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31332–Operating Systems

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BLOCK – I INTRODUCTION

UNIT 1 INTRODUCTION

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1.0 INTRODUCTION

Operating system is the interface between the hardware and software. The purpose of an operating system is to provide an environment in which a user can execute programs in a convenient and efficient manner. An operating system is a software that manages the computer hardware. The hardware must provide appropriate mechanisms to ensure the correct operation of the computer system and to prevent user programs from interfering with the proper operation of the system. This unit covers the basics of operating system and how the entire computer system is organized. Definition of Operating System can be defined as,

- An operating system is a program that controls the execution of application programs and acts as an interface between the user of a computer and the computer hardware.
- A more common definition is that the operating system is the one program running at all times on the computer (usually called the kernel), with all else being application programs.
- An operating system is concerned with the allocation of resources and services, such as memory, processors, devices, and information. The operating system correspondingly includes programs to manage these resources, such as a traffic controller, a scheduler, memory management module, I/O programs, and a file system.

1.1 OBJECTIVE

This not helps the user to

- Understand operating system

- Learn different computer system organization

1.2 OPERATING SYSTEM

computer system can be divided roughly into four components: the hardware, the operating system, the software programs, and the users. The hardware—the central processing unit (CPU), the memory, and the input/output (I/O) devices—provide the simple computing sources for the system. The software programs—such as phrase processors, spreadsheets, compilers, and Web browsers—define the methods in which these assets are used to remedy users' computing problems. The running gadget controls the hardware and coordinates its use amongst the variety of utility programs for the variety of users. In view a laptop device as consisting of hardware, software program and data. The operating gadget offers the means for appropriate use of these assets in the operation of the pc system. An operating system is comparable to a government. Like a government, it performs no useful feature by way of itself. It truly gives an environment inside which other programs can do beneficial work.

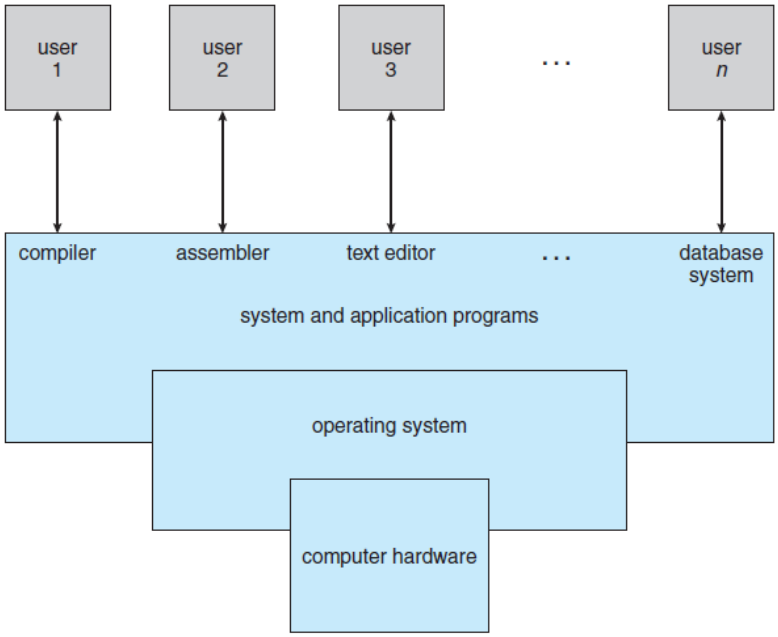

Figure 1.1 Abstract view of the components of a computer system.

1.2.1 User View

The user's view of the laptop varies according to the interface being used. Most laptop customers take a seat in the front of a PC, consisting of a monitor, keyboard, mouse, and system unit. Such a gadget is designed for one user. The purpose is to maximize the work (or play) that the user is performing. In this case, the operating system is designed mostly for ease of use, with some interest paid to overall performance and none paid to resource utilization—how more than a few hardware and software program sources are shared. Performance is, of course, necessary to the user;

however, such systems are optimized for the single-user trip as a substitute than the necessities of multiple users. In other cases, a user sits at a terminal related to a mainframe or a minicomputer. Other customers are having access to the same laptop through different terminals. These customers share sources and can also trade information.

The working machine in such cases is designed to maximize aid utilization— to guarantee that all handy CPU time, memory, and I/O are used efficiently and that no man or woman person takes greater than her truthful share. In still other cases, customers sit down at workstations related to networks of different workstations and servers. These customers have dedicated resources at their disposal; however, they additionally share sources such as networking and servers, such as file, compute, and print servers. Therefore, their running machine is designed to compromise between person usability and useful resource utilization.

Recently, many types of mobile computers, such as smartphones and tablets, have come into fashion. Most mobile computers are standalone gadgets for individual users. Quite often, they are related to networks through mobile or other Wi-Fi technologies. Increasingly, these cell devices are replacing computer and laptop computers for human beings who are exceptionally interested in the usage of computers for electronic mail and web browsing. The user interface for cellular computer systems normally aspects a touch screen, the place the person interacts with the device with the aid of pressing and swiping fingers throughout the display as an alternative than using a physical keyboard and mouse. Some computers have little or no user view. For example, embedded computers in home units and cars may additionally have numeric keypads and might also turn indicator lights on or off to show status, however they and their running structures are designed notably to run without user intervention

1.2.2 System View

From the computer's point of view, the operating device is the application most intimately worried with the hardware. In this context, we can view an operating device as a resource allocator. A computer device has many resources that may be required to remedy a problem: CPU time, reminiscence space, file-storage space, I/O devices, and so on. The running system acts as the manager of these resources. Facing numerous and maybe conflicting requests for resources, the operating device ought to figure out how to allocate them to precise applications and users so that it can operate the laptop machine effectively and fairly. As the, aid allocation is especially important where many users access the identical mainframe or minicomputer. A barely special view of an operating system emphasizes the need to control the range of I/O devices and user programs. An operating system is a manipulate program. A manage software manages the execution of user programs to forestall errors and unsuitable use of the computer. It is especially worried with the operation and manages of I/O device.

Notes

1.3 DEFINITION OF OPERATING SYSTEM

A set of software that controls the ordinary operation of a laptop system, generally through performing such tasks as reminiscence allocation, job scheduling, and input/output control. A running machine is a program that manages the laptop hardware. It also offers a basis for software applications and acts as an intermediary between the laptop person and the laptop hardware. An operating system acts as an intermediary between the consumer of the computer and computer hardware. The cause of a working gadget is to grant surroundings in which a person can execute applications in a convenient and efficient manner.

An operating machine is software program that manages the computer hardware. The hardware has to provide appropriate mechanisms to ensure the correct operation of laptop gadget and to prevent user applications from interfering with proper operation of the system.

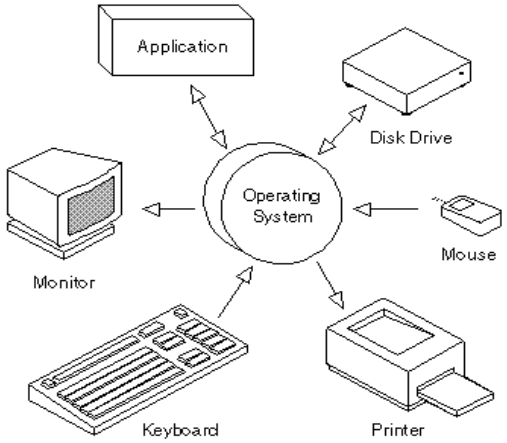

Fig 1.2 working of Operating System

In addition, we have no universally generic definition of what is section of the running system. A simple viewpoint is that it includes the whole thing a seller ships when you order "the running system." The facets included, however, fluctuate significantly across systems. Some systems take up much less than a megabyte of space and lack even a full-screen editor, whereas others require gigabytes of space and are based entirely on graphical windowing systems. A greater common definition, and the one that we generally follow, is that the working machine is the one application walking at all instances on the computer—usually called the kernel.

Along with the kernel, there are two other types of programs: system programs, which are related with the operating device but are now not necessarily phase of the kernel, and application programs, which consist of all programs now not associated with the operation of the system. The matter of what constitutes a working device grew to be increasingly necessary as personal computer systems grew to be greater extensive and working structures grew increasingly more sophisticated. In 1998, the United States Department of Justice filed go well with against Microsoft,

in essence claiming that Microsoft blanketed too plenty functionality in its running structures and consequently avoided application companies from competing.

For example, a Web browser was a necessary phase of the working systems. As a result, Microsoft was once determined guilty of the use of its operating-system monopoly to limit competition. Today, however, if we seem to be at running systems for cellular devices, we see that once again the variety of features constituting the running gadget

1.4 COMPUTER SYSTEM ORGANIZATION

1.4.1 Computer System Operation

A modern-day general-purpose computer gadget consists of one or extra CPUs and a quantity of machine controllers connected via a frequent bus that presents get right of entry to shared memory. Each device controller is in charge of a particular type of machine (for example, disk drives, audio devices, or video displays). The CPU and the system controllers can execute in parallel, competing for reminiscence cycles. To make certain orderly get entry to the shared memory, a reminiscence controller synchronizes get entry to the memory.

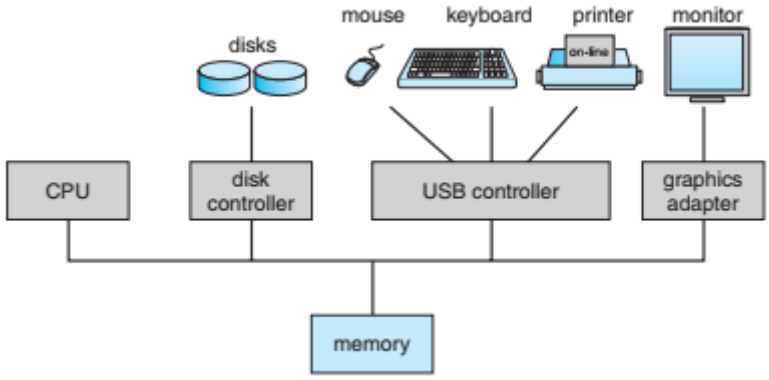

Figure 1.3 modernized computer system

There are numerous elements however three of them are main components in a pc system. They are the Central Processing Unit (CPU), reMemory (RAM and ROM) and Input, Output devices. The CPU is the predominant unit that technique data. Memory holds records required for processing. The input and output devices allow the customers to communicate with the computer.

The mechanism for every of the components to talk with every different is the bus architecture. It is a digital verbal exchange system, which includes information via electronic pathways known as circuit lines. The gadget bus is divided into three kinds referred to as tackle bus, facts bus and manipulates bus.

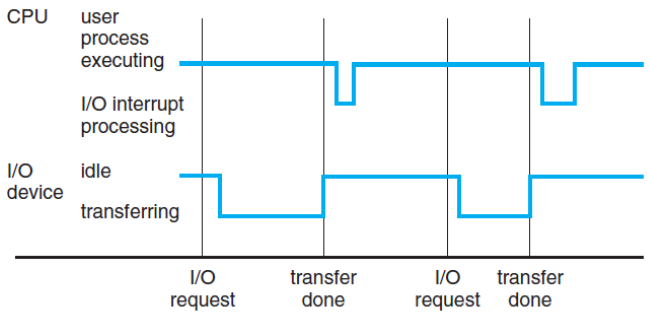

Figure 1.4 Timeline of Interrupts

Once the kernel is loaded and executing, it can begin offering services to the machine and its users. Some services are supplied outside of the kernel, through device programs that are loaded into memory at boot time to come to be gadget processes, or system daemons that run the entire time the kernel is running. On UNIX, the first machine method is "init," and it begins many other daemons. Once this phase is complete, the system is entirely booted, and the device waits for some event to occur. The prevalence of a tournament is generally signaled through an interrupt from both the hardware or the software. Hardware might also set off an interrupt at any time via sending a signal to the CPU, normally by using way of the device bus. Software may additionally set off an interrupt via executing a one-of-a-kind operation called a system call (also called a display call).

When the CPU is interrupted, it stops what it is doing and right away transfers execution to a constant location. The constant place typically contains the beginning tackle the place the service movements for the interrupt is located. The interrupt service hobby executes; on completion, the CPU resumes the interrupted computation. A timeline of this operation is proven in Figure 1.4. Interrupts are a necessary section of pc architecture. Each laptop graph has its own interrupt mechanism, but a number of features are common. The interrupt should switch and manipulate to the excellent interrupt carrier routine. The easy approach for handling this switch would be to invoke usual pursuits to examine the interrupt information. The routine, in turn, would call the interrupt-specific handler.

However, interrupts need to be treated quickly. Since only a predefined number of interrupts is possible, a desk of pointers to interrupt routines can be used as an alternative to provide the vital speed. The interrupt movement is known as indirectly through the table, with no intermediate hobbies needed. Generally, the desk of pointers is stored in low reminiscence (the first hundred or so locations). These areas preserve the addresses of the interrupt carrier routines for the number devices. This array, or interrupt vector, of addresses is then listed via a unique machine number, given with the interrupt request, to grant the address of the interrupt service routine for the interrupting device. Operating systems as different as Windows and UNIX dispatch interrupts in this manner.

The interrupt structure must additionally retailer the address of the interrupted instruction. Many historical designs truly stored the interrupt tackle in a fixed place or in a location listed by way of the gadget number. More current architectures save the return address on the system stack. If the interrupt activities wish to regulate the processor state—for instance, through modifying register values—it has to explicitly shop the modern-day kingdom and then restore that nation earlier than returning. After the interrupt is serviced, the saved return address is loaded into the program counter, and the interrupted computation resumes as even though the interrupt had not occurred.

1.4.2 Storage Structure

The CPU can load instructions only from memory, so any packages to run have to be stored there. General-purpose computer systems run most of their programs from rewritable memory, referred to as principal memory (also called random-access memory, or RAM). Main reminiscence frequently is implemented in a semiconductor science known as dynamic random-access reminiscence (DRAM). Computers use other forms of memory as well. We have already stated read-only memory, ROM) and electrically erasable programmable read-only memory, EEPROM). Because ROM can't be changed, solely static programs, such as the bootstrap application described earlier, are stored there.

The immutability of ROM is of use in game cartridges. EEPROM can be changed however cannot be changed frequently and so carries often static programs. For example, smartphones have EEPROM to keep their factory-installed programs. All forms of reminiscence grant an array of bytes. Each byte has its personal address. Interaction is achieved via a sequence of load or store instructions to unique memory addresses. The load training moves a byte or word from most important reminiscence to an inner register inside the CPU, whereas the keep instruction moves the content material of a register to primary memory. Aside from explicit hundreds and stores, the CPU automatically masses directions from principal memory for execution.

A regular instruction–execution cycle, as executed on a machine with von Neumann architecture, first fetches an instruction from reminiscence and shops that instruction in the coaching register. The coaching is then decoded and can also cause operands to be fetched from reminiscence and stored in some internal register. After the coaching on the operands has been executed, the end result may also be saved lower back in memory. Notice that the memory unit sees solely a flow of memory addresses. It does not comprehend how they are generated (by the guidance counter, indexing, indirection, literal addresses, or some different means) or what they are for (instructions or data).

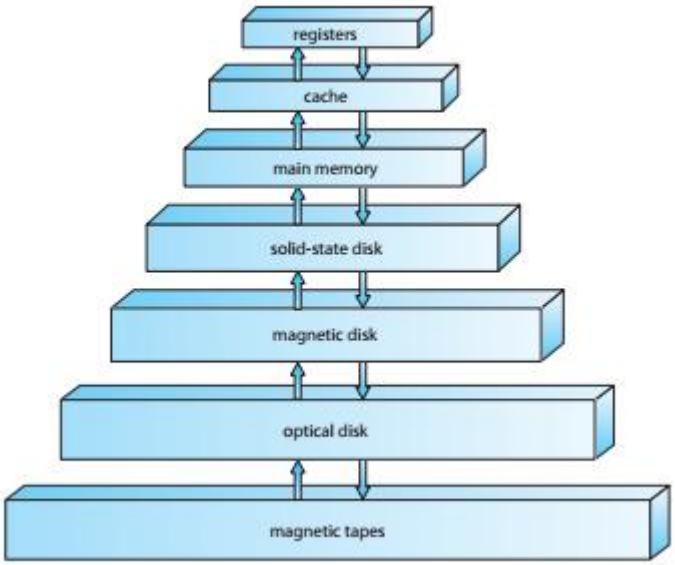

Figure 1.5 Hierarchy of Storage Device

Accordingly, we can omit how a reminiscence address is generated through a program. We are involved only in the sequence of memory addresses generated by way of the going for walks program. Ideally, we prefer the applications and facts to reside in major memory permanently. This association usually is not feasible for the following two reasons: 1. Main reminiscence is commonly too small to shop all needed programs and records permanently.2. Main memory is an unstable storage system that loses its contents when energy is turned off or otherwise lost. Thus, most pc systems supply secondary storage as an extension of important memory. The principal requirement for secondary storage is that it be able to maintain large portions of statistics permanently. The most frequent secondary-storage machine is a magnetic disk, which affords storage for both packages and data. Most programs (system and application) are stored on a disk until they are loaded into memory. Many programs then use the Hence, the applicable management of disk storage is of central importance to a pc system, as we talk about in. In a larger sense, however, the storage shape that we have described current of registers, principal memory, and magnetic disks—is only one of many possible storage systems. Others consist of cache memory, CD-ROM, magnetic tapes, and so on. Each storage system affords the simple functions of storing a datum and keeping that datum until it is retrieved at a later time. The most important variations among the various storage structures lie in speed, cost, size, and Volatility. The huge range of storage structures can be organized in a hierarchy (Figure 1.4) in accordance to speed and cost. The higher stages are expensive; however, they are fast. As we move down the hierarchy, the price per bit usually decreases, whereas the get right of entry to time commonly increases. This trade-off is reasonable; if a given storage machine have been each quicker and much less luxurious than another—other homes being the same—then there would be no motive to use the slower, extra high priced memory.

In fact, many early storage devices, which includes paper tape and core memories, are relegated to museums now that magnetic tape and semiconductor memory have end up faster and cheaper. The top 4 degrees of memory in Figure 1.4 can also be constructed the use of semiconductor memory. In addition to differing in velocity and cost, a range of storage systems are both unstable or nonvolatile. As stated earlier, unstable storage loses its contents when the energy to the gadget is removed. In the absence of highly-priced battery and generator backup systems, statistics must be written to non-volatile storage for safekeeping.

The storage systems above the solid-state disk are volatile, whereas these which includes the solid-state disk and under are nonvolatile. Solid-state disks have countless editions but in regularly occurring are quicker than magnetic disks and are nonvolatile. One type of solid-state disk stores information in a large DRAM array during everyday operation however also contains a hidden magnetic difficult disk and a battery for backup power. If exterior strength is interrupted, this solid-state disk's controller copies the facts from RAM to the magnetic disk.

When exterior strength is restored, the controller copies the facts lower back into RAM. Another form of solid-state disk is flash memory, which is popular in cameras and private digital assistants (PDAs), in robots, and increasingly more for storage on general-purpose computers. Flash memory is slower than DRAM however needs no strength to retain its contents. Another structure of nonvolatile storage is NVRAM, which is DRAM with battery backup power. This memory can be as fast as DRAM and (as lengthy as the battery lasts) is nonvolatile. The sketch of a whole reminiscence gadget needs to stability all the elements just discussed: it have to use solely as lots pricey memory as crucial whilst presenting as an awful lot inexpensive, nonvolatile memory as possible. Caches can be established to enhance overall performance where a massive disparity in get right of entry to time or transfer fee exists between two components.

1.4.3 I/O Structure

Storage is solely one of many kinds of I/O gadgets within a computer. A large element of working device code is committed to managing I/O, each because of its importance to the reliability and overall performance of a gadget and due to the fact of the various nature of the devices. Next, we grant an overview of I/O. A general-purpose pc device consists of CPUs and a couple of system controllers that are connected through a common bus. Each machine controller is in cost of a precise kind of device. Depending on the controller, more than one device may also be attached. For instance, seven or more units can be attached to the small computer-systems interface (SCSI) controller. A gadget controller continues some local buffer storage and a set of special-purpose registers. The gadget controller is accountable for moving the records between the peripheral units that it controls and its nearby buffer storage.

Typically, working structures have a machine driver for every gadget controller. This machine driver is familiar with the machine controller and

provides the rest of the running system with a uniform interface to the device. To begin an I/O operation, the gadget driver masses the appropriate registers within the device controller. The gadget controller, in turn, examines the contents of these registers to determine what action to take (such as "read a personality from the keyboard"). The controller starts off evolved the transfer of records from the machine to its nearby buffer. Once the switch of statistics is complete, the system controller informs the gadget driver via an interrupt that it has finished its operation. The device driver then returns control to the running system, possibly returning the statistics or a pointer to the facts if the operation was once a read. For other operations, the system driver returns repute information. This form of interrupt-driven I/O is great for transferring small amounts of data but can produce high overhead when used for bulk data motion such as disk I/O. To remedy this problem, direct reminiscence get right of entry to (DMA) is used. After placing up buffers, pointers, and counters for the I/O device, the gadget controller transfers a whole block of information immediately to or from its very own buffer storage to memory, with no intervention by the CPU. Only one interrupt is generated per block, to inform the device driver that the operation has completed, as a substitute than the one interrupt per byte generated for low-speed devices. While the system controller is performing these operations, the CPU is reachable to accomplish other work. Some high-end structures use switch as an alternative than bus architecture. On these systems, multiple factors can discuss to different factors concurrently, instead than competing for cycles on a shared bus. In this case, DMA is even more effective. Figure 1.6 suggests the interplay of all factors of a laptop system.

Check your Progress

1. What is an operating system?
2. What is the kernel?
3. What are the various components of a computer system?
4. What are the types of ROM?
5. What is SCSI?

1.5. ANSWERS TO CHECK YOUR PROGRESS

1. An operating system is a program that manages the computer hardware. it acts as an intermediate between a user's of a computer and the computer hardware. It controls and coordinates the use of the hardware among the various application programs for the various users.
2. A more common definition is that the OS is the one program running at all times on the computer, usually called the kernel, with all else being application programs.

3. A computer system can be divided roughly into four components: the hardware, the operating system, the software programs, and the users.
4. There are five basic ROM types:
    - ROM.
    - PROM.
    - EPROM.
    - EEPROM.
    - Flash memory
5. SCSI - Small computer systems interface is a type of interface used for computer components such as hard drives, optical drives, scanners and tape drives. It is a competing technology to standard IDE (Integrated Drive Electronics).

1.6. SUMMARY

- A computer system can be divided roughly into four components: the hardware, the operating system, the software programs, and the users.
- An operating system is a program that controls the execution of application programs and acts as an interface between the user of a computer and the computer hardware.
- When the CPU is interrupted, it stops what it is doing and right away transfers execution to a constant location.
- To begin an I/O operation, the gadget driver masses the appropriate registers within the device controller.
- Flash memory is slower than DRAM however needs no strength to retain its contents.
- The CPU can load instructions only from memory, so any packages to run have to be stored there.

1.7. KEYWORDS

Operating system: An operating machine is software program that manages the computer hardware.

Storage system: The storage systems above the solid-state disk are volatile, whereas these which includes the solid-state disk and under are nonvolatile.

Interrupt: Interrupt is the mechanism by which modules like I/O or memory may interrupt the normal processing by CPU.

1.8. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. Explain the concept of the batched operating systems?

2. What is purpose of different operating systems?
3. Difference between User View and System View?
4. Define I/O Structure?
5. Define Storage Structure?

Long Answer questions:

1. Explain Hierarchy of Storage Device?
2. Define Operating System and his working?
3. Define Computer System Organization?

1.9. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

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UNIT II
COMPUTER SYSTEM ARCHITECTURE

Structure

2.0 Introduction
2.1 Objective
2.2 Computer-System Architecture
2.3 Operating-System Operations
2.4 Check Your Progress
2.5 Answers to Check Your Progress Questions
2.6 Summary
2.7 Key Words
2.8 Self-Assessment Questions and Exercises
2.9 Further Readings

2.0 INTRODUCTION

This unit explains the structure of the operating system and the operations associated with it. Computer architecture is a set of rules and methods that describe the functionality, organization, and implementation of computer systems. Some definitions of architecture define it as describing the capabilities and programming model of a computer but not a particular implementation. In other definitions computer architecture involves instruction set architecture design, microarchitecture design, logic design, and implementation. The structure of the system and the various types are explained briefly. The different types of computer architecture and its working are explained clearly.

2.1 OBJECTIVE

This unit helps the user to

- Understand the various computer architecture
- Learn the operations of operating system

2.2 COMPUTER-SYSTEM ARCHITECTURE

The laptop machine can be defined under many classes which are listed out one with the aid of one below.

2.2.1 Multiprocessor structures or Parallel Systems

Multiprocessor systems with more than one CPU in close communication. Tightly coupled machine – processors share reminiscence and a clock; conversation typically takes location thru the shared memory. Although single-processor systems are most common, multiprocessor structures (also known as parallel systems or tightly coupled systems) are growing in

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importance. Such structures have two or more processors in close communication, sharing the pc bus and every now and then the clock, memory, and peripheral devices.

Advantages of parallel system:

- Increased throughput- By increasing the no of processors, work is accomplished in less time.
- Economical – multiprocessor system can shop more money because they can share peripheral, mass storage and power supply.
- Increased reliability- If one processor fields then the last processors will share the work of the failed processors.

  This is acknowledged as graceful degradation or fault tolerant

  1. Increased throughput. By growing the quantity of processors, we count on to get more work performed in less time.
  2. Economy of scale.
  3. Increased reliability.

  The ability to continue offering provider proportional to the stage of surviving hardware is called graceful degradation. Some structures go past swish degradation and are referred to as fault tolerant, because they can go through a failure of any single component and nevertheless continue operation.

  • The multiple-processor structures in use today are of two types.

  • Some structures use asymmetric multiprocessing, in which every processor is assigned a particular task.

  A master processor controls the system; the other processors both appear to the master for instruction or have predefined tasks. This scheme defines a master-slave relationship. The grasp processor schedules and allocates work to the slave processors. The most frequent structures use symmetric multiprocessing (SMP), in which each processor performs all duties within the working system. SMP capacity that all processors are peers; no master-slave relationship exists between processors.

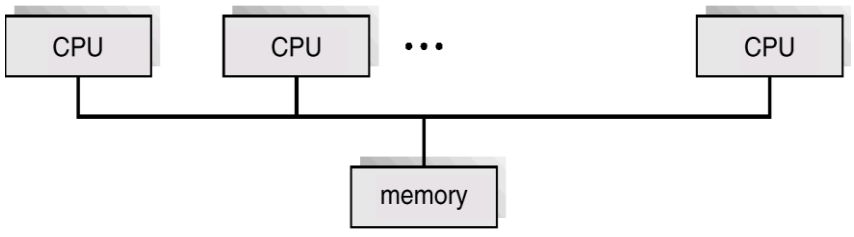

Fig 2.1 Symmetric Multiprocessing Architecture

Symmetric multiprocessing (SMP)

- Each processor runs a same reproduction of the running system.
- Many processes can run at once except performance deterioration.

- Most contemporary operating structures support SMP

Asymmetric multiprocessing

- Each processor is assigned a unique task; master processor schedules and allocates work to slave processors.
- More common in extraordinarily massive systems

2.2.2 Desktop Systems

- Personal computers – pc device committed to a single user.
- I/O units – keyboards, mice, display screens, small printers.
- User comfort and responsiveness.
- Can undertake science developed for larger operating system.
- Often individuals have sole use of pc and do not want superior CPU utilization or safety features.

  May run quite a few exclusive types of working systems (Windows, MacOS, UNIX, Linux)

2.2.3 The Multi programmed systems

Keeps more than one job in reminiscence simultaneously. When a job performs I/O, OS switches to every other job. It will increase CPU scheduling. All jobs enter the machine saved in the job pool on a disk scheduler brings jobs from pool into memory. Selecting the job from job pool is recognized as Job scheduling. Once the job loaded into memory, it is ready to execute, if numerous jobs are prepared to run at the same time, the machine have to pick among them, making this choice is CPU scheduling. The merit of CPU is never idle

2.2.4 Time-Sharing Systems–Interactive Computing

Also called as multi-tasking system. Multi person, single processor OS. Time sharing or multi-tasking permits more than one application to run concurrently. Multitasking is the capacity to execute extra than one task at the same time. A challenge is a program. In multitasking only one CPU is involved, the CPU switches from one program to any other so rapidly that it gives the look of executing all of the application runs at the same time.

Two types of multitasking

1. Pre-emptive - Time slice given to CPU with the aid of OS
2. Cooperative or non-preemptive - In this every program can manage the CPU for as lengthy as it wants CPU.

2.2.5 Distributed Systems

A distributed machine consists of a collection of self sufficient computers, linked thru a community and distribution middleware, which permits computer systems to coordinate their activities and to share the sources of the system, so that users discover the system as a single, integrated computing facility. Distribute the computation among several physical processors. Loosely coupled

device – each processor has its personal neighborhood memory; processors speak with one another thru a range of communications lines, such as excessive speed buses or telephone lines.

Advantages

- Resources Sharing
- Computation speed up – load sharing
- Reliability
- Communications
- Openness
- Concurrency
- Scalability
- Fault Tolerance
- Transparency

Characteristics of disbursed systems.

- One component with non-autonomous parts
- Component shared via customers all the time
- All resources accessible
- Software runs in a single process
- Single Point of control
- Single Point of failure
- Multiple self sufficient components
- Components are no longer shared by means of all users
- Resources might also not be accessible
- Software runs in concurrent procedures on distinct processors
- Multiple Points of control
- Multiple Points of failure

2.2.6 Client server systems

- In centralized system, a single machine acts as a server device to satisfy request generated by customer systems, this structure of specialized distributed gadget is known as client-server system.
- Server structures can be generally categorized as compute servers and file servers. The compute-server machine provides an interface to which a patron can send a request to operate an action (for example, study data); in response, the server executes the action and sends returned results to the client. A server going for walks a database that responds to customer requests for facts is an example of such a system. The file-server machine affords a file-system interface where consumers can create, update, read, and delete files. An example of such a device is an internet server that supplies archives to purchasers running net browsers.

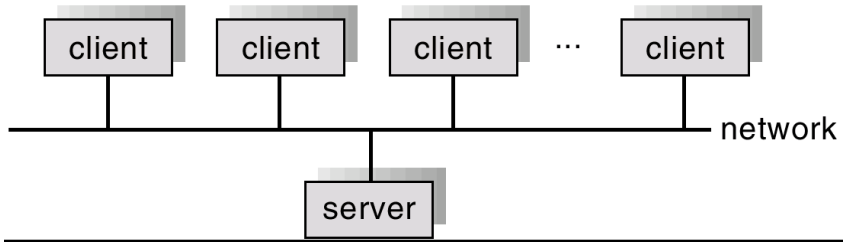

Figure 2.2 General Structure of Client-Server

2.2.7 Peer to Peer System

- The growth of the computer networks leads to the internet. Virtually all modem PCs and workstations are capable of running a web browser for accessing hypertext documents on the web. Several operating systems now include the web browsers, electronic mail, and remote login and file transfer clients and servers.
- In this model, clients and servers are not distinguished from one another; instead, all nodes within the system are considered peers, and each may act as either a client or a server, depending on whether it is requesting or providing a service.
- Peer-to-peer systems offer an advantage over traditional client-server systems.
    - In a client-server system, the server is a bottleneck;
    - But in a peer-to-peer system, services can be provided by several nodes distributed throughout the network.
- To participate in a peer-to-peer system, a node must first join the network of peers. Once a node has joined the network, it can begin providing services to—and requesting services from—other nodes in the network.
- Determining what services are available is accomplished in one of two general ways:
    - When a node joins a network, it registers its service with a centralized lookup service on the network. Any node desiring a specific service first contacts this centralized lookup service to determine which node provides the service. The remainder of the communication takes place between the client and the service provider.
    - A peer acting as a client must first discover what node provides a desired service by broadcasting a request for the service to all other nodes in the network. The node (or nodes) providing that service responds to the peer making the request. To support this approach, a discovery protocol must be provided that allows peers to discover services provided by other peers in the network.

2.2.8 Clustered Systems

Clustered systems gather together multiple CPUs to accomplish computational work.

- Clustering allows two or more systems to share storage.
- Provides high reliability.
- ***Clustered Systems*** **-** Another type of multiple-CPU system is the clustered system.
- 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 coupled together.
- Clustered computers share storage and are closely linked via a local-area network (LAN) or a faster interconnect network.
- Clustering is usually used to provide high-availability 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.
- Clustering can be structured asymmetrically or symmetrically.
    - Asymmetric clustering: one server standby while the other runs the application. The standby server monitors the active machine.
    - Symmetric clustering: all N hosts are running the application and they monitor each other.
- Other forms of clusters include parallel clusters and clustering over a wide-area network (WAN).
- Parallel clusters allow multiple hosts to access the same data on the shared storage.
- Because most operating systems lack support for simultaneous data access by multiple hosts, parallel clusters are usually accomplished by use of special versions of software and special releases of applications.
- Example: Oracle Parallel Server is a version of Oracle's database that has been designed to run on a parallel cluster.

2.2.9 Real-Time Systems

- Often used as a control device in a dedicated application such as controlling scientific experiments, medical imaging systems, industrial control systems, and some display systems.
- Well-defined fixed-time constraints.
- Real-Time systems may be either hard or soft real-time.
- Hard real-time:
    - Secondary storage limited or absent, data stored in short term memory, or read-only memory (ROM)

- Conflicts with time-sharing systems, not supported by general-purpose operating systems.

- Soft real-time
  - Limited utility in industrial control of robotics
  - Useful in applications (multimedia, virtual reality) requiring advanced operating system features.

2.3 Operating-System Operations

There are no procedures to execute, no I/O devices to service, and no customers to whom to respond, a running gadget will sit down quietly, waiting for something to happen. Events are almost constantly signaled by the occurrence of an interrupt or a trap. A trap (or an exception) is a software-generated interrupt brought on either with the aid of an error (for example, division by using zero or invalid memory access) or with the aid of a precise request from a consumer program that an operating-system carrier be performed. The interrupt-driven nature of an running machine defines that system's accepted structure. For each type of interrupt, separate segments of code in the working device decide what action ought to be taken.

An interrupt service routine is supplied to deal with the interrupt. Since the operating machine and the customers share the hardware and software program assets of the computer system, we need to make sure that an error in person software ought to motive problems only for the one application running. With sharing, many procedures ought to be adversely affected through a worm in one program. For example, if a process gets caught in an infinite loop, this loop may want to prevent the right operation of many different processes. More refined blunders can occur in a multiprogramming system, where one faulty software may alter some other program, the information of every other program, or even the working machine itself. Without safety towards these sorts of errors, both the pc ought to execute only one method at a time or all output must be suspect. A right designed working device has to make certain that a flawed (or malicious) program cannot motive different programs to execute incorrectly.

2.3.1 Dual-Mode and Multimode Operation

In order to make certain the appropriate execution of the working system, we should be able to distinguish between the execution of operating-system code and consumer defined code. The method taken through most computer systems is to supply hardware help that lets in us to differentiate among more than a few modes of execution at the very least; we need two separate modes of operation: person mode and kernel mode (also known as supervisor mode, machine mode, or privileged mode). A bit, known as the mode bit, is introduced to the hardware of the pc to point out the modern-day mode: kernel (0) or person (1). With the mode bit, we can distinguish between a mission that is carried out on behalf of the running device and one that is finished on behalf of the user. When the laptop machine is executing on behalf of a consumer application, the system is in person

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mode. However, when a consumer software requests a provider from the running device (via a machine call), the device ought to transition from person to kernel mode to fulfil the request. As we shall see, this architectural enhancement is beneficial for many different factors of device operation as well. At system boot time, the hardware starts off evolved in kernel mode. The running device is then loaded and starts off evolved consumer functions in consumer mode.

Whenever a trap or interrupt occurs, the hardware switches from person mode to kernel mode (that is, modifications the country of the mode bit to 0). Thus, each time the running device positive aspects manipulate of the computer, it is in kernel mode. The gadget usually switches to person mode (by placing the mode bit to 1) earlier than passing manage to a user program. The twin mode of operation presents us with the skill for protecting the running system from errant users—and errant customers from one another. We accomplish this safety by designating some of the machine directions that may purpose harm as privileged instructions. The hardware approves privileged instructions to be finished only in kernel mode. If an attempt is made to execute a privileged preparation in person mode, the hardware does no longer execute the coaching however instead treats it as illegal and traps it to the working system. The coaching to switch to kernel mode is an instance of a privileged instruction. Some different examples encompass I/O control, timer management, and interrupt management.

As we shall see at some point of the text, there are many extra privileged instructions. The concept of modes can be prolonged past two modes (in which case the CPU uses greater than one bit to set and take a look at the mode). CPUs that support virtualization (Section 16.1) regularly have a separate mode to point out when the digital desktop manager (VMM)—and the virtualization management software—are in control of the system. In this mode, the VMM has more privileges than consumer methods but fewer than the kernel. It desires that stage of privilege so it can create and control digital machines, altering the CPU state to do so. Sometimes, too, exceptional modes are used by way of number kernel components. We observe that, as an alternative to modes, the CPU fashion designer may use different methods to differentiate operational privileges. The Intel 64 household of CPUs supports 4 privilege levels, for example, and helps virtualization but does now not have a separate mode for virtualization. We can now see the life cycle of training execution in a computer system. Initial control resides in the operating system, where instructions are executed in kernel mode. When control is given to a user application, the mode is set to person mode. Eventually, manipulate is switched lower back to the operating device through an interrupt, a trap, or a machine call. System calls supply the ability for person software to ask the operating machine to function duties reserved for the running device on the user program's behalf. A system call is invoked in a range of ways, relying on the functionality provided by the underlying processor.

