Operating System

MODULE - I

Introduction - Mainframe systems – Desktop Systems – Multiprocessor Systems – Distributed Systems – Clustered Systems – Real Time Systems – Handheld Systems - Hardware Protection - System Components – Operating System Services – System Calls – System Programs - Process Concept – Process Scheduling – Operations on Processes – Cooperating Processes – Inter-process Communication.

Mainframe Systems

Mainframe computer systems were the first computers used to tackle many commercial and scientific applications. In this section, we trace the growth of mainframe systems from simple **batch systems**, where the computer runs one —and only one—application, to **time-shared systems**, which allow for user interaction with the computer system.

1.2.1 Batch Systems

Early computers were physically enormous machines run from a console. The common input devices were card readers and tape drives. The common output devices were line printers, tape drives, and card punches. The user did not interact directly with the computer systems. Rather, the user prepared a job —which consisted of the program, the data, and some control information about the nature of the job (control cards)—and submitted it to the computer operator. The job was usually in the form of punch cards. At some later time (after minutes, hours, or days), the output appeared. The output consisted of the result of the program, as well as a dump of the final memory and register contents for debugging.

Mainframe computer systems were the first computers used to tackle many commercial and scientific applications. In this section, we trace the growth of mainframe systems from simple **batch systems**, where the computer runs one —and only one—application, to **time-shared systems**, which allow for user interaction with the computer system.

1.2.1 Batch Systems

Early computers were physically enormous machines run from a console. The common input devices were card readers and tape drives. The common output devices were line printers, tape drives, and card punches. The user did not interact directly with the computer systems. Rather, the user prepared a job —which consisted of the program, the data, and some control information about the nature of the job (control cards)—and submitted it to the computer operator. The job was usually in the form of punch cards. At some later time (after minutes, hours, or days), the output appeared. The output consisted of the result of the program, as well as a dump of the final memory and register contents for debugging.

1.2.2 Multiprogrammed Systems

The most important aspect of job scheduling is the ability to multiprogram. A single user cannot, in general, keep either the CPU or the I/O devices busy at all times. **Multiprogramming** increases CPU utilization by organizing jobs so that the CPU always has one to execute.

The idea is as follows: The operating system keeps several jobs in memory simultaneously (Figure 1.3). This set of jobs is a subset of the jobs kept in the job pool—since the number of jobs that can be kept simultaneously in memory is usually much smaller than the number of jobs that can be in the job pool. The operating system picks and begins to execute one of the jobs in the memory. Eventually, the job may have to wait for some task, such as an I/O operation, to complete. In a non-multiprogrammed system, the CPU would sit idle. In a multiprogramming system, the operating system simply switches to, and executes, another job. When *that* job needs to wait, the CPU is switched to *another* job, and so on. Eventually, the first job finishes waiting and gets the CPU back. As long as at least one job needs to execute, the CPU is never idle.

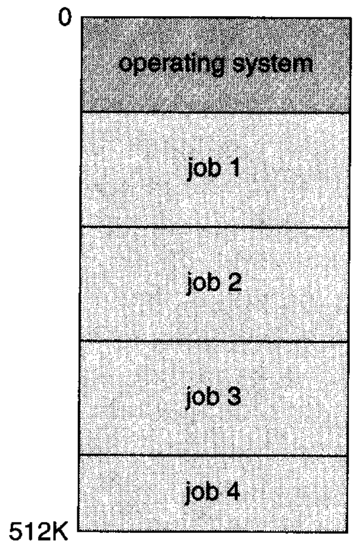


Figure 1.3 Memory layout for a multiprogramming system.

1.2.3 Time-Sharing Systems

Multiprogrammed, batched systems provided an environment where the various system resources (for example, CPU, memory, peripheral devices) were utilized effectively, but it did not provide for user interaction with the computer system. **Time sharing** (or **multitasking**) is a logical extension of multiprogramming. The CPU executes multiple jobs by switching among them, but the switches occur so frequently that the users can interact with each program while it is running.

An **interactive** (or **hands-on**) **computer system** provides direct communication between the user and the system. The user gives instructions to the operating system or to a program directly, using a keyboard or a mouse, and waits for immediate results. Accordingly, the **response time** should be short—typically within 1 second or so.

A time-shared operating system allows many users to share the computer simultaneously. Since each action or command in a time-shared system tends to be short, only a little CPU time is needed for each user. As the system switches rapidly from one user to the next, each user is given the impression that the entire computer system is dedicated to her use, even though it is being shared among many users.

Reduce setup time by batching similar jobs Automatic job sequencing – automatically transfers control from one job to another. First rudimentary operating system. Resident monitor

- initial control in monitor
- control transfers to job
- when job completes control transfers pack to monitor

Desktop System

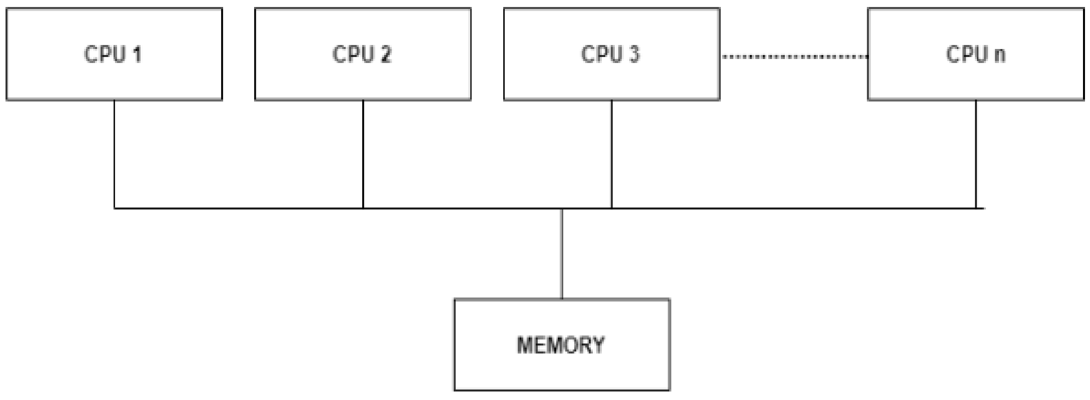
Personal computers PCs appeared in the 1970s. During their first decade, the CPUs in PCs lacked the features needed to protect an operating system from user programs. PC operating systems therefore were neither multiuser nor multitasking. However, the goals of these operating systems have changed with time; instead of maximizing CPU and peripheral utilization, the systems opt for maximizing user convenience and responsiveness. These systems include PCs running Microsoft Windows and the Apple Macintosh. The MS-DOS operating system from Microsoft has been superseded by multiple flavors of Microsoft Windows, and IBM has upgraded MS-DOS to the OS/2 multitasking system.

Operating systems for these computers have benefited in several ways from the development of operating systems for mainframes. Microcomputers were immediately able to adopt some of the technology developed for larger operating systems. On the other hand, the hardware costs for microcomputers are sufficiently low that individuals have sole use of the computer, and CPU utilization is no longer a prime concern. Thus, some of the design decisions made in operating systems for mainframes may not be appropriate for smaller systems.

