

- 2.23 How are iOS and Android similar? How are they different?
- 2.24 Explain why Java programs running on Android systems do not use the standard Java API and virtual machine.
- 2.25 The experimental Synthesis operating system has an assembler incorporated in the kernel. To optimize system-call performance, the kernel assembles routines within kernel space to minimize the path that the system call must take through the kernel. This approach is the antithesis of the layered approach, in which the path through the kernel is extended to make building the operating system easier. Discuss the pros and cons of the Synthesis approach to kernel design and system-performance optimization.

Programming Problems

- 2.26 In Section 2.3, we described a program that copies the contents of one file to a destination file. This program works by first prompting the user for the name of the source and destination files. Write this program using either the Windows or POSIX API. Be sure to include all necessary error checking, including ensuring that the source file exists.

Once you have correctly designed and tested the program, if you used a system that supports it, run the program using a utility that traces system calls. Linux systems provide the `strace` utility, and Solaris and Mac OS X systems use the `dtrace` command. As Windows systems do not provide such features, you will have to trace through the Windows version of this program using a debugger.

Programming Projects Start HERE

Linux Kernel Modules

In this project, you will learn how to create a kernel module and load it into the Linux kernel. The project can be completed using the Linux virtual machine that is available with this text. Although you may use an editor to write these C programs, you will have to use the *terminal* application to compile the programs, and you will have to enter commands on the command line to manage the modules in the kernel.

As you'll discover, the advantage of developing kernel modules is that it is a relatively easy method of interacting with the kernel, thus allowing you to write programs that directly invoke kernel functions. It is important for you to keep in mind that you are indeed writing *kernel code* that directly interacts with the kernel. That normally means that any errors in the code could crash the system! However, since you will be using a virtual machine, any failures will at worst only require rebooting the system.

Part I—Creating Kernel Modules

The first part of this project involves following a series of steps for creating and inserting a module into the Linux kernel.

You can list all kernel modules that are currently loaded by entering the command

```
lsmod
```

This command will list the current kernel modules in three columns: name, size, and where the module is being used.

The following program (named `simple.c` and available with the source code for this text) illustrates a very basic kernel module that prints appropriate messages when the kernel module is loaded and unloaded.

```
#include <linux/init.h>
#include <linux/kernel.h>
#include <linux/module.h>

/* This function is called when the module is loaded. */
int simple_init(void)
{
    printk(KERN_INFO "Loading Module\n");

    return 0;
}

/* This function is called when the module is removed. */
void simple_exit(void)
{
    printk(KERN_INFO "Removing Module\n");
}

/* Macros for registering module entry and exit points. */
module_init(simple_init);
module_exit(simple_exit);

MODULE_LICENSE("GPL");
MODULE_DESCRIPTION("Simple Module");
MODULE_AUTHOR("SGG");
```

The function `simple_init()` is the **module entry point**, which represents the function that is invoked when the module is loaded into the kernel. Similarly, the `simple_exit()` function is the **module exit point**—the function that is called when the module is removed from the kernel.

The module entry point function must return an integer value, with 0 representing success and any other value representing failure. The module exit point function returns void. Neither the module entry point nor the module exit point is passed any parameters. The two following macros are used for registering the module entry and exit points with the kernel:

```
module_init()
```

```
module_exit()
```

Notice how both the module entry and exit point functions make calls to the `printk()` function. `printk()` is the kernel equivalent of `printf()`, yet its output is sent to a kernel log buffer whose contents can be read by the `dmesg` command. One difference between `printf()` and `printk()` is that `printk()` allows us to specify a priority flag whose values are given in the `<linux/printk.h>` include file. In this instance, the priority is `KERN_INFO`, which is defined as an *informational* message.

The final lines—`MODULE_LICENSE()`, `MODULE_DESCRIPTION()`, and `MODULE_AUTHOR()`—represent details regarding the software license, description of the module, and author. For our purposes, we do not depend on this information, but we include it because it is standard practice in developing kernel modules.

This kernel module `simple.c` is compiled using the Makefile accompanying the source code with this project. To compile the module, enter the following on the command line:

```
make
```

The compilation produces several files. The file `simple.ko` represents the compiled kernel module. The following step illustrates inserting this module into the Linux kernel.

Loading and Removing Kernel Modules

Kernel modules are loaded using the `insmod` command, which is run as follows:

```
sudo insmod simple.ko
```

To check whether the module has loaded, enter the `lsmod` command and search for the module `simple`. Recall that the module entry point is invoked when the module is inserted into the kernel. To check the contents of this message in the kernel log buffer, enter the command

```
dmesg
```

You should see the message "Loading Module."

Removing the kernel module involves invoking the `rmmmod` command (notice that the `.ko` suffix is unnecessary):

```
sudo rmmmod simple
```

Be sure to check with the `dmesg` command to ensure the module has been removed.

Because the kernel log buffer can fill up quickly, it often makes sense to clear the buffer periodically. This can be accomplished as follows:

```
sudo dmesg -c
```