~]$ if ((0)); then echo "It is true."; fi
[me@linuxbox ~]$
```

Using (( )), we can slightly simplify the test-integer2 script like this:

```
#!/bin/bash

# test-integer2a: evaluate the value of an integer.

INT=-5

if [[ "$INT" =~ ^-?[0-9]+$ ]]; then
      if ((INT == 0)); then
            echo "INT is zero."
      else
            if ((INT < 0)); then
                  echo "INT is negative."
            else
                  echo "INT is positive."
            fi
            if (( ((INT % 2)) == 0)); then
                  echo "INT is even."
            else
                  echo "INT is odd."
            fi
      fi
else
      echo "INT is not an integer." >&2
      exit 1
fi
```

Notice that we use less-than and greater-than signs and that == is used to test for equivalence. This is a more natural-looking syntax for working with integers. Notice too, that because the compound command (( )) is part of the shell syntax rather than an ordinary command and it deals only with integers, it is able to recognize variables by name and does not require expansion to be performed. We'll discuss (( )) and the related arithmetic expansion further in Chapter 34.

## Combining Expressions

It's also possible to combine expressions to create more complex evaluations. Expressions are combined by using logical operators. We saw these in Chapter 17 when we learned about the find command. There are three logical operations for test and [[ ]]. They are AND, OR, and NOT. test and [[ ]] use different operators to represent these operations, as shown in Table 27-4.

**Table 27-4:** Logical Operators

| Operation | test | [[ ]] and (( )) |
|---|---|---|
| AND | -a | && |
| OR | -o | \|\| |
| NOT | ! | ! |

Here's an example of an AND operation. The following script determines whether an integer is within a range of values:

```
#!/bin/bash

# test-integer3: determine if an integer is within a
# specified range of values.

MIN_VAL=1
MAX_VAL=100

INT=50

if [[ "$INT" =~ ^-?[0-9]+$ ]]; then
      if [[ "$INT" -ge "$MIN_VAL" && "$INT" -le "$MAX_VAL" ]]; then
            echo "$INT is within $MIN_VAL to $MAX_VAL."
      else
            echo "$INT is out of range."
      fi
else
        echo "INT is not an integer." >&2
        exit 1
fi
```

In this script, we determine whether the value of integer INT lies between the values of MIN_VAL and MAX_VAL. This is performed by a single use of [[ ]], which includes two expressions separated by the && operator. We also could have coded this using test:

```
      if [ "$INT" -ge "$MIN_VAL" -a "$INT" -le "$MAX_VAL" ]; then
            echo "$INT is within $MIN_VAL to $MAX_VAL."
      else
            echo "$INT is out of range."
      fi
```

The ! negation operator reverses the outcome of an expression. It returns true if an expression is false, and it returns false if an expression is true. In the following script, we modify the logic of our evaluation to find values of INT that are outside the specified range:

```
#!/bin/bash

# test-integer4: determine if an integer is outside a
# specified range of values.

MIN_VAL=1
MAX_VAL=100

INT=50

if [[ "$INT" =~ ^-?[0-9]+$ ]]; then
      if [[ ! ("$INT" -ge "$MIN_VAL" && "$INT" -le "$MAX_VAL") ]]; then
            echo "$INT is outside $MIN_VAL to $MAX_VAL."
      else
            echo "$INT is in range."
      fi
else
        echo "INT is not an integer." >&2
        exit 1
fi
```

We also include parentheses around the expression, for grouping. If these were not included, the negation would only apply to the first expression and not the combination of the two. Coding this with test would be done this way:

```
      if [ ! \( "$INT" -ge "$MIN_VAL" -a "$INT" -le "$MAX_VAL" \) ]; then
            echo "$INT is outside $MIN_VAL to $MAX_VAL."
      else
            echo "$INT is in range."
      fi
```

Since all expressions and operators used by test are treated as command arguments by the shell (unlike [[ ]] and (( )) ), characters that have special meaning to bash, such as <, >, (, and ), must be quoted or escaped.

Seeing that test and [[ ]] do roughly the same thing, which is preferable? test is traditional (and part of the POSIX specification for standard shells, which are often used for system startup scripts), whereas [[ ]] is specific to bash (and a few other modern shells). It's important to know how to use test since it is widely used, but [[ ]] is clearly more useful and is easier to code, so it is preferred for modern scripts.

**PORTABILITY IS THE HOBGOBLIN OF LITTLE MINDS**

If you talk to "real" Unix people, you quickly discover that many of them don't like Linux very much. They regard it as impure and unclean. One tenet of Unix users is that everything should be "portable." This means that any script you write should be able to run, unchanged, on any Unix-like system.

Unix people have good reason to believe this. Having seen what proprietary extensions to commands and shells did to the Unix world before POSIX, they are naturally wary of the effect of Linux on their beloved OS.

But *portability* has a serious downside. It prevents progress. It requires that things are always done using "lowest common denominator" techniques. In the case of shell programming, it means making everything compatible with sh, the original Bourne shell.

This downside is the excuse that proprietary software vendors use to justify their proprietary extensions, only they call them "innovations." But they are really just lock-in devices for their customers.

The GNU tools, such as bash, have no such restrictions. They encourage portability by supporting standards and by being universally available. You can install bash and the other GNU tools on almost any kind of system, even Windows, without cost. So feel free to use all the features of bash. It's *really* portable.

## Control Operators: Another Way to Branch

bash provides two control operators that can perform branching. The && (AND) and || (OR) operators work like the logical operators in the [[ ]] compound command. Here is the syntax for &&:

```
command1 && command2
```

Here is the syntax for ||:

```
command1 || command2
```

It is important to understand the behavior of these. With the && operator, *command1* is executed, and *command2* is executed if, *and only if*, *command1* is successful. With the || operator, *command1* is executed and *command2* is executed if, *and only if*, *command1* is unsuccessful.

In practical terms, it means that we can do something like this:

```
[me@linuxbox ~]$ mkdir temp && cd temp
```

This will create a directory named *temp*, and if it succeeds, the current working directory will be changed to *temp*. The second command is attempted only if the `mkdir` command is successful. Likewise, a command like this:

```
[me@linuxbox ~]$ [[ -d temp ]] || mkdir temp
```

will test for the existence of the directory *temp*, and only if the test fails will the directory be created. This type of construct is handy for handling errors in scripts, a subject we will discuss more in later chapters. For example, we could do this in a script:

```
[ -d temp ] || exit 1
```

If the script requires the directory *temp* and it does not exist, then the script will terminate with an exit status of 1.

## Summing Up

We started this chapter with a question. How could we make our `sys_info_page` script detect whether the user had permission to read all the home directories? With our knowledge of `if`, we can solve the problem by adding this code to the `report_home_space` function:

```
report_home_space () {
      if [[ "$(id -u)" -eq 0 ]]; then
            cat <<- _EOF_
                  <h2>Home Space Utilization (All Users)</h2>
                  <pre>$(du -sh /home/*)</pre>
                  _EOF_
      else
            cat <<- _EOF_
                  <h2>Home Space Utilization ($USER)</h2>
                  <pre>$(du -sh $HOME)</pre>
                  _EOF_
      fi
      return
}
```

We evaluate the output of the `id` command. With the `-u` option, `id` outputs the numeric user ID number of the effective user. The superuser is always ID zero, and every other user is a number greater than zero. Knowing this, we can construct two different here documents, one taking advantage of superuser privileges and the other restricted to the user's own home directory.

We are going to take a break from the `sys_info_page` program, but don't worry. It will be back. In the meantime, we'll cover some topics that we'll need when we resume our work.

# 28

## READING KEYBOARD INPUT

The scripts we have written so far lack a feature common in most computer programs: *interactivity*, or the capability of the program to interact with the user. While many programs don't need to be interactive, some programs benefit from being able to accept input directly from the user. Take, for example, this script from the previous chapter:

```
#!/bin/bash

# test-integer2: evaluate the value of an integer.

INT=-5

if [[ "$INT" =~ ^-?[0-9]+$ ]]; then
      if [ "$INT" -eq 0 ]; then
            echo "INT is zero."
```

```
        else
                if [ "$INT" -lt 0 ]; then
                        echo "INT is negative."
                else
                        echo "INT is positive."
                fi
                if [ $((INT % 2)) -eq 0 ]; then
                        echo "INT is even."
                else
                        echo "INT is odd."
                fi
        fi
else
        echo "INT is not an integer." >&2
        exit 1
fi
```

Each time we want to change the value of INT, we have to edit the script. It would be much more useful if the script could ask the user for a value. In this chapter, we will begin to look at how we can add interactivity to our programs.

## read—Read Values from Standard Input

The read builtin command is used to read a single line of standard input. This command can be used to read keyboard input or, when redirection is employed, a line of data from a file. The command has the following syntax:

```
read [-options] [variable...]
```

where *options* is one or more of the available options listed later in Table 28-1 and *variable* is the name of one or more variables used to hold the input value. If no variable name is supplied, the shell variable REPLY contains the line of data.

Basically, read assigns fields from standard input to the specified variables. If we modify our integer evaluation script to use read, it might look like this:

```
#!/bin/bash

# read-integer: evaluate the value of an integer.

echo -n "Please enter an integer -> "
read int

if [[ "$int" =~ ^-?[0-9]+$ ]]; then
        if [ "$int" -eq 0 ]; then
                echo "$int is zero."
        else
                if [ "$int" -lt 0 ]; then
                        echo "$int is negative."
```

```
            else
                  echo "$int is positive."
            fi
            if [ $((int % 2)) -eq 0 ]; then
                  echo "$int is even."
            else
                  echo "$int is odd."
            fi
      fi
else
      echo "Input value is not an integer." >&2
      exit 1
fi
```

We use echo with the -n option (which suppresses the trailing newline on output) to display a prompt, and then we use read to input a value for the variable int. Running this script results in this:

```
[me@linuxbox ~]$ read-integer
Please enter an integer -> 5
5 is positive.
5 is odd.
```

read can assign input to multiple variables, as shown in this script:

```
#!/bin/bash

# read-multiple: read multiple values from keyboard

echo -n "Enter one or more values > "
read var1 var2 var3 var4 var5

echo "var1 = '$var1'"
echo "var2 = '$var2'"
echo "var3 = '$var3'"
echo "var4 = '$var4'"
echo "var5 = '$var5'"
```

In this script, we assign and display up to five values. Notice how read behaves when given different numbers of values, shown here:

```
[me@linuxbox ~]$ read-multiple
Enter one or more values > a b c d e
var1 = 'a'
var2 = 'b'
var3 = 'c'
var4 = 'd'
var5 = 'e'
[me@linuxbox ~]$ read-multiple
Enter one or more values > a
var1 = 'a'
var2 = ''
var3 = ''
```

```
var4 = ''
var5 = ''
[me@linuxbox ~]$ read-multiple
Enter one or more values > a b c d e f g
var1 = 'a'
var2 = 'b'
var3 = 'c'
var4 = 'd'
var5 = 'e f g'
```

If read receives fewer than the expected number, the extra variables are empty, while an excessive amount of input results in the final variable containing all of the extra input.

If no variables are listed after the read command, a shell variable, REPLY, will be assigned all the input.

```
#!/bin/bash

# read-single: read multiple values into default variable

echo -n "Enter one or more values > "
read

echo "REPLY = '$REPLY'"
```

Running this script results in this:

```
[me@linuxbox ~]$ read-single
Enter one or more values > a b c d
REPLY = 'a b c d'
```

## Options

read supports the options described in Table 28-1.

**Table 28-1:** read Options

| Option | Description |
|---|---|
| -a *array* | Assign the input to *array*, starting with index zero. We will cover arrays in Chapter 35. |
| -d *delimiter* | The first character in the string *delimiter* is used to indicate the end of input, rather than a newline character. |
| -e | Use Readline to handle input. This permits input editing in the same manner as the command line. |
| -i *string* | Use *string* as a default reply if the user simply presses ENTER. Requires the -e option. |
| -n *num* | Read *num* characters of input, rather than an entire line. |
| -p *prompt* | Display a prompt for input using the string *prompt*. |

| Option | Description |
|---|---|
| -r | Raw mode. Do not interpret backslash characters as escapes. |
| -s | Silent mode. Do not echo characters to the display as they are typed. This is useful when inputting passwords and other confidential information. |
| -t *seconds* | Timeout. Terminate input after *seconds*. read returns a non-zero exit status if an input times out. |
| -u *fd* | Use input from file descriptor *fd*, rather than standard input. |

Using the various options, we can do interesting things with read. For example, with the -p option, we can provide a prompt string.

```
#!/bin/bash

# read-single: read multiple values into default variable

read -p "Enter one or more values > "

echo "REPLY = '$REPLY'"
```

With the -t and -s options, we can write a script that reads "secret" input and times out if the input is not completed in a specified time.

```
#!/bin/bash

# read-secret: input a secret passphrase

if read -t 10 -sp "Enter secret passphrase > " secret_pass; then
      echo -e "\nSecret passphrase = '$secret_pass'"
else
      echo -e "\nInput timed out" >&2
      exit 1
fi
```

The script prompts the user for a secret passphrase and waits ten seconds for input. If the entry is not completed within the specified time, the script exits with an error. Because the -s option is included, the characters of the passphrase are not echoed to the display as they are typed.

It's possible to supply the user with a default response using the -e and -i options together.

```
#!/bin/bash

# read-default: supply a default value if user presses Enter key.

read -e -p "What is your user name? " -i $USER
echo "You answered: '$REPLY'"
```

In this script, we prompt the user to enter a username and use the environment variable USER to provide a default value. When the script is run, it displays the default string, and if the user simply presses ENTER, read will assign the default string to the REPLY variable.

```
[me@linuxbox ~]$ read-default
What is your user name? me
You answered: 'me'
```

## IFS

Normally, the shell performs word-splitting on the input provided to read. As we have seen, this means that multiple words separated by one or more spaces become separate items on the input line and are assigned to separate variables by read. This behavior is configured by a shell variable named IFS (for Internal Field Separator). The default value of IFS contains a space, a tab, and a newline character, each of which will separate items from one another.

We can adjust the value of IFS to control the separation of fields input to read. For example, the */etc/passwd* file contains lines of data that use the colon character as a field separator. By changing the value of IFS to a single colon, we can use read to input the contents of */etc/passwd* and successfully separate fields into different variables. Here we have a script that does just that:

```
#!/bin/bash

# read-ifs: read fields from a file

FILE=/etc/passwd

read -p "Enter a username > " user_name

file_info="$(grep "^$user_name:" $FILE)"

if [ -n "$file_info" ]; then
      IFS=":" read user pw uid gid name home shell <<< "$file_info"
      echo "User =      '$user'"
      echo "UID =       '$uid'"
      echo "GID =       '$gid'"
      echo "Full Name = '$name'"
      echo "Home Dir. = '$home'"
      echo "Shell =     '$shell'"
else
      echo "No such user '$user_name'" >&2
      exit 1
fi
```

This script prompts the user to enter the username of an account on the system and then displays the different fields found in the user's record in the */etc/passwd* file. The script contains two interesting lines. The first is as follows:

```
file_info=$(grep "^$user_name:" $FILE)
```

This line assigns the results of a `grep` command to the variable `file_info`. The regular expression used by `grep` assures that the username will match only a single line in the */etc/passwd* file.

The second interesting line is this one:

```
IFS=":" read user pw uid gid name home shell <<< "$file_info"
```

The line consists of three parts: a variable assignment, a `read` command with a list of variable names as arguments, and a strange new redirection operator. We'll look at the variable assignment first.

The shell allows one or more variable assignments to take place immediately before a command. These assignments alter the environment for the command that follows. The effect of the assignment is temporary, changing the environment only for the duration of the command. In our case, the value of `IFS` is changed to a colon character. Alternately, we could have coded it this way:

```
OLD_IFS="$IFS"
IFS=":"
read user pw uid gid name home shell <<< "$file_info"
IFS="$OLD_IFS"
```

where we store the value of `IFS`, assign a new value, perform the `read` command, and then restore `IFS` to its original value. Clearly, placing the variable assignment in front of the command is a more concise way of doing the same thing.

The `<<<` operator indicates a *here string*. A here string is like a here document, only shorter, consisting of a single string. In our example, the line of data from the */etc/passwd* file is fed to the standard input of the `read` command. We might wonder why this rather oblique method was chosen rather than this:

```
echo "$file_info" | IFS=":" read user pw uid gid name home shell
```

Well, there's a reason . . .

**YOU CAN'T PIPE READ**

While the `read` command normally takes input from standard input, you cannot do this:

