Custom EBook 3

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Operating_System_95_105

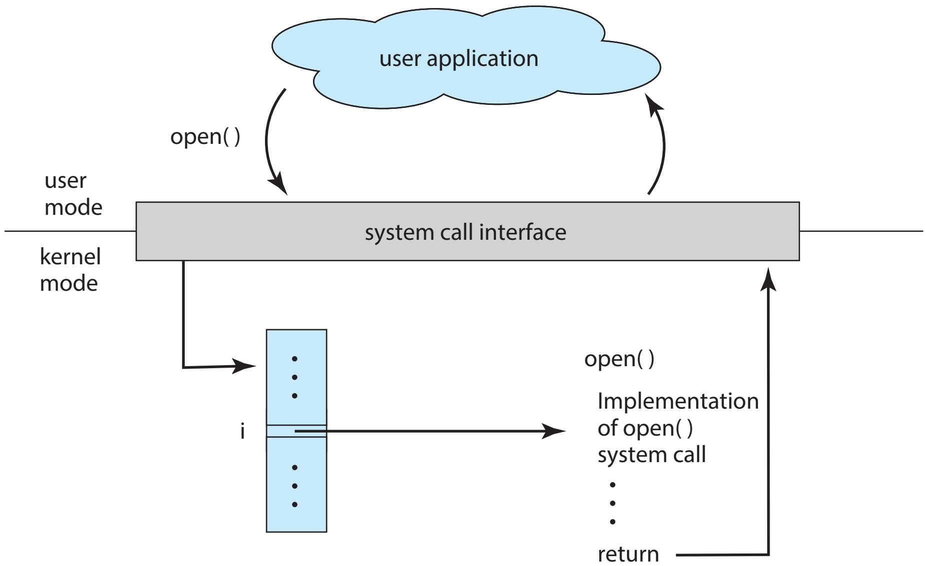


Figure 2.6 The handling of a user application invoking the `open()` system call.

system-call interface that serves as the link to system calls made available by the operating system. The system-call interface intercepts function calls in the API and invokes the necessary system calls within the operating system. Typically, a number is associated with each system call, and the system-call interface maintains a table indexed according to these numbers. The system-call interface then invokes the intended system call in the operating-system kernel and returns the status of the system call.

The caller need know nothing about how the system call is implemented or what it does during execution. Rather, the caller need only obey the API and understand what the operating system will do as a result of the execution of that system call. Thus, most of the details of the operating-system interface are hidden from the programmer by the API and are managed by the RTE. The relationship among an API, the system-call interface, and the operating system is shown in Figure 2.6, which illustrates how the operating system handles a user application invoking the `open()` system call.

System calls occur in different ways, depending on the computer in use. Often, more information is required than simply the identity of the desired system call. The exact type and amount of information vary according to the particular operating system and call. For example, to get input, we may need to specify the file or device to use as the source, as well as the address and length of the memory buffer into which the input should be read. Of course, the device or file and length may be implicit in the call.

Three general methods are used to pass parameters to the operating system. The simplest approach is to pass the parameters in registers. In some cases, however, there may be more parameters than registers. In these cases, the parameters are generally stored in a block, or table, in memory, and the address of the block is passed as a parameter in a register (Figure 2.7). Linux uses a combination of these approaches. If there are five or fewer parameters,

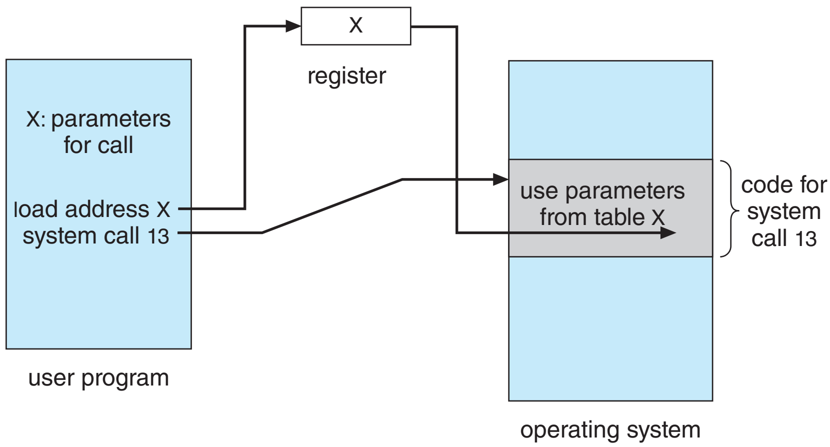


Figure 2.7 Passing of parameters as a table.