In all forms, it is the approach used by way of a procedure to request action through the operating system. A gadget call typically takes the form of an entice to a precise location in the interrupt vector. This entice can be completed via a normal entice instruction, although some structures (such as MIPS) have a precise machine name coaching to invoke a device call. When a gadget name is executed, it is typically dealt with by using the hardware as software interrupts. Control passes via the interrupt vector to carrier events in the working system, and the mode bit is set to kernel mode. The system-call provider hobbies are a section of the running system. The kernel examines the interrupting preparation to decide what machine name has occurred; a parameter suggests what kind of carrier the person program is requesting. Additional facts wished for the request may additionally be handed in registers, on the stack, or in memory (with pointers to the memory locations Passed in registers). The kernel verifies that the parameters are right and legal, executes the request, and returns control to the coaching following the device call. The lack of a hardware-supported dual mode can cause serious shortcomings in an operating system. For instance, MS-DOS was written for the Intel 8088 architecture, which has no mode bit and therefore no twin mode.

A consumer software going for walks awry can wipe out the working machine by way of writing over it with data; and a couple of applications are capable to write to a device at the same time, with probably disastrous results. Modern versions of the Intel CPU do provide dual-mode operation. Accordingly, most present day operating systems—such as Microsoft Windows 7, as well as UNIX and Linux—take advantage of this dual-mode function and furnish higher protection for the running system. Once hardware safety is in place, it detects blunders that violate modes.

These errors are generally treated by the running system. If a consumer program fails in some way—such as via making an attempt either to execute an illegal preparation or to access reminiscence that is now not in the user's address space—then the hardware traps to the running system. The trap transfers manage thru the interrupt vector to the operating system, just as an interrupt does. When a program error occurs, the running device have to terminate the application abnormally. This state of affairs is handled by way of the identical code as a user-requested strange termination. A gorgeous error message is given, and the memory of the program may additionally be dumped. The memory dump is generally written to a file so that the user or programmer can observe it and possibly right it and restart the program.

2.3.2 Timer

A timer can be set to interrupt the computer after a targeted period. The length may also be constant (for example, 1/60 second) or variable (for example, from 1 millisecond to 1 second). A variable timer is normally implemented by a fixed-rate clock and a counter. The working gadget sets the counter. Every time the clock ticks, the counter is decremented. When the counter reaches 0, an interrupt occurs. For instance, a 10-bit counter

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with 1-millisecond clock permits interrupts at intervals from 1 millisecond to 1,024 milliseconds, in steps of 1 millisecond.

Before turning over manipulate to the user, the operating machine ensures that the timer is set to interrupt. If the timer interrupts, manipulate transfers robotically to the working system, which may deal with the interrupt as a fatal error or can also provide the program greater time. Clearly, guidelines that adjust the content of the timer are privileged. We can use the timer to forestall a person program from walking too long. An easy technique is to initialize a counter with the amount of time that an application is allowed to run. Software with a 7-minute time limit, for example, would have its counter initialized to 420. Every second, the timer interrupts, and the counter is decremented by way of 1. As long as the counter is positive, control is lower back to the user program. When the counter will become negative, the running machine terminates the program for exceeding the assigned time limit.

Check your Progress

1. What is a Real-Time System?
2. What are the different operating systems?
3. What is dual-mode operation?
4. What are the different types of Real-Time Scheduling?
5. What are operating system services?

2.4. ANSWERS TO CHECK YOUR PROGRESS

1. A real time process is a process that must respond to the events within a certain time period. A real time operating system is an operating system that can run Realtime processes successfully.
2. Some of the Operating systems is:
   - Batched operating systems
   - Multi-programmed operating systems
   - Timesharing operating systems
   - Distributed operating systems
   - Real-time operating systems.
3. In order to protect the operating systems and the system programs from the malfunctioning programs the two mode operations were evolved.
   - System mode
   - User mode
4. There are two types of Real-Time Scheduling:
   - Hard real-time systems required to complete a critical task within a guaranteed amount of time.
   - Soft real-time computing requires that critical processes receive priority over less fortunate ones.

5. An Operating System provides services are:
    - Program execution
    - I/O operations
    - File System manipulation
    - Communication
    - Error Detection
    - Resource Allocation
    - Protection

2.5. SUMMARY

- A distributed machine consists of a collection of self sufficient computers, linked via community and distribution middleware, which permits computer systems to coordinate their activities and to share the sources of the system, so that users discover the system as a single, integrated computing facility.
- In centralized system, a single machine acts as a server device to satisfy request generated by customer systems, this structure of specialized distributed gadget is known as client-server system.
- Server structures can be generally categorized as compute servers and file servers.
- A peer acting as a client must first discover what node provides a desired service by broadcasting a request for the service to all other nodes in the network.
- Clustered systems gather together multiple CPUs to accomplish computational work.
- In order to make certain the appropriate execution of the working system, we should be able to distinguish between the execution of operating-system code and consumer defined code.

2.6. KEYWORDS

Symmetric multiprocessing (SMP): Each processor runs a same reproduction of the running system.

Asymmetric multiprocessing: Each processor is assigned a unique task; master processor schedules and allocates work to slave processors.

Two types of multitasking: Pre-emptive and Non Pre-emptive

Job scheduling: Selecting the job from job pool is recognized as Job scheduling.

Timer: A timer can be set to interrupt the computer after a targeted period.

2.7. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What are the Types of Operating System?
2. What is Desktop System?
3. What is Time-Sharing Systems?
4. Explain about Dual-Mode and Multimode Operation?
5. What are the advantages of Peer to Peer system?

Long Answer questions:

1. What are the differences between Real Time System and Timesharing System?
2. Explain the Computer-System Architecture?
3. Explain about Operating System and its Types?

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UNIT III SYSTEM STRUCTURES

Structure

3.0 Introduction
3.1 Objective
3.2 Operating-System Structure
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3.0 INTRODUCTION

The structure of the operating system and how it is connected with the system is important because the operating is the first booting in the system. The kernel is the core of an operating system. It is the software responsible for running programs and providing secure access to the machine's hardware. Since there are many programs, and resources are limited, the kernel also decides when and how long a program should run. This is called scheduling. Accessing the hardware directly can be very complex, since there are many different hardware designs for the same type of component. Kernels usually implement some level of hardware abstraction (a set of instructions universal to all devices of a certain type) to hide the underlying complexity from applications and provide a clean and uniform interface. The booting is calling of the system with the design and implementation of operating system is explained in this unit.

3.1 OBJECTIVE

This unit helps the user for

- Understanding the various services provided by the operating system
- Design an operating system
- Implementing an operating system

3.2 OPERATING-SYSTEM STRUCTURE

A device as large and complicated as a cutting-edge working device ought to be engineered carefully if it is to feature properly and be modified easily. A common strategy is to partition the challenge into small components, or modules, alternatively than have one monolithic system.

Each of these modules should be a well-defined element of the system, with cautiously defined inputs, outputs, and functions.

3.2.1 SIMPLE STRUCTURE

Many operating structures do not have well-defined structures. Frequently, such structures began as small, simple, and limited systems and then grew past their authentic scope. MS-DOS is an example of such a system. It was at the beginning designed and carried out by using a few humans who had no thinking that it would become so popular. It was once written to supply the most performance in the least space, so it was once now not carefully divided into modules. In MS-DOS, the interfaces and stages of performance are now not well separated. For instance, utility packages are in a position to get entry to the basic I/O routines to write immediately to the display and disk drives. Such freedom leaves MS-DOS susceptible to errant (or malicious) programs, inflicting complete system crashes when consumer applications fail. Of course, MS-DOS was additionally restrained with the aid of the hardware of its era. Because the Intel 8088 for which it used to be written gives no dual mode and no hardware protection, the designers of MS-DOS had no choice but to leave the base hardware accessible. Another instance of restrained structuring is the unique UNIX running system. Like MS-DOS, UNIX initially was once restrained by means of hardware functionality. It consists of two separable parts: the kernel and the gadget programs

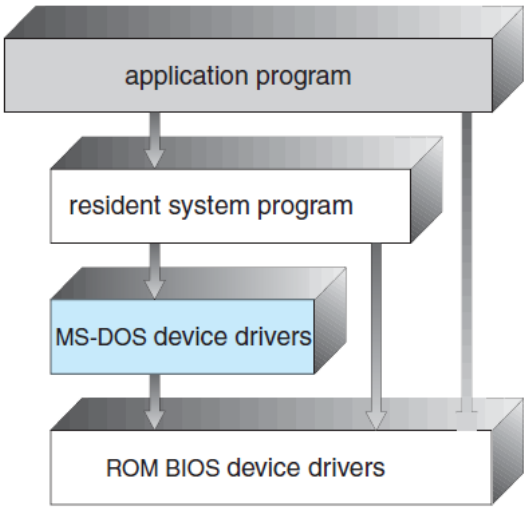

Figure 3.1 MS-DOS layer structures

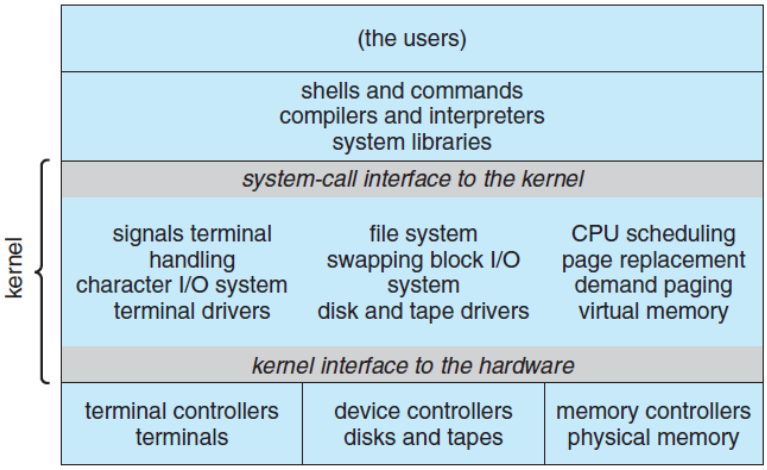

Figure 3.2 Traditional UNIX system structure

3.2.2 Layered Approach

With perfect hardware support, working structures can be damaged into portions that are smaller and extra splendid than these allowed with the aid of the unique MS-DOS and UNIX systems. The operating machine can then retain a lot higher manage over the computer and over the purposes that make use of that computer. Implementers have more freedom in altering the internal workings of the gadget and in growing modular running systems. Under a pinnacle down approach, the universal functionality and features are determined and are separated into components. Information hiding is also important, because it leaves programmers free to put into effect the low-level routines as they see fit, provided that the exterior interface of the activities stays unchanged and that the events itself performs the marketed task. A machine can be made modular in many ways. One technique is the layered approach, in which the running device is broken into a number of layers (levels). The backside layer (layer 0) is the hardware; the perfect (layer N) is the consumer interface.

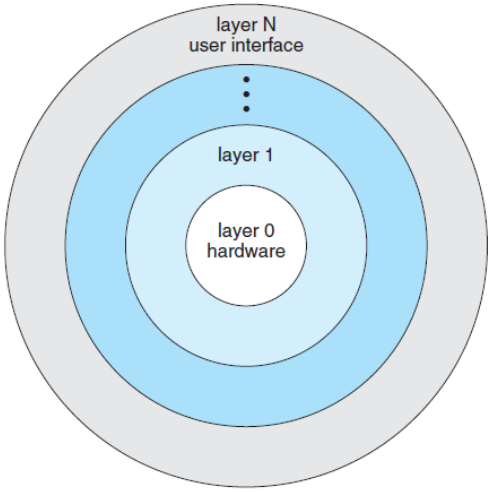

Figure 3.3 Layered operating system.

The main advantage of the layered approach is simplicity of construction and debugging. The layers are selected so that each uses functions (operations) and services of only lower-level layers. This approach simplifies debugging and system verification. The first layer can be debugged without any concern for the rest of the system, because, by definition, it uses only the basic hardware (which is assumed correct) to implement its functions. Once the first layer is debugged, its correct functioning can be assumed while the second layer is debugged, and so on. If an error is found during the debugging of a particular layer, the error must be on that layer, because the layers below it are already debugged. Thus, the design and implementation of the system are simplified.

Each layer is implemented only with operations provided by lower-level layers. A layer does not need to know how these operations are implemented; it needs to know only what these operations do. Hence, each layer hides the existence of certain data structures, operations, and hardware from higher-level layers.

The major difficulty with the layered approach involves appropriately defining the various layers. Because a layer can use only lower-level layers, careful planning is necessary. For example, the device driver for the backing store (disk space used by virtual-memory algorithms) must be at a lower level than the memory-management routines, because memory management requires the ability to use the backing store.

3.3.3 Microkernels

The main function of the microkernel is to provide communication between the client program and the various services that are also running in user space. Communication is provided through message passing,

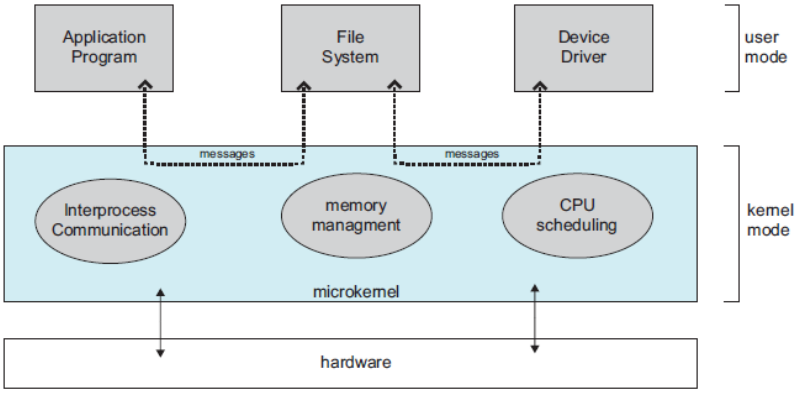

Figure 3.4 Architecture of a typical microkernel

One benefit of the microkernel approach is that it makes extending the operating system easier. All new services are added to user space and consequently do not require modification of the kernel. When the kernel

does have to be modified, the changes tend to be fewer, because the microkernel is a smaller kernel. The resulting operating system is easier to port from one hardware design to another. The microkernel also provides more security and reliability, since most services are running as user— rather than kernel— processes. If a service fails, the rest of the operating system remains untouched

3.3.4 Modules

The idea of the design is for the kernel to provide core services while other services are implemented dynamically, as the kernel is running. Linking services dynamically is preferable to adding new features directly to the kernel, which would require recompiling the kernel every time a change was made. Thus, for example, we might build CPU scheduling and memory management algorithms directly into the kernel and then add support for different file systems by way of loadable modules.

The Solaris operating system structure is organized around a core kernel with seven types of loadable kernel modules:

1. Scheduling classes

2. File systems

3. Loadable system calls

4. Executable formats

5. STREAMS modules

6. Miscellaneous

7. Device and bus drivers

Linux also uses loadable kernel modules, primarily for supporting device drivers and file systems

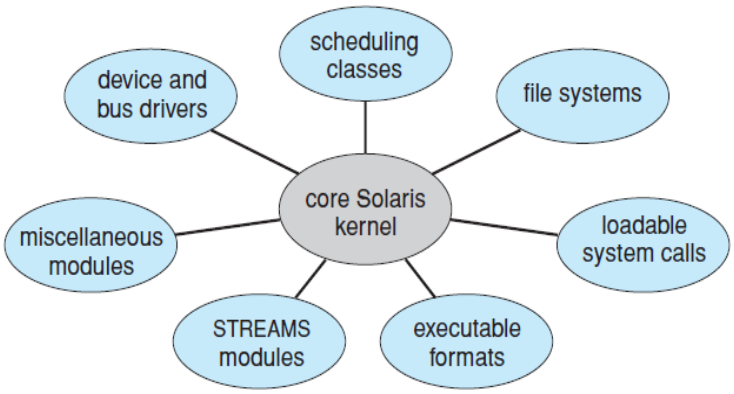

Figure 3.5 Solaris loadable modules

3.3.5 Hybrid Systems

In practice, very few operating systems adopt a single, strictly defined structure. Instead, they combine different structures, resulting in hybrid systems that address performance, security, and usability issues. For example, both Linux and Solaris are monolithic, because having the operating system in a single address space provides very efficient performance. However, they are also modular, so that new functionality can be dynamically added to the kernel. Windows is largely monolithic as well (again primarily for performance reasons), but it retains some behavior typical of microkernel systems, including providing support for separate subsystems (known as operating-system personalities) that run as user-mode processes

3.3.6 Mac OS X

The top layers include the Aqua user interface and a set of application environments and services. Notably, the Cocoa environment specifies an API for the Objective-C programming language, which is used for writing Mac OS X applications. Below these layers is the kernel environment, which consists primarily of the Mach microkernel and the BSD UNIX kernel. Mach provides memory management; support for remote procedure calls (RPCs) and interproceses communication (IPC) facilities, including message passing; and thread scheduling. The BSD component provides a BSD command-line interface, support for networking and file systems, and an implementation of POSIX APIs, including Pthreads. In addition to Mach and BSD, the kernel environment provides an I/O kit for development of device drivers and dynamically loadable modules (which Mac OS X refers to as kernel extensions).

3.3.7 iOS

iOS is a mobile operating system designed by Apple to run its smartphone, the iPhone, as well as its tablet computer, the iPad. iOS is structured on the Mac OS X operating system, with added functionality pertinent to mobile devices, but does not directly run Mac OS X applications

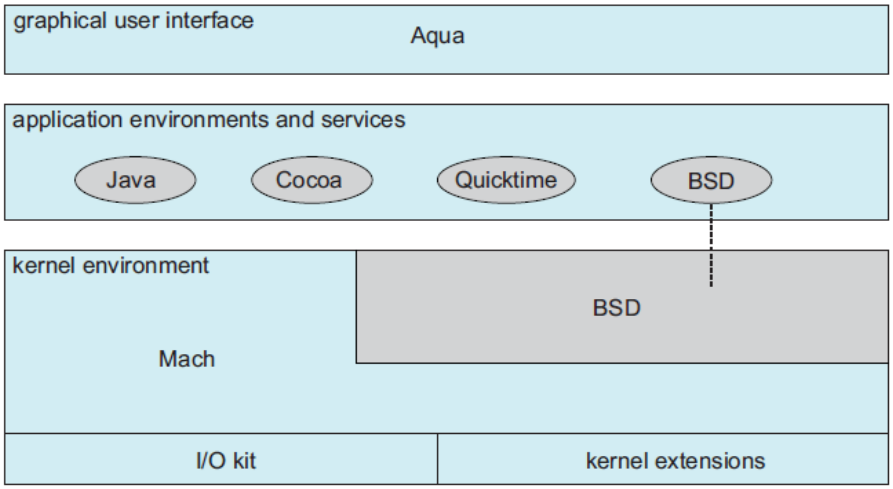

Figure 3.6 The Mac OS X structure

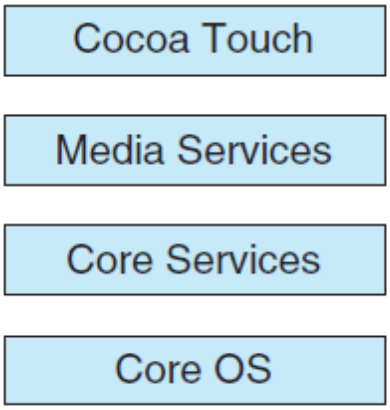

Figure 3.7 Architecture of Apple's iOS.

3.3.8 Android

The Android operating system was designed by the Open Handset Alliance (led primarily by Google) and was developed for Android smartphones and tablet computers. Whereas iOS is designed to run on Apple mobile devices and is close-sourced, Android runs on a variety of mobile platforms and is open-sourced, partly explaining its rapid rise in popularity Android is similar to iOS in that it is a layered stack of software that provides a rich set of frameworks for developing mobile applications. At the bottom of this software stack is the Linux kernel, although it has been modified by Google and is currently outside the normal distribution of Linux releases

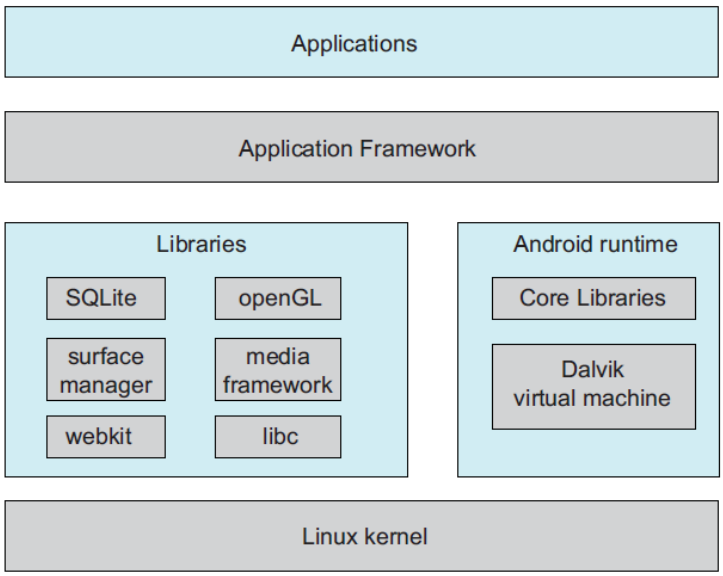

Figure 3.8 Architecture of Google's Android

3.4 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 make the programming task easier. Figure 2.1 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 systems have a user interface (UI). This interface can take several forms. One is a command-line interface (CLI), which uses text commands and a method for entering them (say, a keyboard for typing in commands in a specific format with specific options). Another is a batch interface, in which commands and directives to control those commands are entered into files, and those files are executed. 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 menus, and make selections and a keyboard to enter text. Some systems provide two or all three of these variations.

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 (indicating error).

I/O operations: A running program may require I/O, which may involve a file or an I/O 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/O devices directly. Therefore, the operating system must provide a means to do I/O.

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 operating systems 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 may 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 memory, in which two or more processes read and write to a shared section of memory, or message passing, in which packets of information in predefined formats are moved between processes by the operating system.

Error detection: The operating system needs to be detecting and correcting errors constantly. Errors may occur in the CPU and memory hardware (such as a memory error or a power failure), in I/O devices (such as a parity error on disk, 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. Sometimes, it has no choice but to halt the system. At other times, it might terminate an error-causing process or return an error code to a process for the process to detect and possibly correct. Another set of operating system function exists not for helping the user but rather for ensuring the efficient operation of the system itself. Systems with multiple users can gain efficiency by sharing the computer resources among the users.

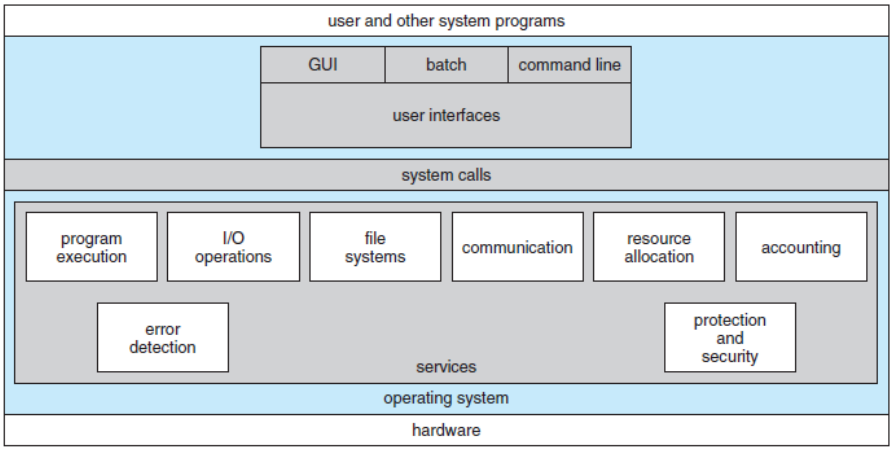

Figure 3.9 Services of Operating System

Resource allocation: When there are multiple users or multiple jobs running at the same time, resources must be allocated to each of them. The operating system manages many different types of resources. Some (such as CPU cycles, main memory, and file storage) may have special allocation code, whereas others (such as I/O 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, USB storage drives, and other peripheral devices.

Accounting: We want to keep track of which users 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. Protection involves ensuring that all access to system resources is controlled. Security of the system from outsiders is also important. Such security starts with requiring each user to authenticate him or her to the system, usually by means of a password, to gain access to system resources. It extends to defending external I/O devices, including network adapters, from invalid access attempts and to recording all such connections for detection of break-ins. If a system is to be protected and secure, precautions must be instituted throughout it. A chain is only as strong as its weakest link.

3.5. 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 have 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. 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/O system calls. Once the two file names have been obtained, the program must open the input file and create the output file. Each of these operations requires another system call. Possible error conditions for each operation can require additional system calls. When the program tries to open the input file, for example, 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 (yet 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. When both files are set up, we enter a loop that reads from the input file (a system call) and writes to the output file (another system call). Each read and write must return status information regarding various possible error conditions. On input, the program may find that the end of the file has been reached or that there was a hardware failure in the read (such as a parity error).

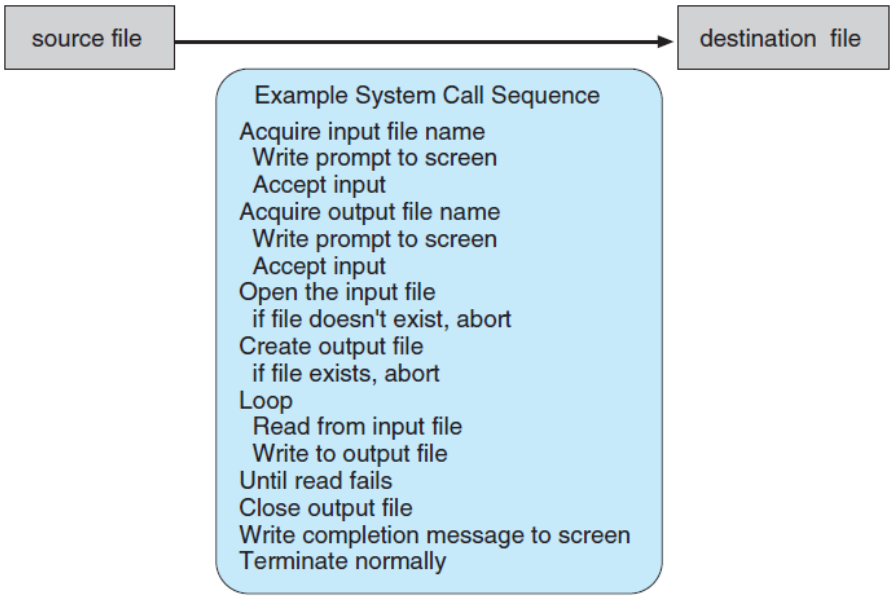

Figure 3.10 working of System Call

The write operation may encounter various errors, depending on the output device (for example, no more disk space). Finally, after the entire file is copied, the program may close both files (another system call), write a message to the console or window (more system calls), and finally terminate normally (the final system call). This system-call sequence is shown in Figure 2.5. As you can see, even simple programs may make heavy use of the operating system. Frequently, systems execute thousands of system calls per second. Most programmers never see this level of detail, however. Typically, application developers design programs according to an application programming interface (API). The API specifies a set of functions that are available to an application programmer, including the parameters that are passed to each function and the return values the programmer can expect.

Three of the most common APIs available to application programmers are the Windows API for Windows systems, the POSIX API for POSIX-based systems (which include virtually all versions of UNIX, Linux, and Mac OSX), and the Java API for programs that run on the Java virtual machine. A programmer accesses an API via a library of code provided by the operating system. In the case of UNIX and Linux for programs written in the C language, the library is called libc. Note that—unless specified—the system-call names used throughout this text are generic examples. Each

operating system has its own name for each system call. Behind the scenes, the functions that make up an API typically invoke the actual system calls on behalf of the application programmer.

There are several reasons for doing so. One benefit concerns program portability. An application programmer designing a program using an API can expect her program to compile and run on any system that supports the same API (although, in reality, architectural differences often make this more difficult than it may appear). Furthermore, actual system calls can often be more detailed and difficult to work with than the API available to an application programmer. Nevertheless, there often exists a strong correlation between a function in the API and its associated system call within the kernel. In fact, many of the POSIX and Windows APIs are similar to the native system calls provided by the UNIX, Linux, and Windows operating systems. For most programming languages, the run-time support system (a set of functions built into libraries included with a compiler) provides a 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 and any return values.

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 run-time

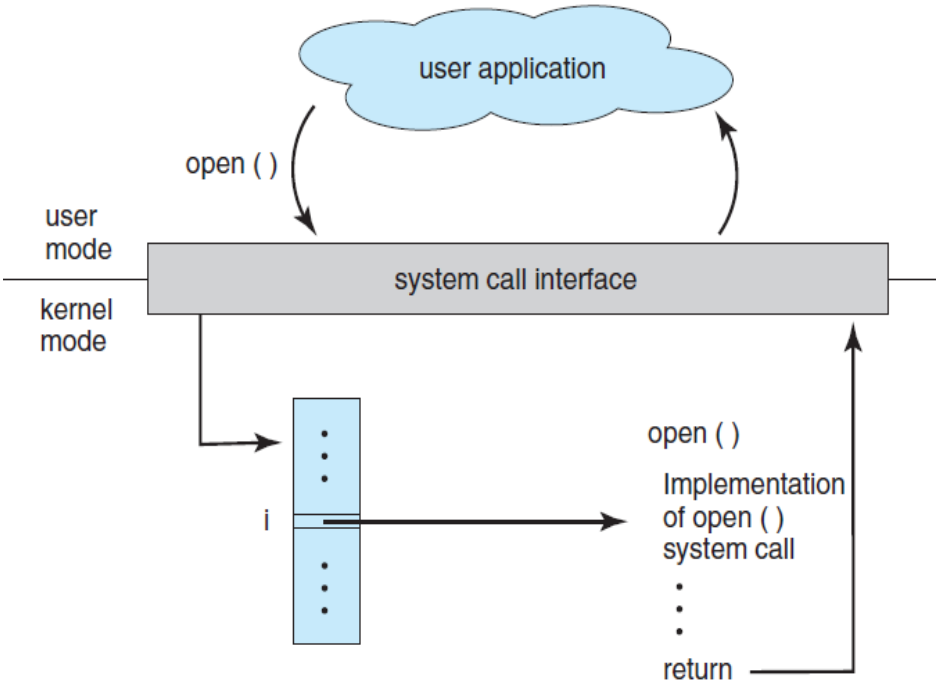

Figure 3.11 using application call ()

Support library. The relationship between 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.

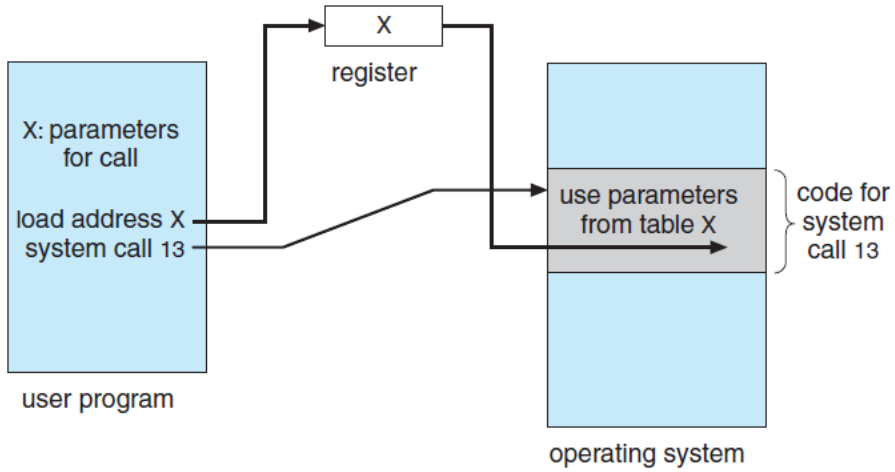

Figure 3.12 Parameter passing

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). This is the approach taken by Linux and Solaris. Parameters also can be placed, or pushed, onto the 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.

3.5.1 Types of System Calls

System calls can be grouped roughly into five major categories: process control, file manipulation, device manipulation, information maintenance, and communications.

- Process control
  - end, abort
  - load, execute
  - create process, terminate process
  - get process attributes, set process attributes
  - wait for time
  - 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

3.6 SYSTEM PROGRAMS

- System programs provide a convenient environment for program development and execution.
- This can be divided into:
    - **File management** - Create, delete, copy, rename, print, dump, list, and generally manipulate files and directories
    - Status information
        - Some ask the system for info - date, time, amount of available memory, disk space, number of users
        - Others provide detailed performance, logging, and debugging information
        - Typically, these programs format and print the output to the terminal or other output devices
        - Some systems implement a registry - 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, relocatable loaders, linkage editors, and overlay loaders. Debugging systems for either higher-level languages or machine language are needed as well.
    - **Communications** - Provide the mechanism for creating virtual connections among processes, users, and computer systems. They allow users to send messages to one another's screens, browse web pages, send electronic-mail messages, log in remotely, transfer files from one machine to another
- Most users' view of the operation system is defined by system programs, not the actual system calls
- Some of them are simply user interfaces to system calls; others are considerably more complex
- In addition to systems programs, most operating systems are supplied with programs that are useful in solving common problems or performing common operations. Such programs include web browsers, word processors and text formatters, spreadsheets, database systems, compilers, plotting and statistical-analysis packages, and games. These programs are known as system utilities or application programs.

3.7 OPERATING-SYSTEM DESIGN AND IMPLEMENTATION

Early operating systems were written in assembly language. Now, although some operating systems are still written in assembly language, most are written in a higher-level language such as C or an even higher-level language such as C++. Actually, an operating system can be written in more than one language.

The lowest levels of the kernel might be assembly language. Higher-level routines might be in C, and system programs might be in C or C++, in interpreted scripting languages like PERL or Python, or in shell scripts. In fact, a given Linux distribution probably includes programs written in all of those languages.

The first system that was not written in assembly language was probably the Master Control Program (MCP) for Burroughs computers. MCP was written in a variant of ALGOL. MULTICS, developed at MIT, was written mainly in the system programming language PL/1. The Linux and Windows operating system kernels are written mostly in C, although there are some small sections of assembly code for device drivers and for saving and restoring the state of registers.

The advantages of using a higher-level language, or at least a systems implementation Language, for implementing operating systems are the same as those gained when the language is used for application programs: the code can be written faster, is more compact, and is easier to understand and debug.

In addition, improvements in compiler technology will improve the generated code for the entire operating system by simple recompilation. Finally, an operating system is far easier to port—to move to some other hardware— if it is written in a higher-level language. For example, MS-DOS was written in Intel 8088 assembly language. Consequently, it runs natively only on the Intel X86 family of CPUs. (Note that although MS-DOS runs natively only on Intel X86, emulators of the X86 instruction set allow the operating system to run on other CPUs—but more slowly, and with higher resource use. The only possible disadvantages of implementing an operating system in a higher-level language are reduced speed and increased storage requirements.

This, however, is no longer a major issue in today's systems. Although an expert assembly-language programmer can produce efficient small routines, for large programs a modern compiler can perform complex analysis and apply sophisticated optimizations that produce excellent code. Modern processors have deep pipelining and multiple functional units that can handle the details of complex dependencies much more easily than can the human mind. As is true in other systems, major performance

improvements in operating systems are more likely to be the result of better data structures and algorithms than of excellent assembly-language code. In addition, although operating systems are large, only a small amount of the code is critical to high performance; the interrupt handler, I/O manager, memory manager, and CPU scheduler are probably the most critical routines.

Check your Progress

1. What are system calls?
2. What are the types of system calls?
3. What are the types of Loadable kernel modules?
4. What is the difference between microkernel and macro kernel?
5. What are System Programs?

3.8. ANSWERS TO CHECK YOUR PROGRESS

1. System calls provide the interface between a process and the operating system. System calls for modern Microsoft windows platforms are part of the win32 API, which is available for all the compilers written for Microsoft windows.
2. System calls can be grouped roughly into five major categories:
   - process control
   - file manipulation
   - device manipulation
   - information maintenance
   - communications.
3. A core kernel with seven types of loadable kernel modules:
   - Scheduling classes
   - File systems
   - Loadable system calls
   - Executable formats
   - STREAMS modules
   - Miscellaneous
   - Device and bus drivers
4. Some of the difference are:
   - **Micro-Kernel** : A micro-kernel is a minimal operating system that performs only the essential functions of an operating system. All other operating system functions are performed by system processes.
   - **Monolithic** : A monolithic operating system is one where all operating system code is in a single executable image and all operating system code runs in system mode.
5. System programs provide a convenient environment for program development and execution. This can be divided into:
   - File management
   - Status information

- File modification
- Programming-language support
- Program loading and execution
- Communications

3.9. SUMMARY

- The main function of the microkernel is to provide communication between the client program and the various services that are also running in user space.
- The idea of the design is for the kernel to provide core services while other services are implemented dynamically, as the kernel is running.
- The Solaris operating system structure is organized around a core kernel with seven types of loadable kernel modules
- iOS is a mobile operating system designed by Apple to run its smartphone, the iPhone, as well as its tablet computer, the iPad.
- The Android operating system was designed by the Open Handset Alliance (led primarily by Google) and was developed for Android smartphones and tablet computers.
- System calls can be grouped roughly into five major categories: process control, file manipulation, device manipulation, information maintenance, and communications.