```
echo "foo" | read
```

We would expect this to work, but it does not. The command will appear to succeed, but the `REPLY` variable will always be empty. Why is this?

The explanation has to do with the way the shell handles pipelines. In `bash` (and other shells such as `sh`), pipelines create *subshells*. These are copies of the shell and its environment that are used to execute the command in the pipeline. In the previous example, `read` is executed in a subshell.

Subshells in Unix-like systems create copies of the environment for the processes to use while they execute. When the processes finishes, the copy of the environment is destroyed. This means that *a subshell can never alter the environment of its parent process*. `read` assigns variables, which then become part of the environment. In the previous example, `read` assigns the value `foo` to the variable `REPLY` in its subshell's environment, but when the command exits, the subshell and its environment are destroyed, and the effect of the assignment is lost.

Using here strings is one way to work around this behavior. Another method is discussed in Chapter 36.

## Validating Input

With our new ability to have keyboard input comes an additional programming challenge: validating input. Often the difference between a well-written program and a poorly written one lies in the program's ability to deal with the unexpected. Frequently, the unexpected appears in the form of bad input. We've done a little of this with our evaluation programs in the previous chapter, where we checked the values of integers and screened out empty values and non-numeric characters. It is important to perform these kinds of programming checks every time a program receives input to guard against invalid data. This is especially important for programs that are shared by multiple users. Omitting these safeguards in the interests of economy might be excused if a program is to be used once and only by the author to perform some special task. Even then, if the program performs dangerous tasks such as deleting files, it would be wise to include data validation, just in case.

Here we have an example program that validates various kinds of input:

```
#!/bin/bash

# read-validate: validate input

invalid_input () {
      echo "Invalid input '$REPLY'" >&2
      exit 1
}

read -p "Enter a single item > "

# input is empty (invalid)
[[ -z "$REPLY" ]] && invalid_input

# input is multiple items (invalid)
(( "$(echo "$REPLY" | wc -w)" > 1 )) && invalid_input

# is input a valid filename?
if [[ "$REPLY" =~ ^[-[:alnum:]\._]+$ ]]; then
      echo "'$REPLY' is a valid filename."
      if [[ -e "$REPLY" ]]; then
            echo "And file '$REPLY' exists."
      else
            echo "However, file '$REPLY' does not exist."
      fi

      # is input a floating point number?
      if [[ "$REPLY" =~ ^-?[[:digit:]]*\.[[:digit:]]+$ ]]; then
            echo "'$REPLY' is a floating point number."
      else
            echo "'$REPLY' is not a floating point number."
      fi

      # is input an integer?
      if [[ "$REPLY" =~ ^-?[[:digit:]]+$ ]]; then
            echo "'$REPLY' is an integer."
      else
            echo "'$REPLY' is not an integer."
      fi
else
      echo "The string '$REPLY' is not a valid filename."
fi
```

This script prompts the user to enter an item. The item is subsequently analyzed to determine its contents. As we can see, the script makes use of many of the concepts that we have covered thus far, including shell functions, `[[ ]]`, `(( ))`, the control operator `&&`, and `if`, as well as a healthy dose of regular expressions.

## Menus

A common type of interactivity is called *menu-driven*. In menu-driven programs, the user is presented with a list of choices and is asked to choose one. For example, we could imagine a program that presented the following:

```
Please Select:

1. Display System Information
2. Display Disk Space
3. Display Home Space Utilization
0. Quit

Enter selection [0-3] >
```

Using what we learned from writing our `sys_info_page` program, we can construct a menu-driven program to perform the tasks on the previous menu.

```
#!/bin/bash

# read-menu: a menu driven system information program

clear
echo "
Please Select:

1. Display System Information
2. Display Disk Space
3. Display Home Space Utilization
0. Quit
"
read -p "Enter selection [0-3] > "

if [[ "$REPLY" =~ ^[0-3]$ ]]; then
      if [[ "$REPLY" == 0 ]]; then
            echo "Program terminated."
            exit
      fi
      if [[ "$REPLY" == 1 ]]; then
            echo "Hostname: $HOSTNAME"
            uptime
            exit
      fi
      if [[ "$REPLY" == 2 ]]; then
            df -h
            exit
      fi
      if [[ "$REPLY" == 3 ]]; then
            if [[ "$(id -u)" -eq 0 ]]; then
                  echo "Home Space Utilization (All Users)"
                  du -sh /home/*
            else
                  echo "Home Space Utilization ($USER)"
```

```
                du -sh "$HOME"
            fi
            exit
        fi
else
        echo "Invalid entry." >&2
        exit 1
fi
```

This script is logically divided into two parts. The first part displays the menu and inputs the response from the user. The second part identifies the response and carries out the selected action. Notice the use of the `exit` command in this script. It is used here to prevent the script from executing unnecessary code after an action has been carried out. The presence of multiple exit points in a program is generally a bad idea (it makes program logic harder to understand), but it works in this script.

## Summing Up

In this chapter, we took our first steps toward interactivity, allowing users to input data into our programs via the keyboard. Using the techniques presented thus far, it is possible to write many useful programs, such as specialized calculation programs and easy-to-use front ends for arcane command line tools. In the next chapter, we will build on the menu-driven program concept to make it even better.

## Extra Credit

It is important to study the programs in this chapter carefully and have a complete understanding of the way they are logically structured, as the programs to come will be increasingly complex. As an exercise, rewrite the programs in this chapter using the `test` command rather than the `[[ ]]` compound command. Hint: Use `grep` to evaluate the regular expressions and evaluate the exit status. This will be good practice.

# 29

## FLOW CONTROL: LOOPING WITH WHILE/UNTIL

In the previous chapter, we developed a menu-driven program to produce various kinds of system information. The program works, but it still has a significant usability problem. It executes only a single choice and then terminates. Even worse, if an invalid selection is made, the program terminates with an error, without giving the user an opportunity to try again. It would be better if we could somehow construct the program so that it could repeat the menu display and selection over and over, until the user chooses to exit the program.

In this chapter, we will look at a programming concept called *looping*, which can be used to make portions of programs repeat. The shell provides three compound commands for looping. We will look at two of them in this chapter and the third in a later chapter.

## Looping

Daily life is full of repeated activities. Going to work each day, walking the dog, and slicing a carrot are all tasks that involve repeating a series of steps. Let's consider slicing a carrot. If we express this activity in pseudocode, it might look something like this:

1. Get cutting board.
2. Get knife.
3. Place carrot on cutting board.
4. Lift knife.
5. Advance carrot.
6. Slice carrot.
7. If entire carrot sliced, then quit; else go to step 4.

Steps 4 through 7 form a *loop*. The actions within the loop are repeated until the condition, "entire carrot sliced," is reached.

### *while*

bash can express a similar idea. Let's say we wanted to display five numbers in sequential order from 1 to 5. A bash script could be constructed as follows:

```
#!/bin/bash

# while-count: display a series of numbers

count=1

while [[ "$count" -le 5 ]]; do
      echo "$count"
      count=$((count + 1))
done
echo "Finished."
```

When executed, this script displays the following:

```
[me@linuxbox ~]$ while-count
1
2
3
4
5
Finished.
```

The syntax of the while command is as follows:

**while** *commands*; **do** *commands*; **done**

Like `if`, `while` evaluates the exit status of a list of commands. As long as the exit status is zero, it performs the commands inside the loop. In the previous script, the variable `count` is created and assigned an initial value of 1. The `while` command evaluates the exit status of the `[[]]` compound command. As long as the `[[]]` command returns an exit status of zero, the commands within the loop are executed. At the end of each cycle, the `[[]]` command is repeated. After 5 iterations of the loop, the value of `count` has increased to 6, the `[[]]` command no longer returns an exit status of zero, and the loop terminates. The program continues with the next statement following the loop.

We can use a *while loop* to improve the `read-menu` program from the previous chapter.

```
#!/bin/bash

# while-menu: a menu driven system information program

DELAY=3 # Number of seconds to display results

while [[ "$REPLY" != 0 ]]; do
      clear
      cat <<- _EOF_
            Please Select:

            1. Display System Information
            2. Display Disk Space
            3. Display Home Space Utilization
            0. Quit

      _EOF_
      read -p "Enter selection [0-3] > "

      if [[ "$REPLY" =~ ^[0-3]$ ]]; then
            if [[ $REPLY == 1 ]]; then
                  echo "Hostname: $HOSTNAME"
                  uptime
                  sleep "$DELAY"
            fi
            if [[ "$REPLY" == 2 ]]; then
                  df -h
                  sleep "$DELAY"
            fi
            if [[ "$REPLY" == 3 ]]; then
                  if [[ "$(id -u)" -eq 0 ]]; then
                        echo "Home Space Utilization (All Users)"
                        du -sh /home/*
                  else
                        echo "Home Space Utilization ($USER)"
                        du -sh "$HOME"
                  fi
                  sleep "$DELAY"
            fi
```

```
      else
            echo "Invalid entry."
            sleep "$DELAY"
      fi
done
echo "Program terminated."
```

By enclosing the menu in a `while` loop, we are able to have the program repeat the menu display after each selection. The loop continues as long as `REPLY` is not equal to 0 and the menu is displayed again, giving the user the opportunity to make another selection. At the end of each action, a `sleep` command is executed, so the program will pause for a few seconds to allow the results of the selection to be seen before the screen is cleared and the menu is redisplayed. Once `REPLY` is equal to 0, indicating the "quit" selection, the loop terminates, and execution continues with the line following `done`.

## Breaking Out of a Loop

`bash` provides two builtin commands that can be used to control program flow inside loops. The `break` command immediately terminates a loop, and program control resumes with the next statement following the loop. The `continue` command causes the remainder of the loop to be skipped, and program control resumes with the next iteration of the loop. Here we see a version of the `while-menu` program incorporating both `break` and `continue`:

```
#!/bin/bash

# while-menu2: a menu driven system information program

DELAY=3 # Number of seconds to display results

while true; do
      clear
      cat <<- _EOF_
            Please Select:

            1. Display System Information
            2. Display Disk Space
            3. Display Home Space Utilization
            0. Quit

      _EOF_
      read -p "Enter selection [0-3] > "

      if [[ "$REPLY" =~ ^[0-3]$ ]]; then
            if [[ "$REPLY" == 1 ]]; then
                  echo "Hostname: $HOSTNAME"
                  uptime
                  sleep "$DELAY"
                  continue
            fi
```

```
            if [[ "$REPLY" == 2 ]]; then
                  df -h
                  sleep "$DELAY"
                  continue
            fi
            if [[ "$REPLY" == 3 ]]; then
                  if [[ "$(id -u)" -eq 0 ]]; then
                        echo "Home Space Utilization (All Users)"
                        du -sh /home/*
                  else
                        echo "Home Space Utilization ($USER)"
                        du -sh "$HOME"
                  fi
                  sleep "$DELAY"
                  continue
            fi
            if [[ "$REPLY" == 0 ]]; then
                  break
            fi
      else
            echo "Invalid entry."
            sleep "$DELAY"
      fi
done
echo "Program terminated."
```

In this version of the script, we set up an *endless loop* (one that never terminates on its own) by using the `true` command to supply an exit status to `while`. Since `true` will always exit with an exit status of zero, the loop will never end. This is a surprisingly common scripting technique. Since the loop will never end on its own, it's up to the programmer to provide some way to break out of the loop when the time is right. In this script, the `break` command is used to exit the loop when the 0 selection is chosen. The `continue` command has been included at the end of the other script choices to allow for more efficient execution. By using `continue`, the script will skip over code that is not needed when a selection is identified. For example, if the 1 selection is chosen and identified, there is no reason to test for the other selections.

### until

The `until` compound command is much like `while`, except instead of exiting a loop when a non-zero exit status is encountered, it does the opposite. An *until loop* continues until it receives a zero exit status. In our `while-count` script, we continued the loop as long as the value of the `count` variable was less than or equal to 5. We could get the same result by coding the script with `until`.

```
#!/bin/bash

# until-count: display a series of numbers
```

```
count=1

until [[ "$count" -gt 5 ]]; do
      echo "$count"
      count=$((count + 1))
done
echo "Finished."
```

By changing the test expression to `$count -gt 5`, `until` will terminate the loop at the correct time. The decision of whether to use the `while` or `until` loop is usually a matter of choosing the one that allows the clearest test to be written.

## Reading Files with Loops

`while` and `until` can process standard input. This allows files to be processed with `while` and `until` loops. In the following example, we will display the contents of the *distros.txt* file used in earlier chapters:

```
#!/bin/bash

# while-read: read lines from a file

while read distro version release; do
      printf "Distro: %s\tVersion: %s\tReleased: %s\n" \
            "$distro" \
            "$version" \
            "$release"
done < distros.txt
```

To redirect a file to the loop, we place the redirection operator after the `done` statement. The loop will use `read` to input the fields from the redirected file. The `read` command will exit after each line is read, with a zero exit status until the end-of-file is reached. At that point, it will exit with a non-zero exit status, thereby terminating the loop. It is also possible to pipe standard input into a loop.

```
#!/bin/bash

# while-read2: read lines from a file

sort -k 1,1 -k 2n distros.txt | while read distro version release; do
      printf "Distro: %s\tVersion: %s\tReleased: %s\n" \
            "$distro" \
            "$version" \
            "$release"
done
```

Here we take the output of the `sort` command and display the stream of text. However, it is important to remember that since a pipe will execute the loop in a subshell, any variables created or assigned within the loop will be lost when the loop terminates.

## Summing Up

With the introduction of loops and our previous encounters with branching, subroutines, and sequences, we have covered the major types of flow control used in programs. `bash` has some more tricks up its sleeve, but they are refinements on these basic concepts.

# 30

# TROUBLESHOOTING

Now that our scripts become more complex, it's time to look at what happens when things go wrong. In this chapter, we'll look at some of the common kinds of errors that occur in scripts and examine a few useful techniques that can be used to track down and eradicate problems.

## Syntactic Errors

One general class of errors is *syntactic*. Syntactic errors involve mistyping some element of shell syntax. The shell will stop executing a script when it encounters this type of error.

In the following discussions, we will use this script to demonstrate common types of errors.

```
#!/bin/bash

# trouble: script to demonstrate common errors

number=1

if [ $number = 1 ]; then
      echo "Number is equal to 1."
else
      echo "Number is not equal to 1."
fi
```

As written, this script runs successfully.

```
[me@linuxbox ~]$ trouble
Number is equal to 1.
```

### *Missing Quotes*

Let's edit our script and remove the trailing quote from the argument following the first echo command.

```
#!/bin/bash

# trouble: script to demonstrate common errors

number=1

if [ $number = 1 ]; then
      echo "Number is equal to 1.
else
      echo "Number is not equal to 1."
fi
```

Here is what happens:

```
[me@linuxbox ~]$ trouble
/home/me/bin/trouble: line 10: unexpected EOF while looking for matching `"'
/home/me/bin/trouble: line 13: syntax error: unexpected end of file
```

It generates two errors. Interestingly, the line numbers reported by the error messages are not where the missing quote was removed but rather much later in the program. If we follow the program after the missing quote, we can see why. bash will continue looking for the closing quote until it finds one, which it does, immediately after the second echo command. After that, bash becomes very confused. The syntax of the

subsequent if command is broken because the fi statement is now inside a quoted (but open) string.

In long scripts, this kind of error can be quite hard to find. Using an editor with syntax highlighting will help since, in most cases, it will display quoted strings in a distinctive manner from other kinds of shell syntax. If a complete version of vim is installed, syntax highlighting can be enabled by entering this command:

```
:syntax on
```

### Missing or Unexpected Tokens

Another common mistake is forgetting to complete a compound command, such as if or while. Let's look at what happens if we remove the semicolon after test in the if command:

```
#!/bin/bash

# trouble: script to demonstrate common errors

number=1

if [ $number = 1 ] then
      echo "Number is equal to 1."
else
      echo "Number is not equal to 1."
fi
```

The result is this:

```
[me@linuxbox ~]$ trouble
/home/me/bin/trouble: line 9: syntax error near unexpected token `else'
/home/me/bin/trouble: line 9: `else'
```

Again, the error message points to an error that occurs later than the actual problem. What happens is really pretty interesting. As we recall, if accepts a list of commands and evaluates the exit code of the last command in the list. In our program, we intend this list to consist of a single command, [, a synonym for test. The [ command takes what follows it as a list of arguments; in our case, that's four arguments: $number, 1, =, and ]. With the semicolon removed, the word then is added to the list of arguments, which is syntactically legal. The following echo command is legal, too. It's interpreted as another command in the list of commands that if will evaluate for an exit code. The else is encountered next, but it's out of place since the shell recognizes it as a *reserved word* (a word that has special meaning to the shell) and not the name of a command, which is the reason for the error message.

### *Unanticipated Expansions*

It's possible to have errors that occur only intermittently in a script. Sometimes the script will run fine, and other times it will fail because of the results of an expansion. If we return our missing semicolon and change the value of number to an empty variable, we can demonstrate.