registers are used. If there are more than five parameters, the block method is used. Parameters also can be placed, or **pushed**, onto a **stack** by the program and **popped** off the stack by the operating system. Some operating systems prefer the block or stack method because those approaches do not limit the number or length of parameters being passed.

2.3.3 Types of System Calls

System calls can be grouped roughly into six major categories: **process control**, **fil management**, **device management**, **information maintenance**, **communications**, and **protection**. Below, we briefly discuss the types of system calls that may be provided by an operating system. Most of these system calls support, or are supported by, concepts and functions that are discussed in later chapters. Figure 2.8 summarizes the types of system calls normally provided by an operating system. As mentioned, in this text, we normally refer to the system calls by generic names. Throughout the text, however, we provide examples of the actual counterparts to the system calls for UNIX, Linux, and Windows systems.

2.3.3.1 Process Control

A running program needs to be able to halt its execution either normally (`end()`) or abnormally (`abort()`). If a system call is made to terminate the currently running program abnormally, or if the program runs into a problem and causes an error trap, a dump of memory is sometimes taken and an error message generated. The dump is written to a special log file on disk and may be examined by a **debugger**—a system program designed to aid the programmer in finding and correcting errors, or **bugs**—to determine the cause of the problem. Under either normal or abnormal circumstances, the operating system must transfer control to the invoking command interpreter. The command interpreter then reads the next command. In an interactive system, the command interpreter simply continues with the next command; it is assumed that the user will issue an appropriate command to respond to

- Process control
  - create process, terminate process
  - load, execute
  - get process attributes, set process attributes
  - wait event, signal event
  - allocate and free memory
- File management
  - create file, delete file
  - open, close
  - read, write, reposition
  - get file attributes, set file attributes
- Device management
  - request device, release device
  - read, write, reposition
  - get device attributes, set device attributes
  - logically attach or detach devices
- Information maintenance
  - get time or date, set time or date
  - get system data, set system data
  - get process, file, or device attributes
  - set process, file, or device attributes
- Communications
  - create, delete communication connection
  - send, receive messages
  - transfer status information
  - attach or detach remote devices
- Protection
  - get file permissions
  - set file permissions

Figure 2.8 Types of system calls.

EXAMPLES OF WINDOWS AND UNIX SYSTEM CALLS

The following illustrates various equivalent system calls for Windows and UNIX operating systems.

	Windows	Unix

Process control	`CreateProcess()`
	`ExitProcess()`
	`WaitForSingleObject()`
		`fork()`
		`exit()`
		`wait()`

File management	`CreateFile()`
	`ReadFile()`
	`WriteFile()`
	`CloseHandle()`
		`open()`
		`read()`
		`write()`
		`close()`

Device management	`SetConsoleMode()`
	`ReadConsole()`
	`WriteConsole()`
		`ioctl()`
		`read()`
		`write()`

Information maintenance	`GetCurrentProcessID()`
	`SetTimer()`
	`Sleep()`
		`getpid()`
		`alarm()`
		`sleep()`

Communications	`CreatePipe()`
	`CreateFileMapping()`
	`MapViewOfFile()`
		`pipe()`
		`shm_open()`
		`mmap()`

Protection	`SetFileSecurity()`
	`InitlializeSecurityDescriptor()`
	`SetSecurityDescriptorGroup()`
		`chmod()`
		`umask()`
		`chown()`