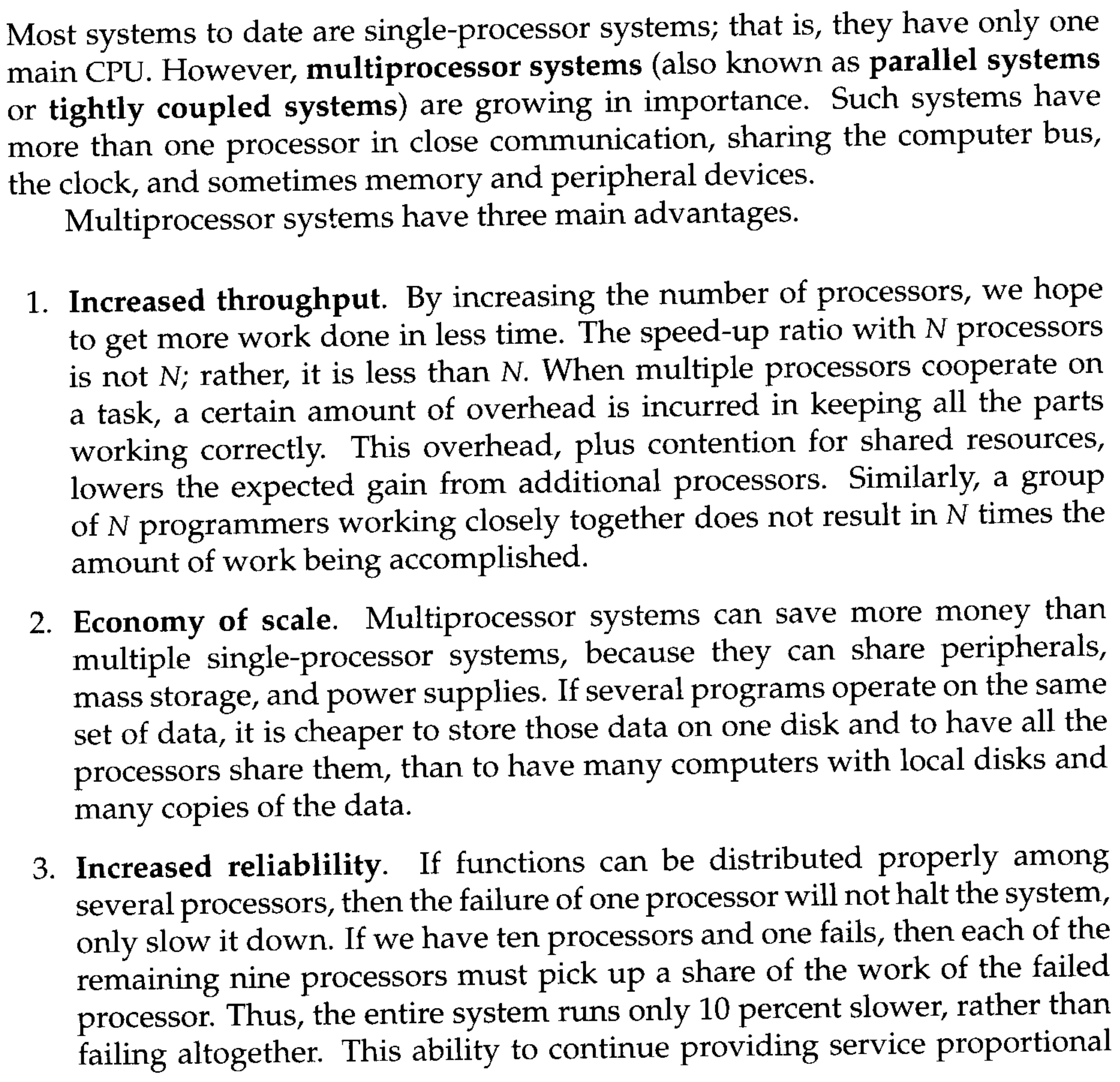
A desktop computer is a personal computer designed for regular use at a single location on or near a desk or table due to its size and power requirements. The most common configuration has a case that houses the power supply, motherboard (a printed circuit board with a microprocessor as the central processing unit (CPU), memory, bus, and other electronic components), disk storage (usually one or more hard disk drives, solid state drives, optical disc drives, and in early models a floppy disk drive); a keyboard and mouse for input; and a computer monitor, speakers, and, often, a printer for output. The case may be oriented horizontally or vertically and placed either underneath, beside, or on top of a desk.

Multiprocessor Systems

Most computer systems are single processor systems i.e they only have one processor. However, multiprocessor or parallel systems are increasing in importance nowadays. These systems have multiple processors working in parallel that share the computer clock, memory, bus, peripheral devices etc. An image demonstrating the multiprocessor architecture is:



Multiprocessing Architecture


Most systems to date are single-processor systems; that is, they have only one main CPU. However, **multiprocessor systems** (also known as **parallel systems** or **tightly coupled systems**) are growing in importance. Such systems have more than one processor in close communication, sharing the computer bus, the clock, and sometimes memory and peripheral devices.

Multiprocessor systems have three main advantages.

1. **Increased throughput**. By increasing the number of processors, we hope to get more work done in less time. The speed-up ratio with *N* processors is not *N*; rather, it is less than *N*. When multiple processors cooperate on a task, a certain amount of overhead is incurred in keeping all the parts working correctly. This overhead, plus contention for shared resources, lowers the expected gain from additional processors. Similarly, a group of *N* programmers working closely together does not result in *N* times the amount of work being accomplished.
2. **Economy of scale**. Multiprocessor systems can save more money than multiple single-processor systems, because they can share peripherals, mass storage, and power supplies. If several programs operate on the same set of data, it is cheaper to store those data on one disk and to have all the processors share them, than to have many computers with local disks and many copies of the data.
3. **Increased reliablility**. If functions can be distributed properly among several processors, then the failure of one processor will not halt the system, only slow it down. If we have ten processors and one fails, then each of the remaining nine processors must pick up a share of the work of the failed processor. Thus, the entire system runs only 10 percent slower, rather than failing altogether. This ability to continue providing service proportional

Types of Multiprocessors

There are mainly two types of multiprocessors i.e. symmetric and asymmetric multiprocessors. Details about them are as follows:

Symmetric Multiprocessors : In these types of systems, each processor contains a similar copy of the operating system and they all communicate with each other. All the processors are in a peer to peer relationship i.e. no master - slave relationship exists between them.

An example of the symmetric multiprocessing system is the Encore version of Unix for the Multimax Computer.

Asymmetric Multiprocessors : In asymmetric systems, each processor is given a predefined task. There is a master processor that gives instruction to all the other processors. Asymmetric multiprocessor system contains a master slave relationship.

Asymmetric multiprocessor was the only type of multiprocessor available before symmetric multiprocessors were created. Now also, this is the cheaper option.

Distributed System

A distributed system is a collection of physically separate, possibly heterogeneous, computer systems that are networked to provide the users with access to the various resources that the system maintains. Access to a shared resource increases computation speed, functionality, data availability, and reliability.

Some operating systems generalize network access as a form of file access, with the details of networking contained in the network interface's device driver. Others make users specifically invoke network functions. Generally, systems contain a mix of the two modes-for example FTP and NFS. The protocols that create a distributed system can greatly affect that system's utility and popularity.

Some operating systems have taken the concept of networks and distributed systems further than the notion of providing network connectivity. A network operating system is an operating system that provides features such as file sharing across the network and that includes a communication scheme that allows different processes on different computers to exchange messages.

Clustered Systems

Another type of multiple-CPU system is the Clustered Systems. Like multiprocessor systems, clustered systems gather together multiple CPUs to accomplish computational work. Clustered systems differ from multiprocessor systems, however, in that they are composed of two or more individual systems-or nodes-joined together. The definition of the term clustered is not concrete; many commercial packages wrestle with what a clustered system is and why one form is better than another.

The generally accepted definition is that clustered computers share storage and are closely linked via a LAN or a faster interconnect, such as InfiniBand. Clustering is usually used to provide service; that is, service will continue even if one or more systems in the cluster fail High availability is generally obtained by adding a level of redundancy in the system. A layer of cluster software runs on the cluster nodes. Each node can monitor one or more of the others (over the LAN). If the monitored machine fails, the monitoring machine can take ownership of its storage and restart the applications that were running on the failed machine. The users and clients of the applications see only a brief interruption of service.

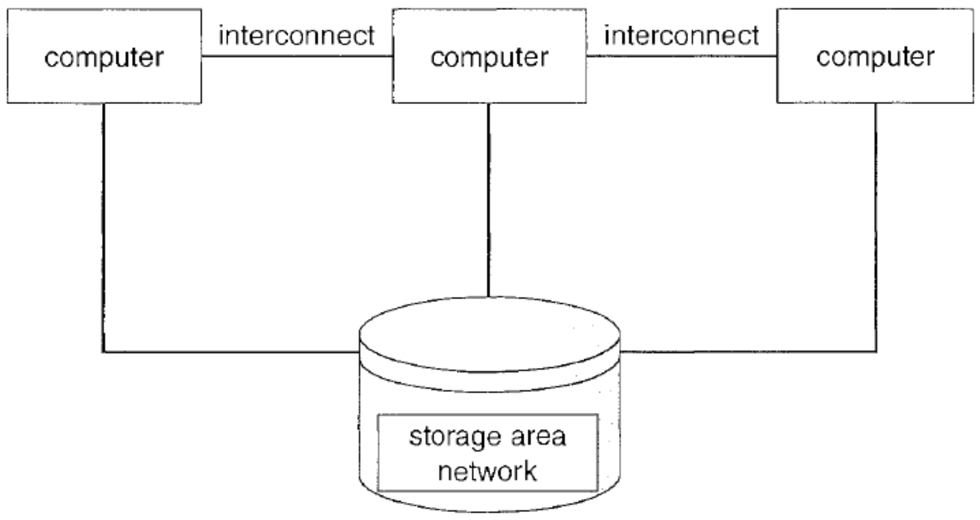


Figure 1.8 General structure of a clustered system.