```
#!/bin/bash

# trouble: script to demonstrate common errors

number=

if [ $number = 1 ]; then
      echo "Number is equal to 1."
else
      echo "Number is not equal to 1."
fi
```

Running the script with this change results in the following output:

```
[me@linuxbox ~]$ trouble
/home/me/bin/trouble: line 7: [: =: unary operator expected
Number is not equal to 1.
```

We get this rather cryptic error message, followed by the output of the second echo command. The problem is the expansion of the number variable within the test command. When the following command:

```
[ $number = 1 ]
```

undergoes expansion with number being empty, the result is this:

```
[  = 1 ]
```

which is invalid and the error is generated. The = operator is a binary operator (it requires a value on each side), but the first value is missing, so the test command expects a unary operator (such as -z) instead. Further, since the test failed (because of the error), the if command receives a non-zero exit code and acts accordingly, and the second echo command is executed.

This problem can be corrected by adding quotes around the first argument in the test command.

```
[ "$number" = 1 ]
```

Then when expansion occurs, the result will be this:

```
[ "" = 1 ]
```

This yields the correct number of arguments. In addition to empty strings, quotes should be used in cases where a value could expand into multiword strings, as with filenames containing embedded spaces.

**NOTE** *Make it a rule to always enclose variables and command substitutions in double quotes unless word splitting is needed.*

## Logical Errors

Unlike syntactic errors, *logical errors* do not prevent a script from running. The script will run, but it will not produce the desired result because of a problem with its logic. There are countless numbers of possible logical errors, but here are a few of the most common kinds found in scripts:

- **Incorrect conditional expressions.** It's easy to incorrectly code an `if/then/else` expression and have the wrong logic carried out. Sometimes the logic will be reversed, or it will be incomplete.
- **"Off by one" errors.** When coding loops that employ counters, it is possible to overlook that the loop may require that the counting start with zero, rather than one, for the count to conclude at the correct point. These kinds of errors result in either a loop "going off the end" by counting too far or a loop missing the last iteration by terminating one iteration too soon.
- **Unanticipated situations.** Most logic errors result from a program encountering data or situations that were unforeseen by the programmer. As we have seen, this can also include unanticipated expansions, such as a filename that contains embedded spaces that expands into multiple command arguments rather than a single filename.

### *Defensive Programming*

It is important to verify assumptions when programming. This means a careful evaluation of the exit status of programs and commands that are used by a script. Here is an example, based on a true story. An unfortunate system administrator wrote a script to perform a maintenance task on an important server. The script contained the following two lines of code:

```
cd $dir_name
rm *
```

There is nothing intrinsically wrong with these two lines, as long as the directory named in the variable, `dir_name`, exists. But what happens if it does not? In that case, the `cd` command fails, and the script continues to the next line and deletes the files in the current working directory. Not the desired outcome at all! The hapless administrator destroyed an important part of the server because of this design decision.

Let's look at some ways this design could be improved. First, it might be wise to ensure that the `dir_name` variable expands into only one word by quoting it and make the execution of `rm` contingent on the success of `cd`.

```
cd "$dir_name" && rm *
```

This way, if the `cd` command fails, the `rm` command is not carried out. This is better but still leaves open the possibility that the variable, `dir_name`, is unset or empty, which would result in the files in the user's home directory being deleted. This could also be avoided by checking to see that `dir_name` actually contains the name of an existing directory.

```
[[ -d "$dir_name" ]] && cd "$dir_name" && rm *
```

Often, it is best to include logic to terminate the script and report an error when a situation such as the one shown previously occurs.

```
# Delete files in directory $dir_name
if [[ ! -d "$dir_name" ]]; then
      echo "No such directory: '$dir_name'" >&2
      exit 1
fi
if ! cd "$dir_name"; then
      echo "Cannot cd to '$dir_name'" >&2
      exit 1
fi
if ! rm *; then
      echo "File deletion failed. Check results" >&2
      exit 1
fi
```

Here, we check both the name, to see that it is an existing directory, and the success of the `cd` command. If either fails, a descriptive error message is sent to standard error, and the script terminates with an exit status of one to indicate a failure.

### *Watch Out for Filenames*

There is another problem with this file deletion script that is more obscure but could be very dangerous. Unix (and Unix-like operating systems) has, in the opinion of many, a serious design flaw when it comes to filenames. Unix is extremely permissive about them. In fact, there are only two characters that cannot be included in a filename. The first is the / character since it is used to separate elements of a pathname, and the second is the null character (a zero byte), which is used internally to mark the ends of strings. Everything else is legal including spaces, tabs, line feeds, leading hyphens, carriage returns, and so on.

Of particular concern are leading hyphens. For example, it's perfectly legal to have a file named *-rf ~*. Consider for a moment what happens when that filename is passed to `rm`.

To defend against this problem, we want to change our `rm` command in the file deletion script from this:

```
rm *
```

to the following:

```
rm ./*
```

This will prevent a filename starting with a hyphen from being interpreted as a command option. As a general rule, always precede wildcards (such as `*` and `?`) with `./` to prevent misinterpretation by commands. This includes things like `*.pdf` and `???.mp3`, for example.

**PORTABLE FILENAMES**

To ensure that a filename is portable between multiple platforms (i.e., different types of computers and operating systems), care must be taken to limit which characters are included in a filename. There is a standard called the POSIX Portable Filename Character Set that can be used to maximize the chances that a filename will work across different systems. The standard is pretty simple. The only characters allowed are the uppercase letters *A–Z*, the lowercase letters *a–z*, the numerals 0–9, period (.), hyphen (-), and underscore (_). The standard further suggests that filenames not begin with a hyphen.

## Verifying Input

A general rule of good programming is that if a program accepts input, it must be able to deal with anything it receives. This usually means that input must be carefully screened to ensure that only valid input is accepted for further processing. We saw an example of this in the previous chapter when we studied the `read` command. One script contained the following test to verify a menu selection:

```
[[ $REPLY =~ ^[0-3]$ ]]
```

This test is very specific. It will return a zero exit status only if the string entered by the user is a numeral in the range of zero to three. Nothing else will be accepted. Sometimes these kinds of tests can be challenging to write, but the effort is necessary to produce a high-quality script.

**DESIGN IS A FUNCTION OF TIME**

When I was a college student studying industrial design, a wise professor stated that the amount of design on a project was determined by the amount of time given to the designer. If you were given five minutes to design a device "that kills flies," you designed a flyswatter. If you were given five months, you might come up with a laser-guided "antifly system" instead.

The same principle applies to programming. Sometimes a "quick-and-dirty" script will do if it's going to be used once and only by the programmer. That kind of script is common and should be developed quickly to make the effort economical. Such scripts don't need a lot of comments and defensive checks. On the other hand, if a script is intended for *production use*, that is, a script that will be used over and over for an important task or by multiple users, it needs much more careful development.

## Testing

Testing is an important step in every kind of software development, including scripts. There is a saying in the open source world, "release early, release often," that reflects this fact. By releasing early and often, software gets more exposure to use and testing. Experience has shown that bugs are much easier to find, and much less expensive to fix, if they are found early in the development cycle.

In Chapter 26, we saw how stubs can be used to verify program flow. From the earliest stages of script development, they are a valuable technique to check the progress of our work.

Let's look at the file-deletion problem shown previously and see how this could be coded for easy testing. Testing the original fragment of code would be dangerous since its purpose is to delete files, but we could modify the code to make the test safe.

```
if [[ -d $dir_name ]]; then
      if cd $dir_name; then
            echo rm * # TESTING
      else
            echo "cannot cd to '$dir_name'" >&2
            exit 1
      fi
else
      echo "no such directory: '$dir_name'" >&2
      exit 1
fi
exit # TESTING
```

Because the error conditions already output useful messages, we don't have to add any. The most important change is placing an `echo` command just

before the `rm` command to allow the command and its expanded argument list to be displayed, rather than the command actually being executed. This change allows safe execution of the code. At the end of the code fragment, we place an `exit` command to conclude the test and prevent any other part of the script from being carried out. The need for this will vary according to the design of the script.

We also include some comments that act as "markers" for our test-related changes. These can be used to help find and remove the changes when testing is complete.

### Test Cases

To perform useful testing, it's important to develop and apply good *test cases*. This is done by carefully choosing input data or operating conditions that reflect *edge* and *corner* cases. In our code fragment (which is simple), we want to know how the code performs under three specific conditions.

- `dir_name` contains the name of an existing directory.
- `dir_name` contains the name of a nonexistent directory.
- `dir_name` is empty.

By performing the test with each of these conditions, good *test coverage* is achieved.

Just as with design, testing is a function of time, as well. Not every script feature needs to be extensively tested. It's really a matter of determining what is most important. Since it could be so potentially destructive if it malfunctioned, our code fragment deserves careful consideration during both its design and testing.

## Debugging

If testing reveals a problem with a script, the next step is debugging. "A problem" usually means that the script is, in some way, not performing to the programmer's expectations. If this is the case, we need to carefully determine exactly what the script is actually doing and why. Finding bugs can sometimes involve a lot of detective work.

A well-designed script will try to help. It should be programmed defensively to detect abnormal conditions and provide useful feedback to the user. Sometimes, however, problems are quite strange and unexpected, and more involved techniques are required.

### Finding the Problem Area

In some scripts, particularly long ones, it is sometimes useful to isolate the area of the script that is related to the problem. This won't always be the actual error, but isolation will often provide insights into the actual cause. One technique that can be used to isolate code is "commenting out" sections of a script. For example, our file deletion fragment could be modified to determine whether the removed section was related to an error.

```
if [[ -d $dir_name ]]; then
      if cd $dir_name; then
            rm *
      else
            echo "cannot cd to '$dir_name'" >&2
            exit 1
      fi
# else
#      echo "no such directory: '$dir_name'" >&2
#      exit 1
fi
```

By placing comment symbols at the beginning of each line in a logical section of a script, we prevent that section from being executed. Testing can then be performed again to see whether the removal of the code has any impact on the behavior of the bug.

### *Tracing*

Bugs are often cases of unexpected logical flow within a script. That is, portions of the script either are never being executed or are being executed in the wrong order or at the wrong time. To view the actual flow of the program, we use a technique called *tracing*.

One tracing method involves placing informative messages in a script that display the location of execution. We can add messages to our code fragment.

```
echo "preparing to delete files" >&2
if [[ -d $dir_name ]]; then
      if cd $dir_name; then
echo "deleting files" >&2
            rm *
      else
            echo "cannot cd to '$dir_name'" >&2
            exit 1
      fi
else
      echo "no such directory: '$dir_name'" >&2
      exit 1
fi
echo "file deletion complete" >&2
```

We send the messages to standard error to separate them from normal output. We also do not indent the lines containing the messages, so it is easier to find when it's time to remove them.

Now when the script is executed, it's possible to see that the file deletion has been performed.

```
[me@linuxbox ~]$ deletion-script
preparing to delete files
deleting files
```

```
file deletion complete
[me@linuxbox ~]$
```

bash also provides a method of tracing, implemented by the -x option and the set command with the -x option. Using our earlier trouble script, we can activate tracing for the entire script by adding the -x option to the first line.

```
#!/bin/bash -x

# trouble: script to demonstrate common errors

number=1

if [ $number = 1 ]; then
      echo "Number is equal to 1."
else
      echo "Number is not equal to 1."
fi
```

When executed, the results look like this:

```
[me@linuxbox ~]$ trouble
+ number=1
+ '[' 1 = 1 ']'
+ echo 'Number is equal to 1.'
Number is equal to 1.
```

With tracing enabled, we see the commands performed with expansions applied. The leading plus signs indicate the display of the trace to distinguish them from lines of regular output. The plus sign is the default character for trace output. It is contained in the PS4 (prompt string 4) shell variable. The contents of this variable can be adjusted to make the prompt more useful. Here, we modify the contents of the variable to include the current line number in the script where the trace is performed. Note that single quotes are required to prevent expansion until the prompt is actually used.

```
[me@linuxbox ~]$ export PS4='$LINENO + '
[me@linuxbox ~]$ trouble
5 + number=1
7 + '[' 1 = 1 ']'
8 + echo 'Number is equal to 1.'
Number is equal to 1.
```

To perform a trace on a selected portion of a script, rather than the entire script, we can use the set command with the -x option.

```
#!/bin/bash

# trouble: script to demonstrate common errors

number=1
```

```
set -x # Turn on tracing
if [ $number = 1 ]; then
      echo "Number is equal to 1."
else
      echo "Number is not equal to 1."
fi
set +x # Turn off tracing
```

We use the set command with the -x option to activate tracing and the +x option to deactivate tracing. This technique can be used to examine multiple portions of a troublesome script.

### *Examining Values During Execution*

It is often useful, along with tracing, to display the content of variables to see the internal workings of a script while it is being executed. Applying additional echo statements will usually do the trick.

```
#!/bin/bash

# trouble: script to demonstrate common errors

number=1

echo "number=$number" # DEBUG
set -x # Turn on tracing
if [ $number = 1 ]; then
      echo "Number is equal to 1."
else
      echo "Number is not equal to 1."
fi
set +x # Turn off tracing
```

In this trivial example, we simply display the value of the variable number and mark the added line with a comment to facilitate its later identification and removal. This technique is particularly useful when watching the behavior of loops and arithmetic within scripts.

## Summing Up

In this chapter, we looked at just a few of the problems that can crop up during script development. Of course, there are many more. The techniques described here will enable finding most common bugs. Debugging is a fine art that is developed through experience, both in knowing how to avoid bugs (testing constantly throughout development) and in finding bugs (effective use of tracing).

# 31

## FLOW CONTROL: BRANCHING WITH CASE

In this chapter, we will continue our look at flow control. In Chapter 28, we constructed some simple menus and built the logic used to act on a user's selection. To do this, we used a series of `if` commands to identify which of the possible choices had been selected. This type of logical construct appears frequently in programs—so much so that many programming languages (including the shell) provide a special flow control mechanism for multiple-choice decisions.

## The case Command

In bash, the multiple-choice compound command is called case. It has the following syntax.

```
case word in
        [pattern [| pattern]...) commands ;;]...
esac
```

If we look at the read-menu program from Chapter 28, we see the logic used to act on a user's selection.

```
#!/bin/bash

# read-menu: a menu driven system information program

clear
echo "
Please Select:

1. Display System Information
2. Display Disk Space
3. Display Home Space Utilization
0. Quit
"
read -p "Enter selection [0-3] > "

if [[ "$REPLY" =~ ^[0-3]$ ]]; then
      if [[ "$REPLY" == 0 ]]; then
            echo "Program terminated."
            exit
      fi
      if [[ "$REPLY" == 1 ]]; then
            echo "Hostname: $HOSTNAME"
            uptime
            exit
      fi
      if [[ "$REPLY" == 2 ]]; then
            df -h
            exit
      fi
      if [[ "$REPLY" == 3 ]]; then
            if [[ "$(id -u)" -eq 0 ]]; then
                  echo "Home Space Utilization (All Users)"
                  du -sh /home/*
            else
                  echo "Home Space Utilization ($USER)"
                  du -sh "$HOME"
            fi
            exit
      fi
else
      echo "Invalid entry." >&2
```

```
    exit 1
fi
```

Using case, we can replace this logic with something simpler.