3.10. KEYWORDS

- **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 (indicating error).
- **I/O operations**: A running program may require I/O, which may involve a file or an I/O device.
- **Resource allocation**: When there are multiple users or multiple jobs running at the same time, resources must be allocated to each of them.
- **System calls:** System calls provide an interface to the services made available by an operating system.

3.11. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What are Modules?
2. What is layered approach?
3. What are Hybrid systems?
4. What is Resource allocation?
5. Explain about Layered operating system?

Long Answer questions:

1. Explain about system calls and its types?
2. Explain about Operating-System Design and his Implementation?
3. Explain about system programs and its types?

3.12 FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

Deitel, H.M., Deitel, P.J. and Choffnes, D.R., 2004. Operating systems. Delhi.: Pearson Education: Dorling Kindersley.

Stallings, W., 2012. Operating systems: internals and design principles. Boston: Prentice Hall,.

BLOCK – II INTRODUCTION

UNIT IV PROCESS CONCEPT

Structure

4.0 Introduction
4.1 Objective
4.2 Process Concept
4.3 Process Scheduling
4.4Operations on Processes
4.4.1 Process Creation
4.4.2 Process Termination
4.5 Inter process Communication
4.6 Answers to Check Your Progress Questions
4.7 Summary
4.8 Key Words
4.9 Self Assessment Questions and Exercises
4.10 Further Readings

4.0 INTRODUCTION

he scheduling of process is a tedious task and needs to organized to perform this effectively the operating system introduces a concept process scheduling and the various operations on process in explaining by how it is performed. The process scheduling is the activity of the process manager that handles the removal of the running process from the CPU and the selection of another process on the basis of a particular strategy.

Process scheduling is an essential part of a Multiprogramming operating systems. Such operating systems allow more than one process to be loaded into the executable memory at a time and the loaded process shares the CPU using time multiplexing. The inter process communication between the system is also explained.

4.1 OBJECTIVE

This unit helps to understand the

- Process scheduling concepts
- Various operations on process
- Inter process communication

4.2 PROCESS CONCEPT

A batch system executes jobs, whereas a time-shared system has user programs, or tasks. Even on a single-user system, a user maybe able to run several programs at one time: a word processor, a Web browser, and an e-mail package. And even if a user can execute only one program at a time, such as on an embedded device that does not support multitasking, 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 terms job and process are used almost interchangeably in this text. Although we personally prefer the term process, much of operating-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 simply because process has superseded job.

4.2.1The Process

A program becomes a process when an executable file is loaded into memory. Two common techniques for loading executable files are double-clicking an icon representing the executable file and entering the name of the executable file on the command line (as in prog.exe or a. out). 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. Each of these is a separate process; and although the text sections are equivalent, the data, heap, and stack sections vary. It is also common to have a process that spawns many processes as it runs. Note that a process itself can be an execution environment for other code. The Java programming environment provides a good example. In most circumstances, an executable Java program is executed within the Java virtual machine (JVM). The JVM executes as a process that interprets the loaded Java code and takes actions (via native machine instructions) on behalf of that code.

For example, to run the compiled Java program. Class, we would enter java Program the command java runs the JVM as an ordinary process, which in turns executes the Java program in the virtual machine. The concept is the same as simulation, except that the code, instead of being written for a different instruction set, is written in the Java language

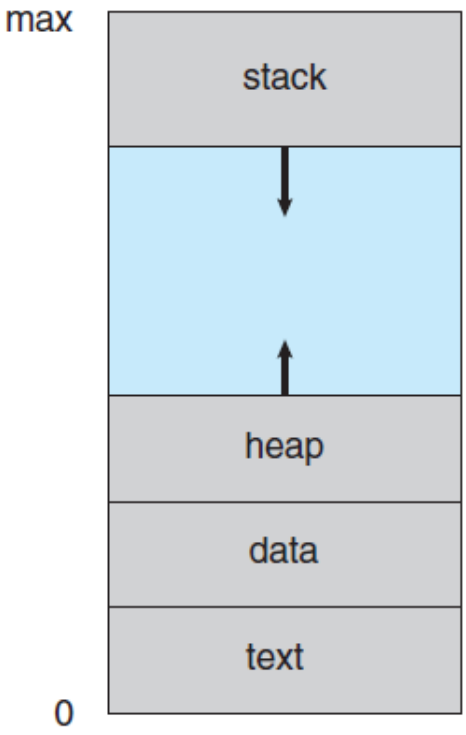

Figure 4.1 Processes in a Memory

4.2.2 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. A 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/O 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, however. The state diagram corresponding to these states is presented in Figure

4.2.3 Process Control Block

Each process is represented in the operating system by a process control block (PCB)—also called a task control block. APCB is shown in Figure

3.3. 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. Along with the program counter, this state information must be saved when an interrupt occurs, to allow the process to be continued correctly afterward
- **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 items as the value of the base and limit registers and the page tables, or the segment tables, depending on the memory system used by the operating system.

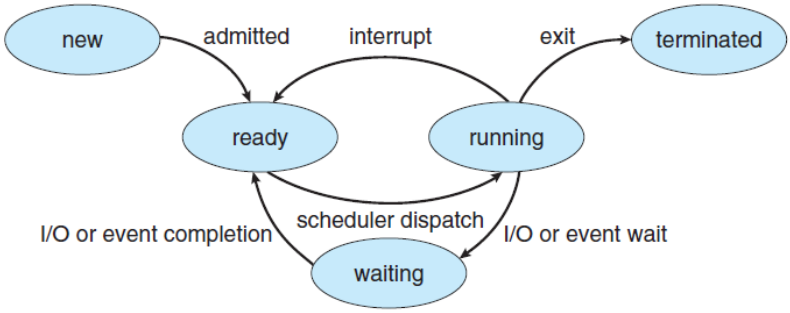

Figure 4.2 Process State

- **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.

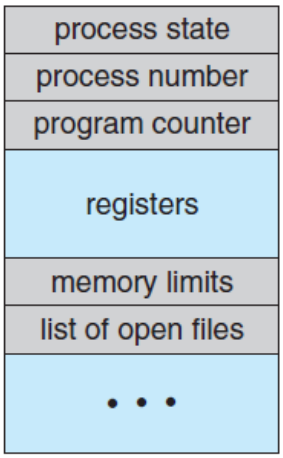

Figure 4.3 Process control Block

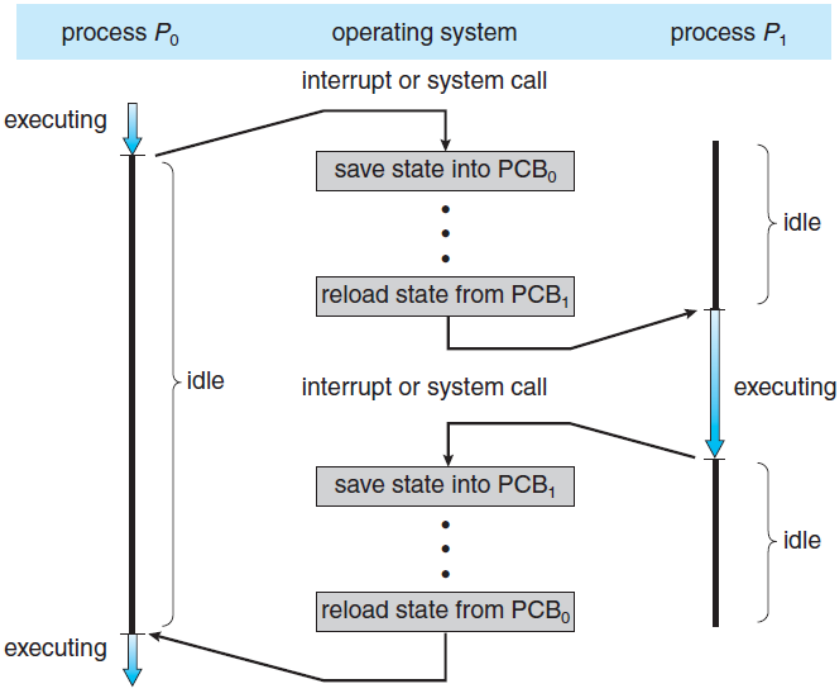

Figure 4.4 CPU switch from process to process

4.2.4 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 a time. The user cannot simultaneously type in characters and run the spell checker within the same process, for example. Most 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. This feature is especially beneficial on multicore systems, where multiple threads can run in parallel. On a system that supports threads, the PCB is expanded to include information for each thread. Other changes throughout the system are also needed to support threads.

4.3 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 then 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 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.

4.4 OPERATIONS 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 mechanisms involved in creating processes and illustrate process creation on UNIX and Windows systems

4.4.1 Process Creation

During the course of execution, a process may create several new processes. As mentioned earlier, 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, Linux, and Windows) identify processes according to a unique process identifier (or pid), which is typically an integer number. The pid provides a unique value for each process in the system, and it can be used as an index to access various attributes of a process within the kernel. Figure 3.8 illustrates a typical process tree for the Linux operating system, showing the name of each process and it’s pid. (We use the term process rather loosely, as Linux prefers the term task instead.) The init process (which always has a pid of 1) serves as the root parent process for all user processes. Once the system has booted, the init process can also create various user processes, such as a web or print server, an ssh server, and the like.

The kthreadd process is responsible for creating additional processes that perform tasks on behalf of the kernel (in this situation, khelper and pdflush). The sshd process is responsible for managing clients that connect to the system by using ssh (which is short for secure shell). The login process is responsible for managing clients that directly log onto the system. In this example, a client has logged on and is using the bash shell, which has been assigned pid 8416. Using the bash command-line interface, this user has created the process ps as well as the emacs editor. On UNIX and Linux systems, we can obtain a listing of processes by using the ps command. For example, the command ps –el will list complete information for all processes currently active in the system.

In general, when a process creates a child process, that child process will need certain resources (CPU time, memory, files, I/O devices) to accomplish its task. A child 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 child processes. In addition to supplying various physical and logical resources, the parent process may pass along initialization data (input) to the child process. For example, consider a process whose function is to display the contents of a file —say, image.jpg—on the screen of a terminal. When the process is created, it will get, as an input from its parent process, the name of the file image.jpg. Using that file name, it will open the file and write the contents out. It may also get the name of the output device. Alternatively, some operating systems pass resources to child processes. On such a system, the new process may get two open files, image.jpg and the terminal device, and may simply transfer the datum between the two. When a process creates a new process, two possibilities for execution exist:

1. The parent continues to execute concurrently with its children.

2. The parent waits until some or all of its children have terminated.

There are also two address-space possibilities for the new process:

1. The child process is a duplicate of the parent process (it has the same program and data as the parent).

2. The child process has a new program loaded into it.

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. After a fork() system call, one of the two processes typically uses the exec() system call 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 a wait() system call to move itself off the ready queue until the termination of the child. Because the call to exec() overlays the process's address space with a new program, the call to exec() does not return control unless an error occurs.

The only difference is that the value of pi value greater than zero (in fact, it is the actual pid of the child process). The child process inherits privileges and scheduling attributes from the parent, as well certain resources, such as open files. The child process then overlays its address space with the UNIX command /bin/ls (used to get a directory listing) using the execlp() system call (execlp() is a version of the exec() system call). The parent waits for the child process to complete with the wait() system call. When the child process completes (by either implicitly or explicitly invoking exit()), the parent process resumes from the call to wait(), where it completes using the exit() system call.

Of course, there is nothing to prevent the child from ***not*** invoking exec() and instead continuing to execute as a copy of the parent process. In this scenario, the parent and child are concurrent processes running the same code instructions. Because the child is a copy of the parent, each process has its own copy of any data. As an alternative example, we next consider process creation in Windows. Processes are created in the Windows API using the CreateProcess() function, which is similar to fork() in that a parent creates a new child process. However, whereas fork() has the child process inheriting the address space of its parent, CreateProcess() requires loading a specified program into the address space of the child process at process creation. Furthermore, whereas fork() is passed no parameters, CreateProcess() expects no fewer than ten parameters.

We opt for many of the default values of the ten parameters passed to CreateProcess(). Readers interested in pursuing the details of process creation and management in the Windows API are encouraged to consult the bibliographical notes at the end of this chapter. The two parameters passed to the CreateProcess() function are instances of the STARTUPINFO and PROCESS INFORMATION structures. STARTUPINFO specifies many properties of the new process, such as window size and appearance and handles to standard input and output files. The PROCESS INFORMATION structure contains a handle and the identifiers to the newly created process and its thread. We invoke the ZeroMemory() function to allocate memory for each of these structures before proceeding with CreateProcess().

The first two parameters passed to CreateProcess() are the application name and command-line parameters. If the application name is NULL (as it is in this case), the command-line parameter specifies the application to load. In this instance, we are loading the Microsoft Windows mspaint.exe application. Beyond these two initial parameters, we use the default parameters for inheriting process and thread handles as well as specifying that there will be no creation flags. Also use the parent's existing environment block and starting directory. Last, we provide two pointers to the STARTUPINFO and PROCESS - INFORMATION structures created at the beginning of the program.

4.4.2 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, then 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/O 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 Windows).

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 if it is to terminate them. 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 must 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.

Some systems do not allow a child to exist if its parent has terminated. In such systems, if a process terminates (either normally or abnormally), then all its children must also be terminated.

This phenomenon, referred to as cascading termination, is normally initiated by the operating system. To illustrate process execution and termination, consider that, in Linux and UNIX systems, we can terminate a process by using the exit() system call, providing an exit status as a parameter:

```
/* exit with status 1 */
```

```
exit(1);
```

In fact, under normal termination, exit() may be called either directly (as shown above) or indirectly (by a return statement in main()). A parent process may wait for the termination of a child process by using the wait() system call. The wait() system call is passed a parameter that allows the parent to obtain the exit status of the child. This system call also returns the process identifier of the terminated child so that the parent can tell which of its children has terminated:

```
pid t pid;

int status;

pid = wait(&status);
```

When a process terminates, its resources are deallocated by the operating system. However, its entry in the process table must remain there until the parent calls wait(), because the process table contains the process's exit status. A process that has terminated, but whose parent has not yet called wait(), is known as a zombie process. All processes transition to this state when they terminate, but generally they exist as zombies only briefly.

Once the parent calls wait(), the process identifier of the zombie process and its entry in the process table are released. Now consider what would happen if a parent did not invoke wait() and instead terminated, thereby leaving its child processes as orphans. Linux and UNIX address this scenario by assigning the init process as the new parent to orphan processes. The init process periodically invokes wait(), thereby allowing the exit status of any orphaned process to be collected and releasing the orphan's process identifier and process-table entry.

4.5 INTERPROCESS COMMUNICATION

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 cores.

• **Modularit**y. We may want to construct the system in a modular fashion, dividing the system functions into separate processes or threads, as we discussed in Chapter 2.

• **Convenience**. Even an individual user may work on many tasks at the same time. For instance, a user may be editing, listening to music, and compiling in parallel.

Cooperating processes require an interprocess communication (IPC) mechanism that will allow them to exchange data and information. There are two fundamental models of interprocess communication: shared memory and message passing. In the shared-memory model, a region of memory that is shared by cooperating processes is established. Processes can then exchange information by reading and writing data to the shared region. In the message-passing model, communication takes place by means of messages exchanged between the cooperating processes.

Both of the models just mentioned 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 in a distributed system than shared memory. (Although there are systems that provide distributed shared memory, we do not consider them in this text

Shared memory can be faster than message passing, since message-passing systems are typically implemented using system calls and thus require the more time-consuming task of kernel intervention. 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. Recent research on systems with several processing cores indicates that message passing provides better performance than shared memory on such systems. Shared memory suffers from cache coherency issues, which arise because shared data migrate among the several caches. As the number of processing cores on systems increases, it is possible that we will see message passing as the preferred mechanism for IPC. In the remainder of this section, we explore shared-memory and message passing systems in more detail.

4.5.1 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 shared-memory segment. Other processes that wish to communicate using this shared-memory 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 exchange 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 that is consumed by an assembler. The assembler, in turn, may produce object modules that are consumed by the loader. The producer–consumer problem also provides a useful metaphor for the client–server paradigm. Generally think of a server as a producer and a client as a consumer. For example, a webserver produces (that is, provides) HTML files and images, which are consumed (that is, read) by the client web browser requesting the resource. One solution to the producer–consumer problem uses shared memory. To allow producer and consumer processes to run concurrently, we must have available a buffer of items that can be filled by the producer and emptied by the consumer. This buffer will reside in a region of memory that is shared by the producer and consumer processes. A producer can produce one item while the consumer is consuming another item. The producer and consumer must be synchronized, so that the consumer does not try to consume an item that has not yet been produced. Two types of buffers can be used. The unbounded buffer places no practical limit on the size of the buffer.

The consumer may have to wait for new items, but the producer can always produce new items. The bounded buffer assumes a fixed buffer size. In this case, the consumer must wait if the buffer is empty, and the producer must wait if the buffer is full.Let's look more closely at how the bounded buffer illustrates interprocess communication using shared memory. The following variables reside in a region of memory shared by the producer and consumer processes:

```
#define BUFFER SIZE 10

typedef struct {

. . .

}item;

item buffer[BUFFER SIZE];

int in = 0;

int out = 0;
```

The shared buffer is implemented as a circular array with two logical pointers: in and out. The variable in points to the next free position in the

buffer; out points to the first full position in the buffer. The buffer is empty when in == out; the buffer is full when ((in + 1) % BUFFER SIZE) == out. The producer process has a local variable next produced in which the new item to be produced is stored. The consumer process has a local variable next consumed in which the item to be consumed is stored.

This scheme allows at most BUFFER SIZE − 1 items in the buffer at the same time. We leave it as an exercise for you to provide a solution in which BUFFER SIZE items can be in the buffer at the same time. In Section 3.5.1, illustrates the POSIX API for shared memory. One issue this illustration does not address concerns the situation in which both the producer process and the consumer process attempt to access the shared buffer concurrently. In Chapter 5, we discuss how synchronization among cooperating processes can be implemented effectively in a shared memory environment.

4.5.2 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. It is particularly useful in a distributed environment, where the communicating processes may reside on different computers connected by a network. For example, an Internet chat program could be designed so that chat participants communicate with one another by exchanging messages. A message-passing facility provides at least two operations: send(message) receive(message) Messages sent by a process can be either fixed or variable in size. If only fixed-sized messages can be sent, the system-level implementation is straightforward.

This restriction, however, makes the task of programming more difficult. Conversely, variable-sized messages require a more complex system level implementation, but the programming task becomes simpler. This is a common kind of tradeoff seen throughout operating-system design. If processes P and want to communicate, they must send messages 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 17) but rather with its logical implementation. Here are several methods for logically implementing a link and the send()/receive() operations:

• Direct or indirect communication

• Synchronous or asynchronous communication

• Automatic or explicit buffering

4.5.2.1 Naming

Processes that want to communicate must have a way to refer to each other. They can use either direct or indirect communication. 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.

This scheme exhibits symmetry in addressing; that is, both the sender process and the receiver process must name the other to communicate. A variant of this scheme employs asymmetry in addressing. Here, only the sender names the recipient; the recipient is not required to name the sender. In this scheme, the send() and receive() primitives are defined as follows:

• send(P, message)—Send a message to

• receive(id, message)—Receive a message from any process. The process P. variable id is set to the name of the process with which communication has taken place. The disadvantage in both of these schemes (symmetric and asymmetric) is the limited modularity of the resulting process definitions. Changing the identifier of a process may necessitate examining all other process definitions. All references to the old identifier must be found, so that they can be modified to the new identifier. In general, any such hard-coding techniques, where identifiers must be explicitly stated, are less desirable than techniques involving indirection, as described next. With indirect communication, the messages are sent to and received from mailboxes, or ports. Mailbox can be viewed abstractly as an object into which messages can be placed by processes and from which messages can be removed.

Each mailbox has a unique identification. For example, POSIX message queues use an integer value to identify a mailbox. A process can communicate with another process via a number of different mailboxes, but two processes can communicate only if they have a shared mailbox. The send() and receive() primitives are defined as follows:

• send(A, message)—Send a message to mailbox A.

• receive(A, message)—Receive a message from mailbox A.

In this scheme, a communication link has the following properties:

• A link is established between a pair of processes only if both members of the pair have a shared mailbox.

• A link may be associated with more than two processes.

• Between each pair of communicating processes, a number of different links may exist, with each link corresponding to one mailbox. Now suppose that processes P1, P2, and P3 all share mailbox A. Process P1 sends a message to A, while both P2 and P3 execute a receive() from A. Which process will receive the message sent by P1? The answer depends on which of the following methods we choose:

• Allow a link to be associated with two processes at most.

• Allow at most one process at a time to execute a receive() operation.

• Allow the system to select arbitrarily which process will receive the message (that is, either P2 or P3, but not both, will receive the message). The system may define an algorithm for selecting which process will receive the message (for example, round robin, where processes take turns receiving messages). The system may identify the receiver to the sender. A mailbox may be owned either by a process or by the operating system.

If the mailbox is owned by a process (that is, the mailbox is part of the address space of the process), then we distinguish between the owner (which can only receive messages through this mailbox) and the user (which can only send messages to the mailbox). Since each mailbox has a unique owner, there can be no confusion about which process should receive a message sent to this mailbox. When a process that owns a mailbox terminates, the mailbox disappears. Any process that subsequently sends a message to this mailbox must be notified that the mailbox no longer exists. In contrast, a mailbox that is owned by the operating system has an existence of its own. It is independent and is not attached to any particular process. The operating system then must provide a mechanism that allows a process to do the following:

• Create a new mailbox.

• Send and receive messages through the mailbox.

• Delete a mailbox.

The process that creates a new mailbox is that mailbox's owner by default. Initially, the owner is the only process that can receive messages through this mailbox. However, the ownership and receiving privilege may be passed to other processes through appropriate system calls. Of course, this provision could result in multiple receivers for each mailbox.

4.5.2.2 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. (Throughout this text, you will encounter the concepts of synchronous and asynchronous behavior in relation to various operating-system algorithms.)

• 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.

Different combinations of send() and receive() are possible.When both send() and receive() are blocking, we have a rendezvous between the sender and the receiver. The solution to the producer–consumer problem becomes trivial when we use blocking send() and receive() statements. The producer merely invokes the blocking send() call and waits until the message is delivered to either the receiver or the mailbox. Likewise, when the consumer invokes receive(), it blocks until a message is available.

4.5.2.3 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 queue 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 queue.

• **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

Check your Progress

1. What is a process?
2. What are the states of a process?
3. What are the process control block?
4. What is Thread?
5. What is Process Termination?

4.6 ANSWERS TO CHECK YOUR PROGRESS

1. A program in execution is called a process. Or it may also be called a unit of work. A process needs some system resources as CPU time, memory, files, and i/o devices to accomplish the task. Each process is represented in the operating system by a process control block or task control block (PCB). Processes are of two types
   - **Operating system processes**
   - **User processes**

2. The states of process are:
   - New
   - Running
   - Waiting
   - Ready
   - Terminated
3. Process Control Block (PCB) contains many pieces of information associated with a specific process, including these:
   - Process state.
   - Program counter.
   - CPU registers
   - CPU-scheduling information.
   - Memory-management information.
   - Accounting information
   - I/O status information.
4. A thread is a flow of execution through the process code, with its own program counter that keeps track of which instruction to execute next, system registers which hold its current working variables.
5. 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, then 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/O 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, Terminate Process () in Windows).

4.7. SUMMARY

- The objective of multiprogramming is to have some process running at all times, to maximize CPU utilization.
- A program becomes a process when an executable file is loaded into memory.
- A process terminates when it finishes executing its final statement and asks the operating system to delete it by using the exit() system call.
- Interprocess communication using shared memory requires communicating processes to establish a region of shared memory.
- Communication between processes takes place through calls to send() and receive() primitives.
- The queue's length is potentially infinite; thus, any number of messages can wait in it.

4.8. KEYWORDS

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. Along with the program counter, this state information must be saved when an interrupt occurs, to allow the process to be continued correctly afterward

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.

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 items as the value of the base and limit registers and the page tables, or the segment tables, depending on the memory system used by the operating system.

4.9. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is interprocess communication?
2. What is process creation?
3. Explain about shared-memory systems?
4. What is Synchronization?

5. Explain the capacity of Buffering?

Long Answer questions:

1. Explain about Operations on processes?
2. Explain about Interprocess Communication ?

4.10. FURTHER READINGS

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UNIT V PROCESS SCHEDULING

Structure

5.0 Introduction
5.1 Objective
5.2 Process Scheduling
5.3 Scheduling Criteria
5.4 Scheduling Algorithms
5.5 Multiple-Processor Scheduling
5.6 Answers to Check Your Progress Questions
5.7 Summary
5.8 Key Words
5.9 Self Assessment Questions and Exercises
5.10 Further Readings

5.0 INTRODUCTION

The scheduling of the process in the operating system has to perform with some criteria and there are many scheduling algorithms which work under different constraints so as to schedule the process effectively. The OS maintains all PCBs in Process Scheduling Queues. The OS maintains a separate queue for each of the process states and PCBs of all processes in the same execution state are placed in the same queue. When the state of a process is changed, its PCB is unlinked from its current queue and moved to its new state queue. This unit covers the scheduling algorithms with an illustration of its working. The multiple processor scheduling is covered with its working.

5.1 OBJECTIVE

This unit covers the following

- Learn the scheduling algorithms
- Understand the scheduling concepts
- Explore the multiple processor scheduling

5.2 PROCESS SCHEDULING

5.2.1 Scheduling concepts

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. 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 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/O 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/O request of some other process. The process therefore may have to wait for the disk. The list of processes waiting for a particular I/O device is called a device queue.

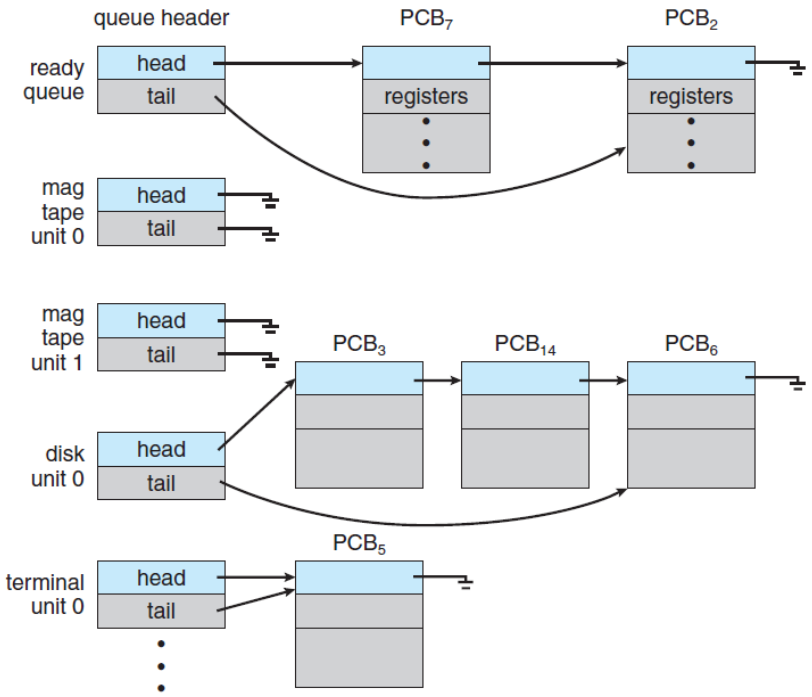


Figure 5.1 Ready Queue and I/O devices queue

A common representation of process scheduling is a queueing diagram, such as that in Figure 5.1. 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 dispatched. Once the process is allocated the CPU and is executing, one of several events could occur:

• The process could issue an I/O request and then be placed in an I/O queue.

• The process could create a new child process and wait for the child'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. 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.

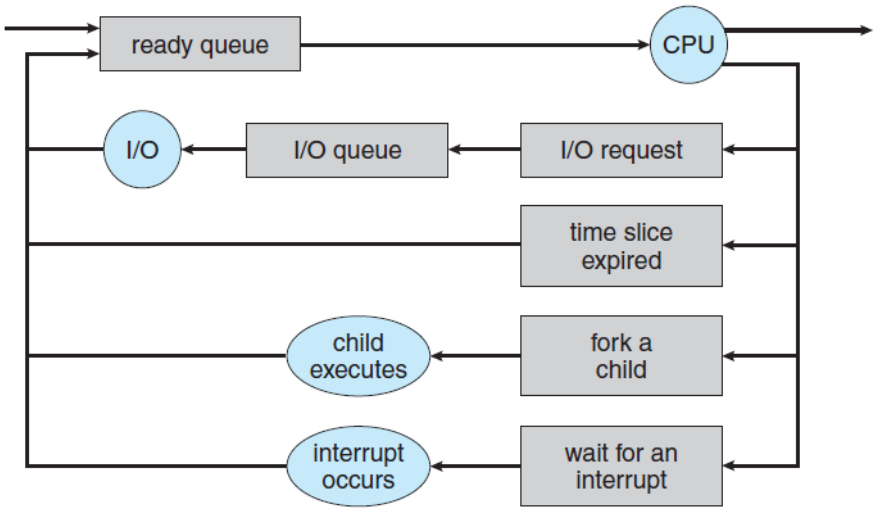


Figure 5.2 Process Scheduling Queuing

5.3 SCHEDULING CRITERIA

Different CPU-scheduling algorithms have different properties, and the choice of a particular algorithm may favor one class of processes over another. In choosing which algorithm to use in a particular situation, we must consider the properties of the various algorithms. Many criteria have been suggested for comparing CPU-scheduling algorithms. Which characteristics are used for comparison can make a substantial difference in which algorithm is judged to be best. The criteria include the following:

• **CPU utilization**. We want to keep the CPU as busy as possible. Conceptually, CPU utilization can range from 0 to 100 percent. In a real system, it should range from 40 percent (for a lightly loaded system) to 90 percent (for a heavily loaded system).

• **Throughput**. If the CPU is busy executing processes, then work is being done. One measure of work is the number of processes that are completed per time unit, called throughput. For long processes, this rate may be one process per hour; for short transactions, it may be ten processes per second.

• **Turnaround time**. From the point of view of a particular process, the important criterion is how long it takes to execute that process. The interval from the time of submission of a process to the time of completion is the turnaround time. Turnaround time is the sum of the periods spent waiting to get into memory, waiting in the ready queue, executing on the CPU, and doing I/O.

• **Waiting time**. The CPU-scheduling algorithm does not affect the amount of time during which a process executes or does I/O. It affects only the amount of time that a process spends waiting in the ready queue. Waiting time is the sum of the periods spent waiting in the ready queue.

• **Response time**. In an interactive system, turnaround time may not be the best criterion. Often, a process can produce some output fairly early and can continue computing new results while previous results are being output to the user. Thus, another measure is the time from the submission of a request until the first response is produced. This measure, called response time, is the time it takes to start responding, not the time it takes to output the response.

The turnaround time is generally limited by the speed of the output device. It is desirable to maximize CPU utilization and throughput and to minimize turnaround time, waiting time, and response time. In most cases, we optimize the average measure. However, under some circumstances, we prefer to optimize the minimum or maximum values rather than the average. For example, to guarantee that all users get good service, we may want to minimize the maximum response time. Investigators have suggested that, for interactive systems (such as desktop systems), it is more important to minimize the variance in the response time than to minimize the average response time. A system with reasonable and predictable response time may be considered more desirable than a system that is faster on the average but is highly variable.

However, little work has been done on CPU-scheduling algorithms that minimize variance. As we discuss various CPU-scheduling algorithms in the following section, we illustrate their operation. An accurate illustration should involve many processes, each a sequence of several hundred CPU bursts and I/O bursts. For simplicity, though, we consider only one CPU burst (in milliseconds) per process in our examples.

5.4 SCHEDULING ALGORITHMS

5.4.1 First-Come, First-Served Scheduling

By far the simplest CPU-scheduling algorithm is the first-come, first-served (FCFS) scheduling algorithm. With this scheme, the process that requests the CPU first is allocated the CPU first. The implementation of the FCFS policy is easily managed with a FIFO queue. When a process enters the ready queue, its PCB is linked onto the tail of the queue. When the CPU is free, it is allocated to the process at the head of the queue. The running process is then removed from the queue. The code for FCFS scheduling is simple to write and understand. On the negative side, the average waiting time under the FCFS policy is often quite long. Consider the following set of processes that arrive at time 0, with the length of the PU burst given in milliseconds:

Process	Burst time
P1	3
P2	6
P3	4
P4	2

Gantt chart:

P1	P2	P3	P4
0	3	9	10

15

Waiting time

Process	waiting time
P1	0
P2	3
P3	9
P4	13

Average waiting time=(0+3+9+13)/4 = 6.25 ms

Figure 5.3 Waiting time

Turn around time (TAT):

TAT=waiting time + burst time

Process	TAT
P1	3
P2	9
P3	13
P4	15

Average TAT=(3+9+13+15)/4=10 ms

Figure 5.4 Turn Around Time

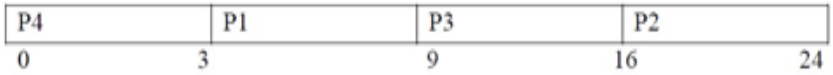
5.4.2 Shortest-Job-First Scheduling

A different approach to CPU scheduling is the shortest-job-first (SJF) scheduling algorithm. This algorithm associates with each process the length of the process's next CPU burst. When the CPU is available, it is assigned to the process that has the smallest next CPU burst. If the next CPU bursts of two processes are the same, FCFS scheduling is used to break the tie. Note that a more appropriate term for this scheduling method would be the shortest-next- CPU-burst algorithm, because scheduling depends on the length of the next CPU burst of a process, rather than its total length. We use the term SJF because most people and textbooks use this term to refer to this type of scheduling. As an example of SJF scheduling, consider the following set of processes, with the length of the CPU burst given in millisecond

Example

Process	Burst time
P1	6
P2	8
P3	7
P4	3

Gantt chart:



Waiting time

Process	waiting time
P1	3
P2	16
P3	9
P4	0

Average waiting time=(3+16+9+0)/4 = 7 ms

Turn around time (TAT):

TAT=waiting time + burst time

Process	TAT
P1	9
P2	24
P3	16
P4	3

Average TAT=(9+24+16+3)/4=13 ms

5.4.3 Priority Scheduling

The SJF algorithm is a special case of the general priority-scheduling algorithm. Apriority is associated with each process, and the CPUis allocated to the process with the highest priority. Equal-priority processes are scheduled in FCFS order. An SJF algorithm is simply a priority algorithm where the priority (p) is the inverse of the (predicted) next CPU burst. The larger the CPU burst, the lower the priority, and vice versa. Note that we discuss scheduling in terms of high priority and low priority. Priorities are generally indicated by some fixed range of numbers, such as 0 to 7 or 0 to 4,095. However, there is no general agreement on whether 0 is the highest or lowest priority. Some systems use low numbers to represent low priority; others use low numbers for high priority. This difference can lead to confusion. In this text, we assume that low numbers represent high priority. As an example, consider the following set of

processes, assumed to have arrived at time 0 in the order P1, P2, · · ·, P5, with the length of the CPU burst given in milliseconds

Example

Waiting time

Process	waiting time
P1	6
P2	0
P3	16
P4	18
P5	1

Average waiting time=(6+0+16+18+1)/5 = 8.2ms

Turn around time (TAT):

TAT=waiting time + burst time

Process	TAT
P1	16
P2	1
P3	18
P4	19
P5	6

Average TAT=(16+1+18+19+6)/5=12 ms

5.4.4 Round-Robin Scheduling

The round-robin (RR) scheduling algorithm is designed especially for timesharing systems. It is similar to FCFS scheduling, but pre-emption is added to enable the system to switch between processes. A small unit of time, called a time quantum or time slice, is defined. A time quantum is generally from 10 to 100 milliseconds in length. The ready queue is treated as a circular queue. The CPU scheduler goes around the ready queue, allocating the CPU to each process for a time interval of up to 1 time quantum. To implement RR scheduling, we again treat the ready queue as a FIFO queue of processes. New processes are added to the tail of the ready queue. The CPU scheduler picks the first process from the ready queue, sets a timer to interrupt after 1 time quantum, and dispatches the process. One of two things will then happen. The process may have a CPU burst of less than 1 time quantum. In this case, the process itself will release the CPU voluntarily.