Cluster technology is changing rapidly. Some cluster products support dozens of systems in a cluster, as well as clustered nodes that are separated by miles. Many of these improvements are made possible by Storage Area Network (SANs), which allow many systems to attach to a pool of storage. If the applications and their data are stored on the SAN, then the cluster software can assign the application to run on any host that is attached to the SAN. If the host fails, then any other host can take over. In a database cluster, dozens of hosts can share the same database, greatly increasing performance and reliability.

Real-Time Embedded Systems

Embedded computers are the most prevalent form of computers in existence. These devices are found everywhere, from car engines and manufacturing robots to DVDs and microwave ovens. They tend to have very specific tasks. The systems they run on are usually primitive, and so the operating systems provide limited features. Usually, they have little or no user interface, preferring to spend their time monitoring and managing hardware devices, such as automobile engines and robotic arms.

These embedded systems vary considerably. Some are general-purpose computers, running standard operating systems-such as UNIX-with special-purpose applications to implement the functionality. Others are hardware devices with a special-purpose embedded operating system providing just the functionality desired.

Yet others are hardware devices with application-specific integrated circuits(ASIC) that perform their tasks without an operating system.

The use of embedded systems continues to expand. The power of these devices, both as standalone units and as elements of networks and the Web, is sure to increase as well. Even now, entire houses can be computerized, so that a central computer-either a general-purpose computer or an embedded system-can control heating and lighting, alarm systems, and even coffee makers. Web access can enable a home owner to tell the house to heat up before she arrives home. Someday, the refrigerator may call the grocery store when it notices the milk is gone.

Embedded systems almost always run real time systems. A real-time system is used when rigid time requirements were placed on the operation of a processor or the flow of data; thus, it is often used as a control device in a dedicated application. Sensors bring data to the computer.

The computer must analyze the data and possibly adjust controls to modify the sensor inputs. Systems that control scientific experiments, medical imaging systems, industrial control systems, and certain display systems are realtime systems. Some automobile-engine fuel-injection systems, home-appliance controllers, and weapon systems are also real-time systems.

A real-time system has well-defined, fixed time constraints. Processing must be done within the defined constraints, or the system will fail. For instance, it would not do for a robot arm to be instructed to halt after it had smashed into the car it was building. A real-time system functions correctly only if it returns the correct result within its time constraints. Contrast this system with a time-sharing system, where it is desirable (but not mandatory) to respond quickly or a batch system, which may have no time constraints at all.

Handheld Systems

Handheld Systems include personal digital assistants (PDAs), such as Palm and Pocket-Pes, and cellular telephones, many of which use special-purpose embedded operating systems. Developers of handheld systems and applications face many challenges, most of which are due to the limited size of such devices. For example, a PDA is typically about 5 inches in height and 3 inches in width, and it weighs less than one-half pound. Because of their size, most handheld devices have small amounts of memory, slow processors, and small display screens. We take a look now at each of these limitations.

The amount of physical memory in a handheld depends on the device, but typically it is somewhere between 1 MB and 1 GB. (Contrast this with a typical PC or workstation, which may have several gigabytes of memory.) As a result, the operating system and applications must manage memory efficiently. This includes returning all allocated memory to the memory manager when thememory is not being used. In Chapter 9, we explore virtual memory, which allows developers to write programs that behave as if the system has more memory than is physically available. Currently, not many handheld devices use virtual memory techniques, so program developers must work within the confines of limited physical memory.

A second issue of concern to developers of handheld devices is the speed of the processor used in the devices. Processors for most handheld devices run at a fraction of the speed of a processor in a PC. Faster processors require more power. To include a faster processor in a handheld device would require a larger battery, which would take up more space and would have to be replaced (or recharged) more frequently. Most handheld devices use smaller, slower processors that consume less power. Therefore, the operating system and applications must be designed not to tax the processor.

The last issue confronting program designers for handheld devices is l/0. A lack of physical space limits input methods to small keyboards, handwriting recognition, or small screen-based keyboards. The small display screens limit output options. Whereas a monitor for a home computer may measure up to 30 inches, the display for a handheld device is often no more than 3 inches square. Familiar tasks, such as reading e-mail and browsing Web pages, must be condensed into smaller displays. One approach for displaying the content in Web pages is web clipping, where only a small subset of a Web page is delivered and displayed on the handheld device.

Hardware Protection

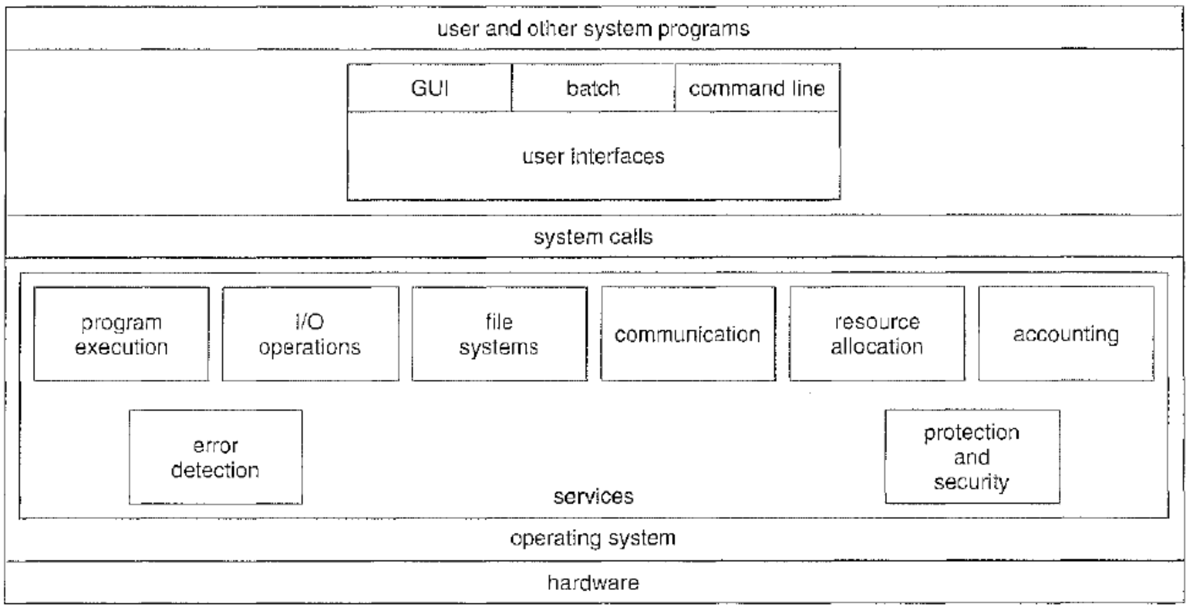
Protection, then, is any mechanism for controlling the access of processes or users-to the resources defined by a computer system. This mechanism must provide means to specify the controls to be imposed and means to enforce the controls. Protection can improve reliability by detecting latent errors at the interfaces between component subsystems. Early detection of interface errors can often prevent contamination of a healthy subsystem by another subsystem that is malfunctioning. Furthermore, an unprotected resource cannot defend against use (or misuse) by an unauthorized or incompetent user. A protection-oriented system provides a means to distinguish between authorized and unauthorized usage, A system can have adequate protection but still be prone to failure and allow inappropriate access. Consider a user whose authentication information is stolen. Their data could be copied or deleted even though file and memory protection are working. It is the job of security to defend a system from external and internal attacks.

Once hardware protection is in place, it detects errors that violate modes. These errors are normally handled by the operating system. If a user program fails in some way-such as by making an attempt either to execute an illegal instruction or to access memory that is not in the user's address space-then the hardware traps to the operating system. The trap transfers control through the interrupt vector to the operating system, just as an interrupt does. When a program error occurs, the operating system must terminate the program abnormally. This situation is handled by the same code as a user-requested abnormal termination. An appropriate error message is given, and the memory of the program may be dumped. The memory dump is usually written to a file so that the user or programmer can examine it and perhaps correct it and restart the program.