```
#!/bin/bash

# case-menu: a menu driven system information program

clear
echo "
Please Select:

1. Display System Information
2. Display Disk Space
3. Display Home Space Utilization
0. Quit
"
read -p "Enter selection [0-3] > "

case "$REPLY" in
    0)      echo "Program terminated."
            exit
            ;;
    1)      echo "Hostname: $HOSTNAME"
            uptime
            ;;
    2)      df -h
            ;;
    3)      if [[ "$(id -u)" -eq 0 ]]; then
                echo "Home Space Utilization (All Users)"
                du -sh /home/*
            else
                echo "Home Space Utilization ($USER)"
                du -sh "$HOME"
            fi
            ;;
    *)      echo "Invalid entry" >&2
            exit 1
            ;;
esac
```

The case command looks at the value of *word*, which in our example is the value of the REPLY variable, and then attempts to match it against one of the specified *patterns*. When a match is found, the commands associated with the specified pattern are executed. After a match is found, no further matches are attempted.

## Patterns

The patterns used by case are the same as those used by pathname expansion. Patterns are terminated with a ) character. Table 31-1 describes some valid patterns.

**Table 31-1:** case Pattern Examples

| Pattern | Description |
|---|---|
| a) | Matches if *word* equals a. |
| [[:alpha:]]) | Matches if *word* is a single alphabetic character. |
| ???) | Matches if *word* is exactly three characters long. |
| *.txt) | Matches if *word* ends with the characters *.txt*. |
| *) | Matches any value of *word*. It is good practice to include this as the last pattern in a case command to catch any values of *word* that did not match a previous pattern, that is, to catch any possible invalid values. |

Here is an example of patterns at work:

```
#!/bin/bash

read -p "enter word > "

case "$REPLY" in
    [[:alpha:]])   echo "is a single alphabetic character." ;;
    [ABC][0-9])    echo "is A, B, or C followed by a digit." ;;
    ???)           echo "is three characters long." ;;
    *.txt)         echo "is a word ending in '.txt'" ;;
    *)             echo "is something else." ;;
esac
```

It is also possible to combine multiple patterns using the vertical bar character as a separator. This creates an "or" conditional pattern. This is useful for such things as handling both uppercase and lowercase characters. Here's an example:

```
#!/bin/bash

# case-menu: a menu driven system information program

clear
echo "
Please Select:

A. Display System Information
B. Display Disk Space
C. Display Home Space Utilization
Q. Quit
"
read -p "Enter selection [A, B, C or Q] > "

case "$REPLY" in
    q|Q)    echo "Program terminated."
            exit
            ;;
    a|A)    echo "Hostname: $HOSTNAME"
            uptime
```

```
            ;;
    b|B)    df -h
            ;;
    c|C)    if [[ "$(id -u)" -eq 0 ]]; then
                echo "Home Space Utilization (All Users)"
                du -sh /home/*
            else
                echo "Home Space Utilization ($USER)"
                du -sh "$HOME"
            fi
            ;;
    *)      echo "Invalid entry" >&2
            exit 1
            ;;
esac
```

Here, we modify the `case-menu` program to use letters instead of digits for menu selection. Notice how the new patterns allow for entry of both uppercase and lowercase letters.

### *Performing Multiple Actions*

In versions of `bash` prior to 4.0, `case` allowed only one action to be performed on a successful match. After a successful match, the command would terminate. Here we see a script that tests a character:

```
#!/bin/bash

# case4-1: test a character

read -n 1 -p "Type a character > "
echo
case "$REPLY" in
    [[:upper:]])    echo "'$REPLY' is upper case." ;;
    [[:lower:]])    echo "'$REPLY' is lower case." ;;
    [[:alpha:]])    echo "'$REPLY' is alphabetic." ;;
    [[:digit:]])    echo "'$REPLY' is a digit." ;;
    [[:graph:]])    echo "'$REPLY' is a visible character." ;;
    [[:punct:]])    echo "'$REPLY' is a punctuation symbol." ;;
    [[:space:]])    echo "'$REPLY' is a whitespace character." ;;
    [[:xdigit:]])   echo "'$REPLY' is a hexadecimal digit." ;;
esac
```

Running this script produces this:

```
[me@linuxbox ~]$ case4-1
Type a character > a
'a' is lower case.
```

The script works for the most part but fails if a character matches more than one of the POSIX character classes. For example, the character `a` is both lowercase and alphabetic, as well as a hexadecimal digit. In `bash` prior

to version 4.0, there was no way for case to match more than one test. Modern versions of bash add the ;;& notation to terminate each action, so now we can do this:

```
#!/bin/bash

# case4-2: test a character

read -n 1 -p "Type a character > "
echo
case "$REPLY" in
    [[:upper:]])    echo "'$REPLY' is upper case." ;;&
    [[:lower:]])    echo "'$REPLY' is lower case." ;;&
    [[:alpha:]])    echo "'$REPLY' is alphabetic." ;;&
    [[:digit:]])    echo "'$REPLY' is a digit." ;;&
    [[:graph:]])    echo "'$REPLY' is a visible character." ;;&
    [[:punct:]])    echo "'$REPLY' is a punctuation symbol." ;;&
    [[:space:]])    echo "'$REPLY' is a whitespace character." ;;&
    [[:xdigit:]])   echo "'$REPLY' is a hexadecimal digit." ;;&
esac
```

When we run this script, we get this:

```
[me@linuxbox ~]$ case4-2
Type a character > a
'a' is lower case.
'a' is alphabetic.
'a' is a visible character.
'a' is a hexadecimal digit.
```

The addition of the ;;& syntax allows case to continue to the next test rather than simply terminating.

## Summing Up

The case command is a handy addition to our bag of programming tricks. As we will see in the next chapter, it's the perfect tool for handling certain types of problems.

# 32

# POSITIONAL PARAMETERS

One feature that has been missing from our programs so far is the ability to accept and process command line options and arguments. In this chapter, we will examine the shell features that allow our programs to get access to the contents of the command line.

## Accessing the Command Line

The shell provides a set of variables called *positional parameters* that contain the individual words on the command line. The variables are named 0 through 9. They can be demonstrated this way:

```
#!/bin/bash

# posit-param: script to view command line parameters

echo "
\$0 = $0
```

```
\$1 = $1
\$2 = $2
\$3 = $3
\$4 = $4
\$5 = $5
\$6 = $6
\$7 = $7
\$8 = $8
\$9 = $9
"
```

This is a simple script that displays the values of the variables `$0`–`$9`. When executed with no command line arguments, the result is this:

```
[me@linuxbox ~]$ posit-param

$0 = /home/me/bin/posit-param
$1 =
$2 =
$3 =
$4 =
$5 =
$6 =
$7 =
$8 =
$9 =
```

Even when no arguments are provided, `$0` will always contain the first item appearing on the command line, which is the pathname of the program being executed. When arguments are provided, we see these results:

```
[me@linuxbox ~]$ posit-param a b c d

$0 = /home/me/bin/posit-param
$1 = a
$2 = b
$3 = c
$4 = d
$5 =
$6 =
$7 =
$8 =
$9 =
```

**NOTE** *You can actually access more than nine parameters using parameter expansion. To specify a number greater than nine, surround the number in braces, as in `${10}`, `${55}`, `${211}`, and so on.*

### Determining the Number of Arguments

The shell also provides a variable, `$#`, that contains the number of arguments on the command line.

```
#!/bin/bash

# posit-param: script to view command line parameters

echo "
Number of arguments: $#
\$0 = $0
\$1 = $1
\$2 = $2
\$3 = $3
\$4 = $4
\$5 = $5
\$6 = $6
\$7 = $7
\$8 = $8
\$9 = $9
"
```

This is the result:

```
[me@linuxbox ~]$ posit-param a b c d

Number of arguments: 4
$0 = /home/me/bin/posit-param
$1 = a
$2 = b
$3 = c
$4 = d
$5 =
$6 =
$7 =
$8 =
$9 =
```

## *shift—Getting Access to Many Arguments*

But what happens when we give the program a large number of arguments such as the following?

```
[me@linuxbox ~]$ posit-param *

Number of arguments: 82
$0 = /home/me/bin/posit-param
$1 = addresses.ldif
$2 = bin
$3 = bookmarks.html
$4 = debian-500-i386-netinst.iso
$5 = debian-500-i386-netinst.jigdo
$6 = debian-500-i386-netinst.template
$7 = debian-cd_info.tar.gz
$8 = Desktop
$9 = dirlist-bin.txt
```

On this example system, the wildcard * expands into 82 arguments. How can we process that many? The shell provides a method, albeit a clumsy one, to do this. The shift command causes all the parameters to "move down one" each time it is executed. In fact, by using shift, it is possible to get by with only one parameter (in addition to $0, which never changes).

```
#!/bin/bash

# posit-param2: script to display all arguments

count=1

while [[ $# -gt 0 ]]; do
      echo "Argument $count = $1"
      count=$((count + 1))
      shift
done
```

Each time shift is executed, the value of $2 is moved to $1, the value of $3 is moved to $2, and so on. The value of $# is also reduced by one.

In the posit-param2 program, we create a loop that evaluates the number of arguments remaining and continues as long as there is at least one. We display the current argument, increment the variable count with each iteration of the loop to provide a running count of the number of arguments processed, and, finally, execute a shift to load $1 with the next argument. Here is the program at work:

```
[me@linuxbox ~]$ posit-param2 a b c d
Argument 1 = a
Argument 2 = b
Argument 3 = c
Argument 4 = d
```

## Simple Applications

Even without shift, it's possible to write useful applications using positional parameters. By way of example, here is a simple file information program:

```
#!/bin/bash

# file-info: simple file information program

PROGNAME="$(basename "$0")"

if [[ -e "$1" ]]; then
      echo -e "\nFile Type:"
      file "$1"
      echo -e "\nFile Status:"
      stat "$1"
else
      echo "$PROGNAME: usage: $PROGNAME file" >&2
```

```
      exit 1
fi
```

This program displays the file type (determined by the `file` command) and the file status (from the `stat` command) of a specified file. One interesting feature of this program is the `PROGNAME` variable. It is given the value that results from the `basename "$0"` command. The `basename` command removes the leading portion of a pathname, leaving only the base name of a file. In our example, `basename` removes the leading portion of the pathname contained in the `$0` parameter, the full pathname of our example program. This value is useful when constructing messages such as the usage message at the end of the program. By coding it this way, the script can be renamed, and the message automatically adjusts to contain the name of the program.

### *Using Positional Parameters with Shell Functions*

Just as positional parameters are used to pass arguments to shell scripts, they can also be used to pass arguments to shell functions. To demonstrate, we will convert the `file_info` script into a shell function.

```
file_info () {

      # file_info: function to display file information

      if [[ -e "$1" ]]; then
            echo -e "\nFile Type:"
            file "$1"
            echo -e "\nFile Status:"
            stat "$1"
      else
            echo "$FUNCNAME: usage: $FUNCNAME file" >&2
            return 1
      fi
}
```

Now, if a script that incorporates the `file_info` shell function calls the function with a filename argument, the argument will be passed to the function.

With this capability, we can write many useful shell functions that not only can be used in scripts but also can be used within our *.bashrc* files.

Notice that the `PROGNAME` variable was changed to the shell variable `FUNCNAME`. The shell automatically updates this variable to keep track of the currently executed shell function. Note that `$0` always contains the full pathname of the first item on the command line (i.e., the name of the program) and does not contain the name of the shell function as we might expect.

## Handling Positional Parameters en Masse

It is sometimes useful to manage all the positional parameters as a group. For example, we might want to write a "wrapper" around another program.

This means we create a script or shell function that simplifies the invocation of another program. The wrapper, in this case, supplies a list of arcane command line options and then passes a list of arguments to the lower-level program.

The shell provides two special parameters for this purpose. They both expand into the complete list of positional parameters but differ in rather subtle ways. Table 32-1 describes these parameters.

**Table 32-1:** The * and @ Special Parameters

| Parameter | Description |
|---|---|
| $* | Expands into the list of positional parameters, starting with 1. When surrounded by double quotes, it expands into a double-quoted string containing all of the positional parameters, each separated by the first character of the IFS shell variable (by default a space character). |
| $@ | Expands into the list of positional parameters, starting with 1. When surrounded by double quotes, it expands each positional parameter into a separate word as if it was surrounded by double quotes. |

Here is a script that shows these special parameters in action:

```
#!/bin/bash

# posit-params3: script to demonstrate $* and $@

print_params () {
      echo "\$1 = $1"
      echo "\$2 = $2"
      echo "\$3 = $3"
      echo "\$4 = $4"
}

pass_params () {
      echo -e "\n" '$* :';   print_params $*
      echo -e "\n" '"$*" :'; print_params "$*"
      echo -e "\n" '$@ :';   print_params $@
      echo -e "\n" '"$@" :'; print_params "$@"
}

pass_params "word" "words with spaces"
```

In this rather convoluted program, we create two arguments, called `word` and `words with spaces`, and pass them to the `pass_params` function. That function, in turn, passes them on to the `print_params` function, using each of the four methods available with the special parameters `$*` and `$@`. When executed, the script reveals the differences.

```
[me@linuxbox ~]$ posit-param3

 $* :
```

```
$1 = word
$2 = words
$3 = with
$4 = spaces

 "$*" :
$1 = word words with spaces
$2 =
$3 =
$4 =

 $@ :
$1 = word
$2 = words
$3 = with
$4 = spaces

 "$@" :
$1 = word
$2 = words with spaces
$3 =
$4 =
```

With our arguments, both `$*` and `$@` produce a four-word result.

```
word words with spaces
```

`"$*"` produces a one-word result.

```
"word words with spaces"
```

`"$@"` produces a two-word result.

```
"word" "words with spaces"
```

This matches our actual intent. The lesson to take from this is that even though the shell provides four different ways of getting the list of positional parameters, `"$@"` is by far the most useful for most situations because it preserves the integrity of each positional parameter. To ensure safety, it should always be used, unless we have a compelling reason not to use it.

## A More Complete Application

After a long hiatus, we are going to resume work on our `sys_info_page` program, last seen in Chapter 27. Our next addition will add several command line options to the program as follows:

**Output file** We will add an option to specify a name for a file to contain the program's output. It will be specified as either `-f` *`file`* or `--file` *`file`*.

**Interactive mode** This option will prompt the user for an output filename and will determine whether the specified file already exists. If it does, the user will be prompted before the existing file is overwritten. This option will be specified by either `-i` or `--interactive`.

**Help** Either `-h` or `--help` may be specified to cause the program to output an informative usage message.

Here is the code needed to implement the command line processing:

```
usage () {
      echo "$PROGNAME: usage: $PROGNAME [-f file | -i]"
      return
}

# process command line options

interactive=
filename=

while [[ -n "$1" ]]; do
      case "$1" in
            -f | --file)            shift
                                    filename="$1"
                                    ;;
            -i | --interactive)     interactive=1
                                    ;;
            -h | --help)            usage
                                    exit
                                    ;;
            *)                      usage >&2
                                    exit 1
                                    ;;
      esac
      shift
done
```

First, we add a shell function called `usage` to display a message when the help option is invoked or an unknown option is attempted.

Next, we begin the processing loop. This loop continues while the positional parameter `$1` is not empty. At the end of the loop, we have a `shift` command to advance the positional parameters to ensure that the loop will eventually terminate.

Within the loop, we have a `case` statement that examines the current positional parameter to see whether it matches any of the supported choices. If a supported parameter is found, it is acted upon. If an unknown choice is found, the usage message is displayed, and the script terminates with an error.

The `-f` parameter is handled in an interesting way. When detected, it causes an additional `shift` to occur, which advances the positional parameter `$1` to the filename argument supplied to the `-f` option.

We next add the code to implement the interactive mode.

```
# interactive mode

if [[ -n "$interactive" ]]; then
      while true; do
            read -p "Enter name of output file: " filename
            if [[ -e "$filename" ]]; then
                  read -p "'$filename' exists. Overwrite? [y/n/q] > "
                  case "$REPLY" in
                      Y|y)    break
                              ;;
                      Q|q)    echo "Program terminated."
                              exit
                              ;;
                      *)      continue
                              ;;
                  esac
            elif [[ -z "$filename" ]]; then
                  continue
            else
                  break
            fi
      done
fi
```

If the interactive variable is not empty, an endless loop is started, which contains the filename prompt and subsequent existing file-handling code. If the desired output file already exists, the user is prompted to overwrite, choose another filename, or quit the program. If the user chooses to overwrite an existing file, a break is executed to terminate the loop. Notice how the case statement detects only whether the user chooses to overwrite or quit. Any other choice causes the loop to continue and prompts the user again.

To implement the output filename feature, we must first convert the existing page-writing code into a shell function, for reasons that will become clear in a moment.