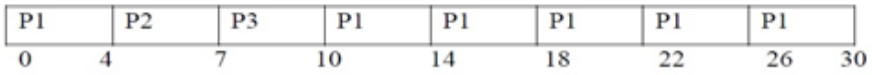
The scheduler will then proceed to the next process in the ready queue. If the CPU burst of the currently running process is longer than 1 time quantum, the timer will go off and will cause an interrupt to the operating system. A context switch will be executed, and the process will be put at the detail of the ready queue. The CPU scheduler will then select the next process in the ready queue. The average waiting time under the RR policy

is often long. Consider the following set of processes that arrive at time 0, with the length of the CPU burst given in milliseconds:

Example given time quantum=4ms

Process	Burst time
P1	24
P2	3
P3	3

Gantt chart:



Waiting time

Process	waiting time
P1	10-4=6
P2	4
P3	7

Average waiting time=(6+4+7)/3 = 5.6 ms

Turn around time (TAT):

TAT=waiting time + burst time

Process	TAT
P1	30
P2	7
P3	10

Average TAT=(30+7+10)/3=15.6 ms

5.4.5 Multilevel Queue Scheduling

A multilevel queue scheduling algorithm partitions the ready queue into several separate queues (Figure 6.6). The processes are permanently assigned to one queue, generally based on some property of the process, such as memory size, process priority, or process type. Each queue has its own scheduling algorithm. For example, separate queues might be used for foreground and background processes. The foreground queue might be scheduled by an RR algorithm, while the background queue is scheduled by an FCFS algorithm. In addition, there must be scheduling among the queues, which is commonly implemented as fixed-priority pre-emptive scheduling. For example, the foreground queue may have absolute priority over the background queue. Let's look at an example of a multilevel queue scheduling algorithm with five queues, listed below in order of priority:

1. System processes

2. Interactive processes

3. Interactive editing processes

4. Batch processes

5. Student processes

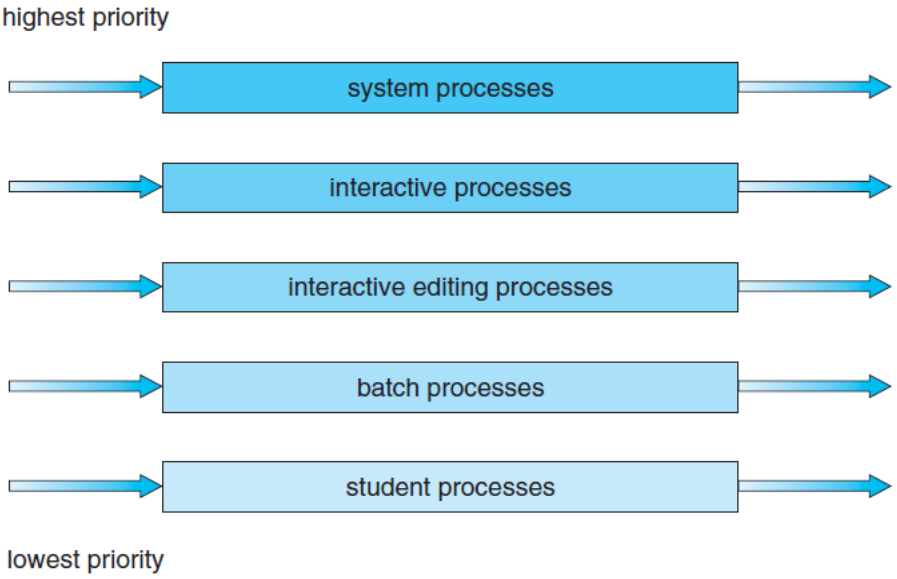


Figure 5.4 Multi level queues

Each queue has absolute priority over lower-priority queues. No process in the batch queue, for example, could run unless the queues for system processes, interactive processes, and interactive editing processes were all empty. If an interactive editing process entered the ready queue while a batch process was running, the batch process would be pre-empted. Another possibility is to time-slice among the queues. Here, each queue gets a certain portion of the CPU time, which it can then schedule among its various processes. For instance, in the foreground–background queue example, the foreground queue can be given 80 percent of the CPU time for RR scheduling among its processes, while the background queue receives 20 percent of the CPU to give to its processes on an FCFS basis.

5.4.6 Multilevel Feedback Queue Scheduling

The multilevel feedback queue scheduling algorithm, in contrast, allows a process to move between queues. The idea is to separate processes according to the characteristics of their CPU bursts. If a process uses too much CPU time, it will be moved to a lower-priority queue. This scheme leaves I/O-bound and interactive processes in the higher-priority queues. In addition, a process that waits too long in a lower-priority queue may be moved to a higher-priority queue. This form of aging prevents starvation.

The scheduler first executes processes in queue 0. Only when queue 0 is empty will it execute processes in queue 1. Similarly, processes in queue 2 will be executed only if queues 0 and 1 are empty. A process that arrives for queue 1 will preempt a process in queue 2. A process in queue 1 will in turn be preempted by a process arriving for queue 0. A process entering the ready queue is put in queue 0. A process in queue 0 is given a time quantum of 8 milliseconds. If it does not finish within this time, it is moved

to the tail of queue 1. If queue 0 is empty, the process at the head of queue 1 is given a quantum of 16 milliseconds. If it does not complete, it is preempted and is put into queue 2. Processes in queue 2 are run on an FCFS basis but are run only when queues 0 and 1 are empty. This scheduling algorithm gives highest priority to any process with a CPU burst of 8 milliseconds or less. Such a process will quickly get the CPU, finish its CPU burst, and go off to its next I/O burst. Processes that need more than8 but less than 24 milliseconds are also served quickly, although with lower priority than shorter processes. Long processes automatically sink to queue 2 and are served in FCFS order with any CPU cycles left over from queues 0 and 1. In general, a multilevel feedback queue scheduler is defined by the following parameters:

• The number of queues

• The scheduling algorithm for each queue

• The method used to determine when to upgrade a process to a higher priority queue

• The method used to determine when to demote a process to a lower priority queue

• The method used to determine which queue a process will enter when that process needs service

The definition of a multilevel feedback queue scheduler makes it the most general CPU-scheduling algorithm. It can be configured to match a specific system under design. Unfortunately, it is also the most complex algorithm, since defining the best scheduler requires some means by which to select values for all the parameters.

5.4.7 Thread Scheduling

User-level threads are managed by a thread library, and the kernel is unaware of them. To run on a CPU, user-level threads must ultimately be mapped to an associated kernel-level thread, although this mapping may be indirect and may use a lightweight process (LWP). In this section, we explore scheduling issues involving user-level and kernel-level threads and offer specific examples of scheduling for Pthreads

Contention Scope

One distinction between user-level and kernel-level threads lies in how they are scheduled. On systems implementing the many-to-one and many-to-many models, the thread library schedules user-level threads to run on an available LWP. This scheme is known as process contention scope (PCS), since competition for the CPU takes place among threads belonging to the same process. (When we say the thread library schedules user threads onto available LWPs, we do not mean that the threads are actually running on a CPU. That would require the operating system to schedule the kernel thread onto a physical CPU.) To decide which kernel-level thread to

schedule onto a CPU, the kernel uses system-contention scope (SCS). Competition for the CPU with SCS scheduling takes place among all threads the system. Systems using the one-to-one model, such as Windows, Linux, and Solaris, schedule threads using only SCS. Typically, PCS is done according to priority—the scheduler selects the runnable thread with the highest priority to run. User-level thread priorities are set by the programmer and are not adjusted by the thread library, although some thread libraries may allow the programmer to change the priority of a thread. It is important to note that PCS will typically preempt the thread currently running in favor of a higher-priority thread; however, there is no guarantee of time slicing (Section 6.3.4) among threads of equal priority.

5.4.8 Pthread Scheduling

We provided a sample POSIX Pthread program in Section 4.4.1, along with an introduction to thread creation with Pthreads. Now, we highlight the POSIX Pthread API that allows specifying PCS or SCS during thread creation. Pthreads identifies the following contention scope values:

• PTHREAD SCOPE PROCESS schedules threads using PCS scheduling.

• PTHREAD SCOPE SYSTEM schedules threads using SCS scheduling.

On systems implementing the many-to-many model, the PTHREAD SCOPE PROCESS policy schedules user-level threads onto available LWPs. The number of LWPs is maintained by the thread library, perhaps using scheduler activations (Section 4.6.5). The PTHREAD SCOPE SYSTEM scheduling policy will create and bind an LWP for each user-level thread on many-to-many systems, effectively mapping threads using the one-to-one policy. The Pthread IPC provides two functions for getting—and setting—the contention scope policy:

• pthread attr setscope(pthread attr t *attr, int scope)

• pthread attr getscope(pthread attr t *attr, int *scope)

The first parameter for both functions contains a pointer to the attribute set for the thread. The second parameter for the pthread attr setscope() function is passed either the value, indicating how the contention scope is to be set. In the case of pthread attr getscope(), this second parameter contains a pointer to an int value that is set to the current value of the contention scope. If an error occurs, each of these functions returns a nonzero value. In Figure 6.8, we illustrate a Pthread scheduling API. The program first determines the existing contention scope and sets it to PTHREAD SCOPE SYSTEM. It then creates five separate threads that will run using the SCS scheduling policy. Note that on some systems, only certain contention scope values are allowed. For example, Linux and Mac OS X systems allow only PTHREAD SCOPE SYSTEM.

5.5 MULTIPLE-PROCESSOR SCHEDULING

Our discussion thus far has focused on the problems of scheduling the CPU in a system with a single processor. If multiple CPUs are available, load sharing becomes possible—but scheduling problems become correspondingly more complex. Many possibilities have been tried; and as we saw with single processor CPU scheduling, there is no one best solution. Here, we discuss several concerns in multiprocessor scheduling. We concentrate on systems in which the processors are identical—homogeneous —in terms of their functionality. We can then use any available processor to run any process in the queue. Note, however, that even with homogeneous multiprocessors, there are sometimes limitations on scheduling. Consider a system with an I/O device attached to a private bus of one processor. Processes that wish to use that device must be scheduled to run on that processor.

5.5.1 Approaches to Multiple-Processor Scheduling

One approach to CPU scheduling in a multiprocessor system has all scheduling decisions, I/O processing, and other system activities handled by a single processor—the master server. The other processors execute only user code. This asymmetric multiprocessing is simple because only one processor accesses the system data structures, reducing the need for data sharing second approach uses symmetric multiprocessing (SMP), where each processor is self-scheduling. All processes may be in a common ready queue, or each processor may have its own private queue of ready processes. Regardless scheduling proceeds by having the scheduler for each processor examine the ready queue and select a process to execute. As we saw in Chapter 5, if we have multiple processors trying to access and update a common data structure, the scheduler must be programmed carefully. We must ensure that two separate processors do not choose to schedule the same process and that processes are not lost from the queue. Virtually all modern operating systems support SMP, including Windows, Linux, and Mac OS X. In the remainder of this section, we discuss issues concerning SMP systems.

5.5.2 Processor Affinity

Consider what happens to cache memory when a process has been running on a specific processor. The data most recently accessed by the process populate the cache for the processor. As a result, successive memory accesses by then process are often satisfied in cache memory. Now consider what happens if the process migrates to another processor. The contents of cache memory must be invalidated for the first processor, and the cache for the second processor must be repopulated. Because of the high cost of invalidating and repopulating caches, most SMP systems try to avoid migration of processes from one processor to another and instead attempt to keep a process running on the same processor. This is known as processor affinity—that is, a process has an affinity for the processor on which it is currently running. Processor affinity takes several forms.

When an operating system has a policy of attempting to keep a process running on the same processor—but not guaranteeing that it will do so—we have a situation known as soft affinity. Here, the operating system will attempt to keep a process on a single processor, but it is possible for a process to migrate between processors. In contrast, some systems provide system calls that support hard affinity, thereby allowing a process to specify a subset of processors on which it may run.

Many systems provide both soft and hard affinity. For example, Linux implements soft affinity, but it also provides the sched setaffinity() system call, which supports hard affinity. The main-memory architecture of a system can affects processor affinity issues. Typically, this occurs in systems containing combined CPU and memory boards. The CPUs on a board can access the memory on that board faster than they can access memory on other boards in the system.

If the operating system's CPU scheduler and memory-placement algorithms work together, then a process that is assigned affinity to a particular CPU can be allocated memory on the board where that CPU resides. This example also shows that operating systems are frequently not as cleanly defined and implemented as described in operating-system textbooks. Rather, the "solid lines" between sections of an operating system are frequently only "dotted lines," with algorithms creating connections in ways aimed at optimizing performance and reliability.

5.5.3 Load Balancing

On SMP systems, it is important to keep the workload balanced among all processors to fully utilize the benefits of having more than one processor Otherwise; one or more processors may sit idle while other processors have high workloads, along with lists of processes awaiting the CPU. Load balancing attempts to keep the workload evenly distributed across all processors in a SMP system. It is important to note that load balancing is typically necessary only on systems where each processor has its own private queue of eligible processes to execute. On systems with a common run queue, load balancing is often unnecessary, because once a processor becomes idle, it immediately extracts a runnable process from the common run queue. It is also important to note, however, that in most contemporary operating systems supporting SMP, each processor does have a private queue of eligible processes.

There are two general approaches to load balancing: push migration and pull migration. With push migration, a specific task periodically checks the load on each processor and—if it finds an imbalance—evenly distributes the load by moving (or pushing) processes from overloaded to idle or less-busy processors. Pull migration occurs when an idle processor pulls a waiting task from a busy processor. Push and pull migration need not be mutually exclusive and are in fact often implemented in parallel on load-balancing systems. As is often the case in systems engineering, there is no absolute rule concerning what policy is best. Thus, in some systems, an idle processor always pulls a process from a non-idle processor. In other

systems, processes are moved only if the imbalance exceeds a certain threshold.

Otherwise, one or more processors may sit idle while other processors have high workloads, along with lists of processes awaiting the CPU. Load balancing attempts to keep the workload evenly distributed across all processors in an SMP system. It is important to note that load balancing is typically necessary only on systems where each processor has its own private queue of eligible processes to execute. On systems with a common run queue, load balancing is often unnecessary, because once a processor becomes idle, it immediately extracts a runnable process from the common run queue. It is also important to note, however, that in most contemporary operating systems supporting SMP, each processor does have a private queue of eligible processes.

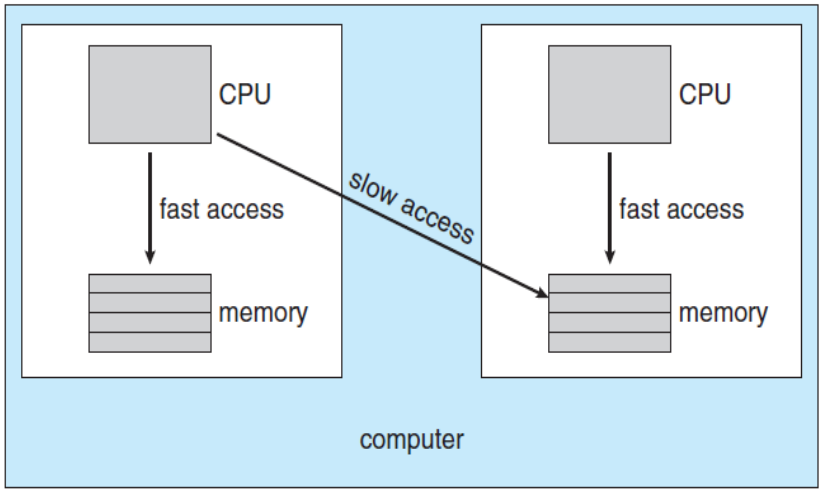


Figure 5.5 NUMA and CPU Scheduling

5.5.4 Multicore Processors

Traditionally, SMP systems have allowed several threads to run concurrently by providing multiple physical processors. However, a recent practice in computer hardware has been to place multiple processor cores on the same physical chip, resulting in a multicore processor. Each core maintains its architectural state and thus appears to the operating system to be a separate physical processor. SMP systems that use multicore processors are faster and consume less power than systems in which each processor has its own physical chip. Multicore processors may complicate scheduling issues. Let's consider how this can happen. Researchers have discovered that when a processor accesses memory, it spends a significant amount of time waiting for the data to become available. This situation, known as a memory stall, may occur for various reasons, such as a cache miss (accessing data that are not in cache memory). To remedy this situation, many recent hardware designs have implemented multithreaded processor cores in which two (or more) hardware threads are assigned to

each core. That way, if one thread stalls while waiting for memory, the core can switch to another thread.

Thus, on a dual-threaded, dual-core system, four logical processors are presented to the operating system. The UltraSPARC T3 CPU has sixteen cores per chip and eight hardware threads per core. From the perspective of the operating system, there appear to be 128 logical processors. In general, there are two ways to multithread a processing core: coarse-grained and fine-grained multithreading.

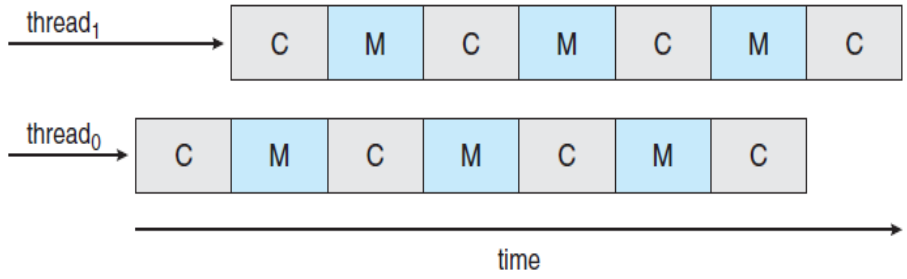


Figure 5.6 Multi-threaded multi core systems

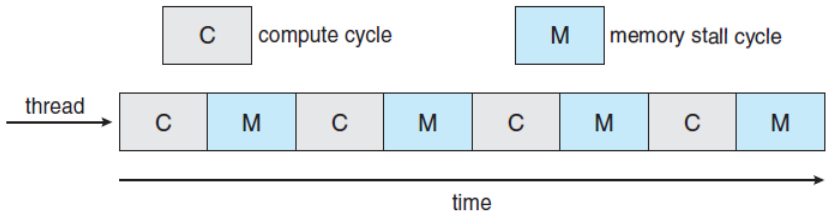


Figure5.7 Memory Stall

With coarse-grained multithreading, a thread executes on a processor until a long-latency event such as a memory stall occurs. Because of the delay caused by the long-latency event, the processor must switch to another thread to begin execution. However, the cost of switching between threads is high, since the instruction pipeline must be flushed before the other thread can begin execution on the processor core. Once this new thread begins execution, it begins filling the pipeline with its instructions. Fine-grained (or interleaved) multithreading switches between threads at a much finer level of granularity—typically at the boundary of an instruction cycle. However, the architectural design of fine-grained systems includes logic for thread switching. As a result, the cost of switching between threads is small.

Check your Progress

1. What is RR scheduling algorithm?
2. Briefly explain FCFS?
3. What are the process Scheduling Algorithms?
4. What is Multiple-Level Queues Scheduling?

5.6 ANSWERS TO CHECK YOUR PROGRESS

1. RR (round-robin) scheduling algorithm is primarily aimed for time-sharing systems. A circular queue is a setup in such a way that the CPU scheduler goes around that queue, allocating CPU to each process for a time interval of up to around 10 to 100 milliseconds.

2. FCFS stands for First-come, first-served. It is one type of scheduling algorithm. In this scheme, the process that requests the CPU first is allocated the CPU first. Implementation is managed by a FIFO queue.

3. Some of the process scheduling algorithms are:
    - First-Come, First-Served Scheduling (FCFS)
    - Shortest-Job-First Scheduling
    - Priority Scheduling
    - Round-Robin Scheduling
    - Multilevel Queue Scheduling
    - Multilevel Feedback Queue Scheduling
    - Thread Scheduling
    - Pthread Scheduling
4. Multiple-level queues is not an independent scheduling algorithm but it makes use of other existing algorithms to group and schedule jobs with common characteristic.
    - Multiple queues are maintained for processes with common characteristic.
    - Each queue can have its own scheduling algorithms.
    - Priorities are assigned to each queue.

5.7. SUMMARY

- The scheduling of the process in the operating system has to perform with some criteria and there are many scheduling algorithms which work under different constraints so as to schedule the process effectively.
- Different CPU-scheduling algorithms have different properties, and the choice of a particular algorithm may favor one class of processes over another.
- A different approach to CPU scheduling is the shortest-job-first (SJF) scheduling algorithm. This algorithm associates with each process the length of the process's next CPU burst.
- The round-robin (RR) scheduling algorithm is designed especially for timesharing systems.

- A multilevel queue scheduling algorithm partitions the ready queue into several separate queues
- The turnaround time is generally limited by the speed of the output device.

5.8. KEYWORDS

CPU utilization. We want to keep the CPU as busy as possible. Conceptually, CPU utilization can range from 0 to 100 percent. In a real system, it should range from 40 percent (for a lightly loaded system) to 90 percent (for a heavily loaded system).
Throughput. If the CPU is busy executing processes, then work is being done. One measure of work is the number of processes that are completed per time unit, called throughput. For long processes, this rate may be one process per hour; for short transactions, it may be ten processes per second.
Response time. In an interactive system, turnaround time may not be the best criterion. **Waiting time**. The CPU-scheduling algorithm does not affect the amount of time during which a process executes or does I/O.

5.9. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:
1. What are Multicore Processors?
2. What are Load Balancing?
3. What is Process Scheduling?
4. Explain about SJF?
5. What are the queues in Multilevel Queue Scheduling?

Long Answer questions:
1. Explain about Scheduling Algorithms?
2. Explain about Multilevel Queue Scheduling and its order of Priority?

5.10. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

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Notes

BLOCK – III
SYNCHRONIZATION

UNIT -VI SYNCHRONIZATION

Structure

6.0 Introduction
6.1 Objective
6.2 The Critical-Section Problem
6.3 Synchronization Hardware
6.4 Semaphores
6.5 Semaphores -Classic Problems of Synchronization
6.6 Semaphores -Classic Problems of Synchronization -Monitors
6.7 Answers to Check Your Progress Questions
6.8 Summary
6.9 Key Words
6.10 Self Assessment Questions and Exercises
6.11 Further Readings

6.0 INTRODUCTION

The allocation of process plays a pivotal role in the operating system and the time in which the execution is performed is also calculated. This unit addresses the critical section problem with regard to synchronization and the usage of semaphores with the classical synchronization problem

6.1 OBJECTIVE

This unit helps to understand the

- Classical problem of synchronization
- Semaphores critical section problem
- Critical section problem
- Synchronization hardware

6.2 THE CRITICAL-SECTION PROBLEM

We begin our consideration of process synchronization by discussing the so called critical-section problem. Consider a system consisting of n processes {P0, P1, ..., Pn−1}. Each process has a segment of code, called a critical section, in which the process may be changing common variables, updating a table, writing a file, and so on. The important feature of the system is that, when one process is executing in its critical section, no other process is allowed to execute in its critical section. That is, no two processes are executing in their critical sections at the same time. The critical-section problem is to design a protocol that the processes can use to

cooperate. Each process must request permission to enter its critical section. The section of code implementing this request is the entry section. The critical section may be followed by an exit section. The remaining code is the remainder section. code. A solution to the critical-section problem must satisfy the following three requirements:

1. **Mutual exclusion**. If process Pi is executing in its critical section, then no other processes can be executing in their critical sections.

2. **Progress**. If no process is executing in its critical section and some processes wish to enter their critical sections, then only those processes that are not executing in their remainder sections can participate in deciding which will enter its critical section next, and this selection cannot be postponed indefinitely.

3. **Bounded waiting**. There exists a bound, or limit, on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.

We assume that each process is executing at a nonzero speed. However, we can make no assumption concerning the relative speed of the n processes. At a given point in time, many kernel-mode processes may be active in the operating system. As a result, the code implementing an operating system (kernel code) is subject to several possible race conditions. Consider as an example a kernel data structure that maintains a list of all open files in the system. This list must be modified when a new file is opened or closed (adding the file to the list or removing it from the list). If two processes were to open files simultaneously, the separate updates to this list could result in a race condition. Other kernel data structures that are prone to possible race conditions include structures for maintaining memory allocation, for maintaining process lists, and for interrupt handling. It is up to kernel developers to ensure that the operating system is free from such race conditions.

Two general approaches are used to handle critical sections in operating systems: pre-emptive kernels and no preemptive kernels. A pre-emptive kernel allows a process to be pre-empted while it is running in kernel mode. A no preemptive kernel does not allow a process running in kernel mode to be pre-empted; a kernel-mode process will run until it exits kernel mode, blocks, or voluntarily yields control of the CPU. Obviously, a no preemptive kernel is essentially free from race conditions on kernel data structures, as only one process is active in the kernel at a time. We cannot say the same about pre-emptive kernels, so they must be carefully designed to ensure that shared kernel data are free from race conditions.

Pre-emptive kernels are especially difficult to design for SMP architectures, since in these environments it is possible for two kernel-mode processes to run simultaneously on different processors. A pre-emptive kernel may be more responsive, since there is less risk that a kernel-mode process will run for an arbitrarily long period before

relinquishing the processor to waiting processes. (Of course, this risk can also be minimized by designing kernel code that does not behave in this way.) Furthermore, a pre-emptive kernel is more suitable for real-time programming, as it will allow a real-time process to pre-empt a process currently running in the kernel. Later in this chapter, we explore how various operating systems manage pre-emption within the kernel.

6.3 SYNCHRONIZATION HARDWARE

We have just described one software-based solution to the critical-section problem. However, as mentioned, software-based solutions such as Peterson's are not guaranteed to work on modern computer architectures. In the following discussions, we explore several more solutions to the critical-section problem using techniques ranging from hardware to software-based APIs available to both kernel developers and application programmers. All these solutions are based on the premise of locking — that is, protecting critical regions through the use of locks. As we shall see, the designs of such locks can be quite sophisticated.

We start by presenting some simple hardware instructions that are available on many systems and showing how they can be used effectively in solving the critical-section problem. Hardware features can make any programming task easier and improve system efficiency. The critical-section problem could be solved simply in a single-processor environment if we could prevent interrupts from occurring while a shared variable was being modified. In this way, we could be sure that the current sequence of instructions would be allowed to execute in order without preemption. No other instructions would be run, so no unexpected modifications could be made to the shared variable. This is often the approach taken by non-preemptive kernels.

```
boolean test and set(boolean *target)

{

boolean rv = *target;

*target = true;

return rv;

}
```

Figure 6.1 The definition of the test and set() instruction.

```
Do

 {

while (test and set(&lock))

; /* do nothing */
```

```
/* critical section */

lock = false;

/* remainder section */

} while (true);
```

Figure 6.2 Mutual-exclusion implementation with test and set().

Unfortunately, this solution is not as feasible in a multiprocessor environment. Disabling interrupts on a multiprocessor can be time consuming, since the message is passed to all the processors. This message passing delays entry into each critical section, and system efficiency decreases. Also consider the effect on a system's clock if the clock is kept updated by interrupts. Many modern computer systems therefore provide special hardware instructions that allow us either to test and modify the content of a word or to swap the contents of two words atomically—that is, as one uninterruptible unit. We can use these special instructions to solve the critical-section problem in a relatively simple manner. Rather than discussing one specific instruction for one specific machine, we abstract the main concepts behind these types of instructions by describing the test and set() and compare and swap() instructions.

The important characteristic of this instruction is that it is executed atomically. Thus, if two test and set() instructions are executed simultaneously (each on a different CPU), they will be executed sequentially in some arbitrary order. If the machine supports the test and set() instruction, then we can implement mutual exclusion by declaring a Boolean variable lock, initialized to false.The compare and swap() instruction, in contrast to the test and set() instruction, operates on three operands. The operand value is set to new value only if the expression (*value == exected) is true. Regardless, compare and swap() always returns the original value of the variable value. Like the test and set() instruction, compare and swap() is int compare and swap(int *value, int expected, int new value) executed atomically.

```
{

int temp = *value;

if (*value == expected)

*value = new value;

return temp;

}
```

Figure 6.3 The definition of the compare and swap() instruction.

Do

{

while (compare and swap(&lock, 0, 1) != 0)

; /* do nothing */

/* critical section */

lock = 0;

/* remainder section */

} while (true);

Figure 6.3 Mutual-exclusion implementation with the compare and swap() instruction.

Mutual exclusion can be provided as follows: a globalvariable (lock) is declared and is initialized to 0. The first process that invokes compare and swap() will set lock to 1. It will then enter its critical section, because the original value of lock was equal to the expected value of 0. Subsequent calls to compare and swap() will not succeed, because lock now is not equal to the expected value of 0. When a process exits its critical section, it sets lock back to 0, which allows another process to enter its critical section. The structure of process Pi is shown in Figure 5.6. Although these algorithms satisfy the mutual-exclusion requirement, they do not satisfy the bounded-waiting requirement. In Figure 5.7, we present another algorithm using the test and set() instruction that satisfies all the critical-section requirements. The common data structures are

do {

waiting[i] = true;

key = true;

while (waiting[i] && key)

key = test and set(&lock);

waiting[i] = false;

/* critical section */

j = (i + 1) % n;

while ((j != i) && !waiting[j])

j = (j + 1) % n;

if (j == i)

lock = false;

else

```
waiting[j] = false;

/* remainder section */

} while (true);
```

Figure 6.4 Bounded-waiting mutual exclusion with test and set().

```
boolean waiting[n];

boolean lock;
```

These data structures are initialized to false. To prove that the mutual exclusion requirement is met, we note that process Pi can enter its critical section only if either waiting[i] == false or key == false. The value of key can become false only if the test and set() is executed. The first process to execute the test and set() will find key == false; all others must wait. The variable waiting[i] can become false only if another process leaves its critical section; only one waiting[i] is set to false, maintaining the mutual-exclusion requirement.

To prove that the progress requirement is met, we note that the arguments presented for mutual exclusion also apply here, since a process exiting the critical section either sets lock to false or sets waiting[j] to false. Both allow a process that is waiting to enter its critical section to proceed. To prove that the bounded-waiting requirement ismet,we note that, when a process leaves its critical section, it scans the array waiting in the cyclic ordering (i + 1, i + 2, ..., n − 1, 0, ..., i − 1). It designates the first process in this ordering that is in the entry section (waiting[j] == true) as the next one to enter the critical section. Any process waiting to enter its critical section will thus do so within n − 1 turns.

Details describing the implementation of the atomic test and set() and compare and swap() instructions are discussed more fully in books on computer architecture.

6.4 SEMAPHORES

Mutex locks, as we mentioned earlier, are generally considered the simplest of synchronization tools. In this section, we examine a more robust tool that can behave similarly to a mutex lock but can also provide more sophisticated ways for processes to synchronize their activities.

A semaphore S is an integer variable that, apart from initialization, is accessed only through two standard atomic operations: wait() and signal(). The wait() operation was originally termed P (from the Dutch proberen, “to test”); signal() was originally called V (from verhogen, “to increment”). The definition of wait() is as follows:

```
wait(S) {

while (S <= 0)
```

; // busy wait

S--;

}

Notes

The definition of signal() is as follows:

signal(S) {

S++;

}

All modifications to the integer value of the semaphore in the wait() and signal() operations must be executed indivisibly. That is, when one process modifies the semaphore value, no other process can simultaneously modify that same semaphore value. In addition, in the case of wait(S), the testing of the integer value of S ($S \leq 0$), as well as its possible modification (S--), must be executed without interruption.

6.4.1 Semaphore Usage

Operating systems often distinguish between counting and binary semaphores. The value of a counting semaphore can range over an unrestricted domain. The value of a binary semaphore can range only between 0 and 1. Thus, binary semaphores behave similarly to mutex locks. In fact, on systems that do not provide mutex locks, binary semaphores can be used instead for providing mutual exclusion. Counting semaphores can be used to control access to a given resource consisting of a finite number of instances. The semaphore is initialized to the number of resources available. Each process that wishes to use a resource performs a wait() operation on the semaphore (thereby decrementing the count).

When a process releases a resource, it performs a signal() operation (incrementing the count). When the count for the semaphore goes to 0, all resources are being used. After that, processes that wish to use a resource will block until the count becomes greater than 0. We can also use semaphores to solve various synchronization problems. For example, consider two concurrently running processes: P1 with a statement S1 and P2 with a statement S2. Suppose we require that S2 be executed only after S1 has completed. We can implement this scheme readily by letting P1 and P2 share a common semaphore synch, initialized to 0. In process P1, we insert the statements

S1;

signal(synch);

In process P2, we insert the statements

wait(synch);

S2;

Because synch is initialized to 0, P2 will execute S2 only after P1 has invoked signal(synch), which is after statement S1 has been executed.

6.4.2 Semaphore Implementation

Recall that the implementation of mutex locks discussed in Section 5.5 suffers from busy waiting. The definitions of the wait() and signal() semaphore operations just described present the same problem. To overcome the need for busy waiting, we can modify the definition of the wait() and signal() operations as follows: When a process executes the wait() operation and finds that the semaphore value is not positive, it must wait. However, rather than engaging in busy waiting, the process can block itself. The block operation places a process into a waiting queue associated with the semaphore, and the state of the process is switched to the waiting state. Then control is transferred to the CPU scheduler, which selects another process to execute. A process that is blocked, waiting on a semaphore S, should be restarted when some other process executes a signal() operation. The process is restarted by a wakeup() operation, which changes the process fromthe waiting state to the ready state. The process is then placed in the ready queue. (The CPU may or may not be switched from the running process to the newly ready process, depending on the CPU-scheduling algorithm.)

To implement semaphores under this definition, we define a semaphore as follows:

```
typedef struct {

int value;

struct process *list;

} semaphore;
```

Each semaphore has an integer value and a list of processes list. When a process must wait on a semaphore, it is added to the list of processes. A signal() operation removes one process from the list of waiting processes and awakens that process. Now, the wait() semaphore operation can be defined as

```
wait(semaphore *S) {

S->value--;

if (S->value < 0) {

add this process to S->list;

block();

}

}
```

The signal() semaphore operation can be defined as

```
signal(semaphore *S) {
S->value++;
if (S->value <= 0) {
remove a process P from S->list;
wakeup(P);
}
}
```

The block() operation suspends the process that invokes it. The wakeup(P) operation resumes the execution of a blocked process P. These two operations are provided by the operating system as basic system calls. Note that in this implementation, semaphore values may be negative, whereas semaphore values are never negative under the classical definition of semaphores with busy waiting. If a semaphore value is negative, its magnitude is the number of processes waiting on that semaphore. This fact results from switching the order of the decrement and the test in the implementation of the wait() operation. The list of waiting processes can be easily implemented by a link field in each process control block (PCB). Each semaphore contains an integer value and a pointer to a list of PCBs. One way to add and remove processes from the list so as to ensure bounded waiting is to use a FIFO queue, where the semaphore contains both head and tail pointers to the queue. In general, however, the list can use any queueing strategy. Correct usage of semaphores does not depend on a particular queueing strategy for the semaphore lists.

It is critical that semaphore operations be executed atomically. We must guarantee that no two processes can execute wait() and signal() operations on the same semaphore at the same time. This is a critical-section problem; and in a single-processor environment, we can solve it by simply inhibiting interrupts during the time the wait() and signal() operations are executing. This scheme works in a single-processor environment because, once interrupts are inhibited, instructions from different processes cannot be interleaved. Only the currently running process executes until interrupts are enabled and the scheduler can regain control. In a multiprocessor environment, interrupts must be disabled on every processor. Otherwise, instructions from different processes (running on different processors) may be interleaved in some arbitrary way. Disabling interrupts on every processor can be a difficult task and furthermore can seriously diminish performance.

Therefore, SMP systems must provide alternative locking techniques—such as compare and swap() or spinlocks—to ensure that wait() and signal() are performed atomically. It is important to admit that we have not completely eliminated busy waiting with this definition of the wait() and

signal() operations. Rather, we have moved busy waiting from the entry section to the critical sections of application programs. Furthermore, we have limited busy waiting to the critical sections of the wait() and signal() operations, and these sections are short (if properly coded, they should be no more than about ten instructions). Thus, the critical section is almost never occupied, and busy waiting occurs rarely, and then for only a short time. An entirely different situation exists with application programs whose critical sections may be long (minutes or even hours) or may almost always be occupied. In such cases, busy waiting is extremely inefficient.

6.5 CLASSIC PROBLEMS OF SYNCHRONIZATION

In this section, we present a number of synchronization problems as examples of a large class of concurrency-control problems. These problems are used for testing nearly every newly proposed synchronization scheme. In our solutions to the problems, we use semaphores for synchronization, since that is the traditional way to present such solutions. However, actual implementations of these solutions could use mutex locks in place of binary semaphores.

6.5.1 The Bounded-Buffer Problem

In our problem, the producer and consumer processes share the following data structures:

int n;

semaphore mutex = 1;

semaphore empty = n;

semaphore full = 0

We assume that the pool consists of n buffers, each capable of holding one item. The mutex semaphore provides mutual exclusion for accesses to the buffer pool and is initialized to the value 1. The empty and full semaphores count the number of empty and full buffers. The semaphore empty is initialized to the value n; the semaphore full is initialized to the value 0. The code for the producer process is shown in Figure 5.9, and the code for the consumer process is shown in Figure 5.10. Note the symmetry between the producer and the consumer. We can interpret this code as the producer producing full buffers for the consumer or as the consumer producing empty buffers for the producer.

do {

wait(full);

wait(mutex);

. . .

/* remove an item from buffer to next consumed */

. . .

signal(mutex);

signal(empty);

. . .

/* consume the item in next consumed */

. . .

} while (true);

Figure 6.5 The structure of the consumer process.

6.5.2 The Readers–Writers Problem

Suppose that a database is to be shared among several concurrent processes. Some of these processes may want only to read the database, whereas others may want to update (that is, to read and write) the database. We distinguish between these two types of processes by referring to the former as readers and to the latter as writers. Obviously, if two readers access the shared data simultaneously, no adverse effects will result. However, if a writer and some other process (either a reader or a writer) access the database simultaneously, chaos may ensue. To ensure that these difficulties do not arise, we require that the writers have exclusive access to the shared database while writing to the database. This synchronization problem is referred to as the readers–writers problem. Since it was originally stated, it has been used to test nearly every new synchronization primitive. The readers–writers problem has several variations, all involving priorities. The simplest one, referred to as the first readers–writers problem, requires that no reader be kept waiting unless a writer has already obtained permission to use the shared object. In other words, no reader should wait for other readers to finish simply because a writer is waiting. The second readers –writers problem requires that, once a writer is ready, that writer perform its write as soon as possible. In other words, if a writer is waiting to access the object, no new readers may start reading.

A solution to either problem may result in starvation. In the first case, writers may starve; in the second case, readers may starve. For this reason, other variants of the problem have been proposed. Next, we present a solution to the first readers–writers problem. See the bibliographical notes at the end of the chapter for references describing starvation-free solutions to the second readers–writers problem.