Operating System Services

An operating system provides an environment for the execution of programs. It provides certain services to programs and to the users of those programs. The specific services provided, of course, differ from one operating system to another, but we can identify common classes. These operating-system services are provided for the convenience of the programmer, to n1.ake the programming task easier. The following figure shows one view of the various operating-system services and how they interrelate. One set of operating-system services provides functions that are helpful to the user.

User interface: Almost all operating system have a user interface. This interface can take several forms. One is a DTrace, command-line Interface, which uses text command a method for entering them. Another is batch interface, in which command and directives to control those commands are entered into files, and those files are excuted. Most commonly, a graphical user interface(GUI) is used. Here, the interface is a window system with a pointing device to direct I/O, choose from menu, and make selections and a keyboard to enter text. Some systems provide two or all three of these variations.



A view of operating system services.

Program Execution : The system must be able to load a program into memory and to run that program. The program must be able to end its execution, either normally or abnormally.

I/O Operations : A running program may require I/0, which may involve a file or an I/0 device. For specific devices, special functions may be desired (such as recording to a CD or DVD drive or blanking a display screen). For efficiency and protection, users usually cannot control I/0 devices directly.

Therefore, the operating system must provide a means to do I/0. File-system manipulation. The file system is of particular interest. Obviously, programs need to read and write files and directories. They also need to create and delete them by name, search for a given file, and list file information. Finally, some programs include permissions management to allow or deny access to files or directories based on file ownership. Many operating systems provide a variety of file systems, sometimes to allow personal choice, and sometimes to provide specific features or performance characteristics.

Communications: There are many circumstances in which one process needs to exchange information with another process. Such communication ncay occur between processes that are executing on the same computer or between processes that are executing on different computer systems tied together by a computer network. Communications may be implemented via shared rnenwry or through message passing, in which packets of information are moved between processes by the operating system.

The operating system needs to be constantly aware of possible errors. Errors may occur in the CPU and memory hardware (such as a memory error or a power failure), in I/0 devices (such as a parity error on tape, a connection failure on a network, or lack of paper in the printer), and in the user program (such as an arithmetic overflow, an attempt to access an illegal memory location, or a too-great use of CPU time). For each type of error, the operating system should take the appropriate action to ensure correct and consistent computing.

Resource allocation: When there are Multiple users or multiple jobs running at the same time, resources must be allocated to each of them. Many different -types of resources are managed by the operating system.

Some (such as CPU cycles, main memory, and file storage) may have special allocation code, whereas others (such as I/0 devices) may have much more general request and release code. For instance, in determining how best to use the CPU, operating systems have CPU-scheduling routines that take into account the speed of the CPU, the jobs that must be executed, the number of registers available, and other factors. There may also be routines to allocate printers, modems, USB storage drives, and other peripheral devices.

Accounting: We want to keep track of which user use how much and what kinds of computer resources. This record keeping may be used for accounting (so that: users can be billed) or simply for accumulating usage statistics. Usage statistics may be a valuable tool for researchers who wish to reconfigure the system to improve computing services.

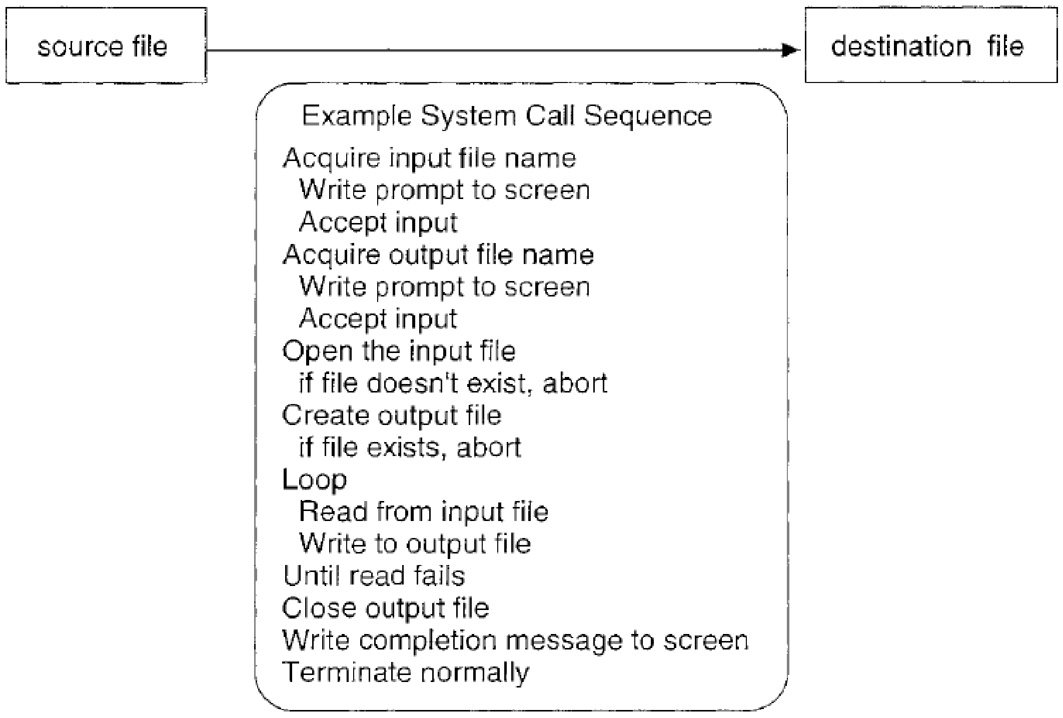
Protection and security: The owners of information stored in a multiuser or networked computer system may want to control use of that information. When several separate processes execute concurrently, it should not be possible for one process to interfere with the others or with the operating system itself.

System Calls

System calls provide an interface to the services made available by an operating system. These calls are generally available as routines written in C and C++, although certain low-level tasks (for example, tasks where hardware must be accessed directly), may need to be written using assembly-language instructions.

Before we discuss how an operating system makes system calls available, let's first use an example to illustrate how system calls are used: writing a simple program to read data from one file and copy them to another file. The first input that the program will need is the names of the two files: the input file and the output file.

These names can be specified in many ways, depending on the operating-system design. One approach is for the program to ask the user for the names of the two files. In an interactive system, this approach will require a sequence of system calls, first to write a prompting message on the screen and then to read from the keyboard the characters that define the two files. On mouse-based and icon-based systems, a menu of file names is usually displayed in a window. The user can then use the mouse to select the source name, and a window can be opened for the destination name to be specified. This sequence requires many I/0 system calls.



```
Acquire input file name
  Write prompt to screen
  Accept input
Acquire output file name
  Write prompt to screen
  Accept input
Open the input file
  if file doesn't exist, abort
Create output file
  if file exists, abort
Loop
  Read from input file
  Write to output file
Until read fails
Close output file
Write completion message to screen
Terminate normally
```

Figure 2.4 Example of how system calls are used.

Once the two file names are obtained, the program must open the input file and create the output file. Each of these operations requires another system call. There are also possible error conditions for each operation. When the program tries to open the input file, it may find that there is no file of that name or that the file is protected against access. In these cases, the program should print a message on the console (another sequence of system calls) and then terminate abnormally (another system call). If the input file exists, then we must create a new output file.

We may find that there is already an output file with the same name. This situation may cause the program to abort (a system call), or we may delete the existing file (another system call) and create a new one (another system call). Another option, in an interactive system, is to ask the user (via a sequence of system calls to output the prompting message and to read the response from the terminal) whether to replace the existing file or to abort the program.

System Programs

Another aspect of a modern system is the collection of system programs. At the lowest level is hardware. Next is the operating system, then the system programs, and finally the application programs. System programs, also known as system utilities, provide a convenient enviromnenf1orprograrn-aevelopmeiiTa1inexecuhon. 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, dump, list, and generally 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 which is used to store and retrieve configuration information.

File modification: 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, Visual Basic, and PERL) are often provided to the user with the operating system.

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, re-locatable 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 concoctions among processes, users, and computer systems. They allow users to send messages to one another's screens, to browse Web pages, to send electronic-mail messages, to log in remotely, or to transfer files from one machine to another.