```
write_html_page () {
      cat <<- _EOF_
      <html>
            <head>
                  <title>$TITLE</title>
            </head>
            <body>
                  <h1>$TITLE</h1>
                  <p>$TIMESTAMP</p>
                  $(report_uptime)
                  $(report_disk_space)
                  $(report_home_space)
            </body>
      </html>
      _EOF_
      return
}
```

```
# output html page

if [[ -n "$filename" ]]; then
      if touch "$filename" && [[ -f "$filename" ]]; then
            write_html_page > "$filename"
      else
            echo "$PROGNAME: Cannot write file '$filename'" >&2
            exit 1
      fi
else
      write_html_page
fi
```

The code that handles the logic of the `-f` option appears at the end of the previous listing. In it, we test for the existence of a filename, and if one is found, a test is performed to see whether the file is indeed writable. To do this, a `touch` is performed, followed by a test to determine whether the resulting file is a regular file. These two tests take care of situations where an invalid pathname is input (`touch` will fail), and, if the file already exists, that it's a regular file.

As we can see, the `write_html_page` function is called to perform the actual generation of the page. Its output is either directed to standard output (if the variable `filename` is empty) or redirected to the specified file. Since we have two possible destinations for the HTML code, it makes sense to convert the `write_html_page` routine to a shell function to avoid redundant code.

## Summing Up

With the addition of positional parameters, we can now write fairly functional scripts. For simple, repetitive tasks, positional parameters make it possible to write very useful shell functions that can be placed in a user's *.bashrc* file.

Our `sys_info_page` program has grown in complexity and sophistication. Here is a complete listing, with the most recent changes highlighted:

```
#!/bin/bash

# sys_info_page: program to output a system information page

PROGNAME="$(basename "$0")"
TITLE="System Information Report For $HOSTNAME"
CURRENT_TIME="$(date +"%x %r %Z")"
TIMESTAMP="Generated $CURRENT_TIME, by $USER"

report_uptime () {
      cat <<- _EOF_
            <h2>System Uptime</h2>
            <pre>$(uptime)</pre>
            _EOF_
      return
```

```
}

report_disk_space () {
      cat <<- _EOF_
            <h2>Disk Space Utilization</h2>
            <pre>$(df -h)</PRE>
            _EOF_
      return
}

report_home_space () {
      if [[ "$(id -u)" -eq 0 ]]; then
            cat <<- _EOF_
                  <h2>Home Space Utilization (All Users)</h2>
                  <pre>$(du -sh /home/*)</pre>
                  _EOF_
      else
            cat <<- _EOF_
                  <h2>Home Space Utilization ($USER)</h2>
                  <pre>$(du -sh "$HOME")</pre>
                  _EOF_
      fi
      return
}

usage () {
      echo "$PROGNAME: usage: $PROGNAME [-f file | -i]"
      return
}

write_html_page () {
      cat <<- _EOF_
      <html>
            <head>
                  <title>$TITLE</title>
            </head>
            <body>
                  <h1>$TITLE</h1>
                  <p>$TIMESTAMP</p>
                  $(report_uptime)
                  $(report_disk_space)
                  $(report_home_space)
            </body>
      </html>
      _EOF_
      return
}

# process command line options

interactive=
filename=

while [[ -n "$1" ]]; do
    case "$1" in
```

```
        -f | --file)        shift
                            filename="$1"
                            ;;
        -i | --interactive) interactive=1
                            ;;
        -h | --help)        usage
                            exit
                            ;;
        *)                  usage >&2
                            exit 1
                            ;;
    esac
    shift
done

# interactive mode

if [[ -n "$interactive" ]]; then
    while true; do
        read -p "Enter name of output file: " filename
        if [[ -e "$filename" ]]; then
            read -p "'$filename' exists. Overwrite? [y/n/q] > "
            case "$REPLY" in
                Y|y)    break
                        ;;
                Q|q)    echo "Program terminated."
                        exit
                        ;;
                *)      continue
                        ;;
            esac
        elif [[ -z "$filename" ]]; then
            continue
        else
            break
        fi
    done
fi

# output html page

if [[ -n "$filename" ]]; then
      if touch "$filename" && [[ -f "$filename" ]]; then
            write_html_page > "$filename"
      else
            echo "$PROGNAME: Cannot write file '$filename'" >&2
            exit 1
      fi
else
      write_html_page
fi
```

We're not done yet. There are still a few more things we can do and improvements we can make.

# 33

# FLOW CONTROL: LOOPING WITH FOR

In this final chapter on flow control, we will look at another of the shell's looping constructs. The *for loop* differs from the `while` and `until` loops in that it provides a means of processing sequences during a loop. This turns out to be very useful when programming. Accordingly, the `for` loop is a popular construct in `bash` scripting.

A `for` loop is implemented, naturally enough, with the `for` compound command. In `bash`, `for` is available in two forms.

## for: Traditional Shell Form

The original `for` command's syntax is as follows:

```
for variable [in words]; do
      commands
done
```

where *variable* is the name of a variable that will increment during the execution of the loop, *words* is an optional list of items that will be sequentially assigned to *variable*, and *commands* are the commands that are to be executed on each iteration of the loop.

The `for` command is useful on the command line. We can easily demonstrate how it works.

```
[me@linuxbox ~]$ for i in A B C D; do echo $i; done
A
B
C
D
```

In this example, `for` is given a list of four words: *A*, *B*, *C*, and *D*. With a list of four words, the loop is executed four times. Each time the loop is executed, a word is assigned to the variable `i`. Inside the loop, we have an `echo` command that displays the value of `i` to show the assignment. As with the `while` and `until` loops, the `done` keyword closes the loop.

The really powerful feature of `for` is the number of interesting ways we can create the list of words. For example, we can do it through brace expansion, like so:

```
[me@linuxbox ~]$ for i in {A..D}; do echo $i; done
A
B
C
D
```

or we could use a pathname expansion, as follows:

```
[me@linuxbox ~]$ for i in distros*.txt; do echo "$i"; done
distros-by-date.txt
distros-dates.txt
distros-key-names.txt
distros-key-vernums.txt
distros-names.txt
distros.txt
distros-vernums.txt
distros-versions.txt
```

Pathname expansion provides a nice, clean list of pathnames that can be processed in the loop. The one precaution needed is to check that the expansion actually matched something. By default, if the expansion fails to match any files, the wildcards themselves (`distros*.txt` in the preceding example) will be returned. To guard against this, we would code the preceding example in a script this way:

```
for i in distros*.txt; do
      if [[ -e "$i" ]]; then
            echo "$i"
```

```
      fi
done
```

By adding a test for file existence, we will ignore a failed expansion.

Another common method of word production is command substitution.

```
#!/bin/bash

# longest-word: find longest string in a file

while [[ -n "$1" ]]; do
      if [[ -r "$1" ]]; then
            max_word=
            max_len=0
            for i in $(strings "$1"); do
                  len="$(echo -n "$i" | wc -c)"
                  if (( len > max_len )); then
                        max_len="$len"
                        max_word="$i"
                  fi
            done
            echo "$1: '$max_word' ($max_len characters)"
      fi
      shift
done
```

In this example, we look for the longest string found within a file. When given one or more filenames on the command line, this program uses the `strings` program (which is included in the GNU binutils package) to generate a list of readable text "words" in each file. The `for` loop processes each word in turn and determines whether the current word is the longest found so far. When the loop concludes, the longest word is displayed.

One thing to note here is that, contrary to our usual practice, we do not surround the command substitution `$(strings "$1")` with double quotes. This is because we actually want word splitting to occur to give us our list. If we had surrounded the command substitution with quotes, it would produce only a single word containing every string in the file. That's not exactly what we are looking for.

If the optional `in` *`words`* portion of the `for` command is omitted, `for` defaults to processing the positional parameters. We will modify our `longest-word` script to use this method:

```
#!/bin/bash

# longest-word2: find longest string in a file

for i; do
      if [[ -r "$i" ]]; then
            max_word=
            max_len=0
            for j in $(strings "$i"); do
                  len="$(echo -n "$j" | wc -c)"
```

```
                if (( len > max_len )); then
                      max_len="$len"
                      max_word="$j"
                fi
          done
          echo "$i: '$max_word' ($max_len characters)"
     fi
done
```

As we can see, we have changed the outermost loop to use `for` in place of `while`. By omitting the list of words in the `for` command, the positional parameters are used instead. Inside the loop, previous instances of the variable `i` have been changed to the variable `j`. The use of `shift` has also been eliminated.

**WHY I?**

You may have noticed that the variable `i` was chosen for each of the previous `for` loop examples. Why? No specific reason actually besides tradition. The variable used with `for` can be any valid variable, but `i` is the most common, followed by `j` and `k`.

The basis of this tradition comes from the Fortran programming language. In Fortran, undeclared variables starting with the letters *I*, *J*, *K*, *L*, and *M* are automatically typed as integers, while variables beginning with any other letter are typed as reals (numbers with decimal fractions). This behavior led programmers to use the variables *I*, *J*, and *K* for loop variables since it was less work to use them when a temporary variable (as loop variables often are) was needed.

It also led to the following Fortran-based witticism: "GOD is real, unless declared integer."

## for: C Language Form

Recent versions of `bash` have added a second form of the `for` command syntax, one that resembles the form found in the C programming language. Many other languages support this form, as well.

```
for (( expression1; expression2; expression3 )); do
      commands
done
```

Here, *`expression1`*, *`expression2`*, and *`expression3`* are arithmetic expressions, and *`commands`* are the commands to be performed during each iteration of the loop.

In terms of behavior, this form is equivalent to the following construct.

```
(( expression1 ))
while (( expression2 )); do
      commands
      (( expression3 ))
done
```

*expression1* is used to initialize conditions for the loop, *expression2* is used to determine when the loop is finished, and *expression3* is carried out at the end of each iteration of the loop.

Here is a typical application:

```
#!/bin/bash

# simple_counter: demo of C style for command

for (( i=0; i<5; i=i+1 )); do
      echo $i
done
```

When executed, it produces the following output:

```
[me@linuxbox ~]$ simple_counter
0
1
2
3
4
```

In this example, *expression1* initializes the variable `i` with the value of zero, *expression2* allows the loop to continue as long as the value of `i` remains less than 5, and *expression3* increments the value of `i` by 1 each time the loop repeats.

The C language form of `for` is useful anytime a numeric sequence is needed. We will see several applications for this in the next two chapters.

## Summing Up

With our knowledge of the `for` command, we will now apply the final improvements to our `sys_info_page` script. Currently, the `report_home_space` function looks like this:

```
report_home_space () {
      if [[ "$(id -u)" -eq 0 ]]; then
            cat <<- _EOF_
                  <h2>Home Space Utilization (All Users)</h2>
                  <pre>$(du -sh /home/*)</pre>
                  _EOF_
      else
            cat <<- _EOF_
                  <h2>Home Space Utilization ($USER)</h2>
```

```
                <pre>$(du -sh "$HOME")</pre>
                _EOF_
        fi
        return
}
```

Next, we will rewrite it to provide more detail for each user's home directory and include the total number of files and subdirectories in each.

```
report_home_space () {

        local format="%8s%10s%10s\n"
        local i dir_list total_files total_dirs total_size user_name

        if [[ "$(id -u)" -eq 0 ]]; then
                dir_list=/home/*
                user_name="All Users"
        else
                dir_list="$HOME"
                user_name="$USER"
        fi

        echo "<h2>Home Space Utilization ($user_name)</h2>"

        for i in $dir_list; do

                total_files="$(find "$i" -type f | wc -l)"
                total_dirs="$(find "$i" -type d | wc -l)"
                total_size="$(du -sh "$i" | cut -f 1)"

                echo "<h3>$i</h3>"
                echo "<pre>"
                printf "$format" "Dirs" "Files" "Size"
                printf "$format" "----" "-----" "----"
                printf "$format" "$total_dirs" "$total_files" "$total_size"
                echo "</pre>"
        done
        return
}
```

This rewrite applies much of what we have learned so far. We still test for the superuser, but instead of performing the complete set of actions as part of the `if`, we set some variables used later in a `for` loop. We have added several local variables to the function and made use of `printf` to format some of the output.

# 34

# STRINGS AND NUMBERS

Computer programs are all about working with data. In past chapters, we have focused on processing data at the file level. However, many programming problems need to be solved using smaller units of data such as strings and numbers.

In this chapter, we will look at several shell features that are used to manipulate strings and numbers. The shell provides a variety of parameter expansions that perform string operations. In addition to arithmetic expansion (which we touched upon in Chapter 7), there is a well-known command line program called `bc`, which performs higher-level math.

## Parameter Expansion

Though parameter expansion came up in Chapter 7, we did not cover it in detail because most parameter expansions are used in scripts rather than on the command line. We have already worked with some forms of parameter expansion, for example, shell variables. The shell provides many more.

**NOTE** *It's always good practice to enclose parameter expansions in double quotes to prevent unwanted word splitting, unless there is a specific reason not to. This is especially true when dealing with filenames since they can often include embedded spaces and other assorted nastiness.*

### Basic Parameters

The simplest form of parameter expansion is reflected in the ordinary use of variables. Here's an example:

```
$a
```

When expanded, this becomes whatever the variable a contains. Simple parameters may also be surrounded by braces.

```
${a}
```

This has no effect on the expansion but is required if the variable is adjacent to other text, which may confuse the shell. In this example, we attempt to create a filename by appending the string _file to the contents of the variable a:

```
[me@linuxbox ~]$ a="foo"
[me@linuxbox ~]$ echo "$a_file"
```

If we perform this sequence of commands, the result will be nothing because the shell will try to expand a variable named a_file rather than a. This problem can be solved by adding braces around the "real" variable name.

```
[me@linuxbox ~]$ echo "${a}_file"
foo_file
```

We have also seen that positional parameters greater than nine can be accessed by surrounding the number in braces. For example, to access the eleventh positional parameter, we can do this:

```
${11}
```

### Expansions to Manage Empty Variables

Several parameter expansions are intended to deal with nonexistent and empty variables. These expansions are handy for handling missing positional parameters and assigning default values to parameters. Here is one such expansion:

```
${parameter:-word}
```

If *parameter* is unset (i.e., does not exist) or is empty, this expansion results in the value of *word*. If *parameter* is not empty, the expansion results in the value of *parameter*.

```
[me@linuxbox ~]$ foo=
[me@linuxbox ~]$ echo ${foo:-"substitute value if unset"}
substitute value if unset
[me@linuxbox ~]$ echo $foo

[me@linuxbox ~]$ foo=bar
[me@linuxbox ~]$ echo ${foo:-"substitute value if unset"}
bar
[me@linuxbox ~]$ echo $foo
bar
```

Here is another expansion, in which we use the equal sign instead of a dash:

```
${parameter:=word}
```

If *parameter* is unset or empty, this expansion results in the value of *word*. In addition, the value of *word* is assigned to *parameter*. If *parameter* is not empty, the expansion results in the value of *parameter*.

```
[me@linuxbox ~]$ foo=
[me@linuxbox ~]$ echo ${foo:="default value if unset"}
default value if unset
[me@linuxbox ~]$ echo $foo
default value if unset
[me@linuxbox ~]$ foo=bar
[me@linuxbox ~]$ echo ${foo:="default value if unset"}
bar
[me@linuxbox ~]$ echo $foo
bar
```

**NOTE** *Positional and other special parameters cannot be assigned this way.*

Here we use a question mark:

```
${parameter:?word}
```

If *parameter* is unset or empty, this expansion causes the script to exit with an error, and the contents of *word* are sent to standard error. If *parameter* is not empty, the expansion results in the value of *parameter*.

```
[me@linuxbox ~]$ foo=
[me@linuxbox ~]$ echo ${foo:?"parameter is empty"}
bash: foo: parameter is empty
[me@linuxbox ~]$ echo $?
1
```

```
[me@linuxbox ~]$ foo=bar
[me@linuxbox ~]$ echo ${foo:?"parameter is empty"}
bar
[me@linuxbox ~]$ echo $?
0
```

Here we use a plus sign:

```
${parameter:+word}
```

If *parameter* is unset or empty, the expansion results in nothing. If *parameter* is not empty, the value of *word* is substituted for *parameter*; however, the value of *parameter* is not changed.

```
[me@linuxbox ~]$ foo=
[me@linuxbox ~]$ echo ${foo:+"substitute value if set"}

[me@linuxbox ~]$ foo=bar
[me@linuxbox ~]$ echo ${foo:+"substitute value if set"}
substitute value if set
```

### Expansions That Return Variable Names

The shell has the ability to return the names of variables. This is used in some rather exotic situations.

```
${!prefix*}
${!prefix@}
```

This expansion returns the names of existing variables with names beginning with *prefix*. According to the `bash` documentation, both forms of the expansion perform identically. Here, we list all the variables in the environment with names that begin with `BASH`:

```
[me@linuxbox ~]$ echo ${!BASH*}
BASH BASH_ARGC BASH_ARGV BASH_COMMAND BASH_COMPLETION BASH_COMPLETION_DIR
BASH_LINENO BASH_SOURCE BASH_SUBSHELL BASH_VERSINFO BASH_VERSION
```

### String Operations

There is a large set of expansions that can be used to operate on strings. Many of these expansions are particularly well suited for operations on pathnames. The following expansion:

```
${#parameter}
```

expands into the length of the string contained by *parameter*. Normally, *parameter* is a string; however, if *parameter* is either `@` or `*`, then the expansion results in the number of positional parameters.

```
[me@linuxbox ~]$ foo="This string is long."
[me@linuxbox ~]$ echo "'$foo' is ${#foo} characters long."
'This string is long.' is 20 characters long.
```

The following expansions are used to extract a portion of the string contained in *parameter*:

```
${parameter:offset}
${parameter:offset:length}
```

The extraction begins at *offset* characters from the beginning of the string and continues until the end of the string, unless *length* is specified.

```
[me@linuxbox ~]$ foo="This string is long."
[me@linuxbox ~]$ echo ${foo:5}
string is long.
[me@linuxbox ~]$ echo ${foo:5:6}
string
```

If the value of *offset* is negative, it is taken to mean it starts from the end of the string rather than the beginning. Note that negative values must be preceded by a space to prevent confusion with the ${*parameter*:-*word*} expansion. *length*, if present, must not be less than zero.

If *parameter* is @, the result of the expansion is *length* positional parameters, starting at *offset*.

```
[me@linuxbox ~]$ foo="This string is long."
[me@linuxbox ~]$ echo ${foo: -5}
long.
[me@linuxbox ~]$ echo ${foo: -5:2}
lo
```

The following expansions remove a leading portion of the string contained in *parameter* defined by *pattern*.

```
${parameter#pattern}
${parameter##pattern}
```

*pattern* is a wildcard pattern like those used in pathname expansion. The difference in the two forms is that the # form removes the shortest match, while the ## form removes the longest match.

```
[me@linuxbox ~]$ foo=file.txt.zip
[me@linuxbox ~]$ echo ${foo#*.}
txt.zip
[me@linuxbox ~]$ echo ${foo##*.}
zip
```

The following are the same as the previous # and ## expansions, except they remove text from the end of the string contained in *parameter* rather than from the beginning.