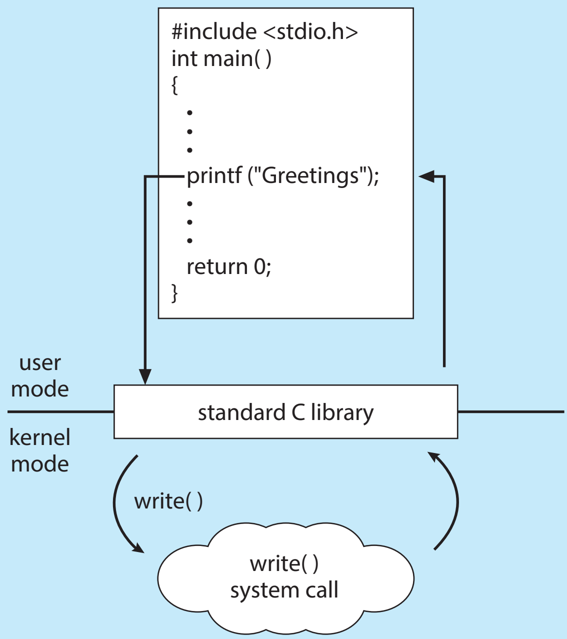
any error. In a GUI system, a pop-up window might alert the user to the error and ask for guidance. Some systems may allow for special recovery actions in case an error occurs. If the program discovers an error in its input and wants to terminate abnormally, it may also want to define an error level. More severe errors can be indicated by a higher-level error parameter. It is then possible to combine normal and abnormal termination by defining a normal termination as an error at level 0. The command interpreter or a following program can use this error level to determine the next action automatically.

A process executing one program may want to `load()` and `execute()` another program. This feature allows the command interpreter to execute a program as directed by, for example, a user command or the click of a mouse. An interesting question is where to return control when the loaded program terminates. This question is related to whether the existing program is lost, saved, or allowed to continue execution concurrently with the new program.

If control returns to the existing program when the new program terminates, we must save the memory image of the existing program; thus, we have

THE STANDARD C LIBRARY

The standard C library provides a portion of the system-call interface for many versions of UNIX and Linux. As an example, let's assume a C program invokes the `printf()` statement. The C library intercepts this call and invokes the necessary system call (or calls) in the operating system—in this instance, the `write()` system call. The C library takes the value returned by `write()` and passes it back to the user program:



effectively created a mechanism for one program to call another program. If both programs continue concurrently, we have created a new process to be multiprogrammed. Often, there is a system call specifically for this purpose (`create_process()`).

If we create a new process, or perhaps even a set of processes, we should be able to control its execution. This control requires the ability to determine and reset the attributes of a process, including the process's priority, its maximum allowable execution time, and so on (`get_process_attributes()` and `set_process_attributes()`). We may also want to terminate a process that we created (`terminate_process()`) if we find that it is incorrect or is no longer needed.

Having created new processes, we may need to wait for them to finish their execution. We may want to wait for a certain amount of time to pass (`wait_time()`). More probably, we will want to wait for a specific event to occur (`wait_event()`). The processes should then signal when that event has occurred (`signal_event()`).

Quite often, two or more processes may share data. To ensure the integrity of the data being shared, operating systems often provide system calls allowing

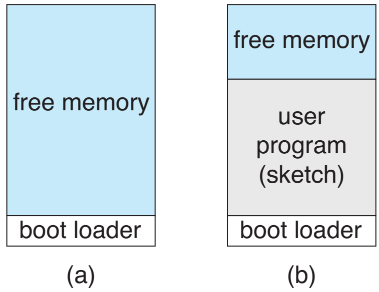


Figure 2.9 Arduino execution. (a) At system startup. (b) Running a sketch.

a process to **lock** shared data. Then, no other process can access the data until the lock is released. Typically, such system calls include `acquire_lock()` and `release_lock()`. System calls of these types, dealing with the coordination of concurrent processes, are discussed in great detail in Chapter 6 and Chapter 7.

There are so many facets of and variations in process control that we next use two examples—one involving a single-tasking system and the other a multitasking system—to clarify these concepts. The Arduino is a simple hardware platform consisting of a microcontroller along with input sensors that respond to a variety of events, such as changes to light, temperature, and barometric pressure, to just name a few. To write a program for the Arduino, we first write the program on a PC and then upload the compiled program (known as a **sketch**) from the PC to the Arduino's flash memory via a USB connection. The standard Arduino platform does not provide an operating system; instead, a small piece of software known as a **boot loader** loads the sketch into a specific region in the Arduino's memory (Figure 2.9). Once the sketch has been loaded, it begins running, waiting for the events that it is programmed to respond to. For example, if the Arduino's temperature sensor detects that the temperature has exceeded a certain threshold, the sketch may have the Arduino start the motor for a fan. An Arduino is considered a single-tasking system, as only one sketch can be present in memory at a time; if another sketch is loaded, it replaces the existing sketch. Furthermore, the Arduino provides no user interface beyond hardware input sensors.