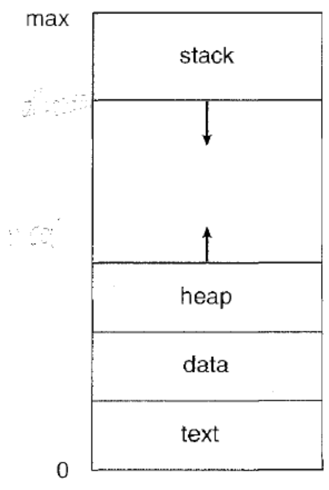
Process Concept

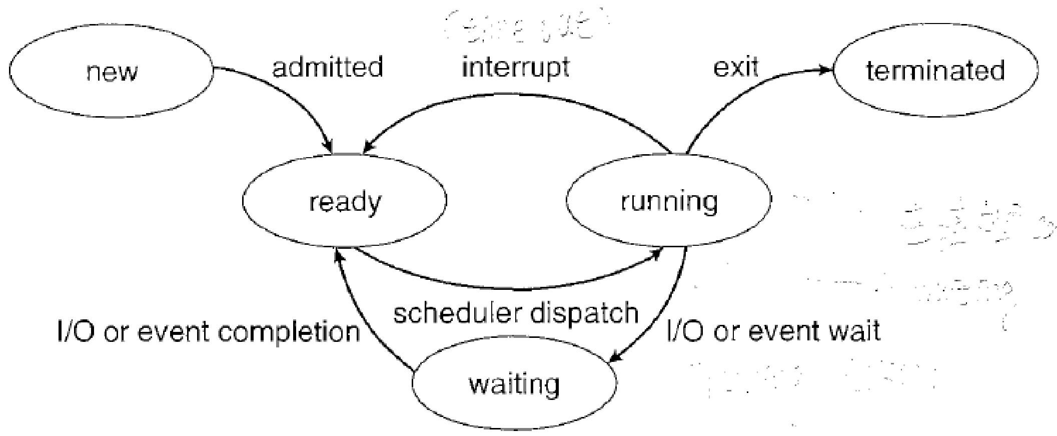
A question that arises in discussing operating systems involves what to call all the CPU activities, A batch system executes jobs, whereas a time-shared system has user programs, or tasks. Even on a single-user system such as Microsoft Windows, a user may be able to run several programs at one time: a word processor, a Web browser, and an e-mail package. And even if the user can execute only one program at a time, the operating system may need to support its own internal programmed activities, such as memory management. In many respects, all these activities are similar, so we call all of them processes. The term job and process are used almost interchangeably in this text.

Although we personally prefer the term process, much of operat1ng-system theory and terminology was developed during a time when the major activity of operating systems was job processing. It would be misleading to avoid the use of commonly accepted terms that include the word job (such as job scheduling) simply because process has superseded job.

The Process

Informally, as mentioned earlier, a process is a program in execution. A process is more than the program code, which is sometimes known as the text section. It also includes the current activity, as represented by the value of the program counter and the contents of the processor's registers. A process generally also includes the process stack, which contains temporary data (such as function parameters, return addresses, and local variables), and a data section, which contains global variables. A process may also include a heap, which is memory that is dynamically allocated during process run time. The structure of a process in memory is shown in following figure.





Process States

Although two processes may be associated with the same program, they are nevertheless considered two separate execution sequences. For instance, several users may be running different copies of the mail program, or the same user may invoke many copies of the Web browser program.

Process State

As a process executes, it changes state. The state of a process is defined in part by the current activity of that process. Each process may be in one of the following states:

New. The process is being created.

Running. Instructions are being executed.

Waiting. The process is waiting for some event to occur (such as an I/0

completion or reception of a signal).

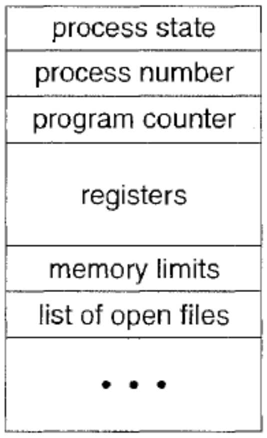
Ready. The process is waiting to be assigned to a processor.

Terminated. The process has finished execution.

These names are arbitrary, and they vary across operating systems. The states that they represent are found on all systems, however. Certain operating systems also more finely delineate process states. It is important to realize that only one process can be running on any processor at any instant. Many processes may be ready and waiting state.

Process Control Block

Each process is represented in the operating system by a process control block(PCB) also called a task control block. A PCB is shown in the following figure. It contains many pieces of information associated with a specific process, including these:



Process state: The state may be new, ready running, waiting, halted, and so on.

Program counter: The counter indicates the address of the next instruction to be executed for this process.

CPU registers: The registers vary in number and type, depending on the computer architecture. They include accumulators, index registers, stack pointers, and general-purpose registers, plus any condition-code information.

CPU-scheduling information: This information includes a process priority, pointers to scheduling queues, and any other scheduling parameters.

Memory-management information; This information may include such information as the value of the base and limit registers, the page tables, or the segment tables, depending on the memory system used by the operating system.

Accounting information: This information includes the amount of CPU and real time used, time limits, account numbers, job or process numbers, and so on.

I/O status information: This information includes the list of I/O devices allocated to the process, a list of open files, and so on.

Threads

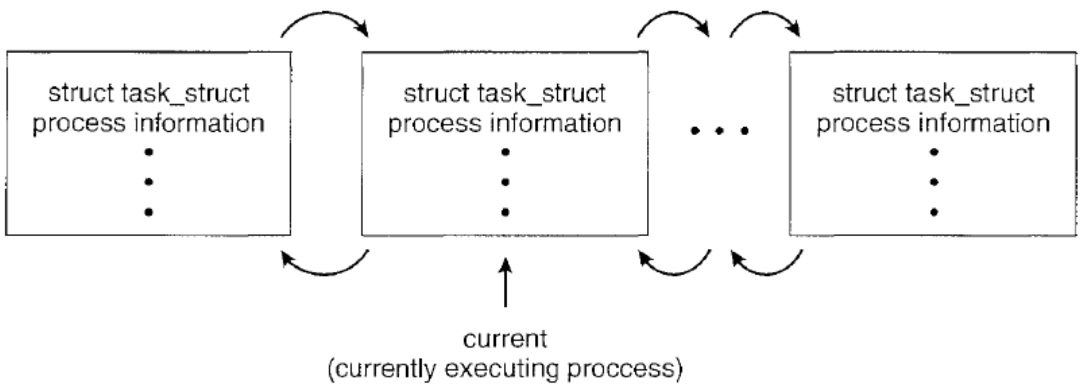
The process model discussed so far has implied that a process is a program that performs a single thread of execution. For example, when a process is running a word-processor program, a single thread of instructions is being executed. This single thread of control allows the process to perform only one task at one time. The user cannot simultaneously type in characters and run the spell checker within the same process, for example. Many modern operating systems have extended the process concept to allow a process to have multiple threads of execution and thus to perform more than one task at a time

Process Scheduling

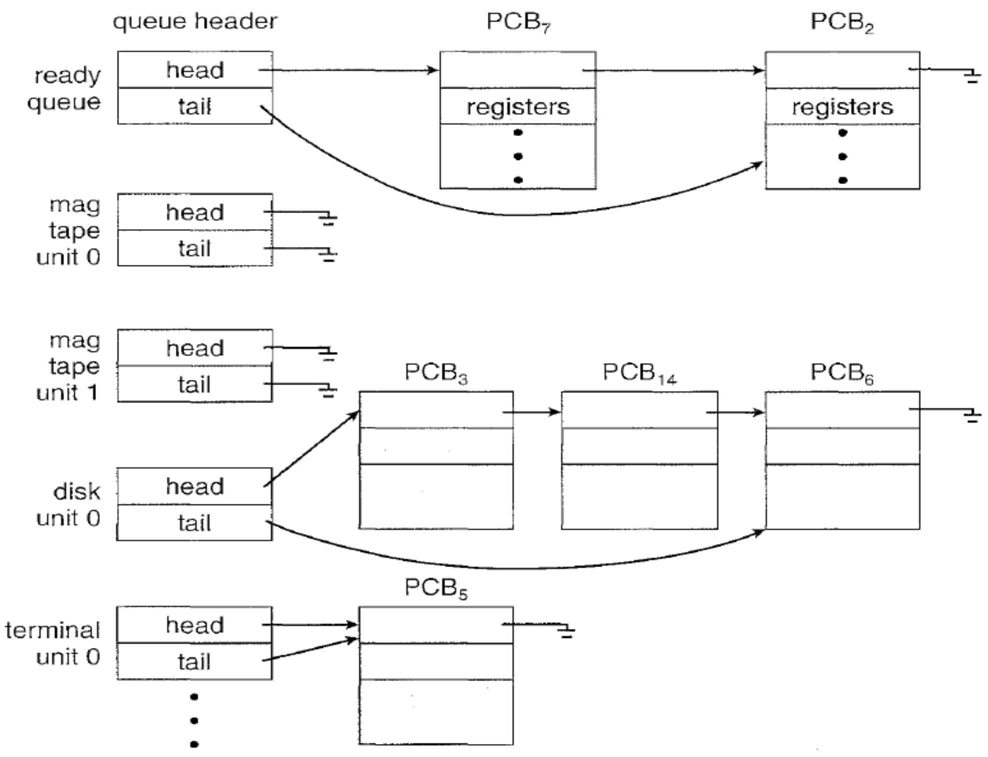
The objective of multiprogramming is to have some process running at all times, to maximize CPU utilization. The objective of time sharing is to switch the CPU among processes so frequently that users can interact with each program while it is running. To meet these objectives, the process scheduler selects an available process (possibly from a set of several available processes) for program execution on the CPU. For a single-processor system, there will never be more than one running process. If there are more processes, the rest will have to wait until the CPU is free and can be rescheduled.