```
${parameter%pattern}
${parameter%%pattern}
```

Here is an example:

```
[me@linuxbox ~]$ foo=file.txt.zip
[me@linuxbox ~]$ echo ${foo%.*}
file.txt
[me@linuxbox ~]$ echo ${foo%%.*}
file
```

The following expansions perform a search-and-replace operation upon the contents of *parameter*:

```
${parameter/pattern/string}
${parameter//pattern/string}
${parameter/#pattern/string}
${parameter/%pattern/string}
```

If text is found matching wildcard *pattern*, it is replaced with the contents of *string*. In the normal form, only the first occurrence of *pattern* is replaced. In the // form, all occurrences are replaced. The /# form requires that the match occur at the beginning of the string, and the /% form requires the match to occur at the end of the string. In every form, /*string* may be omitted, causing the text matched by *pattern* to be deleted.

```
[me@linuxbox ~]$ foo=JPG.JPG
[me@linuxbox ~]$ echo ${foo/JPG/jpg}
jpg.JPG
[me@linuxbox ~]$ echo ${foo//JPG/jpg}
jpg.jpg
[me@linuxbox ~]$ echo ${foo/#JPG/jpg}
jpg.JPG
[me@linuxbox ~]$ echo ${foo/%JPG/jpg}
JPG.jpg
```

Parameter expansion is a good thing to know. The string manipulation expansions can be used as substitutes for other common commands such as sed and cut. Expansions can improve the efficiency of scripts by eliminating the use of external programs. As an example, we will modify the longest-word program discussed in the previous chapter to use the parameter expansion ${#j} in place of the command substitution $(echo -n $j | wc -c) and its resulting subshell, like so:

```
#!/bin/bash

# longest-word3: find longest string in a file
```

```
for i; do
      if [[ -r "$i" ]]; then
            max_word=
            max_len=0
            for j in $(strings $i); do
                  len="${#j}"
                  if (( len > max_len )); then
                        max_len="$len"
                        max_word="$j"
                  fi
            done
            echo "$i: '$max_word' ($max_len characters)"
      fi
done
```

Next, we will compare the efficiency of the two versions by using the `time` command.

```
[me@linuxbox ~]$ time longest-word2 dirlist-usr-bin.txt
dirlist-usr-bin.txt: 'scrollkeeper-get-extended-content-list' (38 characters)

real      0m3.618s
user      0m1.544s
sys       0m1.768s
[me@linuxbox ~]$ time longest-word3 dirlist-usr-bin.txt
dirlist-usr-bin.txt: 'scrollkeeper-get-extended-content-list' (38 characters)

real      0m0.060s
user      0m0.056s
sys       0m0.008s
```

The original version of the script takes 3.618 seconds to scan the text file, while the new version, using parameter expansion, takes only 0.06 seconds, which is a significant improvement.

### Case Conversion

`bash` has four parameter expansions and two `declare` command options to support the uppercase/lowercase conversion of strings.

So, what is case conversion good for? Aside from the obvious aesthetic value, it has an important role in programming. Let's consider the case of a database lookup. Imagine that a user has entered a string into a data input field that we want to look up in a database. It's possible the user will enter the value in all uppercase letters or lowercase letters or a combination of both. We certainly don't want to populate our database with every possible permutation of uppercase and lowercase spellings. What to do?

A common approach to this problem is to *normalize* the user's input. That is, convert it into a standardized form before we attempt the database lookup. We can do this by converting all the characters in the user's input to either lower or uppercase and ensure that the database entries are normalized the same way.

The declare command can be used to normalize strings to either uppercase or lowercase. Using declare, we can force a variable to always contain the desired format no matter what is assigned to it.

```
#!/bin/bash

# ul-declare: demonstrate case conversion via declare

declare -u upper
declare -l lower

if [[ $1 ]]; then
        upper="$1"
        lower="$1"
        echo "$upper"
        echo "$lower"
fi
```

In the preceding script, we use declare to create two variables, upper and lower. We assign the value of the first command line argument (positional parameter 1) to each of the variables and then display them on the screen.

```
[me@linuxbox ~]$ ul-declare aBc
ABC
abc
```

As we can see, the command line argument (aBc) has been normalized.

In addition to declare, there are four parameter expansions that perform upper/lowercase conversion, as described in Table 34-1.

**Table 34-1:** Case Conversion Parameter Expansions

| Format | Result |
|---|---|
| ${*parameter*,,*pattern*} | Expand the value of *parameter* into all lowercase. *pattern* is an optional shell pattern that will limit which characters (for example, [A-F]) will be converted. See the bash man page for a full description of patterns. |
| ${*parameter*,*pattern*} | Expand the value of *parameter*, changing only the first character to lowercase. |
| ${*parameter*^^*pattern*} | Expand the value of *parameter* into all uppercase letters. |
| ${*parameter*^*pattern*} | Expand the value of *parameter*, changing only the first character to uppercase (capitalization). |

Here is a script that demonstrates these expansions:

```
#!/bin/bash

# ul-param: demonstrate case conversion via parameter expansion

if [[ "$1" ]]; then
```

```
        echo "${1,,}"
        echo "${1,}"
        echo "${1^^}"
        echo "${1^}"
fi
```

Here is the script in action:

```
[me@linuxbox ~]$ ul-param aBc
abc
aBc
ABC
ABc
```

Again, we process the first command line argument and output the four variations supported by the parameter expansions. While this script uses the first positional parameter, *parameter* may be any string, variable, or string expression.

## Arithmetic Evaluation and Expansion

We looked at arithmetic expansion in Chapter 7. It is used to perform various arithmetic operations on integers. Its basic form is as follows:

```
$((expression))
```

where *expression* is a valid arithmetic expression.

This is related to the compound command (( )) used for arithmetic evaluation (truth tests) we encountered in Chapter 27.

In previous chapters, we saw some of the common types of expressions and operators. Here, we will look at a more complete list.

### *Number Bases*

In Chapter 9, we got a look at octal (base 8) and hexadecimal (base 16) numbers. In arithmetic expressions, the shell supports integer constants in any base. Table 34-2 shows the notations used to specify the bases.

**Table 34-2:** Specifying Different Number Bases

| Notation | Description |
|---|---|
| *number* | By default, numbers without any notation are treated as decimal (base 10) integers. |
| 0*number* | In arithmetic expressions, numbers with a leading zero are considered octal. |
| 0x*number* | Hexadecimal notation. |
| *base*#*number* | *number* is in *base*. |

Here are some examples:

```
[me@linuxbox ~]$ echo $((0xff))
255
[me@linuxbox ~]$ echo $((2#11111111))
255
```

In the previous examples, we print the value of the hexadecimal number `ff` (the largest two-digit number) and the largest eight-digit binary (base 2) number.

### Unary Operators

There are two unary operators, `+` and `-`, which are used to indicate whether a number is positive or negative, respectively. An example is `-5`.

### Simple Arithmetic

Table 34-3 lists the ordinary arithmetic operators.

**Table 34-3:** Arithmetic Operators

| Operator | Description |
|---|---|
| + | Addition |
| - | Subtraction |
| * | Multiplication |
| / | Integer division |
| ** | Exponentiation |
| % | Modulo (remainder) |

Most of these are self-explanatory, but integer division and modulo require further discussion.

Since the shell's arithmetic operates only on integers, the results of division are always whole numbers.

```
[me@linuxbox ~]$ echo $(( 5 / 2 ))
2
```

This makes the determination of a remainder in a division operation more important.

```
[me@linuxbox ~]$ echo $(( 5 % 2 ))
1
```

By using the division and modulo operators, we can determine that 5 divided by 2 results in 2, with a remainder of 1.

Calculating the remainder is useful in loops. It allows an operation to be performed at specified intervals during the loop's execution. In the following example, we display a line of numbers, highlighting each multiple of 5:

```
#!/bin/bash

# modulo: demonstrate the modulo operator

for ((i = 0; i <= 20; i = i + 1)); do
      remainder=$((i % 5))
      if (( remainder == 0 )); then
            printf "<%d> " "$i"
      else
            printf "%d " "$i"
      fi
done
printf "\n"
```

When executed, the results look like this:

```
[me@linuxbox ~]$ modulo
<0> 1 2 3 4 <5> 6 7 8 9 <10> 11 12 13 14 <15> 16 17 18 19 <20>
```

### Assignment

Although its uses may not be immediately apparent, arithmetic expressions may perform assignment. We have performed assignment many times, though in a different context. Each time we give a variable a value, we are performing assignment. We can also do it within arithmetic expressions.

```
[me@linuxbox ~]$ foo=
[me@linuxbox ~]$ echo $foo

[me@linuxbox ~]$ if (( foo = 5 )); then echo "It is true."; fi
It is true.
[me@linuxbox ~]$ echo $foo
5
```

In the preceding example, we first assign an empty value to the variable `foo` and verify that it is indeed empty. Next, we perform an `if` with the compound command `(( foo = 5 ))`. This process does two interesting things: it assigns the value of 5 to the variable `foo`, and it evaluates to true because `foo` was assigned a non-zero value.

**NOTE** *It is important to remember the exact meaning of = in the previous expression. A single = performs assignment. `foo = 5` says "make `foo` equal to 5," while == evaluates equivalence. `foo == 5` says "does `foo` equal 5?" This is a common feature in many programming languages. In the shell, this can be a little confusing because the `test` command accepts a single = for string equivalence. This is yet another reason to use the more modern `[[ ]]` and `(( ))` compound commands in place of `test`.*

In addition to the = notation, the shell also provides notations that perform some very useful assignments, as described in Table 34-4.

**Table 34-4:** Assignment Operators

| Notation | Description |
|---|---|
| *parameter = value* | Simple assignment. Assigns *value* to *parameter*. |
| *parameter += value* | Addition. Equivalent to *parameter = parameter + value*. |
| *parameter -= value* | Subtraction. Equivalent to *parameter = parameter – value*. |
| *parameter *= value* | Multiplication. Equivalent to *parameter = parameter * value*. |
| *parameter /= value* | Integer division. Equivalent to *parameter = parameter / value*. |
| *parameter %= value* | Modulo. Equivalent to *parameter = parameter % value*. |
| *parameter++* | Variable post-increment. Equivalent to *parameter = parameter* + 1 (however, see the following discussion). |
| *parameter--* | Variable post-decrement. Equivalent to *parameter = parameter* - 1. |
| *++parameter* | Variable pre-increment. Equivalent to *parameter = parameter* + 1. |
| *--parameter* | Variable pre-decrement. Equivalent to *parameter = parameter* - 1. |

These assignment operators provide a convenient shorthand for many common arithmetic tasks. Of special interest are the increment (++) and decrement (--) operators, which increase or decrease the value of their parameters by one. This style of notation is taken from the C programming language and has been incorporated into a number of other programming languages, including bash.

The operators may appear either at the front of a parameter or at the end. While they both either increment or decrement the parameter by one, the two placements have a subtle difference. If placed at the front of the parameter, the parameter is incremented (or decremented) before the parameter is returned. If placed after, the operation is performed *after* the parameter is returned. This is rather strange, but it is the intended behavior. Here is a demonstration:

```
[me@linuxbox ~]$ foo=1
[me@linuxbox ~]$ echo $((foo++))
1
[me@linuxbox ~]$ echo $foo
2
```

If we assign the value of one to the variable foo and then increment it with the ++ operator placed after the parameter name, foo is returned with the value of one. However, if we look at the value of the variable a second time, we see the incremented value. If we place the ++ operator in front of the parameter, we get the more expected behavior.

```
[me@linuxbox ~]$ foo=1
[me@linuxbox ~]$ echo $((++foo))
2
```

```
[me@linuxbox ~]$ echo $foo
2
```

For most shell applications, prefixing the operator will be the most useful.

The ++ and -- operators are often used in conjunction with loops. We will make some improvements to our modulo script to tighten it up a bit.

```
#!/bin/bash

# modulo2: demonstrate the modulo operator

for ((i = 0; i <= 20; ++i )); do
      if (((i % 5) == 0 )); then
            printf "<%d> " "$i"
      else
            printf "%d " "$i"
      fi
done
printf "\n"
```

### *Bit Operations*

One class of operators manipulates numbers in an unusual way. These operators work at the bit level. They are used for certain kinds of low-level tasks, often involving setting or reading bit flags (see Table 34-5).

**Table 34-5:** Bit Operators

| Operator | Description |
|---|---|
| ~ | Bitwise negation. Negate all the bits in a number. |
| << | Left bitwise shift. Shift all the bits in a number to the left. |
| >> | Right bitwise shift. Shift all the bits in a number to the right. |
| & | Bitwise AND. Perform an AND operation on all the bits in two numbers. |
| \| | Bitwise OR. Perform an OR operation on all the bits in two numbers. |
| ^ | Bitwise XOR. Perform an exclusive OR operation on all the bits in two numbers. |

Note that there are also corresponding assignment operators (for example, <<=) for all but bitwise negation.

Here we will demonstrate producing a list of powers of 2, using the left bitwise shift operator:

```
[me@linuxbox ~]$ for ((i=0;i<8;++i)); do echo $((1<<i)); done
1
2
4
8
16
```

```
32
64
128
```

## Logic

As we discovered in Chapter 27, the (( )) compound command supports a variety of comparison operators. There are a few more that can be used to evaluate logic. Table 34-6 provides the complete list.

**Table 34-6:** Comparison Operators

| Operator | Description |
|---|---|
| <= | Less than or equal to. |
| >= | Greater than or equal to. |
| < | Less than. |
| > | Greater than. |
| == | Equal to. |
| != | Not equal to. |
| && | Logical AND. |
| \|\| | Logical OR. |
| *expr1?expr2:expr3* | Comparison (ternary) operator. If expression *expr1* evaluates to be nonzero (arithmetic true), then *expr2*; else *expr3*. |

When used for logical operations, expressions follow the rules of arithmetic logic; that is, expressions that evaluate as zero are considered false, while non-zero expressions are considered true. The (( )) compound command maps the results into the shell's normal exit codes.

```
[me@linuxbox ~]$ if ((1)); then echo "true"; else echo "false"; fi
true
[me@linuxbox ~]$ if ((0)); then echo "true"; else echo "false"; fi
false
```

The strangest of the logical operators is the ternary operator. This operator (which is modeled after the one in the C programming language) performs a stand-alone logical test. It can be used as a kind of if/then/else statement. It acts on three arithmetic expressions (strings won't work), and if the first expression is true (or non-zero), the second expression is performed. Otherwise, the third expression is performed. We can try this on the command line:

```
[me@linuxbox ~]$ a=0
[me@linuxbox ~]$ ((a<1?++a:--a))
[me@linuxbox ~]$ echo $a
1
```

```
[me@linuxbox ~]$ ((a<1?++a:--a))
[me@linuxbox ~]$ echo $a
0
```

Here we see a ternary operator in action. This example implements a toggle. Each time the operator is performed, the value of the variable a switches from zero to one or vice versa.

Please note that performing assignment within the expressions is not straightforward. When attempted, bash will declare an error.

```
[me@linuxbox ~]$ a=0
[me@linuxbox ~]$ ((a<1?a+=1:a-=1))
bash: ((: a<1?a+=1:a-=1: attempted assignment to non-variable (error token is "-=1")
```

This problem can be mitigated by surrounding the assignment expression with parentheses.

```
[me@linuxbox ~]$ ((a<1?(a+=1):(a-=1)))
```

Next is a more complete example of using arithmetic operators in a script that produces a simple table of numbers:

```
#!/bin/bash

# arith-loop: script to demonstrate arithmetic operators

finished=0
a=0
printf "a\ta**2\ta**3\n"
printf "=\t====\t====\n"

until ((finished)); do
      b=$((a**2))
      c=$((a**3))
      printf "%d\t%d\t%d\n" "$a" "$b" "$c"
      ((a<10?++a:(finished=1)))
done
```

In this script, we implement an until loop based on the value of the finished variable. Initially, the variable is set to zero (arithmetic false), and we continue the loop until it becomes non-zero. Within the loop, we calculate the square and cube of the counter variable a. At the end of the loop, the value of the counter variable is evaluated. If it is less than 10 (the maximum number of iterations), it is incremented by one, or else the variable finished is given the value of one, making finished arithmetically true, thereby terminating the loop. Running the script gives this result:

```
[me@linuxbox ~]$ arith-loop
a      a**2      a**3
=      ====      ====
0      0      0
```

```
1       1       1
2       4       8
3       9       27
4       16      64
5       25      125
6       36      216
7       49      343
8       64      512
9       81      729
10      100     1000
```

## bc—An Arbitrary Precision Calculator Language

We have seen how the shell can handle many types of integer arithmetic, but what if we need to perform higher math or even just use floating-point numbers? The answer is, we can't. At least not directly with the shell. To do this, we need to use an external program. There are several approaches we can take. Embedding Perl or AWK programs is one possible solution, but unfortunately, it's outside the scope of this book.

Another approach is to use a specialized calculator program. One such program found on many Linux systems is called `bc`.

The `bc` program reads a file written in its own C-like language and executes it. A `bc` script may be a separate file, or it may be read from standard input. The `bc` language supports quite a few features including variables, loops, and programmer-defined functions. We won't cover `bc` entirely here, just enough to get a taste. `bc` is well documented by its man page.

Let's start with a simple example. We'll write a `bc` script to add 2 plus 2.