FreeBSD (derived from Berkeley UNIX) is an example of a multitasking system. When a user logs on to the system, the shell of the user's choice is run, awaiting commands and running programs the user requests. However, since FreeBSD is a multitasking system, the command interpreter may continue running while another program is executed (Figure 2.10). To start a new process, the shell executes a `fork()` system call. Then, the selected program is loaded into memory via an `exec()` system call, and the program is executed. Depending on how the command was issued, the shell then either waits for the process to finish or runs the process "in the background." In the latter case, the shell immediately waits for another command to be entered. When a process is running in the background, it cannot receive input directly from the keyboard, because the shell is using this resource. I/O is therefore done through files or through a GUI interface. Meanwhile, the user is free to ask the shell to run other programs, to monitor the progress of the running process, to change that program's priority, and so on. When the process is done, it executes an `exit()`

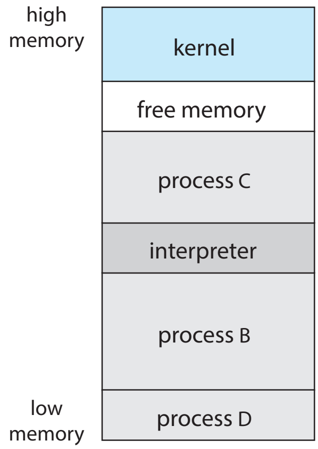


Figure 2.10 FreeBSD running multiple programs.

system call to terminate, returning to the invoking process a status code of 0 or a nonzero error code. This status or error code is then available to the shell or other programs. Processes are discussed in Chapter 3 with a program example using the `fork()` and `exec()` system calls.

2.3.3.2 File Management

The file system is discussed in more detail in Chapter 13 through Chapter 15. Here, we identify several common system calls dealing with files.

We first need to be able to `create()` and `delete()` files. Either system call requires the name of the file and perhaps some of the file's attributes. Once the file is created, we need to `open()` it and to use it. We may also `read()`, `write()`, or `reposition()` (rewind or skip to the end of the file, for example). Finally, we need to `close()` the file, indicating that we are no longer using it.

We may need these same sets of operations for directories if we have a directory structure for organizing files in the file system. In addition, for either files or directories, we need to be able to determine the values of various attributes and perhaps to set them if necessary. File attributes include the file name, file type, protection codes, accounting information, and so on. At least two system calls, `get_file_attributes()` and `set_file_attributes()`, are required for this function. Some operating systems provide many more calls, such as calls for file `move()` and `copy()`. Others might provide an API that performs those operations using code and other system calls, and others might provide system programs to perform the tasks. If the system programs are callable by other programs, then each can be considered an API by other system programs.

2.3.3.3 Device Management

A process may need several resources to execute—main memory, disk drives, access to files, and so on. If the resources are available, they can be granted, and control can be returned to the user process. Otherwise, the process will have to wait until sufficient resources are available.

The various resources controlled by the operating system can be thought of as devices. Some of these devices are physical devices (for example, disk drives), while others can be thought of as abstract or virtual devices (for example, files). A system with multiple users may require us to first `request()` a device, to ensure exclusive use of it. After we are finished with the device, we `release()` it. These functions are similar to the `open()` and `close()` system calls for files. Other operating systems allow unmanaged access to devices. The hazard then is the potential for device contention and perhaps deadlock, which are described in Chapter 8.

Once the device has been requested (and allocated to us), we can `read()`, `write()`, and (possibly) `reposition()` the device, just as we can with files. In fact, the similarity between I/O devices and files is so great that many operating systems, including UNIX, merge the two into a combined file–device structure. In this case, a set of system calls is used on both files and devices. Sometimes, I/O devices are identified by special file names, directory placement, or file attributes.