In the solution to the first readers–writers problem, the reader processes share the following data structures:

semaphore rw mutex = 1;

semaphore mutex = 1;

```
int read count = 0;
```

The semaphores mutex and rw mutex are initialized to 1; read count is initialized to 0. The semaphore rw mutex is common to both reader and writer processes.

```
do {

wait(rw mutex);

. . .

/* writing is performed */

. . .

signal(rw mutex);

} while (true);
```

Figure 6.6 The structure of a writer process.

The mutex semaphore is used to ensure mutual exclusion when the variable read count is updated. The read count variable keeps track of how many processes are currently reading the object. The semaphore rw mutex functions as a mutual exclusion semaphore for the writers. It is also used by the first or last reader that enters or exits the critical section. It is not used by readers who enter or exit while other readers are in their critical sections. The readers–writers problem and its solutions have been generalized to provide reader–writer locks on some systems. Acquiring a reader–writer lock requires specifying the mode of the lock: either read or write access. When a in read mode. A process wishing to modify the shared data must request the lock in write mode. Multiple processes are permitted to concurrently acquire a reader–writer lock in read mode, but only one process may acquire the lock for writing, as exclusive access is required for writers. Reader–writer locks are most useful in the following situations:

```
do {

wait(mutex);

read count++;

if (read count == 1)

wait(rw mutex);

signal(mutex);

. . .

/* reading is performed */
```

```
. . .
wait(mutex);
read count--;
if (read count == 0)
signal(rw mutex);
signal(mutex);
} while (true);
```

Figure 6.7 The structure of a reader process.

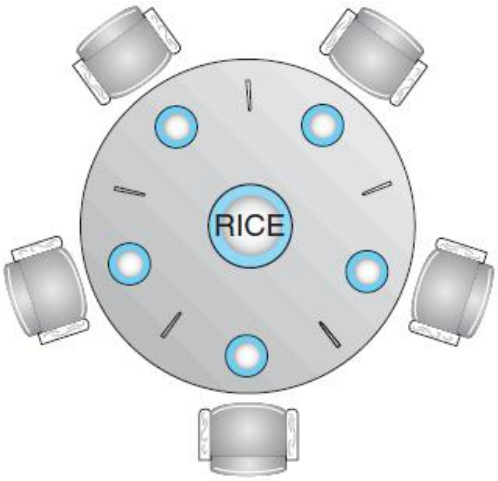

Figure 6.8 The situation of the dining philosophers.

• In applications where it is easy to identify which processes only read shared data and which processes only write shared data.

• In applications that have more readers than writers. This is because reader– writer locks generally require more overhead to establish than semaphores or mutual-exclusion locks. The increased concurrency of allowing multiple readers compensates for the overhead involved in setting up the reader– writer lock.

6.5.3 The Dining-Philosophers Problem

Consider five philosophers who spend their lives thinking and eating. The philosophers share a circular table surrounded by five chairs, each belonging to one philosopher. When a philosopher thinks, she does not interact with her colleagues. From time to time, a philosopher gets hungry and tries to pick up the two chopsticks that are closest to her (the chopsticks that are between her and her left and right neighbors). A philosopher may pick up only one chopstick at a time. Obviously, she

cannot pick up a chopstick that is already in the hand of a neighbor. When a hungry philosopher has both her chopsticks at the same time, she eats without releasing the chopsticks. When she is finished eating, she puts down both chopsticks and starts thinking again. The dining-philosophers problem is considered a classic synchronization problem neither because of its practical importance nor because computer scientists dislike philosophers but because it is an example of a large class of concurrency-control problems. It is a simple representation of the need to allocate several resources among several processes in a deadlock-free and starvation-free manner. One simple solution is to represent each chopstick with a semaphore. A philosopher tries to grab a chopstick by executing a wait() operation on that semaphore. She releases her chopsticks by executing the signal() operation on the appropriate semaphores. Thus, the shared data are where all the elements of chopstick are initialized to 1

```
semaphore chopstick[5];

do {

wait(chopstick[i]);

wait(chopstick[(i+1) % 5]);

. . .

/* eat for awhile */

. . .

signal(chopstick[i]);

signal(chopstick[(i+1) % 5]);

. . .

/* think for awhile */

. . .

} while (true);
```

Figure 6.9 The structure of philosopher i.

Although this solution guarantees that no two neighbors are eating simultaneously, it nevertheless must be rejected because it could create a deadlock. Suppose that all five philosophers become hungry at the same time and each grabs her left chopstick. All the elements of chopstick will now be equal to 0. When each philosopher tries to grab her right chopstick, she will be delayed forever. Several possible remedies to the deadlock problem are replaced by:

• Allow at most four philosophers to be sitting simultaneously at the table.

• Allow a philosopher to pick up her chopsticks only if both chopsticks are available (to do this, she must pick them up in a critical section).

• Use an asymmetric solution—that is, an odd-numbered philosopher picks up first her left chopstick and then her right chopstick, whereas an even numbered philosopher picks up her right chopstick and then her left chopstick.

.6.6 Monitors

Although semaphores provide a convenient and effective mechanism for process synchronization, using them incorrectly can result in timing errors that are difficult to detect, since these errors happen only if particular execution sequences take place and these sequences do not always occur. In that example, the timing problem happened only rarely, and even then the counter value appeared to be reasonable—off by only 1. Nevertheless, the solution is obviously not an acceptable one. It is for this reason that semaphores were introduced in the first place.

Unfortunately, such timing errors can still occur when semaphores are used. To illustrate how, we review the semaphore solution to the critical-section problem. All processes share a semaphore variable mutex, which is initialized to 1. Each process must execute wait(mutex) before entering the critical section and signal(mutex) afterward. If this sequence is not observed, two processes may be in their critical sections simultaneously. Next, we examine the various difficulties that may result. Note that these difficulties will arise even if a single process is not well behaved. This situation may be caused by an honest programming error or an uncooperative programmer.

• Suppose that a process interchanges the order in which the wait() and signal() operations on the semaphore mutex are executed, resulting in the following execution:

signal(mutex);

...

critical section

...

wait(mutex);

In this situation, several processes maybe executing in their critical sections simultaneously, violating the mutual-exclusion requirement. This error may be discovered only if several processes are simultaneously active in their critical sections. Note that this situation may not always be reproducible. Suppose that a process replaces signal(mutex) with wait(mutex). That is, it executes

wait(mutex);

...

critical section

...

wait(mutex);

In this case, a deadlock will occur. Suppose that a process omits the wait(mutex), or the signal(mutex), or both. In this case, either mutual exclusion is violated or a deadlock will occur. These examples illustrate that various types of errors can be generated easily when programmers use semaphores incorrectly to solve the critical-section problem. Similar problems may arise in the other synchronization models discussed in Section 5.7. To deal with such errors, researchers have developed high-level language constructs. In this section, we describe one fundamental high-level synchronization construct—the monitor type.

monitor monitor name

{

/* shared variable declarations */

function P1 (. . .) {

. . .

}

function P2 (. . .) {

. . .

}

.

.

.

function Pn (. . .) {

. . .

}

initialization code (. . .) {

. . .

}

}

Figure 6.10 Syntax of a monitor.

6.6.1 Monitor Usage

An abstract data type—or ADT—encapsulates data with a set of functions to operate on that data that are independent of any specific implementation of the ADT. A monitor type is an ADT that includes a set of programmer defined operations that are provided with mutual exclusion within the monitor.

The monitor type also declares the variables whose values define the state of an instance of that type, along with the bodies of functions that operate on those variables. The syntax of a monitor type is shown in Figure 5.15. The representation of a monitor type cannot be used directly by the various processes. Thus, a function defined within a monitor can access only those variables declared locally within the monitor and its formal parameters. Similarly, the local variables of a monitor can be accessed by only the local functions.

The monitor construct ensures that only one process at a time is active within the monitor. Consequently, the programmer does not need to code this synchronization constraint explicitly (Figure 5.16). However, the monitor construct, as defined so far, is not sufficiently powerful for modeling some synchronization schemes. For this purpose, we need to define additional synchronization mechanisms. These mechanisms are provided by the condition construct. A programmer who needs to write a tailor-made synchronization scheme can define one or more variables of type condition:

condition x, y;

entry queue

shared data

operations

initialization

code

. . .

Figure 6.11 Schematic view of a monitor.

The only operations that can be invoked on a condition variable are wait() and signal(). The operation

x.wait();

means that the process invoking this operation is suspended until another process invokes

x.signal();

The x.signal() operation resumes exactly one suspended process. If noprocess is suspended, then the signal() operation has no effect; that is, the state of x is the same as if the operation had never been executed (Figure 5.17). Contrast this operation with the signal() operation associated with semaphores, which always affects the state of the semaphore.

Now suppose that, when the x.signal() operation is invoked by a process P, there exists a suspended process Q associated with condition x. Clearly, if the suspended process Q is allowed to resume its execution, the signaling process P must wait. Otherwise, both P and Q would be active simultaneously within the monitor. Note, however, that conceptually both processes can continue with their execution. Two possibilities exist:

1. Signal and wait. P either waits until Q leaves the monitor or waits for another condition.

2. Signal and continue. Q either waits until P leaves the monitor or waits for another condition operations queues associated with

x, y conditions

entry queue

shared data

x

y

initialization

code

• • •

Figure 6.12 Monitor with condition variables.

There are reasonable arguments in favor of adopting either option. On the one hand, since P was already executing in the monitor, the signal-and continue method seems more reasonable. On the other, if we allow thread P to continue, then by the time Q is resumed, the logical condition for which Q was waiting may no longer hold. A compromise between these two choices was adopted in the language Concurrent Pascal. When thread P executes the signal operation, it immediately leaves the monitor. Hence, Q is immediately resumed. Many programming languages have incorporated the idea of the monitor as described in this section, including Java and C# (pronounced "C-sharp"). Other languages—such as Erlang—provide some type of concurrency support using a similar mechanism.

6.6.2 Dining-Philosophers Solution Using Monitors

Next, we illustrate monitor concepts by presenting a deadlock-free solution to the dining-philosophers problem. This solution imposes the restriction that a philosopher may pick up her chopsticks only if both of them are

available. To code this solution, we need to distinguish among three states in which we may find a philosopher. For this purpose, we introduce the following data structure:

```
enum {THINKING, HUNGRY, EATING} state[5];
```

Philosopher i can set the variable state[i] = EATING only if her two

neighbors are not eating: (state[(i+4) % 5] != EATING) and(state[(i+1)

% 5] != EATING).

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```
monitor DiningPhilosophers
{
enum {THINKING, HUNGRY, EATING} state[5];
condition self[5];
void pickup(int i) {
state[i] = HUNGRY;
test(i);
if (state[i] != EATING)
self[i].wait();
}
void putdown(int i) {
state[i] = THINKING;
test((i + 4) % 5);
test((i + 1) % 5);
}
void test(int i) {
if ((state[(i + 4) % 5] != EATING) &&
(state[i] == HUNGRY) &&
(state[(i + 1) % 5] != EATING)) {
state[i] = EATING;
self[i].signal();
}
```

```
}

initialization code() {

for (int i = 0; i < 5; i++)

state[i] = THINKING;

}

}
```

Figure 6.13 A monitor solution to the dining-philosopher problem.

We also need to declare condition self; this allows philosopher i to delay herself when she is hungry but is unable to obtain the chopsticks she needs. We are now in a position to describe our solution to the dining-philosophers problem. The distribution of the chopsticks is controlled by the monitor Dining Philosophers, Each philosopher, before starting to eat, must invoke the operation pickup(). This act may result in the suspension of the philosopher process. After the successful completion of the operation, the philosopher may eat. Following this, the philosopher invokes the putdown() operation. Thus, philosopher i must invoke the operations pickup() and putdown() in the following sequence:

```
DiningPhilosophers.pickup(i);

...

eat

...

DiningPhilosophers.putdown(i);
```

It is easy to show that this solution ensures that no two neighbours are eating simultaneously and that no deadlocks will occur. We note, however, that it is possible for a philosopher to starve to death. We do not present a solution to this problem but rather leave it as an exercise for you.

6.6.3 Implementing a Monitor Using Semaphores

We now consider a possible implementation of the monitor mechanism using semaphores. For each monitor, a semaphore mutex (initialized to 1) is provided. A process must execute wait(mutex) before entering the monitor and must execute signal(mutex) after leaving the monitor.

Since a signalling process must wait until the resumed process leaves or waits, an additional semaphore, next, is introduced, initialized to 0. The signalling processes can use next to suspend themselves. An integer variable next count is also provided to count the number of processes suspended on next. Thus, each external function F is replaced by

```
wait(mutex);
```

...

body of F

...

if (next count > 0)

signal(next);

else

signal(mutex);

Mutual exclusion within a monitor is ensured. We can now describe how condition variables are implemented as well. For each condition x, we introduce a semaphore x sem and an integer variable x count, both initialized to 0. The operation x.wait() can now be implemented as

x count++;

if (next count > 0)

signal(next);

else

signal(mutex);

wait(x sem);

x count--;

The operation x.signal() can be implemented as

if (x count > 0) {

next count++;

signal(x sem);

wait(next);

next count--;

}

This implementation is applicable to the definitions of monitors given by both Hoare and Brinch-Hansen (see the bibliographical notes at the end of the chapter). In some cases, however, the generality of the implementation is unnecessary, and a significant improvement in efficiency is possible. We leave this problem to you in Exercise 5.30.

6.6.4 Resuming Processes within a Monitor

We turn now to the subject of process-resumption order within a monitor. If several processes are suspended on condition x, and an x.signal() operation is executed by some process, then how do we determine which of the suspended processes should be resumed next? One simple solution is to use a first-come, first-served (FCFS) ordering, so that the process that has been waiting the longest is resumed first. In many circumstances, however, such a simple scheduling scheme is not adequate. For this purpose, the conditional-wait construct can be used. This construct has the form

x.wait(c);

where c is an integer expression that is evaluated when the wait() operation is executed. The value of c, which is called a priority number, is then stored with the name of the process that is suspended. When x.signal() is executed, the process with the smallest priority number is resumed next. Each process, when requesting an allocation of this resource, specifies the maximum time it plans to use the resource. The monitor allocates the resource to the process that has the shortest time-allocation request. A process that needs to access the resource in question must observe the following sequence:

R.acquire(t);

...

access the resource;

...

R.release();

where R is an instance of type Resource Allocator. Unfortunately, the monitor concept cannot guarantee that the preceding access sequence will be observed. In particular, the following problems can occur. A process might access a resource without first gaining access permission to the resource.

monitor Resource Allocator

{

boolean busy;

condition x;

void acquire(int time) {

if (busy)

x.wait(time);

```
busy = true;
}
void release() {
busy = false;
x.signal();
}
initialization code() {
busy = false;
}
}
```

Figure 6.14 A monitor to allocate a single resource.

• A process might never release a resource once it has been granted access to the resource.

• A process might attempt to release a resource that it never requested.

• A process might request the same resource twice (without first releasing the resource).

The same difficulties are encountered with the use of semaphores, and these difficulties are similar in nature to those that encouraged us to develop the monitor constructs in the first place. Previously, we had to worry about the correct use of semaphores. Now, we have to worry about the correct use of higher-level programmer-defined operations, with which the compiler can no longer assist us.

One possible solution to the current problem is to include the resource access operations within the Resource Allocator monitor. However, using this solution will mean that scheduling is done according to the built-in monitor-scheduling algorithm rather than the one we have coded. To ensure that the processes observe the appropriate sequences, we must inspect all the programs that make use of the Resource Allocator monitor and its managed resource. We must check two conditions to establish the correctness of this system. First, user processes must always make their calls on the monitor in a correct sequence. Second, we must be sure that an uncooperative process does not simply ignore the mutual-exclusion gateway provided by the monitor and try to access the shared resource directly, without using the access protocols. Only if these two conditions can be ensured can we guarantee that no time-dependent errors will occur and that the scheduling algorithm will not be defeated.

Check your Progress

1. What is semaphore?
2. What is binary Semaphore?
3. What is the disadvantage of critical section?
4. What is critical section?
5. What are the problems in Classic Problems of Synchronization?

6.7. ANSWERS TO CHECK YOUR PROGRESS

1. Semaphore is a protected variable or abstract data type that is used to lock the resource being used. The value of the semaphore indicates the status of a common resource. There are two types of semaphore:

    - Binary semaphores
    - Counting semaphores

2. Binary semaphore takes only 0 and 1 as value and used to implement mutual exclusion and synchronize concurrent processes.
3. Higher priority threads may be asked to wait for an indefinite amount of time. Implementation of critical section is not an easy task (from programming perspective), since it has to consider all the possible collateral risks.
4. A critical section is a piece of code that accesses a shared resource (either in the form of data structure or a device) that must not be concurrently accessed by more than one thread of execution (which will otherwise lock it from doing other things).
5. some of the classic problem depicting flaws of process synchronization in systems where cooperating processes are present.
    - Bounded Buffer (Producer-Consumer) Problem
    - Dining Philosophers Problem
    - The Readers Writers Problem

6.8. SUMMARY

- The allocation of process plays a pivotal role in the operating system and the time in which the execution is performed is also calculated.
- If process Pi is executing in its critical section, then no other processes can be executing in their critical sections.
- Pre-emptive kernels are especially difficult to design for SMP architectures, since in these environments it is possible for two kernel-mode processes to run simultaneously on different processors.

- Mutual exclusion can be provided as follows: a globalvariable (lock) is declared and is initialized to 0.
- Mutex locks are generally considered the simplest of synchronization tools.

6.9. KEYWORDS

Semaphore: A semaphore S is an integer variable that, apart from initialization, is accessed only through two standard atomic operations: wait() and signal().

Progress. If no process is executing in its critical section and some processes wish to enter their critical sections, then only those processes that are not executing in their remainder sections can participate in deciding which will enter its critical section next, and this selection cannot be postponed indefinitely.

Bounded waiting. There exists a bound, or limit, on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.

6.10. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is Bounded Buffer Problem?
2. What is Monitor?
3. Explain about Monitor Usage?
4. What is Dining-Philosophers Problem?
5. Explain about Semaphore Implementation?

Long Answer questions:

1. Explain briefly about Semaphore?
2. Explain about Classic Problems of Synchronization?

6.11. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

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UNIT VII DEADLOCK

Structure

7.0 Introduction
7.1 Objective
7.2 Deadlock Characterization
7.3 Methods Handing Deadlocks
7.4 Answers to Check Your Progress Questions
7.5 Summary
7.6 Key Words
7.7 Self Assessment Questions and Exercises
7.8 Further Readings

7.0 INTRODUCTION

This unit helps the user to understand the various characterization of the cause for deadlock and the methods to handle the deadlock situations deadlock is a situation in which two computer programs sharing the same resource are effectively preventing each other from accessing the resource, resulting in both programs ceasing to function.

The earliest computer operating systems ran only one program at a time. All of the resources of the system were available to this one program. Later, operating systems ran multiple programs at once, interleaving them. Programs were required to specify in advance what resources they needed so that they could avoid conflicts with other programs running at the same time. Eventually some operating systems offered dynamic allocation of resources. Programs could request further allocations of resources after they had begun running. This led to the problem of the deadlock. When the process is available but it still can be accessed due to some other requisition of that process. To handle this situation various deadlock methods helps to overcome this situation

7.1 OBJECTIVE

This unit helps the user to understand the

- Characterization of deadlocks
- Methods for handling deadlocks

7.2 DEADLOCK CHARACTERIZATION

In a deadlock, processes never finish executing, and system resources are tied up, preventing other jobs from starting. Before we discuss the various methods for dealing with the deadlock problem, we look more closely at features that characterize deadlocks.

Necessary Conditions

A deadlock situation can arise if the following four conditions hold simultaneously in a system:

1. **Mutual exclusion**. At least one resource must be held in a non-sharable mode; that is, only one process at a time can use the resource. If another process requests that resource, the requesting process must be delayed until the resource has been released.

2. **Hold and wait**. A process must be holding at least one resource and waiting to acquire additional resources that are currently being held by other processes.

3. **No pre-emption**. Resources cannot be pre-empted; that is, a resource can be released only voluntarily by the process holding it, after that process has completed its task.

4. **Circular waits**. A set {P0, P1, ..., Pn} of waiting processes must exist such that P0 is waiting for a resource held by P1, P1 is waiting for a resource held by P2, ..., Pn−1 is waiting for a resource held by Pn, and Pn is waiting for a resource held by P0.

We emphasize that all four conditions must hold for a deadlock to occur. The circular-wait condition implies the hold-and-wait condition, so the four conditions are not completely independent. We shall see in Section 7.4, however, that it is useful to consider each condition separately.

7.2.1 Resource-Allocation Graph

Deadlocks can be described more precisely in terms of a directed graph called a system resource-allocation graph. This graph consists of a set of vertices V and a set of edges E. The set of vertices V is partitioned into two different types of nodes: P = {P1, P2, ..., Pn}, the set consisting of all the active processes in the system, and R = {R1, R2, ..., Rm}, the set consisting of all resource types in the system.

A directed edge from process Pi to resource type Rj is denoted by Pi → Rj ; it signifies that process Pi has requested an instance of resource type Rj and is currently waiting for that resource. A directed edge from resource type Rj to process Pi is denoted by Rj → Pi; it signifies that an instance of resource type Rj has been allocated to process Pi. A directed edge Pi → Rj is called a request edge; a directed edge Rj → Pi is called an assignment edge.

Pictorially, we represent each process Pi as a circle and each resource type Rj as a rectangle. Since resource type Rj may have more than one instance, we represent each such instance as a dot within the rectangle. Note that a request edge points to only the rectangle Rj, whereas an assignment edge must also designate one of the dots in the rectangle. When process Pi requests an instance of resource type Rj, a request edge is inserted in the resource-allocation graph. When this request can be fulfilled, the request edge is instantaneously transformed to an assignment edge. When the process no longer needs access to the resource, it releases the resource. As

a result, the assignment edge is deleted. The resource-allocation graph shown in Figure 7.1 depicts the following situation.

• The sets P, R, and E:

P = {P1, P2, P3}

R = {R1, R2, R3, R4}

E = {P1 → R1, P2 → R3, R1 → P2, R2 → P2, R2 → P1, R3 → P3}

• Resource instances:

One instance of resource type R1

Two instances of resource type R2

One instance of resource type R3

Three instances of resource type R4

• Process states:

Process P1 is holding an instance of resource type R2 and is waiting for an instance of resource type R1. Process s P2 is holding an instance of R1 and an instance of R2 and is waiting for an instance of R3. Process P3 is holding an instance of R3.

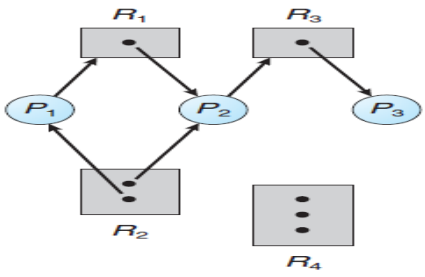

Figure 7.1 Resource Allocation graph

Given the definition of a resource-allocation graph, it can be shown that, if the graph contains no cycles, then no process in the system is deadlocked. If the graph does contain a cycle, then a deadlock may exist. If each resource type has exactly one instance, then a cycle implies that a deadlock has occurred. If the cycle involves only a set of resource types, each of which has only a single instance, then a deadlock has occurred. Each process involved in the cycle is deadlocked. In this case, a cycle in the graph is both a necessary and a sufficient condition for the existence of deadlock. If each resource type has several instances, then a cycle does not necessarily imply that a deadlock has occurred. In this case, a cycle in the graph is a necessary but not a sufficient condition for the existence of deadlock. To illustrate this concept, we return to the resource-allocation graph depicted in Figure 7.1. Suppose that process P3 requests an instance of resource type R2. Since no resource instance is currently available, we

add a request edge P3→ R2 to the graph (Figure 7.2). At this point, two minimal cycles exist in the system:

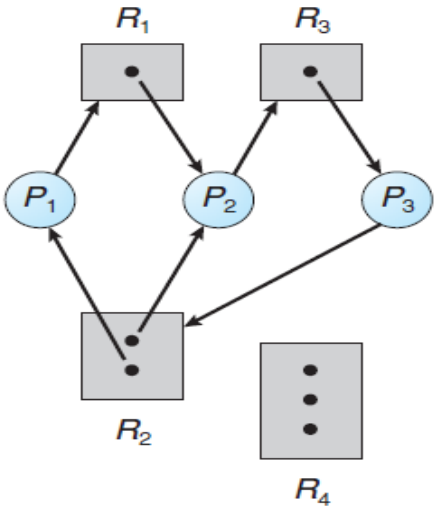

Figure 7.2 Resource Allocation with deadlock

P1 → R1 → P2 → R3 → P3 → R2 → P1

P2 → R3 → P3 → R2 → P2

Processes P1, P2, and P3 are deadlocked. Process P2 is waiting for the resource R3, which is held by process P3. Process P3 is waiting for either process P1 or process P2 to release resource R2. In addition, process P1 is waiting for process P2 to release resource R1.

P1 → R1 → P3 → R2 → P1

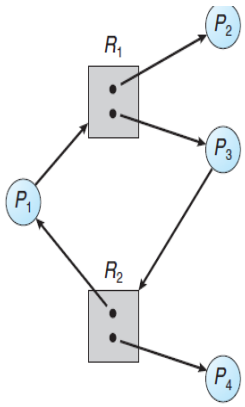

Figure 7.3 resources without deadlock

However, there is no deadlock. Observe that process P4 may release its instance of resource type R2. That resource can then be allocated to P3, breaking the cycle.

7.3 METHODS HANDING DEADLOCKS

Generally speaking, we can deal with the deadlock problem in one of three ways:

• We can use a protocol to prevent or avoid deadlocks, ensuring that the system will never enter a deadlocked state.

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• We can allow the system to enter a deadlocked state, detect it, and recover.

• We can ignore the problem altogether and pretend that deadlocks never occur in the system.

The third solution is the one used by most operating systems, including Linux and Windows. It is then up to the application developer to write programs that handle deadlocks. Next, we elaborate briefly on each of the three methods for handling deadlocks. Before proceeding, we should mention that some researchers have argued that none of the basic approaches alone is appropriate for the entire spectrum of resource-allocation problems in operating systems. The basic approaches can be combined, however, allowing us to select an optimal approach for each class of resources in a system.

To ensure that deadlocks never occur, the system can use either a deadlock prevention or a deadlock-avoidance scheme. These methods prevent deadlocks by constraining how requests for resources can be made. With this additional knowledge, the operating system can decide for each request whether or not the process should wait. To decide whether the current request can be satisfied or must be delayed, the system must consider the resources currently available, the resources currently allocated to each process, and the future requests and releases of each process.

If a system does not employ either a deadlock-prevention or a deadlock avoidance algorithm, then a deadlock situation may arise. In this environment, the system can provide an algorithm that examines the state of the system to determine whether a deadlock has occurred and an algorithm to recover from the deadlock (if a deadlock has indeed occurred).

In the absence of algorithms to detect and recover from deadlocks, we may arrive at a situation in which the system is in a deadlocked state yet has no way of recognizing what has happened. In this case, the undetected deadlock will cause the system's performance to deteriorate, because resources are being held by processes that cannot run and because more and more processes, as they make requests for resources, will enter a deadlocked state. Eventually, the system will stop functioning and will need to be restarted manually. Although this method may not seem to be a viable approach to the deadlock problem, it is nevertheless used in most operating systems, as mentioned earlier. Expense is one important consideration. Ignoring the possibility of deadlocks is cheaper than the

Notes

other approaches. Since in many systems, deadlocks occur infrequently (say, once per year), the extra expense of the other methods may not seem worthwhile.

In addition, methods used to recover from other conditions may be put to use to recover from deadlock. In some circumstances, a system is in a frozen state but not in a deadlocked state. We see this situation, for example, with a real-time process running at the highest priority (or any process running on a non-preemptive scheduler) and never returning control to the operating system. The system must have manual recovery methods for such conditions and may simply use those techniques for deadlock recovery.

Check your Progress

1. What is deadlock?
2. What are the methods for handling deadlock?
3. What is Resource-Allocation Graph?
4. How to avoid deadlock?

7.4. ANSWERS TO CHECK YOUR PROGRESS

1. Deadlock is a specific situation or condition where two processes are waiting for each other to complete so that they can start. But this situation causes hang for both of them.

2. There are three ways to handle deadlock:
    - Deadlock prevention or avoidance: The idea is to not let the system into deadlock state.
      One can zoom into each category individually;
      Prevention is done by negating one of above-mentioned necessary conditions for deadlock.
      Avoidance is kind of futuristic in nature. By using strategy of "Avoidance", we have to make an assumption. We need to ensure that all information about resources which process WILL need are known to us prior to execution of the process. We use Banker's algorithm (Which is in-turn a gift from Dijkstra) in order to avoid deadlock.
    - Deadlock detection and recovery: Let deadlock occur, then do pre-emption to handle it once occurred.
    - Ignore the problem all together: If deadlock is very rare, then let it happen and reboot the system. This is the approach that both Windows and UNIX take.
3. Deadlocks can be described more precisely in terms of a directed graph called a system resource-allocation graph.
4. There must be a fixed number of resources to allocate.

7.5. SUMMARY

- In a deadlock, processes never finish executing, and system resources are tied up, preventing other jobs from starting.
- Deadlocks can be described more precisely in terms of a directed graph called a system resource-allocation graph.
- To ensure that deadlocks never occur, the system can use either a deadlock prevention or a deadlock-avoidance scheme.
- In the absence of algorithms to detect and recover from deadlocks, we may arrive at a situation in which the system is in a deadlocked state yet has no way of recognizing what has happened.

7.6. KEYWORDS

Mutual Exclusion: At least one resource must be held in a non-sharable mode. If any other process requests this resource, then that process must wait for the resource to be released.

Hold and Wait: A process must be simultaneously holding at least one resource and waiting for at least one resource that is currently being held by some other process.

No pre-emption: Once a process is holding a resource (i.e. once its request has been granted), then that resource cannot be taken away from that process until the process voluntarily releases it.

Circular Wait: A set of processes {P0, P1, P2, . . ., PN} must exist such that every P [i] is waiting for P[(i + 1) % (N + 1)].

7.7. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is Mutual Exclusion?
2. What is No Pre-emption?
3. What is the characterization of deadlocks?
4. What is Resource Allocation with deadlock?
5. What are Circular waits?

Long Answer questions:

1. Explain briefly about deadlock characterization?
2. Explain about Methods Handing Deadlocks?

7.8. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

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Stallings, W., 2012. Operating systems: internals and design principles. Boston: Prentice Hall,.

Notes

UNIT VIII
DEADLOCK PREVENTION

Structure

8.0 Introduction
8.1 Objective
8.2 Deadlock Prevention
8.3 Deadlock Avoidance
8.4 Deadlock Detection
8.5 Recovery from Deadlock
8.6 Answers to Check Your Progress Questions
8.7 Summary
8.8 Key Words
8.9 Self Assessment Questions and Exercises
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8.0 INTRODUCTION

Prevention of deadlock is an important strategy where the situation can be avoided and the deadlock can be detected and solved if we simulate deadlock with a table which is standing on its four legs then we can also simulate four legs with the four conditions which when occurs simultaneously, cause the deadlock. However, if we break one of the legs of the table then the table will fall definitely. The same happens with deadlock, if we can be able to violate one of the four necessary conditions and don't let them occur together then we can prevent the deadlock.

Let's see how we can prevent each of the conditions. The deadlock situations can also be recovered with the necessary steps and make the process available.

8.1 OBJECTIVE

This unit helps to

- Learn the prevention of deadlock
- Understand deadlock avoidance
- Implement recovery of deadlocks

8.2 DEADLOCK PREVENTION

For a deadlock to occur, each of the four necessary conditions must hold. By ensuring that at least one of these conditions cannot hold, we can prevent the occurrence of a deadlock. We elaborate on this approach by examining each of the four necessary conditions separately.

8.2.1 Mutual Exclusion

The mutual exclusion condition must hold. That is, at least one resource must be non-sharable. Sharable resources, in contrast, do not require mutually exclusive access and thus cannot be involved in a deadlock. Read-only files are a good example of a sharable resource. If several processes attempt to open a read-only file at the same time, they can be granted simultaneous access to the file. A process never needs to wait for a sharable resource. In general, however, we cannot prevent deadlocks by denying the mutual-exclusion condition, because some resources are intrinsically non-sharable. For example, a mutex lock cannot be simultaneously shared by several processes.

8.2.2 Hold and Wait

To ensure that the hold-and-wait condition never occurs in the system, we must guarantee that, whenever a process requests a resource, it does not hold any other resources. One protocol that we can use requires each process to request and be allocated all its resources before it begins execution. We can implement this provision by requiring that system calls requesting resources for a process precede all other system calls. An alternative protocol allows a process to request resources only when it has none. A process may request some resources and use them. Before it can request any additional resources, it must release all the resources that it is currently allocated.

To illustrate the difference between these two protocols, we consider a process that copies data from a DVD drive to a file on disk, sorts the file, and then prints the results to a printer. If all resources must be requested at the beginning of the process, then the process must initially request the DVD drive, disk file, and printer. It will hold the printer for its entire execution, even though it needs the printer only at the end.

The second method allows the process to request initially only the DVD drive and disk file. It copies from the DVD drive to the disk and then releases both the DVD drive and the disk file. The process must then request the disk file and the printer. After copying the disk file to the printer, it releases these two resources and terminates. Both these protocols have two main disadvantages. First, resource utilization may be low, since resources may be allocated but unused for a long period. In the example given, for instance, we can release the DVD drive and disk file, and then request the disk file and printer, only if we can be sure that our data will remain on the disk file. Otherwise, we must request all resources at the beginning for both protocols.

Second, starvation is possible. A process that needs several popular resources may have to wait indefinitely, because at least one of the resources that it needs is always allocated to some other process.

8.2.3 No Pre-emption

The third necessary condition for deadlocks is that there is no pre-emption of resources that have already been allocated. To ensure that this condition does not hold, we can use the following protocol. If a process is holding some resources and requests another resource that cannot be immediately allocated to it (that is, the process must wait), then all resources the process is currently holding are pre-empted. In other words, these resources are implicitly released. The preempted resources are added to the list of resources for which the process is waiting. The process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting.

Alternatively, if a process requests some resources, we first check whether they are available. If they are, we allocate them. If they are not, we check whether they are allocated to some other process that is waiting for additional resources. If so, we pre-empt the desired resources from the waiting process and allocate them to the requesting process. If the resources are neither available nor held by a waiting process, the requesting process must wait. While it is waiting, some of its resources may be preempted, but only if another process requests them. A process can be restarted only when it is allocated the new resources it is requesting and recovers any resources that were preempted while it was waiting.

This protocol is often applied to resources whose state can be easily saved and restored later, such as CPU registers and memory space. It cannot generally be applied to such resources as mutex locks and semaphores.

8.2.4 Circular Wait

The fourth and final condition for deadlocks is the circular-wait condition. One way to ensure that this condition never holds is to impose a total ordering of all resource types and to require that each process requests resources in an increasing order of enumeration. To illustrate, we let R = {R1, R2, ..., Rm} be the set of resource types. We assign to each resource type a unique integer number, which allows us to compare two resources and to determine whether one precedes another in our ordering. Formally, we define a one-to-one function F: R→N, where N is the set of natural numbers. For example, if the set of resource types R includes tape drives, disk drives, and printers, then the function F might be defined as follows:

F(tape drive) = 1

F(disk drive) = 5

F(printer) = 12

We can now consider the following protocol to prevent deadlocks: Each process can request resources only in an increasing order of enumeration. That is, a process can initially request any number of instances of a resource type —say, Ri. After that, the process can request instances of resource type Rj if and only if F(Rj) > F(Ri). For example, using the

function defined previously, a process that wants to use the tape drive and printer at the same time must first request the tape drive and then request the printer. Alternatively, we can require that a process requesting an instance of resource type Rj must have released any resources Ri such that F(Ri) ≥ F(Rj). Note also that if several instances of the same resource type are needed, a single request for all of them must be issued.

If these two protocols are used, then the circular-wait condition cannot hold. We can demonstrate this fact by assuming that a circular wait exists (proof by contradiction). Let the set of processes involved in the circular wait be {P0, P1, ..., Pn}, where Pi is waiting for a resource Ri , which is held by process Pi+1. (Modulo arithmetic is used on the indexes, so that Pn is waiting for a resource Rn held by P0.) Then, since process Pi+1 is holding resource Ri while requesting resource Ri+1, we must have F(Ri) < F(Ri+1) for all i. But this condition means that F(R0) < F(R1) < ... < F(Rn) < F(R0). By transitivity, F(R0) < F(R0), which is impossible. Therefore, there can be no circular wait.We can accomplish this scheme in an application program by developing an ordering among all synchronization objects in the system. All requests for synchronization objects must be made in increasing order. For example, if the lock ordering in the Pthread program shown in Figure 7.4 was then thread two could not request the locks out of order.

F(first mutex) = 1

F(second mutex) = 5

Keep in mind that developing an ordering, or hierarchy, does not in itself prevent deadlock. It is up to application developers to write programs that follow the ordering. Also note that the function F should be defined according to the normal order of usage of the resources in a system.