```
/* A very simple bc script */

2 + 2
```

The first line of the script is a comment. `bc` uses the same syntax for comments as the C programming language. Comments, which may span multiple lines, begin with `/*` and end with `*/`.

### *Using bc*

If we save the previous `bc` script as `foo.bc`, we can run it this way:

```
[me@linuxbox ~]$ bc foo.bc
bc 1.06.94
Copyright 1991-1994, 1997, 1998, 2000, 2004, 2006 Free Software Foundation, Inc.
This is free software with ABSOLUTELY NO WARRANTY.
For details type `warranty'.
4
```

If we look carefully, we can see the result at the very bottom, after the copyright message. This message can be suppressed with the `-q` (quiet) option.

bc can also be used interactively.

```
[me@linuxbox ~]$ bc -q
2 + 2
4
quit
```

When using bc interactively, we simply type the calculations we want to perform, and the results are immediately displayed. The bc command quit ends the interactive session.

It is also possible to pass a script to bc via standard input.

```
[me@linuxbox ~]$ bc < foo.bc
4
```

The ability to take standard input means that we can use here documents, here strings, and pipes to pass scripts. This is a here string example:

```
[me@linuxbox ~]$ bc <<< "2+2"
4
```

## *An Example Script*

As a real-world example, we will construct a script that performs a common calculation, monthly loan payments. In the script that follows, we use a here document to pass a script to bc:

```
#!/bin/bash

# loan-calc: script to calculate monthly loan payments

PROGNAME="${0##*/}" # Use parameter expansion to get basename

usage () {
      cat <<- EOF
      Usage: $PROGNAME PRINCIPAL INTEREST MONTHS

      Where:

      PRINCIPAL is the amount of the loan.
      INTEREST is the APR as a number (7% = 0.07).
      MONTHS is the length of the loan's term.

      EOF
}

if (($# != 3)); then
      usage
      exit 1
fi

principal=$1
```

```
interest=$2
months=$3

bc <<- EOF
      scale = 10
      i = $interest / 12
      p = $principal
      n = $months
      a = p * ((i * ((1 + i) ^ n)) / (((1 + i) ^ n) - 1))
      print a, "\n"
EOF
```

When executed, the results look like this:

```
[me@linuxbox ~]$ loan-calc 135000 0.0775 180
1270.7222490000
```

This example calculates the monthly payment for a $135,000 loan at 7.75 percent APR for 180 months (15 years). Notice the precision of the answer. This is determined by the value given to the special `scale` variable in the `bc` script. A full description of the `bc` scripting language is provided by the `bc` man page. While its mathematical notation is slightly different from that of the shell (`bc` more closely resembles C), most of it will be quite familiar, based on what we have learned so far.

## Summing Up

In this chapter, we learned about many of the little things that can be used to get the "real work" done in scripts. As our experience with scripting grows, the ability to effectively manipulate strings and numbers will prove extremely valuable. Our `loan-calc` script demonstrates that even simple scripts can be created to do some really useful things.

## Extra Credit

While the basic functionality of the `loan-calc` script is in place, the script is far from complete. For extra credit, try improving the `loan-calc` script with the following features:

- Full verification of the command line arguments
- A command line option to implement an "interactive" mode that will prompt the user to input the principal, interest rate, and term of the loan
- A better format for the output

# 35

# ARRAYS

In the previous chapter, we looked at how the shell can manipulate strings and numbers. The data types we have looked at so far are known in computer science circles as *scalar variables*; that is, they are variables that contain a single value.

In this chapter, we will look at another kind of data structure called an *array*, which holds multiple values. Arrays are a feature of virtually every programming language. The shell supports them, too, though in a rather limited fashion. Even so, they can be very useful for solving some types of programming problems.

## What Are Arrays?

Arrays are variables that hold more than one value at a time. Arrays are organized like a table. Let's consider a spreadsheet as an example. A spreadsheet acts like a *two-dimensional array*. It has both rows and columns, and an

individual cell in the spreadsheet can be located according to its row and column address. An array behaves the same way. An array has cells, which are called *elements*, and each element contains data. An individual array element is accessed using an address called an *index* or *subscript*.

Most programming languages support *multidimensional arrays*. A spreadsheet is an example of a multidimensional array with two dimensions, width and height. Many languages support arrays with an arbitrary number of dimensions, though two- and three-dimensional arrays are probably the most commonly used.

Arrays in `bash` are limited to a single dimension. We can think of them as a spreadsheet with a single column. Even with this limitation, there are many applications for them. Array support first appeared in `bash` version 2. The original Unix shell program, `sh`, did not support arrays at all.

## Creating an Array

Array variables are named just like other `bash` variables and are created automatically when they are accessed. Here is an example:

```
[me@linuxbox ~]$ a[1]=foo
[me@linuxbox ~]$ echo ${a[1]}
foo
```

Here we see an example of both the assignment and access of an array element. With the first command, element 1 of array `a` is assigned the value `foo`. The second command displays the stored value of element 1. The use of braces in the second command is required to prevent the shell from attempting pathname expansion on the name of the array element.

An array can also be created with the `declare` command.

```
[me@linuxbox ~]$ declare -a a
```

Using the `-a` option, this example of `declare` creates the array `a`.

## Assigning Values to an Array

Values may be assigned in one of two ways. Single values may be assigned using the following syntax:

```
name[subscript]=value
```

where *`name`* is the name of the array and *`subscript`* is an integer (or arithmetic expression) greater than or equal to zero. Note that an array's first element is subscript zero, not one. *`value`* is a string or integer assigned to the array element.

Multiple values may be assigned using the following syntax:

```
name=(value1 value2 ...)
```

where *name* is the name of the array and the *value* placeholders are values assigned sequentially to elements of the array, starting with element zero. For example, if we wanted to assign abbreviated days of the week to the array days, we could do this:

```
[me@linuxbox ~]$ days=(Sun Mon Tue Wed Thu Fri Sat)
```

It is also possible to assign values to a specific element by specifying a subscript for each value.

```
[me@linuxbox ~]$ days=([0]=Sun [1]=Mon [2]=Tue [3]=Wed [4]=Thu [5]=Fri [6]=Sat)
```

## Accessing Array Elements

So, what are arrays good for? Just as many data-management tasks can be performed with a spreadsheet program, many programming tasks can be performed with arrays.

Let's consider a simple data-gathering and presentation example. We will construct a script that examines the modification times of the files in a specified directory. From this data, our script will output a table showing at what hour of the day the files were last modified. Such a script could be used to determine when a system is most active. This script, called hours, produces this result:

```
[me@linuxbox ~]$ hours .
Hour  Files  Hour  Files
----  -----  ----  -----
00    0      12    11
01    1      13    7
02    0      14    1
03    0      15    7
04    1      16    6
05    1      17    5
06    6      18    4
07    3      19    4
08    1      20    1
09    14     21    0
10    2      22    0
11    5      23    0

Total files = 80
```

We execute the hours program, specifying the current directory as the target. It produces a table showing, for each hour of the day (0–23), how many files were last modified. The code to produce this is as follows:

```
#!/bin/bash

# hours: script to count files by modification time
```

```
usage () {
      echo "usage: ${0##*/} directory" >&2
}

# Check that argument is a directory
if [[ ! -d "$1" ]]; then
      usage
      exit 1
fi

# Initialize array
for i in {0..23}; do hours[i]=0; done

# Collect data
for i in $(stat -c %y "$1"/* | cut -c 12-13); do
      j="${i#0}"
      ((++hours[j]))
      ((++count))
done

# Display data
echo -e "Hour\tFiles\tHour\tFiles"
echo -e "----\t-----\t----\t-----"
for i in {0..11}; do
      j=$((i + 12))
      printf "%02d\t%d\t%02d\t%d\n" \
            "$i" \
            "${hours[i]}" \
            "$j" \
            "${hours[j]}"
done
printf "\nTotal files = %d\n" $count
```

The script consists of one function (`usage`) and a main body with four sections. In the first section, we check that there is a command line argument and that it is a directory. If it is not, we display the usage message and exit.

The second section initializes the array `hours`. It does this by assigning each element a value of zero. There is no special requirement to prepare arrays prior to use, but our script needs to ensure that no element is empty. Note the interesting way the loop is constructed. By employing brace expansion (`{0..23}`), we are able to easily generate a sequence of words for the `for` command.

The next section gathers the data by running the `stat` program on each file in the directory. We use `cut` to extract the two-digit hour from the result. Inside the loop, we need to remove leading zeros from the hour field since the shell will try (and ultimately fail) to interpret values 00 through 09 as octal numbers (see Table 34-2). Next, we increment the value of the array element corresponding with the hour of the day. Finally, we increment a counter (`count`) to track the total number of files in the directory.

The last section of the script displays the contents of the array. We first output a couple of header lines and then enter a loop that produces four columns of output. Lastly, we output the final tally of files.

## Array Operations

There are many common array operations. Such things as deleting arrays, determining their size, sorting, and so on, have many applications in scripting.

### *Outputting the Entire Contents of an Array*

The subscripts * and @ can be used to access every element in an array. As with positional parameters, the @ notation is the more useful of the two. Here is a demonstration:

```
[me@linuxbox ~]$ animals=("a dog" "a cat" "a fish")
[me@linuxbox ~]$ for i in ${animals[*]}; do echo $i; done
a
dog
a
cat
a
fish
[me@linuxbox ~]$ for i in ${animals[@]}; do echo $i; done
a
dog
a
cat
a
fish
[me@linuxbox ~]$ for i in "${animals[*]}"; do echo $i; done
a dog a cat a fish
[me@linuxbox ~]$ for i in "${animals[@]}"; do echo $i; done
a dog
a cat
a fish
```

We create the array `animals` and assign it three two-word strings. We then execute four loops to see the effect of word splitting on the array contents. The behavior of notations `${animals[*]}` and `${animals[@]}` is identical until they are quoted. The * notation results in a single word containing the array's contents, while the @ notation results in three two-word strings, which matches the array's "real" contents.

### *Determining the Number of Array Elements*

Using parameter expansion, we can determine the number of elements in an array in much the same way as finding the length of a string. Here is an example:

```
[me@linuxbox ~]$ a[100]=foo
[me@linuxbox ~]$ echo ${#a[@]}  # number of array elements
1
[me@linuxbox ~]$ echo ${#a[100]}  # length of element 100
3
```

We create array a and assign the string foo to element 100. Next, we use parameter expansion to examine the length of the array, using the @ notation. Finally, we look at the length of element 100, which contains the string foo. It is interesting to note that while we assigned our string to element 100, bash reports only one element in the array. This differs from the behavior of some other languages in which the unused elements of the array (elements 0–99) would be initialized with empty values and counted. In bash, array elements exist only if they have been assigned a value regardless of their subscript.

### Finding the Subscripts Used by an Array

As bash allows arrays to contain "gaps" in the assignment of subscripts, it is sometimes useful to determine which elements actually exist. This can be done with a parameter expansion using the following forms:

```
${!array[*]}
${!array[@]}
```

where *array* is the name of an array variable. Like the other expansions that use * and @, the @ form enclosed in quotes is the most useful, as it expands into separate words.

```
[me@linuxbox ~]$ foo=([2]=a [4]=b [6]=c)
[me@linuxbox ~]$ for i in "${foo[@]}"; do echo $i; done
a
b
c
[me@linuxbox ~]$ for i in "${!foo[@]}"; do echo $i; done
2
4
6
```

### Adding Elements to the End of an Array

Knowing the number of elements in an array is no help if we need to append values to the end of an array since the values returned by the * and @ notations do not tell us the maximum array index in use. Fortunately, the shell provides us with a solution. By using the += assignment operator, we can automatically append values to the end of an array. Here, we assign three values to the array foo and then append three more:

```
[me@linuxbox ~]$ foo=(a b c)
[me@linuxbox ~]$ echo ${foo[@]}
a b c
[me@linuxbox ~]$ foo+=(d e f)
[me@linuxbox ~]$ echo ${foo[@]}
a b c d e f
```

### Sorting an Array

Just as with spreadsheets, it is often necessary to sort the values in a column of data. The shell has no direct way of doing this, but it's not hard to do with a little coding.

```
#!/bin/bash

# array-sort: Sort an array

a=(f e d c b a)

echo "Original array: ${a[@]}"
a_sorted=($(for i in "${a[@]}"; do echo $i; done | sort))
echo "Sorted array:   ${a_sorted[@]}"
```

When executed, the script produces this:

```
[me@linuxbox ~]$ array-sort
Original array: f e d c b a
Sorted array:   a b c d e f
```

The script operates by copying the contents of the original array (`a`) into a second array (`a_sorted`) with a tricky piece of command substitution. This basic technique can be used to perform many kinds of operations on the array by changing the design of the pipeline.

### Deleting an Array

To delete an array, use the `unset` command.

```
[me@linuxbox ~]$ foo=(a b c d e f)
[me@linuxbox ~]$ echo ${foo[@]}
a b c d e f
[me@linuxbox ~]$ unset foo
[me@linuxbox ~]$ echo ${foo[@]}

[me@linuxbox ~]$
```

`unset` may also be used to delete single array elements.

```
[me@linuxbox ~]$ foo=(a b c d e f)
[me@linuxbox ~]$ echo ${foo[@]}
a b c d e f
[me@linuxbox ~]$ unset 'foo[2]'
[me@linuxbox ~]$ echo ${foo[@]}
a b d e f
```

In this example, we delete the third element of the array, subscript 2. Remember, arrays start with subscript zero, not one! Notice also that the array element must be quoted to prevent the shell from performing pathname expansion.

Interestingly, the assignment of an empty value to an array does not empty its contents.

```
[me@linuxbox ~]$ foo=(a b c d e f)
[me@linuxbox ~]$ foo=
[me@linuxbox ~]$ echo ${foo[@]}
b c d e f
```

Any reference to an array variable without a subscript refers to element zero of the array.

```
[me@linuxbox ~]$ foo=(a b c d e f)
[me@linuxbox ~]$ echo ${foo[@]}
a b c d e f
[me@linuxbox ~]$ foo=A
[me@linuxbox ~]$ echo ${foo[@]}
A b c d e f
```

## Associative Arrays

`bash` versions 4.0 and greater support *associative arrays*. Associative arrays use strings rather than integers as array indexes. This capability allows interesting new approaches to managing data. For example, we can create an array called `colors` and use color names as indexes.

```
declare -A colors
colors["red"]="#ff0000"
colors["green"]="#00ff00"
colors["blue"]="#0000ff"
```

Unlike integer indexed arrays, which are created by merely referencing them, associative arrays must be created with the `declare` command using the new `-A` option. Associative array elements are accessed in much the same way as integer-indexed arrays.

```
echo ${colors["blue"]}
```

In the next chapter, we will look at a script that makes good use of associative arrays to produce an interesting report.

## Summing Up

If we search the `bash` man page for the word *array*, we find many instances of where `bash` makes use of array variables. Most of these are rather obscure, but they may provide occasional utility in some special circumstances. In fact, the entire topic of arrays is rather under-utilized in shell programming

owing largely to the fact that the traditional Unix shell programs (such as `sh`) lacked any support for arrays. This lack of popularity is unfortunate because arrays are widely used in other programming languages and provide a powerful tool for solving many kinds of programming problems.

Arrays and loops have a natural affinity and are often used together. The following form of loop is particularly well-suited to calculating array subscripts:

```
for ((expr; expr; expr))
```

# 36

# EXOTICA

In this, the final chapter of our journey, we will look at some odds and ends. While we have certainly covered a lot of ground in the previous chapters, there are many bash features that we have not covered. Most are fairly obscure and useful mainly to those integrating bash into a Linux distribution. However, there are a few that, while not in common use, are helpful for certain programming problems. We will cover them here.

## Group Commands and Subshells

bash allows commands to be grouped together. This can be done in one of two ways, either with a *group command* or with a *subshell*.

Here is the syntax of a group command:

```
{ command1; command2; [command3; ...] }
```

Here is the syntax of a subshell:

```
(command1; command2; [command3;...])
```

The two forms differ in that a group command surrounds its commands with braces and a subshell uses parentheses. It is important to note that because of the way bash implements group commands, the braces must be separated from the commands by a space and the last command must be terminated with either a semicolon or a newline prior to the closing brace.

So, what are group commands and subshells good for? While they have an important difference (which we will get to in a moment), they are both used to manage redirection. Let's consider a script segment that performs redirections on multiple commands.

```
ls -l > output.txt
echo "Listing of foo.txt" >> output.txt
cat foo.txt >> output.txt
```

This is pretty straightforward. Three commands have their output redirected to a file named *output.txt*. Using a group command, we could code this as follows:

```
{ ls -l; echo "Listing of foo.txt"; cat foo.txt; } > output.txt
```

Using a subshell is similar.