The user interface can also make files and devices appear to be similar, even though the underlying system calls are dissimilar. This is another example of the many design decisions that go into building an operating system and user interface.

2.3.3.4 Information Maintenance

Many system calls exist simply for the purpose of transferring information between the user program and the operating system. For example, most systems have a system call to return the current `time()` and `date()`. Other system calls may return information about the system, such as the version number of the operating system, the amount of free memory or disk space, and so on.

Another set of system calls is helpful in debugging a program. Many systems provide system calls to `dump()` memory. This provision is useful for debugging. The program `strace`, which is available on Linux systems, lists each system call as it is executed. Even microprocessors provide a CPU mode, known as **single step**, in which a trap is executed by the CPU after every instruction. The trap is usually caught by a debugger.

Many operating systems provide a time profile of a program to indicate the amount of time that the program executes at a particular location or set of locations. A time profile requires either a tracing facility or regular timer interrupts. At every occurrence of the timer interrupt, the value of the program counter is recorded. With sufficiently frequent timer interrupts, a statistical picture of the time spent on various parts of the program can be obtained.

In addition, the operating system keeps information about all its processes, and system calls are used to access this information. Generally, calls are also used to get and set the process information (`get_process_attributes()` and `set_process_attributes()`). In Section 3.1.3, we discuss what information is normally kept.

2.3.3.5 Communication

There are two common models of interprocess communication: the message-passing model and the shared-memory model. In the **message-passing model**, the communicating processes exchange messages with one another to transfer information. Messages can be exchanged between the processes either directly or indirectly through a common mailbox. Before communication can take place, a connection must be opened. The name of the other communicator must be known, be it another process on the same system or a process on another computer connected by a communications network. Each computer in a network has a **host name** by which it is commonly known. A host also has a network identifier, such as an IP address. Similarly, each process has a **process name**, and this name is translated into an identifier by which the operating system can refer to the process. The `get_hostid()` and `get_processid()` system calls do this translation. The identifiers are then passed to the general-purpose `open()` and `close()` calls provided by the file system or to specific `open_connection()` and `close_connection()` system calls, depending on the system's model of communication. The recipient process usually must give its permission for communication to take place with an `accept_connection()` call. Most processes that will be receiving connections are special-purpose **daemons**, which are system programs provided for that purpose. They execute a `wait_for_connection()` call and are awakened when a connection is made. The source of the communication, known as the **client**, and the receiving daemon, known as a **server**, then exchange messages by using `read_message()` and `write_message()` system calls. The `close_connection()` call terminates the communication.

In the **shared-memory model**, processes use `shared_memory_create()` and `shared_memory_attach()` system calls to create and gain access to regions of memory owned by other processes. Recall that, normally, the operating system tries to prevent one process from accessing another process's memory. Shared memory requires that two or more processes agree to remove this restriction. They can then exchange information by reading and writing data in the shared areas. The form of the data is determined by the processes and is not under the operating system's control. The processes are also responsible for ensuring that they are not writing to the same location simultaneously. Such mechanisms are discussed in Chapter 6. In Chapter 4, we look at a variation of the process scheme—threads—in which some memory is shared by default.

Both of the models just discussed are common in operating systems, and most systems implement both. Message passing is useful for exchanging smaller amounts of data, because no conflicts need be avoided. It is also easier to implement than is shared memory for intercomputer communication. Shared memory allows maximum speed and convenience of communication, since it can be done at memory transfer speeds when it takes place within a computer. Problems exist, however, in the areas of protection and synchronization between the processes sharing memory.

2.3.3.6 Protection

Protection provides a mechanism for controlling access to the resources provided by a computer system. Historically, protection was a concern only on multiprogrammed computer systems with several users. However, with the advent of networking and the Internet, all computer systems, from servers to mobile handheld devices, must be concerned with protection.

Typically, system calls providing protection include `set_permission()` and `get_permission()`, which manipulate the permission settings of resources such as files and disks. The `allow_user()` and `deny_user()` system calls specify whether particular users can—or cannot—be allowed access to certain resources. We cover protection in Chapter 17 and the much larger issue of security—which involves using protection against external threats—in Chapter 16.