Scheduling Queues

As processes enter the system, they are put into a job queue, which consists of all processes in the system. The processes that are residing in main memory and are ready and waiting to execute are kept on a list called the ready queue. For example, the state of a process is represented by the field long state in this structure. Within the Linux kernel, all active processes are represented using a doubly linked list of task-struct, and the kernel maintains a pointer -current -to the process currently executing on the system.



This queue is generally stored as a linked list. A ready-queue header contains pointers to the first and final PCBs in the list. Each PCB includes a pointer field that points to the next PCB in the ready queue



The ready queue and various 1/0 device queues.

The system also includes other queues. When a process is allocated the CPU, it executes for a while and eventually quits, is interrupted, or waits for the occurrence of a particular event, such as the completion of an I/0 request. Suppose the process makes an I/O request to a shared device, such as a disk. Since there are many processes in the system, the disk may be busy with the I/0 request of some other process. The process therefore may have to wait for the disk. The list of processes waiting for a particular I/0 device is called a **device queue**. Each device has its own device queue.

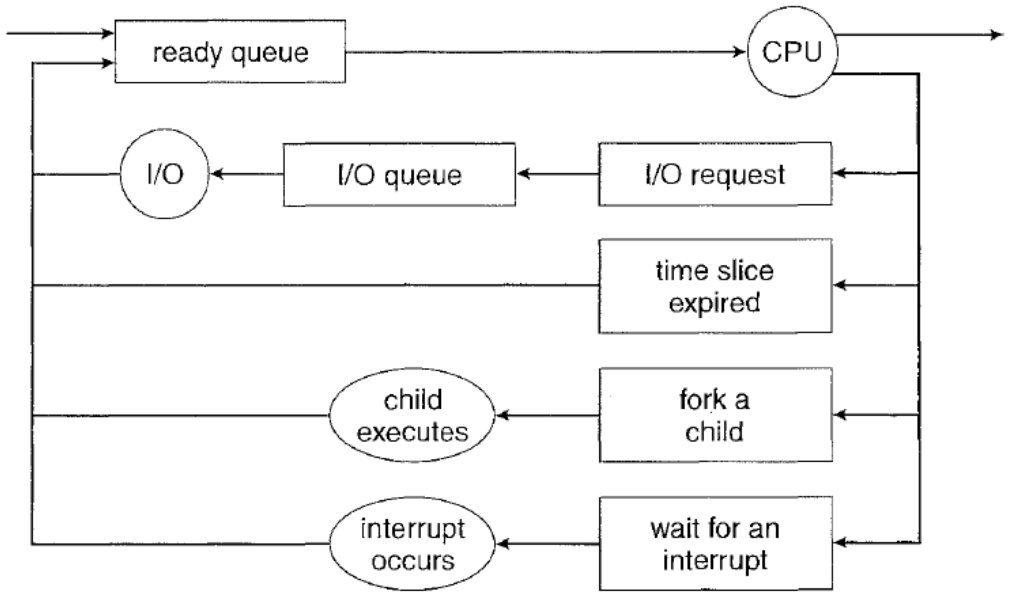
A common representation of process scheduling is a **queuing diagram,** such as that in Figure 3.7. Each rectangular box represents a queue. Two types of queues are present: the ready queue and a set of device queues. The circles represent the resources that serve the queues, and the arrows indicate the flow of processes in the system.

A new process is initially put in the ready queue. It waits there until it is selected for execution, or is **dispatched**. Once the process is allocated the CPU and is executing.

One of several events could occur:

- ❖ The process could issue an I/0 request and then be placed in an I/0 queue.
- ❖ The process could create a new sub process and wait for the sub process's termination.

- ❖ The process could be removed forcibly from the CPU, as a result of an interrupt, and be put back in the ready queue.



Queuing-diagram representation of process scheduling

In the first two cases, the process eventually switches from the waiting state to the ready state and is then put back in the ready queue. A process continues this cycle until it terminates, at which time it is removed from all queues and has its PCB and resources deallocated.

Schedulers:

A process migrates among the various scheduling queues throughout its lifetime. The operating system must select, for scheduling purposes, processes from these queues in some fashion. The selection process is carried out by the appropriate scheduler.

Often, in a batch system, more processes are submitted than can be executed immediately. These processes are spooled to a mass-storage device (typically a disk), where they are kept for later execution. The long-term scheduler, or job scheduler, selects processes from this pool and loads them into memory for execution. The short-term scheduler, or CPU scheduler, selects from among the processes that are ready to execute and allocates the CPU to one of them.

The primary distinction between these two schedulers lies in frequency of execution. The short-term scheduler must select a new process for the CPU frequently. A process may execute for only a few milliseconds before waiting for an I/0 request. Often, the short-term scheduler executes at least once every 100 milliseconds. Because of the short time between executions, the short-term scheduler must be fast. If it takes 10 milliseconds to decide to execute a process for

100 milliseconds, then 10 I (100 + 10) = 9 percent of the CPU is being used (wasted) simply for scheduling the work.

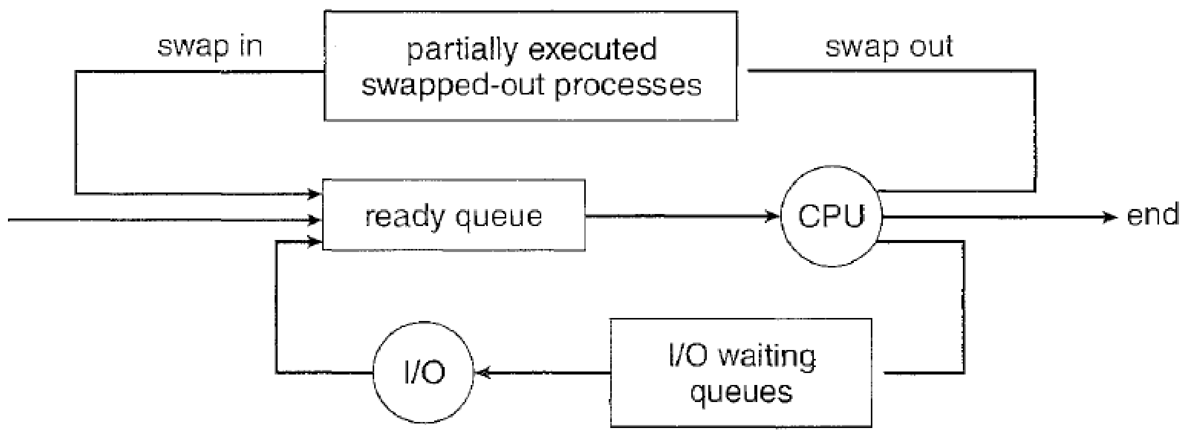
The long-term scheduler executes much less frequently; minutes may separate the creation of one new process and the next. The long-term scheduler

controls the degree of multiprogramming (the number of processes in memory). If the degree of multiprogramming is stable, then the average rate of process creation must be equal to the average departure rate of processes leaving the system. Thus, the long-term scheduler may need to be invoked only when a process leaves the system. Because of the longer interval between executions, the long-term scheduler can afford to take more time to decide which process should be selected for execution.