```
/* thread one runs in this function */

void *do work one(void *param)

{

pthread mutex lock(&first mutex);

pthread mutex lock(&second mutex);

/**

* Do some work

*/

pthread mutex unlock(&second mutex);

pthread mutex unlock(&first mutex);

pthread exit(0);
```

```
}
/* thread two runs in this function */
void *do work two(void *param)
{
pthread mutex lock(&second mutex);
pthread mutex lock(&first mutex);
/**
* Do some work
*/
pthread mutex unlock(&first mutex);
pthread mutex unlock(&second mutex);
pthread exit(0);
}
```

Figure 8.1 Deadlock example.

The tape drive is usually needed before the printer, it would be reasonable to define F(tape drive)<F(printer). Although ensuring that resources are acquired in the proper order is the responsibility of application developers, certain software can be used to verify that locks are acquired in the proper order and to give appropriate warnings when locks are acquired out of order and deadlock is possible. One lock-order verifier, which works on BSD versions of UNIX such as FreeBSD, is known as witness.

It is also important to note that imposing a lock ordering does not guarantee deadlock prevention if locks can be acquired dynamically. For example, assume we have a function that transfers funds between two accounts. To prevent a race condition, each account has an associated mutex lock that is obtained from a get lock() function void transaction(Account from, Account to, double amount)

