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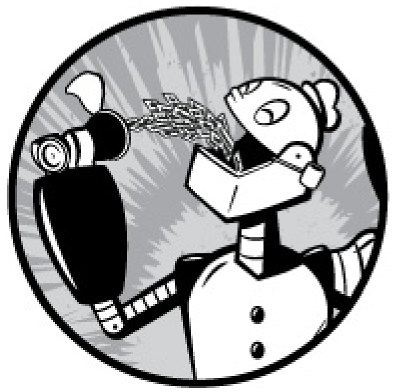
COMPILING PROGRAMS



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.