2.4 System Services

Another aspect of a modern system is its collection of system services. Recall Figure 1.1, which depicted the logical computer hierarchy. At the lowest level is hardware. Next is the operating system, then the system services, and finally the application programs. **System services**, also known as **system utilities**, provide a convenient environment for program development and execution. Some of them are simply user interfaces to system calls. Others are considerably more complex. They can be divided into these categories:

- **File management**. These programs create, delete, copy, rename, print, list, and generally access and manipulate files and directories.
- **Status information**. Some programs simply ask the system for the date, time, amount of available memory or disk space, number of users, or similar status information. Others are more complex, providing detailed performance, logging, and debugging information. Typically, these programs format and print the output to the terminal or other output devices or files or display it in a window of the GUI. Some systems also support a **registry**, which is used to store and retrieve configuration information.
- **File modificatio** . Several text editors may be available to create and modify the content of files stored on disk or other storage devices. There may also be special commands to search contents of files or perform transformations of the text.
- **Programming-language support**. Compilers, assemblers, debuggers, and interpreters for common programming languages (such as C, C++, Java, and Python) are often provided with the operating system or available as a separate download.
- **Program loading and execution**. Once a program is assembled or compiled, it must be loaded into memory to be executed. The system may provide absolute loaders, relocatable loaders, linkage editors, and overlay loaders. Debugging systems for either higher-level languages or machine language are needed as well.
- **Communications**. These programs provide the mechanism for creating virtual connections among processes, users, and computer systems. They allow users to send messages to one another's screens, to browse web pages, to send e-mail messages, to log in remotely, or to transfer files from one machine to another.
- **Background services**. All general-purpose systems have methods for launching certain system-program processes at boot time. Some of these processes terminate after completing their tasks, while others continue to

run until the system is halted. Constantly running system-program processes are known as **services**, **subsystems**, or daemons. One example is the network daemon discussed in Section 2.3.3.5. In that example, a system needed a service to listen for network connections in order to connect those requests to the correct processes. Other examples include process schedulers that start processes according to a specified schedule, system error monitoring services, and print servers. Typical systems have dozens of daemons. In addition, operating systems that run important activities in user context rather than in kernel context may use daemons to run these activities.

Along with system programs, most operating systems are supplied with programs that are useful in solving common problems or performing common operations. Such **application programs** include web browsers, word processors and text formatters, spreadsheets, database systems, compilers, plotting and statistical-analysis packages, and games.

The view of the operating system seen by most users is defined by the application and system programs, rather than by the actual system calls. Consider a user's PC. When a user's computer is running the macOS operating system, the user might see the GUI, featuring a mouse-and-windows interface. Alternatively, or even in one of the windows, the user might have a command-line UNIX shell. Both use the same set of system calls, but the system calls look different and act in different ways. Further confusing the user view, consider the user dual-booting from macOS into Windows. Now the same user on the same hardware has two entirely different interfaces and two sets of applications using the same physical resources. On the same hardware, then, a user can be exposed to multiple user interfaces sequentially or concurrently.

2.5 Linkers and Loaders

Usually, a program resides on disk as a binary executable file—for example, `a.out` or `prog.exe`. To run on a CPU, the program must be brought into memory and placed in the context of a process. In this section, we describe the steps in this procedure, from compiling a program to placing it in memory, where it becomes eligible to run on an available CPU core. The steps are highlighted in Figure 2.11.

Source files are compiled into object files that are designed to be loaded into any physical memory location, a format known as an **relocatable object fil** . Next, the **linker** combines these relocatable object files into a single binary **executable** file. During the linking phase, other object files or libraries may be included as well, such as the standard C or math library (specified with the flag `-lm`).

A **loader** is used to load the binary executable file into memory, where it is eligible to run on a CPU core. An activity associated with linking and loading is **relocation**, which assigns final addresses to the program parts and adjusts code and data in the program to match those addresses so that, for example, the code can call library functions and access its variables as it executes. In Figure 2.11, we see that to run the loader, all that is necessary is to enter the name of the executable file on the command line. When a program name is entered on the