```
(ls -l; echo "Listing of foo.txt"; cat foo.txt) > output.txt
```

Using this technique we have saved ourselves some typing, but where a group command or subshell really shines is with pipelines. When constructing a pipeline of commands, it is often useful to combine the results of several commands into a single stream. Group commands and subshells make this easy.

```
{ ls -l; echo "Listing of foo.txt"; cat foo.txt; } | lpr
```

Here we have combined the output of our three commands and piped them into the input of lpr to produce a printed report.

In the script that follows, we will use groups commands and look at several programming techniques that can be employed in conjunction with associative arrays. This script, called array-2, when given the name of a directory, prints a listing of the files in the directory along with the names of the file's owner and group owner. At the end of the listing, the script prints a tally of the number of files belonging to each owner and group. Here we see the results (condensed for brevity) when the script is given the directory */usr/bin*:

```
[me@linuxbox ~]$ array-2 /usr/bin
/usr/bin/2to3-2.6                        root       root
```

```
/usr/bin/2to3                           root       root
/usr/bin/a2p                            root       root
/usr/bin/abrowser                       root       root
/usr/bin/aconnect                       root       root
/usr/bin/acpi_fakekey                   root       root
/usr/bin/acpi_listen                    root       root
/usr/bin/add-apt-repository             root       root
--snip--
/usr/bin/zipgrep                        root       root
/usr/bin/zipinfo                        root       root
/usr/bin/zipnote                        root       root
/usr/bin/zip                            root       root
/usr/bin/zipsplit                       root       root
/usr/bin/zjsdecode                      root       root
/usr/bin/zsoelim                        root       root

File owners:
daemon    :     1 file(s)
root      :  1394 file(s)

File group owners:
crontab   :     1 file(s)
daemon    :     1 file(s)
lpadmin   :     1 file(s)
mail      :     4 file(s)
mlocate   :     1 file(s)
root      :  1380 file(s)
shadow    :     2 file(s)
ssh       :     1 file(s)
tty       :     2 file(s)
utmp      :     2 file(s)
```

Here is a listing (with line numbers) of the script:

```
1    #!/bin/bash
2
3    # array-2: Use arrays to tally file owners
4
5    declare -A files file_group file_owner groups owners
6
7    if [[ ! -d "$1" ]]; then
8        echo "Usage: array-2 dir" >&2
9        exit 1
10   fi
11
12   for i in "$1"/*; do
13       owner="$(stat -c %U "$i")"
14       group="$(stat -c %G "$i")"
15       files["$i"]="$i"
16       file_owner["$i"]="$owner"
17       file_group["$i"]="$group"
18       ((++owners[$owner]))
19       ((++groups[$group]))
20   done
```

```
21
22    # List the collected files
23    { for i in "${files[@]}"; do
24        printf "%-40s %-10s %-10s\n" \
25            "$i" "${file_owner["$i"]}" "${file_group["$i"]}"
26    done } | sort
27    echo
28
29    # List owners
30    echo "File owners:"
31    { for i in "${!owners[@]}"; do
32        printf "%-10s: %5d file(s)\n" "$i" "${owners["$i"]}"
33    done } | sort
34    echo
35
36    # List groups
37    echo "File group owners:"
38    { for i in "${!groups[@]}"; do
39        printf "%-10s: %5d file(s)\n" "$i" "${groups["$i"]}"
40    done } | sort
```

Let's take a look at the mechanics of this script.

**Line 5:** Associative arrays must be created with the `declare` command using the `-A` option. In this script, we create five arrays as follows:

- `files` contains the names of the files in the directory, indexed by filename.
- `file_group` contains the group owner of each file, indexed by filename.
- `file_owner` contains the owner of each file, indexed by filename.
- `groups` contains the number of files belonging to the indexed group.
- `owners` contains the number of files belonging to the indexed owner.

**Lines 7–10:** These lines check to see that a valid directory name was passed as a positional parameter. If not, a usage message is displayed, and the script exits with an exit status of 1.

**Lines 12–20:** These lines loop through the files in the directory. Using the `stat` command, lines 13 and 14 extract the names of the file owner and group owner and assign the values to their respective arrays (lines 16 and 17) using the name of the file as the array index. Likewise, the filename itself is assigned to the `files` array (line 15).

**Lines 18–19:** The total number of files belonging to the file owner and group owner are incremented by one.

**Lines 22–27:** The list of files is output. This is done using the `"${array[@]}"` parameter expansion, which expands into the entire list of array elements with each element treated as a separate word. This allows for the possibility that a filename may contain embedded spaces. Also note that the entire loop is enclosed in braces thus forming a group

command. This permits the entire output of the loop to be piped into the `sort` command. This is necessary because the expansion of the array elements is not sorted.

**Lines 29–40:** These two loops are similar to the file list loop except that they use the `"${!array[@]}"` expansion, which expands into the list of array indexes rather than the list of array elements.

### *Process Substitution*

While they look similar and can both be used to combine streams for redirection, there is an important difference between group commands and subshells. Whereas a group command executes all of its commands in the current shell, a subshell (as the name suggests) executes its commands in a child copy of the current shell. This means the environment is copied and given to a new instance of the shell. When the subshell exits, the copy of the environment is lost, so any changes made to the subshell's environment (including variable assignment) are lost as well. Therefore, in most cases, unless a script requires a subshell, group commands are preferable to subshells. Group commands are both faster and require less memory.

We saw an example of the subshell environment problem in Chapter 28, when we discovered that a `read` command in a pipeline does not work as we might intuitively expect. To recap, if we construct a pipeline like this:

```
echo "foo" | read
echo $REPLY
```

the content of the `REPLY` variable is always empty because the `read` command is executed in a subshell, and its copy of `REPLY` is destroyed when the subshell terminates.

Because commands in pipelines are always executed in subshells, any command that assigns variables will encounter this issue. Fortunately, the shell provides an exotic form of expansion called *process substitution* that can be used to work around this problem.

Process substitution is expressed in two ways.

For processes that produce standard output, it looks like this:

```
<(list)
```

For processes that intake standard input, it looks like this:

```
>(list)
```

where *`list`* is a list of commands.

To solve our problem with `read`, we can employ process substitution like this.

```
read < <(echo "foo")
echo $REPLY
```

Process substitution allows us to treat the output of a subshell as an ordinary file for purposes of redirection. In fact, since it is a form of expansion, we can examine its real value.

```
[me@linuxbox ~]$ echo <(echo "foo")
/dev/fd/63
```

By using echo to view the result of the expansion, we see that the output of the subshell is being provided by a file named */dev/fd/63*.

Process substitution is often used with loops containing read. Here is an example of a read loop that processes the contents of a directory listing created by a subshell:

```
#!/bin/bash

# pro-sub: demo of process substitution

while read attr links owner group size date time filename; do
      cat << EOF
            Filename:   $filename
            Size:       $size
            Owner:      $owner
            Group:      $group
            Modified:   $date $time
            Links:      $links
            Attributes: $attr

EOF
done < <(ls -l | tail -n +2)
```

The loop executes read for each line of a directory listing. The listing itself is produced on the final line of the script. This line redirects the output of the process substitution into the standard input of the loop. The tail command is included in the process substitution pipeline to eliminate the first line of the listing, which is not needed.

When executed, the script produces output like this:

```
[me@linuxbox ~]$ pro-sub | head -n 20
Filename:   addresses.ldif
Size:       14540
Owner:      me
Group:      me
Modified:   2009-04-02 11:12
Links:      1
Attributes: -rw-r--r—

Filename:   bin
Size:       4096
Owner:      me
Group:      me
Modified:   2009-07-10 07:31
Links:      2
```

```
Attributes: drwxr-xr-x

Filename:   bookmarks.html
Size:       394213
Owner:      me
Group:      me
```

## Traps

In Chapter 10, we saw how programs can respond to signals. We can add this capability to our scripts, too. While the scripts we have written so far have not needed this capability (because they have very short execution times and do not create temporary files), larger and more complicated scripts may benefit from having a signal handling routine.

When we design a large, complicated script, it is important to consider what happens if the user logs off or shuts down the computer while the script is running. When such an event occurs, a signal will be sent to all affected processes. In turn, the programs representing those processes can perform actions to ensure a proper and orderly termination of the program. Let's say, for example, that we wrote a script that created a temporary file during its execution. In the course of good design, we would have the script delete the file when the script finishes its work. It would also be smart to have the script delete the file if a signal is received indicating that the program was going to be terminated prematurely.

`bash` provides a mechanism for this purpose known as a *trap*. Traps are implemented with the appropriately named builtin command, `trap`. `trap` uses the following syntax:

```
trap argument signal [signal...]
```

where *`argument`* is a string that will be read and treated as a command and *`signal`* is the specification of a signal that will trigger the execution of the interpreted command.

Here is a simple example:

```
#!/bin/bash

# trap-demo: simple signal handling demo

trap "echo 'I am ignoring you.'" SIGINT SIGTERM

for i in {1..5}; do
      echo "Iteration $i of 5"
      sleep 5
done
```

This script defines a trap that will execute an `echo` command each time either the `SIGINT` or `SIGTERM` signal is received while the script is running.

Execution of the program looks like this when the user attempts to stop the script by pressing CTRL-C:

```
[me@linuxbox ~]$ trap-demo
Iteration 1 of 5
Iteration 2 of 5
^CI am ignoring you.
Iteration 3 of 5
^CI am ignoring you.
Iteration 4 of 5
Iteration 5 of 5
```

As we can see, each time the user attempts to interrupt the program, the message is printed instead.

Constructing a string to form a useful sequence of commands can be awkward, so it is common practice to specify a shell function as the command. In this example, a separate shell function is specified for each signal to be handled:

```
#!/bin/bash

# trap-demo2: simple signal handling demo

exit_on_signal_SIGINT () {
      echo "Script interrupted." 2>&1
      exit 0
}

exit_on_signal_SIGTERM () {
      echo "Script terminated." 2>&1
      exit 0
}

trap exit_on_signal_SIGINT SIGINT
trap exit_on_signal_SIGTERM SIGTERM

for i in {1..5}; do
      echo "Iteration $i of 5"
      sleep 5
done
```

This script features two `trap` commands, one for each signal. Each trap, in turn, specifies a shell function to be executed when the particular signal is received. Note the inclusion of an `exit` command in each of the signal-handling functions. Without an `exit`, the script would continue after completing the function.

When the user presses CTRL-C during the execution of this script, the results look like this:

```
[me@linuxbox ~]$ trap-demo2
Iteration 1 of 5
Iteration 2 of 5
^CScript interrupted.
```

### TEMPORARY FILES

One reason signal handlers are included in scripts is to remove temporary files that the script may create to hold intermediate results during execution. There is something of an art to naming temporary files. Traditionally, programs on Unix-like systems create their temporary files in the */tmp* directory, a shared directory intended for such files. However, since the directory is shared, this poses certain security concerns, particularly for programs running with superuser privileges. Aside from the obvious step of setting proper permissions for files exposed to all users of the system, it is important to give temporary files nonpredictable filenames. This avoids an exploit known as a *temp race attack*. One way to create a nonpredictable (but still descriptive) name is to do something like this:

```
tempfile=/tmp/$(basename $0).$$.$RANDOM
```

This will create a filename consisting of the program's name, followed by its process ID (PID), followed by a random integer. Note, however, that the `$RANDOM` shell variable returns a value only in the range of 1–32767, which is not a large range in computer terms, so a single instance of the variable is not sufficient to overcome a determined attacker.

A better way is to use the `mktemp` program (not to be confused with the `mktemp` standard library function) to both name and create the temporary file. The `mktemp` program accepts a template as an argument that is used to build the filename. The template should include a series of `X` characters, which are replaced by a corresponding number of random letters and numbers. The longer the series of `X` characters, the longer the series of random characters. Here is an example:

```
tempfile=$(mktemp /tmp/foobar.$$.XXXXXXXXXX)
```

This creates a temporary file and assigns its name to the variable `tempfile`. The `X` characters in the template are replaced with random letters and numbers so that the final filename (which, in this example, also includes the expanded value of the special parameter `$$` to obtain the PID) might be something like this:

```
/tmp/foobar.6593.UOZuvM6654
```

For scripts that are executed by regular users, it may be wise to avoid the use of the */tmp* directory and create a directory for temporary files within the user's home directory, with a line of code such as this:

```
[[ -d $HOME/tmp ]] || mkdir $HOME/tmp
```

## Asynchronous Execution with wait

It is sometimes desirable to perform more than one task at the same time. We have seen how all modern operating systems are at least multitasking if not multiuser as well. Scripts can be constructed to behave in a multitasking fashion.

Usually this involves launching a script that, in turn, launches one or more child scripts to perform an additional task while the parent script continues to run. However, when a series of scripts runs this way, there can be problems keeping the parent and child coordinated. That is, what if the parent or child is dependent on the other and one script must wait for the other to finish its task before finishing its own?

`bash` has a builtin command to help manage *asynchronous execution* such as this. The `wait` command causes a parent script to pause until a specified process (i.e., the child script) finishes. To demonstrate this, we will need two scripts. The first is a parent script.

```
#!/bin/bash

# async-parent: Asynchronous execution demo (parent)

echo "Parent: starting..."

echo "Parent: launching child script..."
async-child &
pid=$!
echo "Parent: child (PID= $pid) launched."

echo "Parent: continuing..."
sleep 2

echo "Parent: pausing to wait for child to finish..."
wait "$pid"

echo "Parent: child is finished. Continuing..."
echo "Parent: parent is done. Exiting."
```

This second is a child script.

```
#!/bin/bash

# async-child: Asynchronous execution demo (child)

echo "Child: child is running..."
sleep 5
echo "Child: child is done. Exiting."
```

In this example, we see that the child script is simple. The real action is being performed by the parent. In the parent script, the child script is launched and put into the background. The process ID of the child script

is recorded by assigning the `pid` variable with the value of the `$!` shell parameter, which will always contain the process ID of the last job put into the background.

The parent script continues and then executes a `wait` command with the PID of the child process. This causes the parent script to pause until the child script exits, at which point the parent script concludes.

When executed, the parent and child scripts produce the following output:

```
[me@linuxbox ~]$ async-parent
Parent: starting...
Parent: launching child script...
Parent: child (PID= 6741) launched.
Parent: continuing...
Child: child is running...
Parent: pausing to wait for child to finish...
Child: child is done. Exiting.
Parent: child is finished. Continuing...
Parent: parent is done. Exiting.
```

## Named Pipes

In most Unix-like systems, it is possible to create a special type of file called a *named pipe*. Named pipes are used to create a connection between two processes and can be used just like other types of files. They are not that popular, but they're good to know about.

There is a common programming architecture called *client-server*, which can make use of a communication method such as named pipes, as well as other kinds of *interprocess communication* such as network connections.

The most widely used type of client-server system is, of course, a web browser communicating with a web server. The web browser acts as the client, making requests to the server, and the server responds to the browser with web pages.

Named pipes behave like files but actually form first-in first-out (FIFO) buffers. As with ordinary (unnamed) pipes, data goes in one end and emerges out the other. With named pipes, it is possible to set up something like this:

```
process1 > named_pipe
```

and this:

```
process2 < named_pipe
```

and it will behave like this:

```
process1 | process2
```

### Setting Up a Named Pipe

First, we must create a named pipe. This is done using the `mkfifo` command.

```
[me@linuxbox ~]$ mkfifo pipe1
[me@linuxbox ~]$ ls -l pipe1
prw-r--r-- 1 me   me    0 2018-07-17 06:41 pipe1
```

Here we use `mkfifo` to create a named pipe called `pipe1`. Using `ls`, we examine the file and see that the first letter in the attributes field is `p`, indicating that it is a named pipe.

### Using Named Pipes

To demonstrate how the named pipe works, we will need two terminal windows (or alternately, two virtual consoles). In the first terminal, we enter a simple command and redirect its output to the named pipe.

```
[me@linuxbox ~]$ ls -l > pipe1
```

After we press ENTER, the command will appear to hang. This is because there is nothing receiving data from the other end of the pipe yet. When this occurs, it is said that the pipe is *blocked*. This condition will clear once we attach a process to the other end and it begins to read input from the pipe. Using the second terminal window, we enter this command:

```
[me@linuxbox ~]$ cat < pipe1
```

The directory listing produced from the first terminal window appears in the second terminal as the output from the `cat` command. The `ls` command in the first terminal successfully completes once it is no longer blocked.

## Summing Up

Well, we have completed our journey. The only thing left to do now is practice, practice, practice. Even though we covered a lot of ground in our trek, we barely scratched the surface as far as the command line goes. There are still thousands of command line programs left to be discovered and enjoyed. Start digging around in */usr/bin* and you'll see!

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**ABOUT THE AUTHOR**

William Shotts has been a software professional and avid Linux user for more than 15 years. He has an extensive background in software development, including technical support, quality assurance, and documentation. He is also the creator of *LinuxCommand.org*, a Linux education and advocacy site featuring news, reviews, and extensive support for using the Linux command line.

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