It is important that the long-term scheduler make a careful selection. In general, most processes can be described as either I/ 0 bound or CPU bound. An I/O-bound process is one that spends more of its time doing I/O than it spends doing computations. A CPU-bound process, in contrast, generates I/0 requests infrequently, using more of its time doing computations. It is important that the long-term scheduler select a good process mix of I/O-bound and CPU-bound processes. If all processes are I/0 bound, the ready queue will almost always be empty, and the short-term scheduler will have little to do. If all processes are CPU bound, the I/0 waiting queue will almost always be empty, devices will go unused, and again the system will be unbalanced. The system with the best performance will thus have a combination of CPU-bound and I/O-bound processes.

On some systems, the long-term scheduler may be absent or minimal. For example, time-sharing systems such as UNIX and Microsoft Windows systems often have no long-term scheduler but simply put every new process in memory for the short-term scheduler. The stability of these systems depends either on a physical limitation (such as the number of available terminals) or on the self-adjusting nature of human users. If performance declines to unacceptable levels on a multiuser system, some users will simply quit.

Some operating systems, such as time-sharing systems, may introduce an additional, intermediate level of scheduling. This medium-term scheduler is diagrammed in Figure 3.8. The key idea behind a medium-term scheduler is that sometimes it can be advantageous to remove processes from memory (and from active contention for the CPU) and thus reduce the degree Of multiprogramming. Later, the process can be reintroduced into memory, and its execution can be continued where it left off. This scheme is called swapping. The process is swapped out, and is later swapped in, by the medium-term scheduler. Swapping may be necessary to improve the process mix or because a change in memory requirements has overcommitted available memory, requiring memory to be freed up.



Addition of medium-term scheduling to the queueing diagram.

Context Switch:

As mentioned in interrupts cause the operating system to change a CPU from its current task and to run a kernel routine. Such operations happen frequently on general-purpose systems. When an interrupt occurs, the system needs to save the current context of the process running on the CPU so that it can restore that context when its processing is done, essentially suspending the process and then resuming it. The context is represented in the PCB of the process; it includes the value of the CPU registers, the process state and memory-management information. Generically, we perform a state save of the current state of the CPU, be it in kernel or user mode, and then a state restore to resume operations. Switching the CPU to another process requires performing a state save of the current process and a state restore of a different process.

This task is known as a context switch. When a context switch occurs, the kernel saves the context of the old process in its PCB and loads the saved context of the new process scheduled to run. Context-switch time is pure overhead, because the system does no useful work while switching. Its speed varies from machine to machine, depending on the memory speed, the number of registers that must be copied, and the existence of special instructions (such as a single instruction to load or store all registers). Typical speeds are a few milliseconds.

Context-switch times are highly dependent on hardware support. For instance, some processors (such as the Sun Ultra SPARC) provide multiple sets of registers. A context switch here simply requires changing the pointer to the current register set. Of course, if there are more active processes than there are register sets, the system resorts to copying register data to and from memory, as before. Also, the more complex the operating system, the more work must be done during a context switch.

Advanced memory-management techniques may require extra data to be switched with each context. For instance, the address space of the current process must be preserved as the space of the next task is prepared for use. How the address space is preserved, and what amount of work is needed to preserve it, depend on the memory-management method of the operating system.

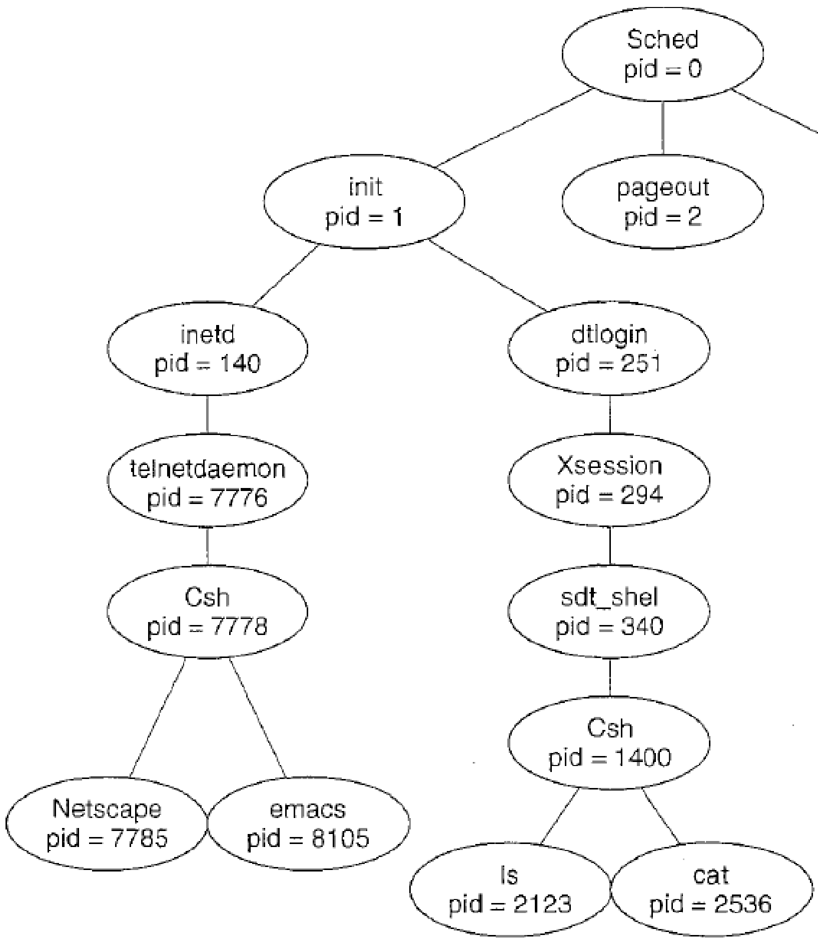
Operation on processes:

The processes in most systems can execute concurrently, and they may be created and deleted dynamically. Thus, these systems must provide a mechanism for process creation and termination. In this section, we explore the n1.echanisms involved in creating processes and illustrate process creation on UNIX and Windows systems.

Process Creation:

A process may create several new processes, via a create-process system call, during the course of execution. The creating process is called a parent process, and the new processes are called the children of that process. Each of these new processes may in turn create other processes, forming a tree of processes. Most operating systems (including UNIX and the Windows family of operating systems) identify processes according to a unique process identifier (or pid), which is typically an integer number. illustrates a typical process tree for the Solaris operating system, showing the name of each process and its pid. In Solaris, the process at the top of the tree is the sched process, with pid of 0. The sched process creates several children processes-including pageout and fsflush. These processes are responsible for managing memory and file systems.

Sub-process may be able to obtain its resources directly from the operating system, or it may be constrained to a subset of the resources of the parent process. The parent may have to partition its resources among its children, or it may be able to share some resources (such as memory or files) among several of its children. Restricting a child process to a subset of the parent's resources prevents any process from overloading the system by creating too many subprocesses.



In addition to the various physical and logical resources that a process obtains when it is created, initialization data (input) may be passed along by the parent process to the child process. For example, consider a process whose function is to display the contents of a file-say, img.jpg-on the screen of a terminal. When it is created, it will get, as an input from its parent process, the name of the file img.jpg, and it will use that file name, open the file, and write the contents out. It may also get the name of the output device. Some operating systems pass resources to child processes. On such a system, the new process may get two open files, img.jpg and the terminal device, and may simply transfer the datum between the two.

When a process creates a new process, two possibilities exist in terms of execution:

- ❖ The parent continues to execute concurrently with its children.
- ❖ The parent waits until some or all of its children have terminated.
- ❖ There are also two possibilities in terms of the address space of the new process:
- ❖ The child process is a duplicate of the parent process (it has the same
- ❖ program and data as the parent).
- ❖ The child process has a new program loaded into it.

To illustrate these differences, let's first consider the UNIX operating system. In UNIX, as we've seen, each process is identified by its process identifier, which is a unique integer. A new process is created by the fork() system call. The new process consists of a copy of the address space of the original process. This mechanism allows the parent process to communicate easily with its child process. Both processes (the parent and the child) continue execution at the instruction after the fork () , with one difference: the return code for the fork() is zero for the new (child) process, whereas the (nonzero) process identifier of the child is returned to the parent.