```
{
mutex lock1, lock2;
lock1 = get lock(from);
lock2 = get lock(to);
acquire(lock1);
acquire(lock2);
```

withdraw(from, amount);

deposit(to, amount);

release(lock2);

release(lock1);

}

Figure 8.2 Deadlock example with lock ordering.

Deadlock is possible if two threads simultaneously invoke the transaction() function, transposing different accounts. That is, one thread might invoke transaction(checking account, savings account, 25); and another might invoke transaction(savings account, checking account, 50);

8.3 DEADLOCK AVOIDANCE

Deadlock-prevention algorithms, prevent deadlocks by limiting how requests can be made. The limits ensure that at least one of the necessary conditions for deadlock cannot occur. Possible side effects of preventing deadlocks by this method, however, are low device utilization and reduced system throughput. An alternative method for avoiding deadlocks is to require additional information about how resources are to be requested. For example, in a system with one tape drive and one printer, the system might need to know that process P will request first the tape drive and then the printer before releasing both resources, whereas process Q will request first the printer and then the tape drive. With this knowledge of the complete sequence of requests and releases for each process, the system can decide for each request whether or not the process should wait in order to avoid a possible future deadlock. Each request requires that in making this decision the system consider the resources currently available, the resources currently allocated to each process, and the future requests and releases of each process.

The various algorithms that use this approach differ in the amount and type of information required. The simplest and most useful model requires that each process declare the maximum number of resources of each type that it may need. Given this a priori information, it is possible to construct an algorithm that ensures that the system will never enter a deadlocked state. A deadlock-avoidance algorithm dynamically examines the resource-allocation state to ensure that a circular-wait condition can never exist. The resource allocation state is defined by the number of available and allocated resources and the maximum demands of the processes. In the following sections, we explore two deadlock-avoidance algorithms.

8.3.1 Safe State

A state is safe if the system can allocate resources to each process (up to its maximum) in some order and still avoid a deadlock. More formally, a system is in a safe state only if there exists a safe sequence. A sequence of

processes <P1, P2, ..., Pn> is a safe sequence for the current allocation state if, for each Pi , the resource requests that Pi can still make can be satisfied by the currently available resources plus the resources held by all Pj, with j < i. In this situation, if the resources that Pi needs are not immediately available, then Pi can wait until all Pj have finished. When they have finished, Pi can obtain all of its needed resources, complete its designated task, return its allocated resources, and terminate. When Pi terminates, Pi+1 can obtain its needed resources, and so on. If no such sequence exists, then the system state is said to be unsafe. A safe state is not a deadlocked state. Conversely, a deadlocked state is an unsafe state. Not all unsafe states are deadlocks,

An unsafe state may lead to a deadlock. As long as the state is safe, the operating system can avoid unsafe (and deadlocked) states. In an unsafe state, the operating system cannot prevent processes from requesting resources in such a way that a deadlock occurs. The behavior of the processes controls unsafe states. To illustrate, we consider a system with twelve magnetic tape drives and three processes: P0, P1, and P2. Process P0 requires ten tape drives, process P1 may need as many as four tape drives, and process P2 may need up to nine tape drives. Suppose that, at time t0, process P0 is holding five tape drives, process P1 is holding two tape drives, and process P2 is holding two tape drives. (Thus, there are three free tape drives.)

Maximum Needs Current Needs

P0 10 5

P1 4 2

P2 9 2

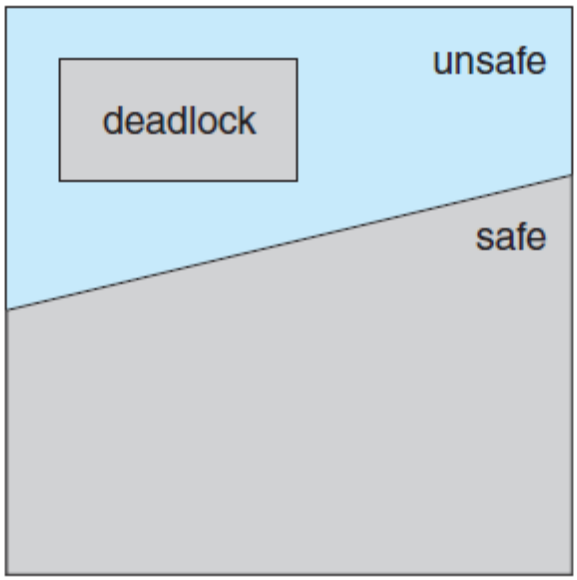

Figure 8.3 Safe, unsafe, and deadlocked state spaces.

At time t0, the system is in a safe state. The sequence <P1, P0, P2> satisfies the safety condition. Process P1 can immediately be allocated all its tape drives and then return them (the system will then have five available tape drives); then process P0 can get all its tape drives and return them (the system will then have ten available tape drives); and finally process P2 can get all its tape drives and return them (the system will then have all twelve tape drives available). A system can go from a safe state to an unsafe state. Suppose that, at time t1, process P2 requests and is allocated one more tape drive. The system is no longer in a safe state. At this point, only process P1 can be allocated all its tape drives. When it returns them, the system will have only four available tape drives. Since process P0 is allocated five tape drives but has a maximum of ten, it may request five more tape drives. If it does so, it will have to wait, because they are unavailable. Similarly, process P2 may request six additional tape drives and have to wait, resulting in a deadlock. Our mistake was in granting the request from process P2 for one more tape drive. If we had made P2 wait until either of the other processes had finished and released its resources, then we could have avoided the deadlock.

Given the concept of a safe state, we can define avoidance algorithms that ensure that the system will never deadlock. The idea is simply to ensure that the system will always remain in a safe state. Initially, the system is in a safe state. Whenever a process requests a resource that is currently available, the system must decide whether the resource can be allocated immediately or whether the process must wait. The request is granted only if the allocation leaves the system in a safe state. In this scheme, if a

process requests a resource that is currently available, it may still have to wait. Thus, resource utilization may be lower than it would otherwise be.

8.3.2 Resource-Allocation-Graph Algorithm

. In addition to the request and assignment edges already described, we introduce a new type of edge, called a claim edge. A claim edge Pi → Rj indicates that process Pi may request resource Rj at some time in the future. This edge resembles a request edge in direction but is represented in the graph by a dashed line. When process Pi requests resource Rj , the claim edge Pi → Rj is converted to a request edge. Similarly, when a resource Rj is released by Pi , the assignment edge Rj → Pi is reconverted to a claim edge Pi → Rj . Note that the resources must be claimed a priori in the system. That is, before process Pi starts executing, all its claim edges must already appear in the resource-allocation graph. We can relax this condition by allowing a claim edge Pi → Rj to be added to the graph only if all the edges associated with process Pi are claim edges.

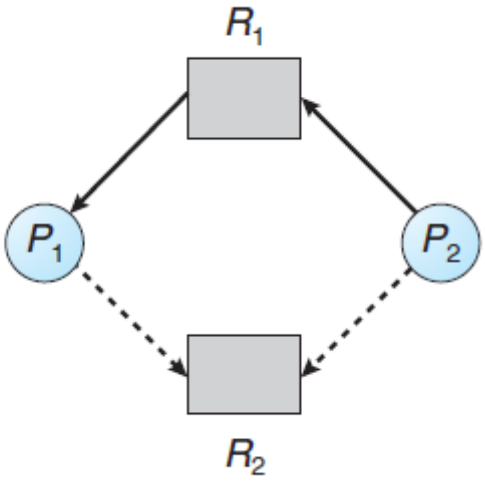

Figure 8.4 Resource-allocation graph for deadlock avoidance.

Now suppose that process Pi requests resource Rj. The request can be granted only if converting the request edge Pi → Rj to an assignment edge Rj → Pi does not result in the formation of a cycle in the resource-allocation graph. We check for safety by using a cycle-detection algorithm. An algorithm for detecting a cycle in this graph requires an order of n2 operations, where n is the number of processes in the system.

If no cycle exists, then the allocation of the resource will leave the system in a safe state. If a cycle is found, then the allocation will put the system in an unsafe state. In that case, process Pi will have to wait for its requests to be satisfied. Suppose that P2 requests R2. Although R2 is currently free, we cannot allocate it to P2, since this action will create a cycle in the graph A cycle, as mentioned, indicates that the system is in an unsafe state. If P1 requests R2, and P2 requests R1, then a deadlock will occur.

8.3.3 Banker's Algorithm

The resource-allocation-graph algorithm is not applicable to a resource allocation system with multiple instances of each resource type. The deadlock avoidance algorithm that we describe next is applicable to such a system but is less efficient than the resource-allocation graph scheme. This algorithm is commonly known as the banker's algorithm. The name was chosen because the algorithm could be used in a banking system to ensure that the bank never allocated its available cash in such a way that it could no longer satisfy the needs of all its customers.

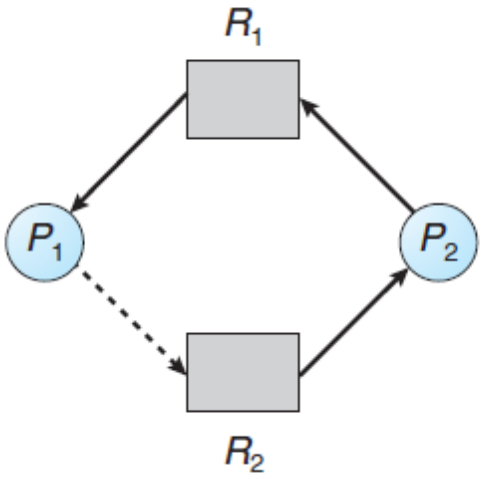

Figure 8.5 An unsafe state in a resource-allocation graph.

When a new process enters the system, it must declare the maximum number of instances of each resource type that it may need. This number may not exceed the total number of resources in the system. When a user requests set of resources, the system must determine whether the allocation of these resources will leave the system in a safe state. If it will, the resources are allocated; otherwise, the process must wait until some other process releases enough resources. Several data structures must be maintained to implement the banker's algorithm. These data structures encode the state of the resource-allocation system. We need the following data structures, where n is the number of processes in the system and m is the number of resource types:

• Available. A vector of length m indicates the number of available resources of each type. If Available[j] equals k, then k instances of resource type Rj are available.

• Max. An n × m matrix defines the maximum demand of each process. If Max[i][j] equals k, then process Pi may request at most k instances of resource type Rj.

• Allocation. An n × m matrix defines the number of resources of each type currently allocated to each process. If Allocation[i][j] equals k, then process Pi is currently allocated k instances of resource type Rj.

• Need. An n × m matrix indicates the remaining resource need of each process. If Need[i][j] equals k, then process Pi may need k more instances of resource type Rj to complete its task. Note that Need[i][j] equals Max[i][j] − Allocation[i][j].

These data structures vary over time in both size and value. To simplify the presentation of the banker's algorithm, we next establish some notation. Let X and Y be vectors of length n. We say that $X \leq Y$ if and only if $X[i] \leq Y[i]$ for all i = 1, 2, ..., n. For example, if X = (1,7,3,2) and Y = (0,3,2,1), then $Y \leq X$. In addition, $Y < X$ if $Y \leq X$ and $Y = X$.

We can treat each row in the matrices Allocation and Need as vectors and refer to them as Allocation i and Need i . The vector Allocation i specifies the resources currently allocated to process Pi; the vector Need i specifies the additional resources that process Pi may still request to complete its task.

8.3.4 Safety Algorithm

We can now present the algorithm for finding out whether or not a system is in a safe state. This algorithm can be described as follows:

1. Let Work and Finish be vectors of length m and n, respectively. Initialize Work = Available and Finish[i] = false for i = 0, 1, ..., n − 1.

2. Find an index i such that both

a. Finish[i] == false

b. Need i ≤Work

If no such i exists, go to step 4.

3. Work =Work + Allocation i

Finish[i] = true

Go to step 2.

4. If Finish[i] == true for all i, then the system is in a safe state.

This algorithm may require an order of m × n 2 operations to determine whether

a state is safe.

8.3.5 Resource-Request Algorithm

Next, we describe the algorithm for determining whether requests can be safely granted. Let Request i be the request vector for process Pi . If Request i [j] == k, then process Pi wants k instances of resource type Rj . When a request for resources is made by process Pi , the following actions are taken:

1. If Request i ≤Need i , go to step 2. Otherwise, raise an error condition, since the process has exceeded its maximum claim.

2. If Request i ≤ Available, go to step 3. Otherwise, Pi must wait, since the resources are not available.

3. Have the system pretend to have allocated the requested resources to process Pi by modifying the state as follows:

Available = Available–Request i;

Allocation i = Allocation i + Request i;

Need i = Need i –Request i;

If the resulting resource-allocation state is safe, the transaction is completed, and process Pi is allocated its resources. However, if the new state is unsafe, then Pi must wait for Request i, and the old resource-allocation state is restored.

8.3.6 An Illustrative Example

To illustrate the use of the banker's algorithm, consider a system with five processes P0 through P4 and three resource types A, B, and C. Resource type A has ten instances, resource type B has five instances, and resource type C has seven instances. Suppose that, at time T0, the following snapshot of the system has been taken:

Allocation Max Available

A B C A B C A B C

P0 0 1 0 7 5 3 3 3 2

P1 2 0 0 3 2 2

P2 3 0 2 9 0 2

P3 2 1 1 2 2 2

P4 0 0 2 4 3 3

The content of the matrix Need is defined to be Max − Allocation and is as follows:

Need

A B C

P0 7 4 3

P1 1 2 2

P2 6 0 0

P3 0 1 1

P4 4 3 1

We claim that the system is currently in a safe state. Indeed, the sequence <P1, P3, P4, P2, P0> satisfies the safety criteria. Suppose now that process P1 requests one additional instance of resource type A and two instances of resource type C, so Request1 = (1,0,2). To decide whether this request can be immediately granted, we first check that Request1 ≤ Available—that is, that (1,0,2) ≤ (3,3,2), which is true. We then pretend that this request has been fulfilled, and we arrive at the following new state:

Allocation Need Available

A B C A B C A B C

P0 0 1 0 7 4 3 2 3 0

P1 3 0 2 0 2 0

P2 3 0 2 6 0 0

P3 2 1 1 0 1 1

P4 0 0 2 4 3 1

We must determine whether this new system state is safe. To do so, we execute our safety algorithm and find that the sequence <P1, P3, P4, P0, P2> satisfies the safety requirement. Hence, we can immediately grant the request of process P1. You should be able to see, however, that when the system is in this state, a request for (3,3,0) by P4 cannot be granted, since the resources are not available. Furthermore, a request for (0,2,0) by P0 cannot be granted, even though the resources are available, since the resulting state is unsafe.

8.4 DEADLOCK DETECTION

If a system does not employ either a deadlock-prevention or a deadlock avoidance algorithm, then a deadlock situation may occur. In this environment, the system may provide:

• An algorithm that examines the state of the system to determine whethera deadlock has occurred

• An algorithm to recover from the deadlock

In the following discussion, we elaborate on these two requirements as they pertain to systems with only a single instance of each resource type, as well as to systems with several instances of each resource type. At this point, however, we note that a detection-and-recovery scheme requires overhead that includes not only the run-time costs of maintaining the necessary information and executing the detection algorithm but also the potential losses inherent in recovering from a deadlock.

8.4.1 Single Instance of Each Resource Type

If all resources have only a single instance, then we can define a deadlock detection algorithm that uses a variant of the resource-allocation graph, called a wait-for graph. We obtain this graph from the resource-allocation graph by removing the resource nodes and collapsing the appropriate edges. More precisely, an edge from Pi to Pj in a wait-for graph implies that process Pi is waiting for process Pj to release a resource that Pi needs. An edge Pi → Pj exists in a wait-for graph if and only if the corresponding resource allocation graph contains two edges Pi → Rq and Rq → Pj for some resource Rq. In Figure 7.9, we present a resource-allocation graph and the corresponding wait-for graph.

As before, a deadlock exists in the system if and only if the wait-for graph contains a cycle. To detect deadlocks, the system needs to maintain the wait for graph and periodically invoke an algorithm that searches for a cycle in the graph. An algorithm to detect a cycle in a graph requires an order of n2 operations, where n is the number of vertices in the graph.

8.4.2 Several Instances of a Resource Type

The wait-for graph scheme is not applicable to a resource-allocation system with multiple instances of each resource type. Detection algorithm that is applicable to such a system. The algorithm employs several time-varying data structures that are similar to those used in the banker's algorithm (Section 7.5.3):

• Available. A vector of length m indicates the number of available resources of each type.

• Allocation. An n × m matrix defines the number of resources of each type currently allocated to each process.

• Request. An n × m matrix indicates the current request of each process.

If Request[i][j] equals k, then process Pi is requesting k more instances of resource type Rj. To simplify notation, we again treat the rows in the matrices Allocation and Request as vectors; we refer to them as Allocation i and Request i. The detection algorithm described here simply investigates every possible allocation sequence for the processes that remain to be completed.

1. Let Work and Finish be vectors of length m and n, respectively. Initialize Work = Available. For i = 0, 1, ..., n–1, if Allocation i = 0, then Finish[i] = false. Otherwise, Finish[i] = true.

2. Find an index i such that both

a. Finish[i] == false

b. Request i ≤Work

If no such i exists, go to step 4.

3. Work =Work + Allocation i

Finish[i] = true

Go to step 2.

4. If Finish[i] ==false for some i, 0≤i<n, then the system is in a deadlocked state.

Moreover, if Finish[i] == false, then process Pi is deadlocked. This algorithm requires an order of m × n2 operations to detect whether the system is in a deadlocked state. You may wonder why we reclaim the resources of process Pi (in step 3) as soon as we determine that Request i ≤ Work (in step 2b). We know that Pi is currently not involved in a deadlock (since Request i ≤ Work). Thus, we take an optimistic attitude and assume that Pi will require no more resources to complete its task; it will thus soon return all currently allocated resources to the system. If our assumption is incorrect, a deadlock may occur later. That deadlock will be detected the next time the deadlock-detection algorithm is invoked.

To illustrate this algorithm, we consider a system with five processes P0 through P4 and three resource types A, B, and C. Resource type A has seven instances, resource type B has two instances, and resource type C has six instances. Suppose that, at time T0, we have the following resource-allocation state:

Allocation Request Available

A B C A B C A B C

P0 0 1 0 0 0 0 0 0

P1 2 0 0 2 0 2

P2 3 0 3 0 0 0

P3 2 1 1 1 0 0

P4 0 0 2 0 0 2

We claim that the system is not in a deadlocked state. Indeed, if we execute our algorithm, we will find that the sequence <P0, P2, P3, P1, P4> results in Finish[i] == true for all i. Suppose now that process P2 makes one additional request for an instance of type C. The Request matrix is modified as follows:

Request

A B C

P0 0 0 0

P1 2 0 2

P2 0 0 1

P3 1 0 0

P4 0 0 2

We claim that the system is now deadlocked. Although we can reclaim the resources held by process P0, the number of available resources is not sufficient to fulfill the requests of the other processes. Thus, a deadlock exists, consisting of processes P1, P2, P3, and P4.

8.4.3 Detection-Algorithm Usage

When should we invoke the detection algorithm? The answer depends on two factors:

1. How often is a deadlock likely to occur?

2. How many processes will be affected by deadlock when it happens?

If deadlocks occur frequently, then the detection algorithm should be invoked frequently. Resources allocated to deadlocked processes will be idle until the deadlock can be broken. In addition, the number of processes involved in the deadlock cycle may grow. Deadlocks occur only when some process makes a request that cannot be granted immediately. This request may be the final request that completes a chain of waiting processes. In the extreme, then, we can invoke the deadlock detection algorithm every time a request for allocation cannot be granted immediately. In this case, we can identify not only the deadlocked set of processes but also the specific process that "caused" the deadlock. (In reality, each of the deadlocked processes is a link in the cycle in the resource graph, soall of them, jointly, caused the deadlock.) If there are many different resource types, one request may create many cycles in the resource graph, each cycle completed by the most recent request and "caused" by the one identifiable process.

Of course, invoking the deadlock-detection algorithm for every resource request will incur considerable overhead in computation time. A less expensive alternative is simply to invoke the algorithm at defined intervals—for example, once per hour or whenever CPU utilization drops below 40 percent. (A deadlock eventually cripples system throughput and causes CPU utilization to drop.) If the detection algorithm is invoked at arbitrary points in time, the resource graph may contain many cycles. In this case, we generally cannot tell which of the many deadlocked processes "caused" the deadlock.

8.5 RECOVERY FROM DEADLOCK

When a detection algorithm determines that a deadlock exists, several alternatives are available. One possibility is to inform the operator that a deadlock has occurred and to let the operator deal with the deadlock manually. Another possibility is to let the system recover from the

deadlock automatically. There are two options for breaking a deadlock. One is simply to abort one or more processes to break the circular wait. The other is to pre-empt some resources from one or more of the deadlocked processes.

8.5.1 Process Termination

To eliminate deadlocks by aborting a process, we use one of two methods. In both methods, the system reclaims all resources allocated to the terminated processes.

• Abort all deadlocked processes. This method clearly will break the deadlock cycle, but at great expense. The deadlocked processes may have computed for a long time, and the results of these partial computations must be discarded and probably will have to be recomputed later.

• Abort one process at a time until the deadlock cycle is eliminated. This method incurs considerable overhead, since after each process is aborted, a deadlock-detection algorithm must be invoked to determine whether any processes are still deadlocked.

Aborting a process may not be easy. If the process was in the midst of updating a file, terminating it will leave that file in an incorrect state. Similarly, if the process was in the midst of printing data on a printer, the system must reset the printer to a correct state before printing the next job. If the partial termination method is used, then we must determine which deadlocked process (or processes) should be terminated. This determination is a policy decision, similar to CPU-scheduling decisions. The question is basically an economic one; we should abort those processes whose termination will incur the minimum cost. Unfortunately, the term minimum cost is not a precise one.

8.5.2 Resource Preemption

To eliminate deadlocks using resource preemption, we successively preempt some resources from processes and give these resources to other processes until the deadlock cycle is broken. If preemption is required to deal with deadlocks, then three issues need to be addressed:

1. Selecting a victim. Which resources and which processes are to be preempted? As in process termination, we must determine the order of preemption to minimize cost. Cost factors may include such parameters as the number of resources a deadlocked process is holding and the amount of time the process has thus far consumed.

2. Rollback. If we preempt a resource from a process, what should be done with that process? Clearly, it cannot continue with its normal execution; it is missing some needed resource. We must roll back the process to some safe state and restart it from that state.

Since, in general, it is difficult to determine what a safe state is, the simplest solution is a total rollback: abort the process and then restart it.

Although it is more effective to roll back the process only as far as necessary to break the deadlock, this method requires the system to keep more information about the state of all running processes.

3. Starvation. How do we ensure that starvation will not occur? That is, how can we guarantee that resources will not always be preempted from the same process?

In a system where victim selection is based primarily on cost factors, it may happen that the same process is always picked as a victim. As a result, this process never completes its designated task, a starvation situation any practical system must address. Clearly, we must ensure that a process can be picked as a victim only a (small) finite number of times. The most common solution is to include the number of rollbacks in the cost factor.

Check your Progress

1. Describe Banker's algorithm?
2. What factors determine whether a detection-algorithm must be utilized in a deadlock avoidance system?
3. What is Starvation?
4. What is aging in operating system?
5. What are the techniques in avoid deadlocks?

8.6. ANSWERS TO CHECK YOUR PROGRESS

1. Banker's algorithm is one form of deadlock-avoidance in a system. It gets its name from a banking system wherein the bank never allocates available cash in such a way that it can no longer satisfy the needs of all of its customers.

2. One is that it depends on how often a deadlock is likely to occur under the implementation of this algorithm. The other has to do with how many processes will be affected by deadlock when this algorithm is applied.

3. Starvation is Resource management problem. In this problem, a waiting process does not get the resources it needs for a long time because the resources are being allocated to other processes.

4. Aging is a technique used to avoid the starvation in resource scheduling system.

5. There are some techniques used to avoid deadlocks. There are two states involved in it.
   - Safe state
   - Unsafe state

8.7. SUMMARY

- If a system does not employ either a deadlock-prevention or a deadlock avoidance algorithm, then a deadlock situation may occur.
- There are two options for breaking a deadlock. One is simply to abort one or more processes to break the circular wait. The other is to pre-empt some resources from one or more of the deadlocked processes.
- The resource-allocation-graph algorithm is not applicable to a resource allocation system with multiple instances of each resource type.
- Deadlock-prevention algorithms, prevent deadlocks by limiting how requests can be made.
- To ensure that the hold-and-wait condition never occurs in the system, we must guarantee that, whenever a process requests a resource, it does not hold any other resources.

8.8. KEYWORDS

Safe State: A state is safe if the system can allocate resources to each process (up to its maximum) in some order and still avoid a deadlock.

Abort all deadlocked processes. This method clearly will break the deadlock cycle, but at great expense. The deadlocked processes may have computed for a long time, and the results of these partial computations must be discarded and probably will have to be recomputed later.

Starvation. How do we ensure that starvation will not occur? That is, how can we guarantee that resources will not always be preempted from the same process?

Selecting a victim. Which resources and which processes are to be preempted? As in process termination, we must determine the order of preemption to minimize cost. Cost factors may include such parameters as the number of resources a deadlocked process is holding and the amount of time the process has thus far consumed.

Rollback. If we preempt a resource from a process, what should be done with that process? Clearly, it cannot continue with its normal execution; it is missing some needed resource. We must roll back the process to some safe state and restart it from that state.

8.9. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is safe state?
2. What is unsafe state?
3. What is Safely Algorithm?
4. What is Resource Request Algorithm?
5. What is Deadlock detection?

Long Answer questions:

1. Explain about Recovery from deadlock?
2. Explain about Banker's algorithm and its types?
3. Explain About Deadlock Prevention and Avoidance

8.10. FURTHER READINGS

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BLOCK – IV
MEMORY MANAGEMENT

UNIT IX
MEMORY MANAGEMENT STRATEGIES

Structure

9.0 Introduction
9.1 Objective
9.2 Swapping
9.3 Swapping-Contiguous Memory Allocation- Paging- Segmentation
9.4 Paging
9.5 Segmentation
9.6 Answers to Check Your Progress Questions
9.7 Summary
9.8 Key Words
9.9 Self Assessment Questions and Exercises
9.10 Further Readings

9.0 INTRODUCTION

Memory is where the data is stored and retrieved. The memory management is performed on how the data can be processed. Memory management is the functionality of an operating system which handles or manages primary memory and moves processes back and forth between main memory and disk during execution. Memory management keeps track of each and every memory location, regardless of either it is allocated to some process or it is free. It checks how much memory is to be allocated to processes. It decides which process will get memory at what time. It tracks whenever some memory gets freed or unallocated and correspondingly it updates the status. There are various techniques grouped with memory management such as paging and segmentation. This unit explains the paging algorithms used for the allocation of pages in the memory and also the segmentation types.

9.1 OBJECTIVE

This unit helps the user to understand the

- Continuous memory allocation
- Paging algorithms
- Segmentation techniques

9.2 SWAPPING

A process must be in memory to be executed. A process, however, can be swapped temporarily out of memory to a backing store and then brought back into memory for continued execution (Figure 8.5). Swapping makes it possible for the total physical address space of all processes to exceed the real physical memory of the system, thus increasing the degree of multiprogramming in a system.

9.2.1 Standard Swapping

Standard swapping involves moving processes between main memory and a backing store. The backing store is commonly a fast disk. It must be large enough to accommodate copies of all memory images for all users, and it must provide direct access to these memory images.

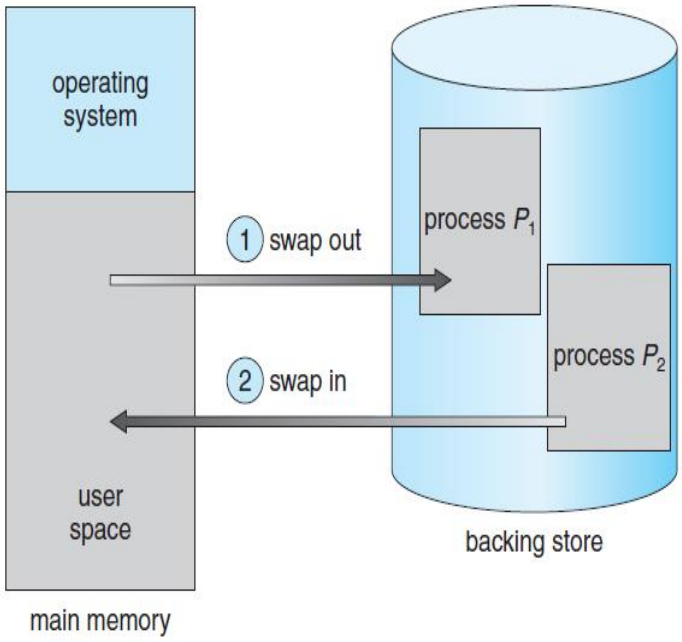


Figure 9.1 Swapping of two processes using a disk as a backing store.

The system maintains a ready queue consisting of all processes whose memory images are on the backing store or in memory and are ready to run. Whenever the CPU scheduler decides to execute a process, it calls the dispatcher. The dispatcher checks to see whether the next process in the queue is in memory. If it is not, and if there is no free memory region, the dispatcher swaps out a process currently in memory and swaps in the desired process. It then reloads registers and transfers control to the selected process.

The context-switch time in such a swapping system is fairly high. To get an idea of the context-switch time, let's assume that the user process is 100 MB in size and the backing store is a standard hard disk with a transfer rate of 50 MB/second. The actual transfer of the 100-MB process to or from main memory takes 100 MB/50 MB per second = 2 seconds. The swap

time is 200 milliseconds. Since we must swap both out and in, the total swap time is about 4,000 milliseconds. (Here, we are ignoring other disk performance aspects, which we cover in Chapter 10.)

Notice that the major part of the swap time is transfer time. The total transfer time is directly proportional to the amount of memory swapped. If we have a computer system with 4 GB of main memory and a resident operating system taking 1 GB, the maximum size of the user process is 3GB. However, many user processes may be much smaller than this—say, 100 MB. A 100-MB process could be swapped out in 2 seconds, compared with the 60 seconds required for swapping 3 GB. Clearly, it would be useful to know exactly how much memory a user process is using, not simply how much it might be using. Then we would need to swap only what is actually used, reducing swap time. For this method to be effective, the user must keep the system informed of any changes in memory requirements. Thus, a process with dynamic memory requirements will need to issue system calls (request memory() and release memory()) to inform the operating system of its changing memory needs.

Swapping is constrained by other factors as well. If we want to swap a process, we must be sure that it is completely idle. Of particular concern is any pending I/O. A process may be waiting for an I/O operation when we want to swap that process to free up memory. However, if the I/O is asynchronously accessing the user memory for I/O buffers, then the process cannot be swapped. Assume that the I/O operation is queued because the device is busy. If we were to swap out process P1 and swap in process P2, the I/O operation might then attempt to use memory that now belongs to process P2. There are two main solutions to this problem: never swap a process with pending I/O, or execute I/O operations only into operating-system buffers. Transfers between operating-system buffers and process memory then occur only when the process is swapped in. Note that this double buffering itself adds overhead.

9.2.2 Swapping on Mobile Systems

Although most operating systems for PCs and servers support some modified version of swapping, mobile systems typically do not support swapping in any form. Mobile devices generally use flash memory rather than more spacious hard disks as their persistent storage. The resulting space constraint is one reason why mobile operating-system designers avoid swapping. Other reasons include the limited number of writes that flash memory can tolerate before it becomes unreliable and the poor throughput between main memory and flash memory in these devices. Instead of using swapping, when free memory falls below a certain threshold, Apple's iOS asks applications to voluntarily relinquish allocated memory. Read-only data (such as code) are removed from the system and later reloaded from flash memory if necessary. Data that have been modified (such as the stack) are never removed. However, any applications that fail to free up sufficient memory may be terminated by the operating system.

Android does not support swapping and adopts a strategy similar to that used by iOS. It may terminate a process if insufficient free memory is available. However, before terminating a process, Android writes its application state to flash memory so that it can be quickly restarted. Because of these restrictions, developers for mobile systems must carefully allocate and release memory to ensure that their applications do not use too much memory or suffer from memory leaks. Note that both iOS and Android support paging, so they do have memory-management abilities

9.3 CONTIGUOUS MEMORY ALLOCATION

The main memory must accommodate both the operating system and the various user processes. We therefore need to allocate main memory in the most efficient way possible. This section explains one early method, contiguous memory allocation.

The memory is usually divided into two partitions: one for the resident operating system and one for the user processes. We can place the operating system in either low memory or high memory. The major factor affecting this decision is the location of the interrupt vector. Since the interrupt vector is often in low memory, programmers usually place the operating system in low memory as well. Thus, in this text, we discuss only the situation in which the operating system resides in low memory. The development of the other situation is similar.

We usually want several user processes to reside in memory at the same time. We therefore need to consider how to allocate available memory to the processes that are in the input queue waiting to be brought into memory. In contiguous memory allocation, each process is contained in a single section of memory that is contiguous to the section containing the next process.

9.3.1 Memory Protection

Before discussing memory allocation further, we must discuss the issue of memory protection. We can prevent a process from accessing memory it does not own by combining two ideas previously discussed. If we have a system with a relocation register (Section 8.1.3), together with a limit register (Section 8.1.1), we accomplish our goal. The relocation register contains the value of the smallest physical address; the limit register contains the range of logical addresses (for example, relocation = 100040 and limit = 74600). Each logical address must fall within the range specified by the limit register. The MMU maps the logical address dynamically by adding the value in the relocation register. This mapped address is sent to memory (Figure 8.6). When the CPU scheduler selects a process for execution, the dispatcher loads the relocation and limit registers with the correct values as part of the context switch. Because every address generated by a CPU is checked against these registers, we can protect both the operating system and the other users' programs and data from being modified by this running process.

The relocation-register scheme provides an effective way to allow the operating system's size to change dynamically. This flexibility is desirable in many situations. For example, the operating system contains code and buffer space for device drivers. If a device driver (or other operating-system service) is not commonly used, we do not want to keep the code and data in memory, as we might be able to use that space for other purposes. Such code is sometimes called transient operating-system code; it comes and goes as needed. Thus, sing this code changes the size of the operating system during program execution.

9.3.2 Memory Allocation

Now we are ready to turn to memory allocation. One of the simplest methods for allocating memory is to divide memory into several fixed-sized partitions. Each partition may contain exactly one process. Thus, the degree of multiprogramming is bound by the number of partitions. In this multiple partition method, when a partition is free, a process is selected from the input queue and is loaded into the free partition. When the process terminates, the partition becomes available for another process. This method was originally used by the IBM OS/360 operating system (called MFT) but is no longer in use.

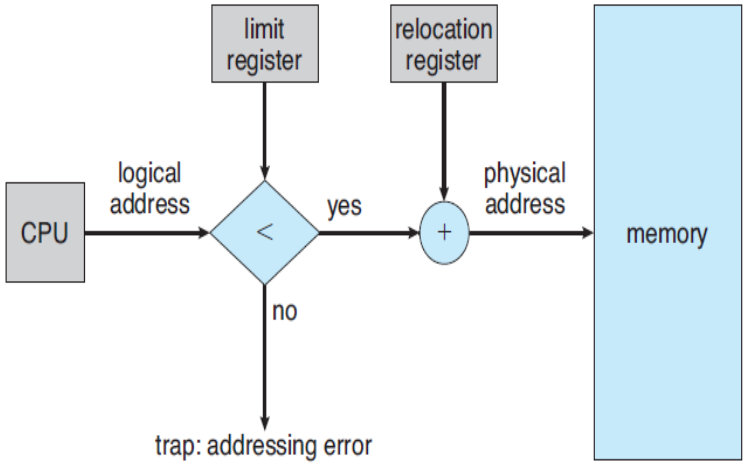


Figure9.2 Hardware support for relocation and limit registers.

The method described next is a generalization of the fixed-partition scheme (called MVT); it is used primarily in batch environments. Many of the ideas presented here are also applicable to a time-sharing environment in which pure segmentation is used for memory management (Section 8.4). In the variable-partition scheme, the operating system keeps a table indicating which parts of memory are available and which are occupied. Initially, all memory is available for user processes and is considered one large block of available memory, a hole. Eventually, as you will see, memory contains a set of holes of various sizes.

As processes enter the system, they are put into an input queue. The operating system takes into account the memory requirements of each process and the amount of available memory space in determining which processes are allocated memory. When a process is allocated space, it is loaded into memory, and it can then compete for CPU time. When a process terminates, it releases its memory, which the operating system may then fill with another process from the input queue.

At any given time, then, we have a list of available block sizes and an input queue. The operating system can order the input queue according to a scheduling algorithm. Memory is allocated to processes until, finally, the memory requirements of the next process cannot be satisfied—that is, no available block of memory (or hole) is large enough to hold that process. The operating system can then wait until a large enough block is available, or it can skip down the input queue to see whether the smaller memory requirements of some other process can be met.

In general, as mentioned, the memory blocks available comprise a set of holes of various sizes scattered throughout memory. When a process arrives and needs memory, the system searches the set for a hole that is large enough for this process. If the hole is too large, it is split into two parts. One part is allocated to the arriving process; the other is returned to the set of holes. When a process terminates, it releases its block of memory, which is then placed back in the set of holes. If the new hole is adjacent to other holes, these adjacent holes are merged to form one larger hole. At this point, the system may need to check whether there are processes waiting for memory and whether this newly freed and recombined memory could satisfy the demands of any of these waiting processes. This procedure is a particular instance of the general dynamic storage allocation problem, which concerns how to satisfy a request of size n from a list of free holes. There are many solutions to this problem. The first-fit, best-fit, and worst-fit strategies are the ones most commonly used to select a free hole from the set of available holes.

• **First fit**. Allocate the first hole that is big enough. Searching can start either at the beginning of the set of holes or at the location where the previous first-fit search ended. We can stop searching as soon as we find a free hole that is large enough.

• **Best fit**. Allocate the smallest hole that is big enough. We must search the entire list, unless the list is ordered by size. This strategy produces the smallest leftover hole.

• **Worst fit**. Allocate the largest hole. Again, we must search the entire list, unless it is sorted by size. This strategy produces the largest leftover hole, which may be more useful than the smaller leftover hole from a best-fit approach.

Simulations have shown that both first fit and best fit are better than worst fit in terms of decreasing time and storage utilization. Neither first fit nor

best fit is clearly better than the other in terms of storage utilization, but first fit is generally faster.

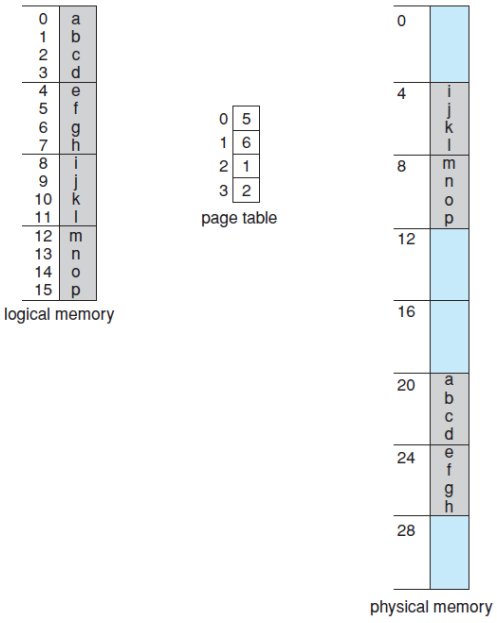


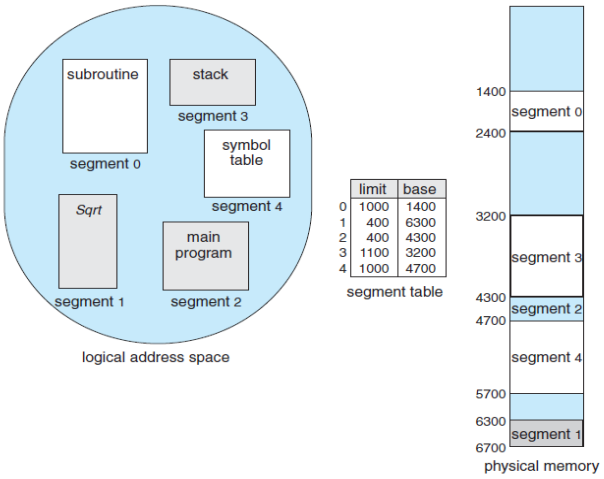
Figure 9.3 example of paging

9.3.3 Fragmentation

Both the first-fit and best-fit strategies for memory allocation suffer from external fragmentation. As processes are loaded and removed from memory, the free memory space is broken into little pieces. External fragmentation exists when there is enough total memory space to satisfy a request but the available spaces are not contiguous: storage is fragmented into a large number of small holes. This fragmentation problem can be severe. In the worst case, we could have a block of free (or wasted) memory between every two processes. If all these small pieces of memory were in one big free block instead, we might be able to run several more processes. Whether we are using the first-fit or best-fit strategy can affect the amount of fragmentation. (First fit is better for some systems, whereas best fit is better for others.) Another factor is which end of a free block is allocated.

Depending on the total amount of memory storage and the average process size, external fragmentation may be a minor or a major problem. Statistical analysis of first fit, for instance, reveals that, even with some optimization, given N allocated blocks, another 0.5 N blocks will be lost to fragmentation. That is, one-third of memory may be unusable! This property is known as the 50-percent rule.

Memory fragmentation can be internal as well as external. Consider a multiple-partition allocation scheme with a hole of 18,464 bytes. Suppose that the next process requests 18,462 bytes. If we allocate exactly the requested block, we are left with a hole of 2 bytes. The overhead to keep



track of this hole will be substantially larger than the whole itself. The general approach to avoiding this problem is to break the physical memory into fixed-sized blocks and allocate memory in units based on block size. With this approach, the memory allocated to a process may be slightly larger than the requested memory. The difference between these two numbers is internal fragmentation—unused memory that is internal to a partition.

One solution to the problem of external fragmentation is compaction. The goal is to shuffle the memory contents so as to place all free memory together in one large block. Compaction is not always possible, however. If relocation is static and is done at assembly or load time, compaction cannot be done. It is possible only if relocation is dynamic and is done at execution time. If addresses are relocated dynamically, relocation requires only moving the program and data and then changing the base register to reflect the new base address. When compaction is possible, we must determine its cost. The simplest compaction algorithm is to move all processes toward one end of memory; all holes move in the other direction, producing one large hole of available memory. This scheme can be expensive.

9.4 PAGING

Segmentation permits the physical address space of a process to be noncontiguous. Paging is another memory-management scheme that offers this advantage. However, paging avoids external fragmentation and the need for compaction, whereas segmentation does not. It also solves the considerable problem of fitting memory chunks of varying sizes onto the backing store. Most memory-management schemes used before the introduction of paging suffered from this problem. The problem arises because, when code fragments or data residing in main memory need to be swapped out, space must be found on the backing store. The backing store has the same fragmentation problems discussed in connection with main memory, but access is much slower, so compaction is impossible. Because of its advantages over earlier methods, paging in its various forms is used

in most operating systems, from those for mainframes through those for smartphones. Paging is implemented through cooperation between the operating system and the computer hardware

Figure 9.4 Segmentation

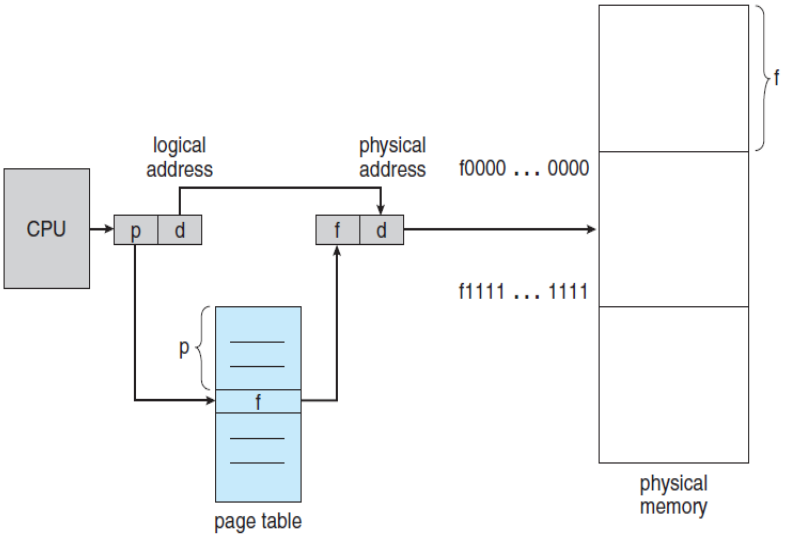


Figure 9.5 Paging model of logical and physical memory.

9.4.1 Basic Method

The basic method for implementing paging involves breaking physical memory into fixed-sized blocks called frames and breaking logical memory into blocks of the same size called pages. When a process is to be executed, its pages are loaded into any available memory frames from their source (a file system or the backing store). The backing store is divided into fixed-sized blocks that are the same size as the memory frames or clusters of multiple frames. This rather simple idea has great functionality and wide ramifications. For example, the logical address space is now totally separate from the physical address space, so a process can have a logical 64-bit address space even though the system has less than 264 bytes of physical memory.

Every address generated by the CPU is divided into two parts: a page number (p) and a page. The page number is used as an index into a page table. The page table contains the base address

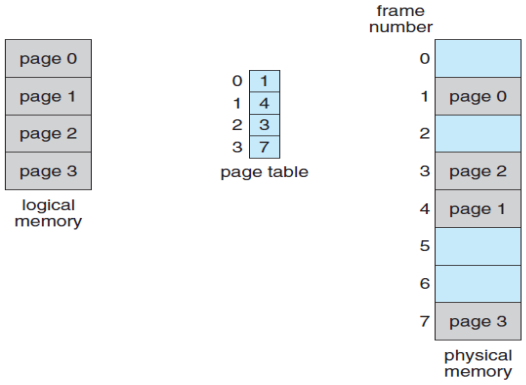


Figure 9.6 Paging hardware.

of each page in physical memory. This base address is combined with the page offset to define the physical memory address that is sent to the memory unit. The paging model of memory is shown in Figure 8.11.

The page size (like the frame size) is defined by the hardware. The size of a page is a power of 2, varying between 512 bytes and 1 GB per page, depending on the computer architecture. The selection of a power of 2 as a page size makes the translation of a logical address into a page number and page offset particularly easy. If the size of the logical address space is 2m, and a page size is 2n bytes, then the high-order m− n bits of a logical address designate the page number, and the n low-order bits designate the page offset. Thus, the logical address is as follows where p is an index into the page table and d is the displacement within the page.

As a concrete (although minuscule) example, consider the memory in Figure 8.12. Here, in the logical address, n= 2 and m = 4. Using a page size of 4 bytes and a physical memory of 32 bytes (8 pages), we show how the programmer's view of memory can be mapped into physical memory. Logical address 0 is page 0, offset 0. Indexing into the page table,

we find that page 0 is in frame 5. Thus, logical address 0 maps to physical address 20 [= (5 × 4) + 0]. Logical address 3 (page 0, offset 3) maps to physical address 23 [= (5 × 4) + 3]. Logical address 4 is page 1, offset 0; according to the page table, page 1 is mapped to frame 6. Thus, logical address 4 maps to physical address 24 [= (6 × 4) + 0]. Logical address 13 maps to physical address 9. You may have noticed that paging itself is a form of dynamic relocation. Every logical address is bound by the paging hardware to some physical address. Using paging is similar to using a table of base (or relocation) registers, one for each frame of memory. When we use a paging scheme, we have no external fragmentation: any free frame can be allocated to a process that needs it. However, we may have some internal fragmentation. Notice that frames are allocated as units. If the memory requirements of a process do not happen to coincide with page boundaries, the last frame allocated may not be completely full. For example, if page size is 2,048 bytes, a process of 72,766 bytes will need 35 pages plus 1,086 bytes. It will be allocated 36 frames, resulting in internal fragmentation of 2,048 − 1,086 = 962 bytes. In the worst case, a process

would need n pages plus 1 byte. It would be allocated n + 1 frames, resulting in internal fragmentation of almost an entire frame. If process size is independent of page size, we expect internal fragmentation to average one-half page per process. This consideration suggests that small page sizes are desirable. However, overhead is involved in each page-table entry, and this overhead is reduced as the size of the pages increases. Also, disk I/O is more efficient when the amount data being transferred is larger (Chapter 10). Generally, page sizes have grown over time as processes, data sets, and main memory have become larger. Today, pages typically are between 4 KB and 8 KB in size, and some systems support even larger page sizes. Some CPUs and kernels even support multiple page sizes. For instance, Solaris uses page sizes of 8 KB and 4 MB, depending on the data stored by the pages. Researchers are now developing support for variable on-the-fly page size. Frequently, on a 32-bit CPU, each page-table entry is 4 bytes long, but that size can vary as well. A 32-bit entry can point to one of 232 physical page frames.

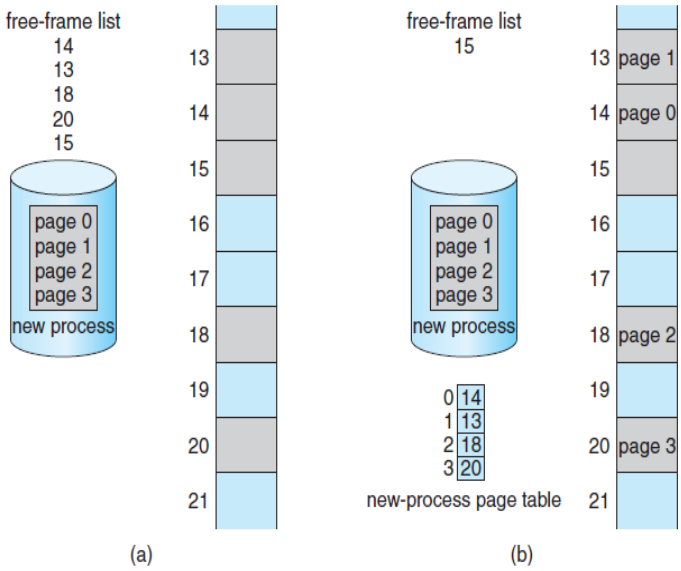


Figure 9.7 Free Frames after allocation

If frame size is 4 KB (212), then a system with 4-byte entries can address 244 bytes (or 16 TB) of physical memory. We should note here that the size of physical memory in a paged memory system is different from the maximum logical size of a process. As we further explore paging, we introduce other information that must be kept in the page-table entries. That information reduces the number of bits available to address page frames. Thus, a system with 32-bit page-table entries may address less physical memory than the possible maximum. A 32-bit CPU uses 32-bit addresses, meaning that a given process space can only be 232 bytes (4 TB). Therefore, paging lets us use physical memory that is larger than what can be addressed by the CPU's address pointer length. When a process arrives in the system to be executed, its size, expressed in pages, is examined. Each page of the process needs one frame. Thus, if the process requires n pages, at least n frames must be available in memory.

An important aspect of paging is the clear separation between the programmer's view of memory and the actual physical memory. The programmer views memory as one single space, containing only this one program. In fact, the user program is scattered throughout physical memory, which also holds other programs. The difference between the programmer's view of memory and the actual physical memory is reconciled by the address-translation hardware. The logical addresses are translated into physical addresses. This mapping is hidden from the programmer and is controlled by the operating system. Notice that the user process by definition is unable to access memory it does not own. It has no way of addressing memory outside of its page table, and the table includes only those pages that the process owns. Since the operating system is managing physical memory, it must be aware of the allocation details of physical memory—which frames are allocated, which frames are available, how many total frames there are, and so on. This information is generally kept in a data structure called a frame table. The frame table has one entry for each physical page frame, indicating whether the latter is free or allocated and, if it is allocated, to which page of which process or processes.

In addition, the operating system must be aware that user processes operate in user space, and all logical addresses must be mapped to produce physical addresses. If a user makes a system call (to do I/O, for example) and provides an address as a parameter (a buffer, for instance), that address must be mapped to produce the correct physical address. The operating system maintains a copy of the page table for each process, just as it maintains a copy of the instruction counter and register contents. This copy is used to translate logical addresses to physical addresses whenever the operating system must map a logical address to a physical address manually. It is also used by the CPU dispatcher to define the hardware page table when a process is to be allocated the CPU. Paging therefore increases the context-switch time.

9.4.2 Hardware Support

Each operating system has its own methods for storing page tables. Some allocate a page table for each process. A pointer to the page table is stored with the other register values (like the instruction counter) in the process control block. When the dispatcher is told to start a process, it must reload the user registers and define the correct hardware page-table values from the stored user page table. Other operating systems provide one or at most a few page tables, which decreases the overhead involved when processes are context-switched.