Typically, the exec() system call is used after a fork() system call by one of the two processes to replace the process's memory space with a new program. The exec() system call loads a binary file into memory (destroying the memory image of the program containing the exec() system call) and starts its execution. In this manner, the two processes are able to communicate and then go their separate ways. The parent can then create more children; or, if it has nothing else to do while the child runs, it can issue await() system call to move itself off the ready queue until the termination of the child.

Process Termination

A process terminates when it finishes executing its final statement and asks the operating system to delete it by using the exit () system calL At that point, the process may return a status value (typically an integer) to its parent process (via the wait() system call). All the resources of the process-including physical and virtual memory, open files, and I/0 buffers-are deallocated by the operating system.

Termination can occur in other circumstances as well A process can cause the termination of another process via an appropriate system call (for example, TerminateProcess () in Win32). Usually, such a system call can be invoked only by the parent of the process that is to be terminated. Otherwise, users could arbitrarily kill each other's jobs. Note that a parent needs to know the identities of its children. Thus, when one process creates a new process, the identity of the newly created process is passed to the parent.

A parent may terminate the execution of one of its children for a variety of reasons, such as these: The child has exceeded its usage of some of the resources that it has been allocated. (To determine whether this has occurred, the parent m.ust have a mechanism to inspect the state of its children.)

The task assigned to the child is no longer required.

The parent is exiting, and the operating system does not allow a child to continue if its parent terminates.

In UNIX, we can terminate a process by using the exit() system call; its parent process may wait for the termination of a child process by using the wait() system call. The wait() system call returns the process identifier of a terminated child so that the parent can tell which of its children has terminated.

Processes executing concurrently in the operating system may be either independent processes or cooperating processes. A process is independent if it cannot affect or be affected by the other processes executing in the system.

Any process that does not share data with any other process is independent. A process is cooperating if it can affect or be affected by the other processes executing in the system. Clearly, any process that shares data with other processes is a cooperating process.

There are several reasons for providing an environment that allows process cooperation:

Information sharing. Since several users may be interested in the same piece of information (for instance, a shared file), we must provide an environment to allow concurrent access to such information.

Computation speedup. If we want a particular task to run faster, we must break it into subtasks, each of which will be executing in parallel with the others. Notice that such a speedup can be achieved only if the computer has multiple processing elements (such as CPUs or I/O channels). Modularity. We may want to construct the system in a modular fashion, dividing the system functions into separate processes or threads. Even an individual user may work on many tasks at the same time. For instance, a user may be editing, printing, and compiling in parallel.

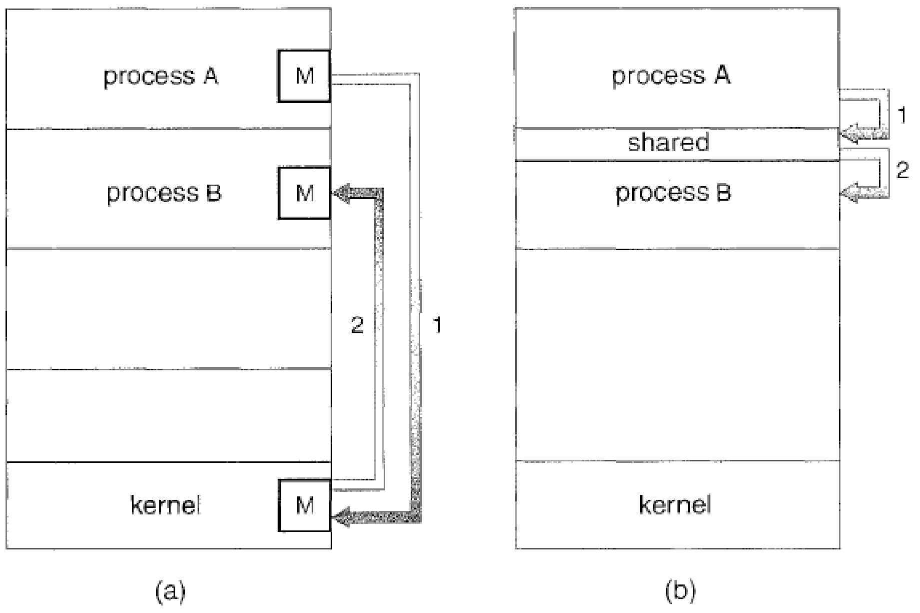


Figure 3.13 Communications models. (a) Message passing. (b) Shared memory.

between the cooperating processes. The two communications models are contrasted. Both of the models just discussed are common in operating systems, and many systems implement both. Message passing is useful for exchanging smaller amounts of data, because no conflicts need be avoided. Message passing is also easier to implement than is shared memory for inter-computer communication. Shared memory allows maximum speed and convenience of communication. Shared memory is faster than message passing, as message-passing systems are typically implemented using system calls and thus require the more time-consuming task of kernel intervention. In contrast, in shared memory systems, system calls are required only to establish shared-memory regions. Once shared memory is established, all accesses are treated as routine memory accesses, and no assistance from the kernel is required. In the remainder of this section, we explore each of these IPC models in more detail.

Shared-Memory Systems

Interprocess communication using shared memory requires communicating processes to establish a region of shared memory. Typically, a shared-memory region resides in the address space of the process creating the sharedmemory segment. Other processes that wish to communicate using this sharedmemory segment must attach it to their address space. 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 excbange information by reading and writing data in the shared areas. The form of the data and the location are determined by these processes and are not under the operating system's control. The processes are also responsible for ensuring that they are not writing to the same location simultaneously.

To illustrate the concept of cooperating processes, let's consider the producer-consumer problem, which is a common paradigm for cooperating processes. A producer process produces information that is consumed by a consumer process. For example, a compiler may produce assembly code, which is consumed by an assembler.

Message-Passing Systems

The scheme requires that these processes share a region of memory and that the code for accessing and manipulating the shared memory be written explicitly by the application programmer. Another way to achieve the same effect is for the operating system to provide the means for cooperating processes to communicate with each other via a message-passing facility.

Message passing provides a mechanism to allow processes to communicate and to synchronize their actions without sharing the same address space and is particularly useful in a distributed environment, where the communicating processes may reside on different computers connected by a network. For example, a chat program used on the World Wide Web could be designed so that chat participants communicate with one another by exchanging messages.

If processes P and Q want to communicate, they must send message to and receive messages from each other; a communication link must exist between them. This link can be implemented in a variety of ways. We are concerned here not with the link's physical implementation (such as shared memory, hardware bus, or network, which are covered in Chapter 16) but rather with its logical implementation. Here are several methods for logically implementing a link and the send 0 I receive() operations:

- ❖ Direct or indirect communication
- ❖ Synchronous or asynchronous communication
- ❖ Automatic or explicit buffering

Under direct communication, each process that wants to communicate must explicitly name the recipient or sender of the communication. In this scheme, the send() and receive() primitives are defined as: send(P, message) -Send a message to process P. receive (Q, message)-Receive a message from process Q.

A communication link in this scheme has the following properties:

A link is established automatically between every pair of processes that want to communicate. The processes need to know only each other's identity to communicate. A link is associated with exactly two processes.

Between each pair of processes, there exists exactly one link.

Synchronization

Communication between processes takes place through calls to send() and receive () primitives. There are different design options for implementing each primitive. Message passing may be either blocking or nonblocking also known as synchronous and asynchronous.

Blocking send. The sending process is blocked until the message is received by the receiving process or by the mailbox.

Nonblocking send. The sending process sends the message and resumes operation. Blocking receive. The receiver blocks until a message is available.

Nonblocking receive. The receiver retrieves either a valid message or a null.

Buffering

Whether communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue. Basically, such queues can be implemented in three ways:

Zero capacity. The queue has a maximum length of zero; thus, the link cannot have any messages waiting in it. In this case, the sender must block until the recipient receives the message.

Bounded capacity. The que~ue has finite length n; thus, at most n messages can reside in it. If the queue is not full when a new message is sent, the message is placed in the queue (either the message is copied or a pointer to the message is kept), and the sender can continue execution without waiting. The link's capacity is finite, however. If the link is full, the sender must block until space is available in the queLie.

Unbounded capacity. The queue's length is potentially infinite; thus, any number of messages can wait in it. The sender never blocks.

The zero-capacity case is sometimes referred to as a message system with no buffering; the other cases are referred to as systems with automatic buffering.