The hardware implementation of the page table can be done in several ways. In the simplest case, the page table is implemented as a set of dedicated registers. These registers should be built with very high-speed logic to make the paging-address translation efficient. Every access to memory must go through the paging map, so efficiency is a major consideration. The CPU dispatcher reloads these registers, just as it reloads the other registers. Instructions to load or modify the page-table registers

are, of course, privileged, so that only the operating system can change the memory map. The DEC PDP-11 is an example of such an architecture. The address consists of 16 bits, and the page size is 8 KB. The page table thus consists of eight entries that are kept in fast registers.

The use of registers for the page table is satisfactory if the page table is reasonably small (for example, 256 entries). Most contemporary computers, however, allow the page table to be very large (for example, 1 million entries). For these machines, the use of fast registers to implement the page table is not feasible. Rather, the page table is kept in main memory, and a page-table base register (PTBR) points to the page table. Changing page tables requires changing only this one register, substantially reducing context-switch time. The problem with this approach is the time required to access a user memory location. If we want to access location i, we must first index into the page table, using the value in the PTBR offset by the page number for i. This task requires a memory access. It provides us with the frame number, which is combined with the page offset to produce the actual address. We can then access the desired place in memory. With this scheme, two memory accesses are needed to access a byte (one for the page-table entry, one for the byte). Thus, memory access is slowed by a factor of 2. This delay would be intolerable under most circumstances. We might as well resort to swapping!

The standard solution to this problem is to use a special, small, fast lookup hardware cache called a translation look-aside buffer (TLB). The TLB is associative, high-speed memory. Each entry in the TLB consists of two parts: a key (or tag) and a value. When the associative memory is presented with an item, the item is compared with all keys simultaneously. If the item is found, the corresponding value field is returned. The search is fast; a TLB lookup in modern hardware is part of the instruction pipeline, essentially adding no performance penalty. To be able to execute the search within a pipeline step, however, the TLB must be kept small. It is typically between 32 and 1,024 entries in size. Some CPUs implement separate instruction and data address TLBs. That cans double the number of TLB entries available, because those lookups occur in different pipeline steps. We can see in this development an example of the evolution of CPU technology: systems have evolved from having no TLBs to having multiple levels of TLBs, just as they have multiple levels of caches.

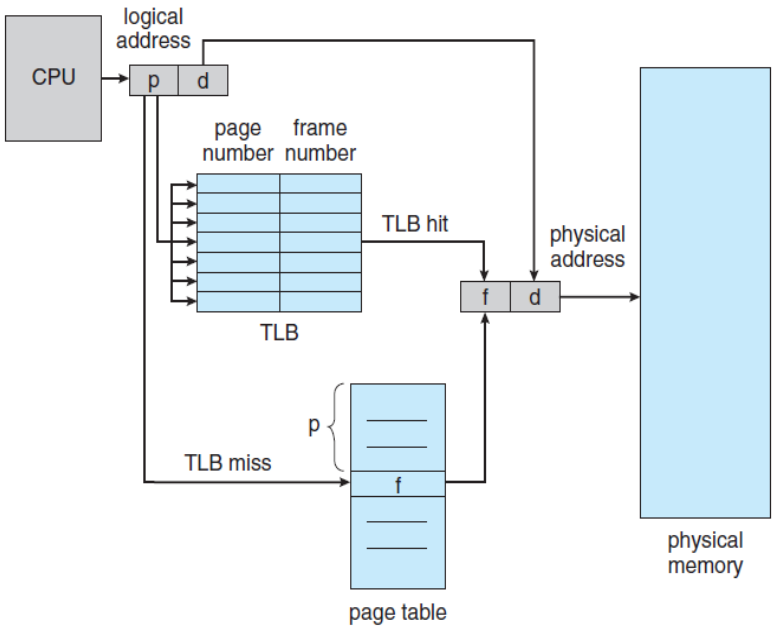


Figure9.8 Paging hardware with TLB

The TLB is used with page tables in the following way. The TLB contains only a few of the page-table entries. When a logical address is generated by the CPU, its page number is presented to the TLB. If the page number is found, its frame number is immediately available and is used to access memory. As just mentioned, these steps are executed as part of the instruction pipeline within the CPU, adding no performance penalty compared with a system that does not implement paging. If the page number is not in the TLB (known as a TLB miss), a memory reference to the page table must be made. Depending on the CPU, this may be done automatically in hardware or via an interrupt to the operating system. When the frame number is obtained, we can use it to access memory (Figure 8.14). In addition, we add the page number and frame number to the TLB, so that they will be found quickly on the next reference. If the TLB is already full of entries, an existing entry must be selected for replacement. Replacement policies range from least recently used (LRU) through round-robin to random. Some CPUs allow the operating system to participate in LRU entry replacement, while others handle the matter themselves. Furthermore, some TLBs allow m certain entries to be wired down, meaning that they cannot be removed from the TLB. Typically, TLB entries for key kernel code are wired down.

Some TLBs store address-space identifiers (ASIDs) in each TLB entry. An ASID uniquely identifies each process and is used to provide address-space protection for that process. When the TLB attempts to resolve virtual page numbers, it ensures that the ASID for the currently running process matches the ASID associated with the virtual page. If the ASIDs do not match, the attempt is treated as a TLB miss. In addition to providing address-space protection, an ASID allows the TLB to contain entries for several different processes simultaneously. If the TLB does not support

separate ASIDs, then every time a new page table is selected (for instance, with each context switch), the TLB must be flushed(or erased) to ensure that the next executing process does not use the wrong translation information. Otherwise, the TLB could include old entries that contain valid virtual addresses but have incorrect or invalid physical addresses left over from the previous process.

The percentage of times that the page number of interest is found in the TLB is called the hit ratio. An 80-percent hit ratio, for example, means that we find the desired page number in the TLB 80 percent of the time. If it takes 100 nanoseconds to access memory, then a mapped-memory access takes 100 nanoseconds when the page number is in the TLB. If we fail to find the page number in the TLB then we must first access memory for the page table and frame number (100 nanoseconds) and then access the desired byte in memory (100 nanoseconds), for a total of 200 nanoseconds. (We are assuming that a page-table lookup takes only one memory access, but it can take more, as we shall see.) To find the effective memory-access time, we weight the case by its probability:

Effective access time = 0.80 × 100 + 0.20 × 200 = 120 nanoseconds

In this example, we suffer a 20-percent slowdown in average memory-access time (from 100 to 120 nanoseconds). For a 99-percent hit ratio, which is much more realistic, we have

Effective access time = 0.99 × 100 + 0.01 × 200 = 101 nanoseconds

This increased hit rate produces only a 1 percent slowdown in access time. As we noted earlier, CPUs today may provide multiple levels of TLBs. Calculating memory access times in modern CPUs is therefore much more complicated than shown in the example above. For instance, the Intel Core i7 CPU has a 128-entry L1 instruction TLB and a 64-entry L1 data TLB. In the case of a miss at L1, it takes the CPU six cycles to check for the entry in the L2 512-entry TLB. A miss in L2 means that the CPU must either walk through the page-table entries in memory to find the associated frame address, which can take hundreds of cycles, or interrupt to the operating system to have it do the work.

A complete performance analysis of paging overhead in such a system would require miss-rate information about each TLB tier. We can see from the general information above, however, that hardware features can have a significant effect on memory performance and that operating-system improvements (such as paging) can result in and, in turn, be affected by hardware changes(such as TLBs).We will further explore the impact of the hit ratio on the TLB in TLBs are a hardware feature and therefore would seem to be of little concerto operating systems and their designers. But the designer needs to understand the function and features of TLBs, which vary by hardware platform. For optimal operation, an operating-system design for a given platform must implement paging according to the platform's TLB design. Likewise, a change in the TLB design (for

example, between generations of Intel CPUs) may necessitate a change in the paging implementation of the operating systems that use it.

9.4.3 Protection

Memory protection in a paged environment is accomplished by protection bits associated with each frame. Normally, these bits are kept in the page table. One bit can define a page to be read–write or read-only. Every reference to memory goes through the page table to find the correct frame number. At the same time that the physical address is being computed, the protection bits can be checked to verify that no writes are being made to a read-only page. An attempt to write to a read-only page causes a hardware trap to the operating system (or memory-protection violation). We can easily expand this approach to provide a finer level of protection. We can create hardware to provide read-only, read–write, or execute-only protection; or, by providing separate protection bits for each kind of access, we can allow any combination of these accesses. Illegal attempts will be trapped to the operating system. One additional bit is generally attached to each entry in the page table: a valid–invalid bit. When this bit is set to valid, the associated page is in the process's logical address space and is thus a legal (or valid) page.

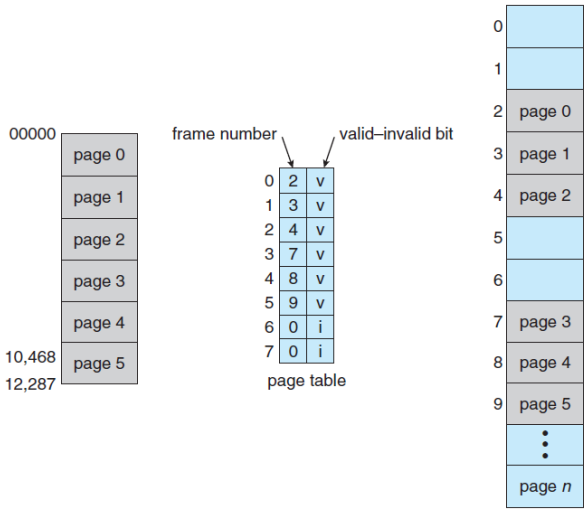


Figure 9.9 valid or invalid bit in page table

When the bit is set to invalid, the page is not in the process's logical address space. Illegal addresses are trapped by use of the valid–invalid bit. The operating system sets this bit for each page to allow or disallow access to the page. Suppose, for example, that in a system with a 14-bit address space (0 to 16383), we have a program that should use only addresses 0 to 10468. Given a page size of 2 KB, we have the situation shown in Figure 8.15. Addresses in pages 0, 1, 2, 3, 4, and 5 are mapped normally through the page table. Any attempt to generate an address in pages 6 or 7, however, will find that the valid–invalid bit is set to invalid, and the

computer will trap to the operating system (invalid page reference). Notice that this scheme has created a problem. Because the program extends only to address 10468, any reference beyond that address is illegal. However, references to page 5 are classified as valid, so accesses to addresses up to 12287 are valid. Only the addresses from 12288 to 16383 are invalid. This problem is a result of the 2-KB page size and reflects the internal fragmentation of paging.

Rarely does a process use all its address range. In fact, many processes use only a small fraction of the address space available to them. It would be wasteful in these cases to create a page table with entries for every page in the address range. Most of this table would be unused but would take up valuable memory space. Some systems provide hardware, in the form of a page-table length register (PTLR), to indicate the size of the page table. This value is checked against every logical address to verify that the address is in the valid range for the process. Failure of this test causes an error trap to the operating system.

9.4.4 Shared Pages

An advantage of paging is the possibility of sharing common code. This consideration is particularly important in a time-sharing environment. Consider a system that supports 40 users, each of whom executes a text editor. If the text editor consists of 150 KB of code and 50 KB of data space, we need 8,000 KB to support the 40 users. If the code is re-entrant code (or pure code), however, it can be shared, as shown in Figure 8.16. Here, we see three processes sharing a three-page editor—each page 50 KB in size (the large page size is used to simplify the figure). Each process has its own data page. Re-entrant code is non-self-modifying code: it never changes during execution. Thus, two or more processes can execute the same code at the same time Each process has its own copy of registers and data storage to hold the data for the process's execution. The data for two different processes will, of course, be different. Only one copy of the editor need be kept in physical memory. Each user's page table maps onto the same physical copy of the editor, but data pages are mapped onto different frames. Thus, to support 40 users, we need only one copy of the editor (150 KB), plus 40 copies of the 50 KB of data space per user. The total space required is now 2,150 KB instead of 8,000 KB—a significant savings.

Other heavily used programs can also be shared—compilers, window systems, run-time libraries, database systems, and so on. To be sharable, the code must be reentrant. The read-only nature of shared code should not be left to the correctness of the code; the operating system should enforce this property.

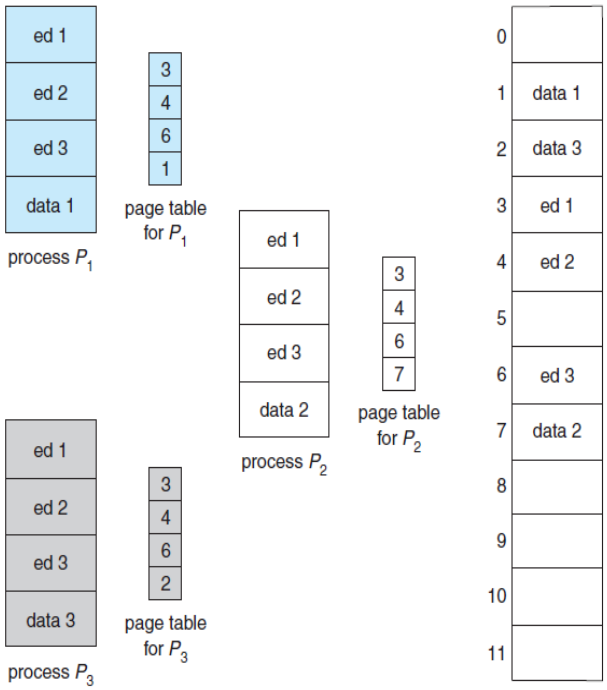


Figure 9.10 Sharing of code

The sharing of memory among processes on a system is similar to the sharing of the address space of a task by threads, described in Chapter 4. Furthermore, recall that in Chapter 3we described shared memory as a method of interprocess communication. Some operating systems implement shared memory using shared pages. Organizing memory according to pages provides numerous benefits in addition to allowing several processes to share the same physical pages. We cover several other benefits in Chapter

9.4.5 Hierarchical Paging

Most modern computer systems support a large logical address space (232 to 264). In such an environment, the page table itself becomes excessively large. For example, consider a system with a 32-bit logical address space. If the page size in such a system is 4 KB (212), then a page table may consist of up to 1 million entries (232/212). Assuming that each entry consists of 4 bytes, each process may need up to 4 MB of physical address space for the page table alone. Clearly, we would not want to allocate the page table contiguously in main memory. One simple solution to this problem is to divide the page table into smaller pieces. We can accomplish this division in several ways. One way is to use a two-level paging algorithm, in which the page table itself is also paged (Figure 8.17). For example, consider again the system with a 32-bit logical address space and a page size of 4 KB. A logical address is divided into a page number consisting of 20 bits and a page offset consisting of 12 bits. Because we page the page table, the page number is further divided into a 10-bit page number and a 10-bit page offset. Thus, a logical address is as follows:

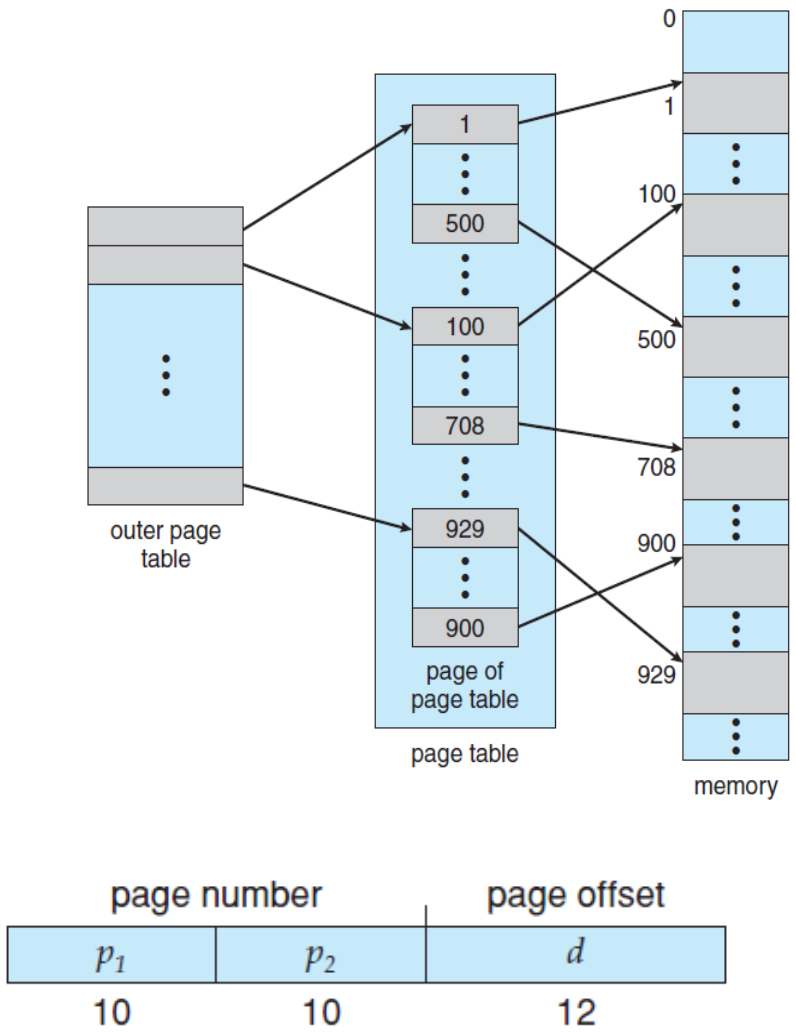


Figure 9.11 Logical Addressing

where p1 is an index into the outer page table and p2 is the displacement within the page of the inner page table. The address-translation method for this architecture is shown in Figure 8.18. Because address translation works from the outer page table inward, this scheme is also known as a forward-mapped page table.

Consider the memory management of one of the classic systems, the VAX minicomputer from Digital Equipment Corporation (DEC). The VAX was the most popular minicomputer of its time and was sold from 1977 through 2000. The VAX architecture supported a variation of two-level paging. The VAX is a 32- bit machine with a page size of 512 bytes. The logical address space of a process is divided into four equal sections, each of which consists of 230 bytes. Each section represents a different part of the logical address space of a process. The first 2 high-order bits of the logical address designate the appropriate section.

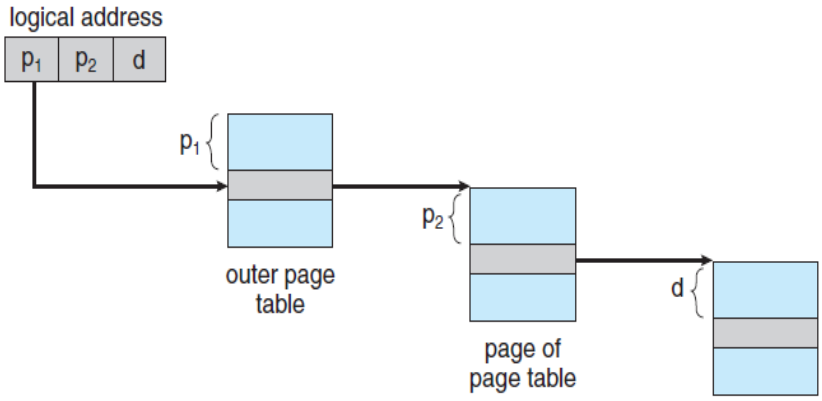


Figure 9.12 Address translation

The next 21 bits represent the logical page number of that section, and the final 9 bits represent an offset in the desired page. By partitioning the page table in this manner, the operating system can leave partitions unused until a process needs them. Entire sections of virtual address space are frequently unused, and multilevel page tables have no entries for these spaces, greatly decreasing the amount of memory needed to store virtual memory data structures.

An address on the VAX architecture is as follows:

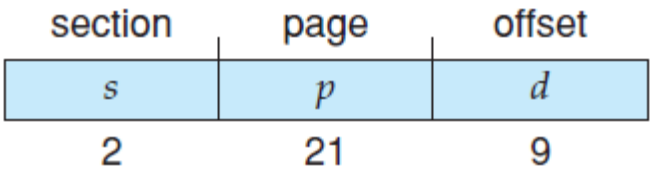


Figure 9.13 VAX architecture address

where s designates the section number, p is an index into the page table, and d is the displacement within the page. Even when this scheme is used, the size of a one-level page table for a VAX process using one section is 221 bits ∗ 4 bytes per entry = 8 MB. To further reduce main-memory use, the VAX pages the user-process page tables.

For a system with a 64-bit logical address space, a two-level paging scheme is no longer appropriate. To illustrate this point, let's suppose that the page size in such a system is 4 KB (212). In this case, the page table consists of up to 252 entries. If we use a two-level paging scheme, then the inner page tables can conveniently be one page long, or contain 210 4-byte entries. The addresses look like this

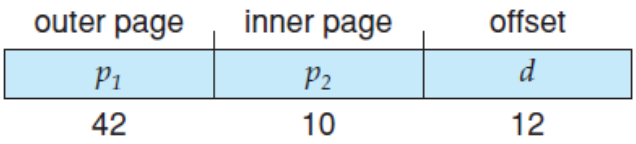


Figure 9.14 VAX architecture address inner page

The outer page table consists of 242 entries, or 244 bytes. The obvious way to avoid such a large table is to divide the outer page table into smaller pieces. (This approach is also used on some 32-bit processors for added flexibility and efficiency.) We can divide the outer page table in various ways. For example, we can page the outer page table, giving us a three-level paging scheme. Suppose that the outer page table is made up of standard-size pages (210 entries, or 212 bytes). In this case, a 64-bit address space is still daunting:

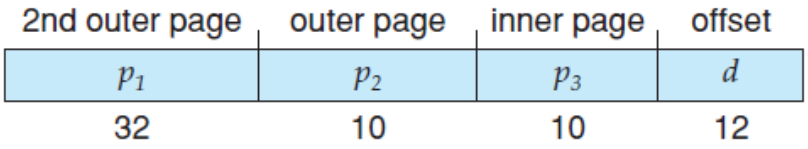


Figure 9.15 VAX architecture address outer page

The outer page table is still 234 bytes (16 GB) in size. The next step would be a four-level paging scheme, where the second-level outer page table itself is also paged, and so forth. The 64-bit UltraSPARC would require seven levels of paging—a prohibitive number of memory accesses— to translate each logical address. You can see from this example why, for 64-bit architectures, hierarchical page tables are generally considered inappropriate

9.4.6 Hashed Page Tables

A common approach for handling address spaces larger than 32 bits is to use a hashed page table, with the hash value being the virtual page number. Each entry in the hash table contains a linked list of elements that hash to the same location (to handle collisions). Each element consists of three fields:

(1) The virtual page number,

(2) The value of the mapped page frame, and

(3) A pointer to the next element in the linked list.

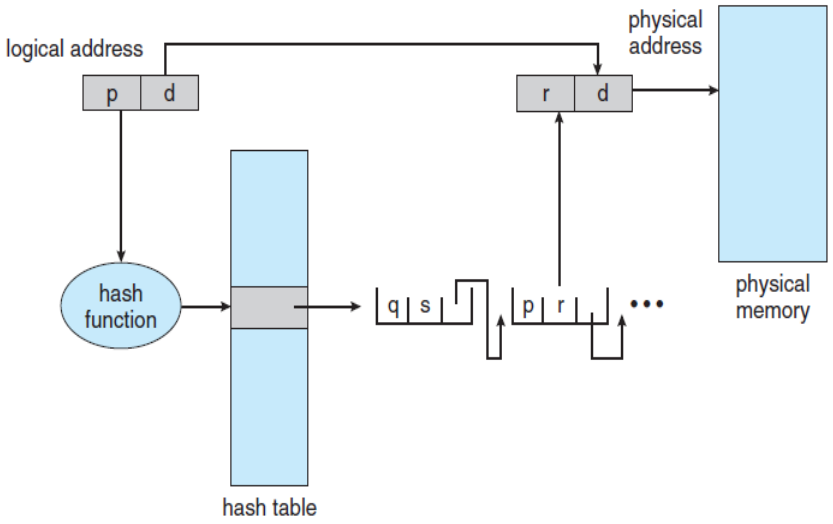


Figure 9.16 Hash Page Table

The algorithm works as follows: The virtual page number in the virtual address is hashed into the hash table. The virtual page number is compared with field 1 in the first element in the linked list. If there is a match, the corresponding page frame (field 2) is used to form the desired physical address. If there is no match, subsequent entries in the linked list are searched for a matching virtual page number. This scheme is shown in Figure 8.19. A variation of this scheme that is useful for 64-bit address spaces has been proposed. This variation uses clustered page tables, which are similar to hashed page tables except that each entry in the hash table refers to several pages (such as 16) rather than a single page. Therefore, a single page-table entry can store the mappings for multiple physical-page frames. Clustered page tables are particularly useful for sparse address spaces, where memory references are non-contiguous and scattered throughout the address space

9.4.7 Inverted Page Tables

Usually, each process has an associated page table. The page table has one entry for each page that the process is using (or one slot for each virtual address, regardless of the latter's validity). This table representation is a natural one, since processes reference pages through the pages' virtual addresses. The operating system must then translate this reference into a physical memory address. Since the table is sorted by virtual address, the operating system is able to calculate where in the table the associated physical address entry is located and to use that value directly. One of the drawbacks of this method is that each page table may consist of millions of entries. These tables may consume large amounts of physical memory just to keep track of how other physical memory is being used.

To solve this problem, we can use an inverted page table. An inverted page table has one entry for each real page (or frame) of memory. Each entry consists of the virtual address of the page stored in that real memory

location, with information about the process that owns the page. Thus, only one page table is in the system, and it has only one entry for each page of physical memory. Figure 8.20 shows the operation of an inverted page table. Compare it with Figure 8.10, which depicts a standard page table in operation. Inverted page tables often require that an address-space identifier (Section 8.5.2) be stored in each entry of the page table, since the table usually contains several different address spaces mapping physical memory. Storing the address-space identifier ensures that a logical page for a particular process is mapped to the corresponding physical page frame. Examples of systems using inverted page tables include the 64-bit UltraSPARC and PowerPC.

To illustrate this method, we describe a simplified version of the inverted page table used in the IBM RT. IBM was the first major company to use inverted page tables, starting with the IBM System 38 and continuing through the RS/6000 and the current IBM Power CPUs. For the IBM RT, each virtual address in the system consists of a triple:

<process-id, page-number, offset>.

Each inverted page-table entry is a pair <process-id, page-number> where the process-id assumes the role of the address-space identifier. When a memory reference occurs, part of the virtual address, consisting of <process-id, page number>, is presented to the memory subsystem. The inverted page table is then searched for a match. If a match is found—say, at entry i—then the physical address <i, offset> is generated. If no match is found, then an illegal address access has been attempted.

Although this scheme decreases the amount of memory needed to store each page table, it increases the amount of time needed to search the table when a page reference occurs. Because the inverted page table is sorted by physical address, but lookups occur on virtual addresses, the whole table might need to be searched before a match is found. This search would take far too long.

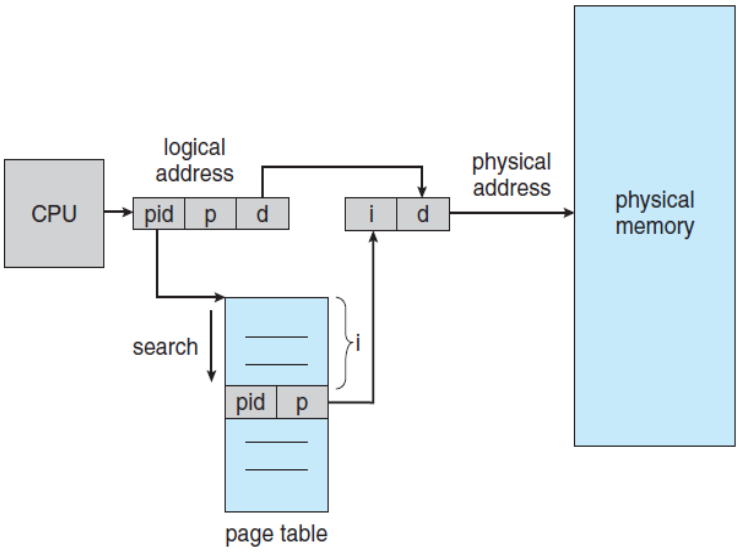


Figure 9.17 Inverted Page Table

To alleviate this problem, we use a hash table, as described in Section 8.6.2, to limit the search to one—or at most a few—page-table entries. Of course, each access to the hash table adds memory reference to the procedure, so one virtual memory reference requires at least two real memory reads—one for the hash-table entry and one for the page table. (Recall that the TLB is searched first, before the hash table is consulted, offering some performance improvement.) Systems that use inverted page tables have difficulty implementing shared memory. Shared memory is usually implemented as multiple virtual addresses (one for each process sharing the memory) that are mapped to one physical address. This standard method cannot be used with inverted page tables; because there is only one virtual page entry for every physical page, one physical page cannot have two (or more) shared virtual addresses. A simple technique for addressing this issue is to allow the page table to contain only one mapping of a virtual address to the shared physical address. This means that references to virtual addresses that are not mapped result in page faults.

9.5 SEGMENTATION

As we've already seen, the user's view of memory is not the same as the actual physical memory. This is equally true of the programmer's view of memory. Indeed, dealing with memory in terms of its physical properties is inconvenient to both the operating system and the programmer. What if the hardware could provide a memory mechanism that mapped the programmer's view to the actual physical memory? The system would have more freedom to manage memory, while the programmer would have a more natural programming environment. Segmentation provides such a mechanism.

9.5.1 Basic Method

Do programmers think of memory as a linear array of bytes, some containing instructions and others containing data? Most programmers would say "no." Rather, they prefer to view memory as a collection of variable-sized segments, with no necessary ordering among the segments (Figure 8.7).

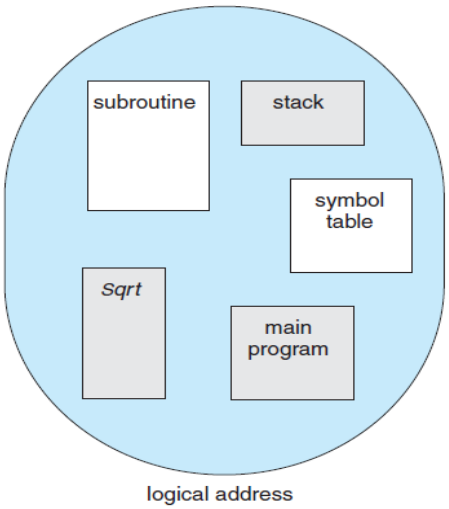


Figure 9.18 Programmers view

When writing a program, a programmer thinks of it as a main program with a set of methods, procedures, or functions. It may also include various data structures: objects, arrays, stacks, variables, and so on. Each of these modules or data elements is referred to by name. The programmer talks about "the stack," "the math library," and "the main program" without caring what addresses in memory these elements occupy. She is not concerned with whether the stack is stored before or after the Sqrt() function. Segments vary in length, and the length of each is intrinsically defined by its purpose in the program. Elements within a segment are identified by their offset from the beginning of the segment: the first statement of the program, the seventh stack frame entry in the stack, the fifth instruction of the Sqrt(), and so on. Segmentation is a memory-management scheme that supports this programmer view of memory. A logical address space is a collection of segments. Each segment has a name and a length. The addresses specify both the segment name and the offset within the segment. The programmer therefore specifies each address by two quantities: a segment name and an offset. For simplicity of implementation, segments are numbered and are referred to by a segment number, rather than by a segment name. Thus, a logical address consists of a two tuple:

<segment-number, offset>.

Normally, when a program is compiled, the compiler automatically constructs segments reflecting the input program. A C compiler might create separate segments for the following:

1. The code

2. Global variables

3. The heap, from which memory is allocated

4. The stacks used by each thread

5. The standard C library

Libraries that are linked in during compile time might be assigned separate segments. The loader would take all these segments and assign them segment numbers.

9.5.2 Segmentation Hardware

Although the programmer can now refer to objects in the program by a two-dimensional address, the actual physical memory is still, of course, a one dimensional sequence of bytes. Thus, we must define an implementation to map two-dimensional user-defined addresses into one-dimensional physical addresses. This mapping is affected by a segment table. Each entry in the segment table has a segment base and a segment limit. The segment base contains the starting physical address where the segment resides in memory, and the segment limit specifies the length of the segment.

The segment number is used as an index to the segment table. The offset d of the logical address must be between 0 and the segment limit. If it is not, we trap to the operating system (logical addressing attempt beyond end of segment). When an offset is legal, it is added to the segment base to produce the address in physical memory of the desired byte. The segment table is thus essentially an array of base–limit register pairs.

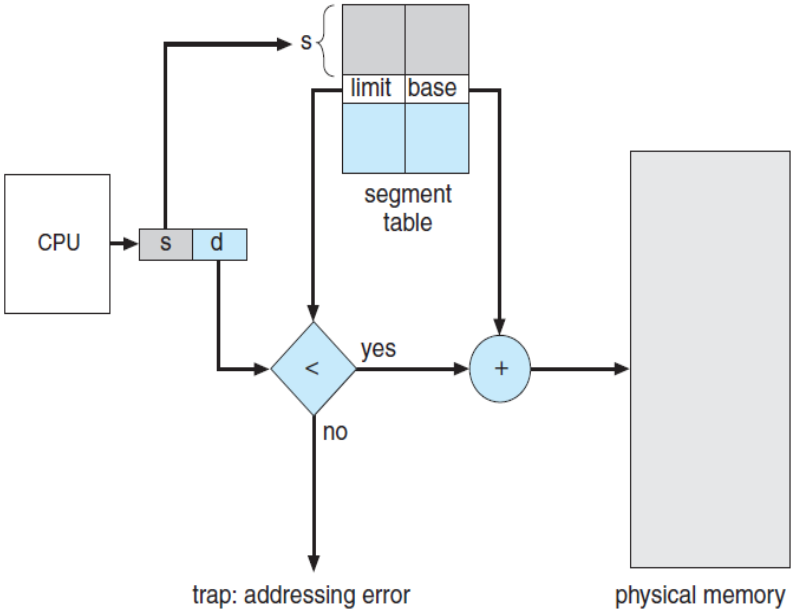


Figure 9.19 Segmentation Hardware

As an example, consider the situation shown in Figure 8.9. We have five segments numbered from 0 through 4. The segments are stored in physical memory as shown. The segment table has a separate entry for each segment, giving the beginning address of the segment in physical memory (or base) and the length of that segment (or limit). For example, segment 2

is 400 bytes long and begins at location 4300. Thus, a reference to byte 53 of segment 2 is mapped onto location 4300 + 53 = 4353. A reference to segment 3, byte 852, is mapped to 3200 (the base of segment 3) + 852 = 4052. A reference to byte 1222 of segment0 would result in a trap to the operating system, as this segment is only 1,000 bytes long.

Check your Progress

1. What is fragmentation?
2. What is the basic function of paging?
3. What is Swapping?
4. What is the use of paging?
5. What is the concept of demand paging?

9.6. ANSWERS TO CHECK YOUR PROGRESS

1. Fragmentation is memory wasted. It can be internal if we are dealing with systems that have fixed-sized allocation units, or external if we are dealing with systems that have variable-sized allocation units.
2. Paging is a memory management scheme that permits the physical address space of a process to be non-contiguous. It avoids the considerable problem of having to fit varied sized memory chunks onto the backing store.
3. A process must be in memory to be executed. A process, however, can be swapped temporarily out of memory to a backing store and then brought back into memory for continued execution. Swapping makes it possible for the total physical address space of all processes to exceed the real physical memory of the system, thus increasing the degree of multiprogramming in a system.
4. Paging is used to solve the external fragmentation problem in operating system. This technique ensures that the data you need is available as quickly as possible.
5. Demand paging specifies that if an area of memory is not currently being used, it is swapped to disk to make room for an application's need.

9.7. SUMMARY

- Standard swapping involves moving processes between main memory and a backing store.
- The main memory must accommodate both the operating system and the various user processes.
- External fragmentation exists when there is enough total memory space to satisfy a request but the available spaces are not contiguous: storage is fragmented into a large number of small holes.

- The basic method for implementing paging involves breaking physical memory into fixed-sized blocks called frames and breaking logical memory into blocks of the same size called pages.
- Memory protection in a paged environment is accomplished by protection bits associated with each frame.
- An inverted page table has one entry for each real page (or frame) of memory.

9.8. KEYWORDS

- **Shared Memory:** Shared memory is usually implemented as multiple virtual addresses (one for each process sharing the memory) that are mapped to one physical address.
- **Segmentation:** Segmentation is a memory-management scheme that supports this programmer view of memory.
- **Offset:** The offset d of the logical address must be between 0 and the segment limit. If it is not, we trap to the operating system (logical addressing attempt beyond end of segment).

9.9. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is Memory Allocation?
2. What is Memory Protection?
3. What are segmentation techniques?
4. What is Paging algorithms?
5. What is Hashed Page Tables?

Long Answer questions:

1. Explain briefly about segmentation and its techniques?
2. Explain briefly about Paging and its types?

9.10. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

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Deitel, H.M., Deitel, P.J. and Choffnes, D.R., 2004. Operating systems. Delhi.: Pearson Education: Dorling Kindersley.

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BLOCK V FILE SYSTEM

UNIT X FILE CONCEPT

Structure

10.0 Introduction
10.1 Objectives
10.2 File Concept
10.3 Access Methods
10.4 Directory Overview
10.5 Answers to Check Your Progress Questions
10.6 Summary
10.7 Key Words
10.8 Self Assessment Questions and Exercises
10.9 Further Readings

10.0 INTRODUCTION

Files are the important storage structures in which data can be easily stores and access. A file is a named collection of related information that is recorded on secondary storage such as magnetic disks, magnetic tapes and optical disks. In general, a file is a sequence of bits, bytes, lines or records whose meaning is defined by the files creator and user. The File is stored inside a directory or it can be called as the path of the file. There are many methods to access the files and various ways to represent the directories. This unit explores the files and directories access.

10.1 OBJECTIVES

This unit helps the user to

- Understand the file access methods
- Learn directories types

10.2 FILE CONCEPT

Computers can store information on various storage media, such as magnetic disks, magnetic tapes, and optical disks. So that the computer system will be convenient to use, the operating system provides a uniform logical view of stored information. The operating system abstracts from the physical properties of its storage devices to define a logical storage unit, the file. Files are mapped by the operating system onto physical devices. These storage devices are usually nonvolatile, so the contents are persistent between system reboots

A file is a named collection of related information that is recorded on secondary storage. From a user's perspective, a file is the smallest allotment of logical secondary storage; that is, data cannot be written to

secondary storage unless they are within a file. Commonly, files represent programs (both source and object forms) and data. Data files may be numeric, alphabetic, alphanumeric, or binary. Files may be free form, such as text files, or may be formatted rigidly. In general, a file is a sequence of bits, bytes, lines, or records, the meaning of which is defined by the file's creator and user. The concept of a file is thus extremely general.

The information in a file is defined by its creator. Many different types of information may be stored in a file—source or executable programs, numeric or text data, photos, music, video, and so on. A file has a certain defined structure, which depends on its type. A text file is a sequence of characters organized into lines (and possibly pages). A source file is a sequence of functions, each of which is further organized as declarations followed by executable statements. An executable file is a series of code sections that the loader can bring into memory and execute

10.2.1 File Attributes

A file is named, for the convenience of its human users, and is referred to by its name. A name is usually a string of characters, such as example.c. Some systems differentiate between uppercase and lowercase characters in names, whereas other systems do not. When a file is named, it becomes independent of the process, the user, and even the system that created it. For instance, one user might create the file example.c, and another user might edit that file by specifying its name. The file's owner might write the file to a USB disk, send it as an e-mail attachment, or copy it across a network, and it could still be called example.c on the destination system.

A file's attributes vary from one operating system to another but typically consist of these:

• **Name**. The symbolic file name is the only information kept in human readable form.

• **Identifier**. This unique tag, usually a number, identifies the file within the file system; it is the non-human-readable name for the file.

• **Type**. This information is needed for systems that support different types of files.

• **Location**. This information is a pointer to a device and to the location of the file on that device.

• **Size**. The current size of the file (in bytes, words, or blocks) and possibly the maximum allowed sizes are included in this attribute.

• **Protection**. Access-control information determines who can do reading, writing, executing, and so on.

• **Time, date, and user identification**. This information may be kept for creation, last modification, and last use. These data can be useful for protection, security, and usage monitoring.

10.2.2 File Operations

A file is an abstract data type. To define a file properly, we need to consider the operations that can be performed on files. The operating system can provide system calls to create, write, read, reposition, delete, and truncate files. Let's examine what the operating system must do to perform each of these six basic file operations. It should then be easy to see how other similar operations, such as renaming a file, can be implemented.

• **Creating a file**. Two steps are necessary to create a file. First, space in the file system must be found for the file. We discuss how to allocate space for the file in Chapter 12. Second, an entry for the new file must be made in the directory.

• **Writing a file**. To write a file, we make a system call specifying both the name of the file and the information to be written to the file. Given the name of the file, the system searches the directory to find the file's location. The system must keep a write pointer to the location in the file where the next write is to take place. The write pointer must be updated whenever a write occurs.

• **Reading a file**. To read from a file, we use a system call that specifies the name of the file and where (in memory) the next block of the file should be put. Again, the directory is searched for the associated entry, and the system needs to keep a read pointer to the location in the file where the next read is to take place. Once the read has taken place, the read pointer is updated. Because a process is usually either reading from or writing to a file, the current operation location can be kept as a per-process current file-position pointer. Both the read and write operations use this same pointer, saving space and reducing system complexity.

• **Repositioning within a file**. The directory is searched for the appropriate entry, and the current-file-position pointer is repositioned to a given value. Repositioning within a file need not involve any actual I/O. This file operation is also known as a file seeks.

• **Deleting a file**. To delete a file, we search the directory for the named file. Having found the associated directory entry, we release all file space, so that it can be reused by other files, and erase the directory entry.

• **Truncating a file**. The user may want to erase the contents of a file but keep its attributes. Rather than forcing the user to delete the file and then recreate it, this function allows all attributes to remain unchanged—except for file length—but lets the file be reset to length zero and its file space released.

10.3 ACCESS METHODS

Files store information. When it is used, this information must be accessed and read into computer memory. The information in the file can be accessed in several ways. Some systems provide only one access method

for files. While others support many access methods, and choosing the right one for a particular application is a major design problem.

10.3.1 Sequential Access

The simplest access method is sequential access. Information in the file is processed in order, one record after the other. This mode of access is by far the most common; for example, editors and compilers usually access files in this fashion. Reads and writes make up the bulk of the operations on a file. A read operation—read next()—reads the next portion of the file and automatically advances a file pointer, which tracks the I/O location. Similarly, the write operation—write next()—appends to the end of the file and advances to the end of the newly written material (the new end of file). Such a file can be reset to the beginning, and on some systems, a program may be able to skip forward or backward n records for some integer n—perhaps only for n = 1. Sequential access, which is depicted in Figure 11.4, is based on a tape model of a file and works as well on sequential-access devices as it does on random-access ones.

10.3.2 Direct Access

Another method is direct access (or relative access). Here, a file is made up of fixed-length logical records that allow programs to read and write records rapidly in no particular order. The direct-access method is based on a disk model of a file, since disks allow random access to any file block. The file is viewed as a numbered sequence of blocks or records. Thus, we may read block 14, then read block 53, and then write block 7. There are no restrictions on the order of reading or writing for a direct-access file.

Direct-access files are of great use for immediate access to large amounts of information. Databases are often of this type. When a query concerning a particular subject arrives, we compute which block contains the answer and then read that block directly to provide the desired information.

As a simple example, on an airline-reservation system, we might store all the information about a particular flight (for example, flight 713) in the block identified by the flight number. Thus, the number of available seats for flight 713 is stored in block 713 of the reservation file. To store information about a larger set, such as people, we might compute a hash function on the people's names or search a small in-memory index to determine a block to read and search.

For the direct-access method, the file operations must be modified to include the block number as a parameter. Thus, we have read(n), where n is the block number, rather than read next(), and write(n) rather than write next(). An alternative approach is to retain read next() and write next(), as with sequential access, and to add an operation position

file(n) where n is the block number. Then, to effect a read(n), we would position file(n) and then read next(). The block number provided by the user to the operating system is normally a relative block number. A relative block number is an index relative to the beginning of the file. Thus, the

first relative block of the file is 0, the next is 1, and so on, even though the absolute disk address may be 14703 for the first block and 3192 for the second. The use of relative block numbers allows the operating system to decide where the file should be placed (called the allocation problem, as we discuss in Chapter 12) and helps to prevent the user from accessing portions of the file system that may not be part of her file. Some systems start their relative block numbers at 0; others start at 1.

How, then, does the system satisfy a request for record N in a file? Assuming we have a logical record length L, the request for record N is turned into an I/O request for L bytes starting at location L ∗ (N) within the file (assuming the first record is N = 0). Since logical records are of a fixed size, it is also easy to read, write, or delete a record.

Not all operating systems support both sequential and direct access for files. Some systems allow only sequential file access; others allow only direct access. Some systems require that a file be defined as sequential or direct when it is created. Such a file can be accessed only in a manner consistent with its declaration. We can easily simulate sequential access on a direct-access file by simply keeping a variable cp that defines our current position, is extremely inefficient and clumsy.

10.3.3 Other Access Methods

Other access methods can be built on top of a direct-access method. These methods generally involve the construction of an index for the file. The index, like an index in the back of a book, contains pointers to the various blocks. To find a record in the file, we first search the index and then use the pointer to access the file directly and to find the desired record. For example, a retail-price file might list the universal product codes (UPCs) for items, with the associated prices. Each record consists of a 10-digit UPC and a 6-digit price, for a 16-byte record. If our disk has 1,024 bytes per block, we can store 64 records per block. A file of 120,000 records would occupy about 2,000 blocks (2 million bytes). By keeping the file sorted by UPC, we can define an index consisting of the first UPC in each block. This index would have 2,000 entries of 10 digits each, or 20,000 bytes, and thus could be kept in memory. To find the price of a particular item, we can make a binary search of the index.

From this search, we learn exactly which block contains the desired record and access that block. This structure allows us to search a large file doing little I/O. With large files, the index file itself may become too large to be kept in memory. One solution is to create an index for the index file. The primary index file contains pointers to secondary index files, which point to the actual data items.

For example, IBM’s indexed sequential-access method (ISAM) uses a small master index that points to disk blocks of a secondary index. The secondary index blocks point to the actual file blocks. The file is kept sorted on a defined key. To find a particular item, we first make a binary search of the master index, which provides the block number of the

secondary index. This block is read in, and again a binary search is used to find the block containing the desired record. Finally, this block is searched sequentially. In this way, any record can be located from its key by at most two direct-access reads. Figure 11.6 shows a similar situation as implemented by VMS index and relative files.

sequential access	implementation for direct access
reset	cp = 0;
read_next	read cp ; cp = cp + 1;
write_next	write cp; cp = cp + 1;

Figure10.1 Simulation of Sequential Access

10.4 DIRECTORY OVERVIEW

The directory can be viewed as a symbol table that translates file names into their directory entries. If we take such a view, we see that the directory itself can be organized in many ways. The organization must allow us to insert entries, to delete entries, to search for a named entry, and to list all the entries in the directory. In this section, we examine several schemes for defining the logical structure of the directory system. When considering a particular directory structure, we need to keep in mind the operations that are to be performed on a directory:

• Search for a file. We need to be able to search a directory structure to find the entry for a particular file. Since files have symbolic names, and similar names may indicate a relationship among files, we may want to be able to find all files whose names match a particular pattern.

• Create a file. New files need to be created and added to the directory.

• Delete a file. When a file is no longer needed, we want to be able to remove it from the directory.

• List a directory. We need to be able to list the files in a directory and the contents of the directory entry for each file in the list.

• Rename a file. Because the name of a file represents its contents to its users, we must be able to change the name when the contents or use of the file

Changes. Renaming a file may also allow its position within the directory structure to be changed.

• Traverse the file system. We may wish to access every directory and every file within a directory structure. For reliability, it is a good idea to save the contents and structure of the entire file system at regular intervals. Often, we do this by copying all files to magnetic tape. This technique provides a backup copy in case of system failure. In addition, if a file is no longer in use, the file can be copied to tape and the disk space of that file released for reuse by another file.

10.4.1 Single-Level Directory

The simplest directory structure is the single-level directory. All files are contained in the same directory, which is easy to support and understand (Figure 11.9). A single-level directory has significant limitations, however, when the number of files increases or when the system has more than one user. Since all files are in the same directory, they must have unique names. If two users call their data file test.txt, then the unique-name rule is violated. For example, in one programming class, 23 students called the program for their second assignment prog2.c; another 11 called it assign2.c. Fortunately, most file systems support file names of up to 255 characters, so it is relatively easy to select unique file names.

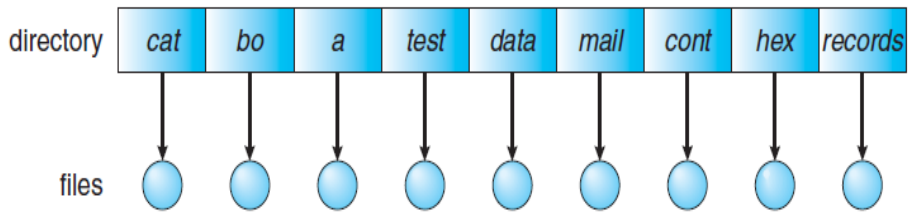

Figure10.2 Single level directory

Even a single user on a single-level directory may find it difficult to remember the names of all the files as the number of files increases. It is not uncommon for a user to have hundreds of files on one computer system and an equal number of additional files on another system. Keeping track of so many files is a daunting task.

10.4.2 Two-Level Directory

As we have seen, a single-level directory often leads to confusion of file names among different users. The standard solution is to create a separate directory for each user. In the two-level directory structure, each user has his own user file directory (UFD). The UFDs have similar structures, but each lists only the files of a single user. When a user job starts or a user logs in, the system's master file directory (MFD) is searched. The MFD is indexed by user name or account number, and each entry points to the UFD for that user (Figure 11.10).

When a user refers to a particular file, only his own UFD is searched. Thus, different users may have files with the same name, as long as all the file names within each UFD are unique. To create a file for a user, the

operating system searches only that user's UFD to ascertain whether another file of that name exists. To delete a file, the operating system confines its search to the local UFD; thus, it cannot accidentally delete another user's file that has the same name.

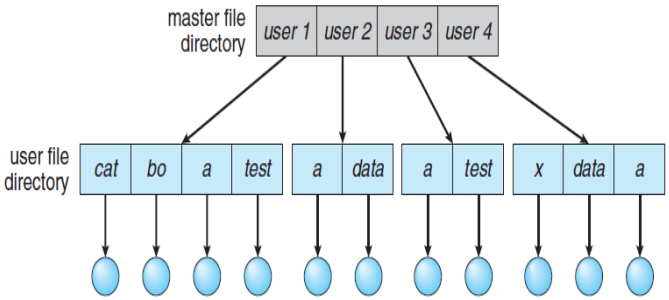

Figure 10.3 Two-level directory structure.

10.4.3 Tree-Structured Directories

Once we have seen how to view a two-level directory as a two-level tree, the natural generalization is to extend the directory structure to a tree of arbitrary height (Figure 11.11). This generalization allows users to create their own subdirectories and to organize their files accordingly. A tree is the most common directory structure. The tree has a root directory, and every file in the system has a unique path name.

A directory (or subdirectory) contains a set of files or subdirectories. A directory is simply another file, but it is treated in a special way. All directories have the same internal format. One bit in each directory entry defines the entry as a file (0) or as a subdirectory (1). Special system calls are used to create and delete directories. In normal use, each process has a current directory. The current directory should contain most of the files that are of current interest to the process. When reference is made to a file, the current directory is searched. If a file is needed that is not in the current directory, then the user usually must either specify a path name or change the current directory to be the directory holding that file. To change directories, a system call is provided that takes a directory name as a parameter and uses it to redefine the current directory. Thus, the user can change her current directory whenever she wants. From one change directory() system call to the next, all open() system calls search the current directory for the specified file. Note that the search path may or may not contain a special entry that stands for "the current directory.

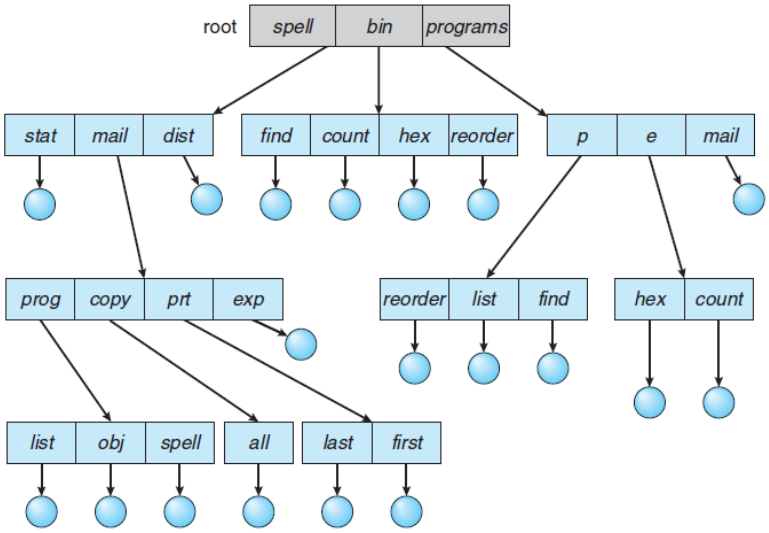

Figure 10.4 Tree-structured directory structure

10.4.4 Acyclic-Graph Directories

Consider two programmers who are working on a joint project. The files associated with that project can be stored in a subdirectory, separating them from other projects and files of the two programmers. But since both programmers are equally responsible for the project, both want the subdirectory to be in their own directories. In this situation, the common subdirectory should be shared.

A shared directory or file exists in the file system in two (or more) places at once. A tree structure prohibits the sharing of files or directories. An acyclic graph —that is, a graph with no cycles—allows directories to share subdirectories and files (Figure 11.12). The same file or subdirectory may be in two different directories. The acyclic graph is a natural generalization of the tree-structured directory scheme.

It is important to note that a shared file (or directory) is not the same as two copies of the file. With two copies, each programmer can view the copy rather than the original, but if one programmer changes the file, the changes will not appear in the other's copy. With a shared file, only one actual file exists, so any changes made by one person are immediately visible to the other. Sharing is particularly important for subdirectories; a new file created by one person will automatically appear in all the shared subdirectories.

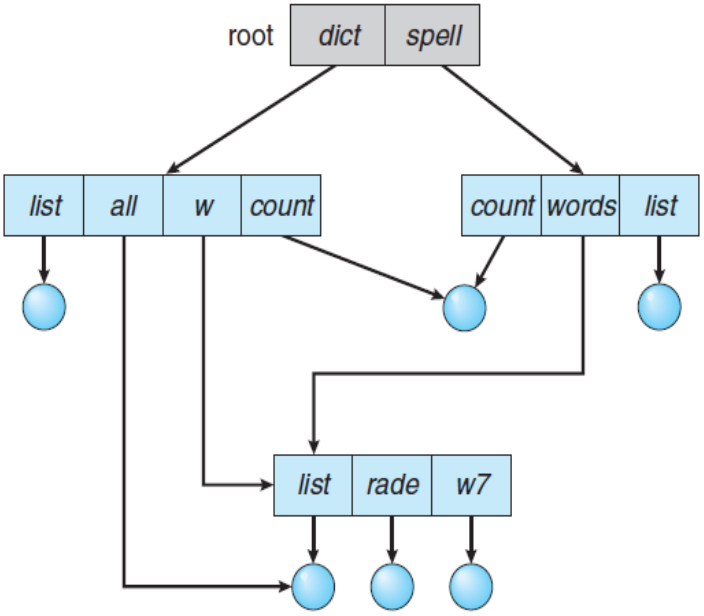

Figure 10.5 Acyclic-graph directory structure.

10.4.5General Graph Directory

A serious problem with using an acyclic-graph structure is ensuring that there are no cycles. If we start with a two-level directory and allow users to create subdirectories, a tree-structured directory results. It should be fairly easy to see that simply adding new files and subdirectories to an existing tree-structured directory preserves the tree-structured nature. However, when we add links, the tree structure is destroyed, resulting in a simple graph structure (Figure 11.13). The primary advantage of an acyclic graph is the relative simplicity of the algorithms to traverse the graph and to determine when there are no more references to a file. We want to avoid traversing shared sections of an acyclic graph twice, mainly for performance reasons. If we have just searched a major shared subdirectory for a particular file without finding it, we want to avoid searching that subdirectory again; the second search would be a waste of time.

If cycles are allowed to exist in the directory, we likewise want to avoid searching any component twice, for reasons of correctness as well as performance. A poorly designed algorithm might result in an infinite loop continually searching through the cycle and never terminating

A similar problem exists when we are trying to determine when a file can be deleted. With acyclic-graph directory structures, a value of 0 in the reference count means that there are no more references to the file or directory, and the file can be deleted. However, when cycles exist, the reference count may not be 0 even when it is no longer possible to refer to a directory or file. This anomaly results from the possibility of self-referencing (or a cycle) in the directory structure. In this case, we generally need to use a garbage collection scheme to determine when the last

reference has been deleted and the disk space can be reallocated. Garbage collection involves traversing the entire file system, marking everything that can be accessed. Then, a second pass collects everything that is not marked onto a list of free space. (A similar marking procedure can be used to ensure that a traversal or search will cover everything in the file system once and only once.) Garbage collection for a disk-based file system, however, is extremely time consuming and is thus seldom attempted.

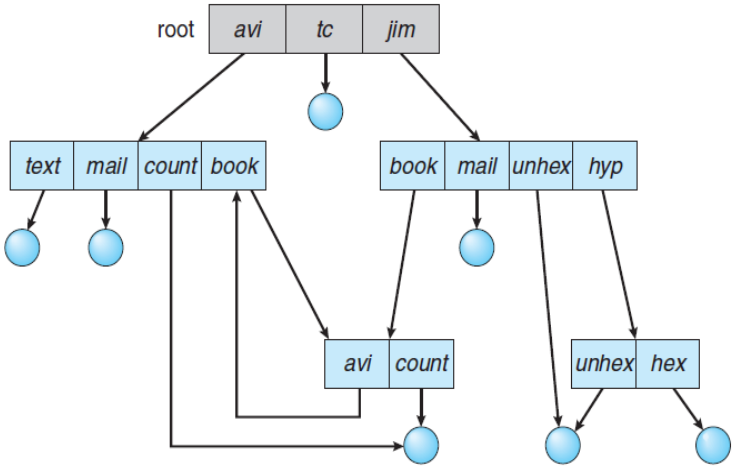

Figure 10.6 General graph directory

Garbage collection is necessary only because of possible cycles in the graph. Thus, an acyclic-graph structure is much easier to work with. The difficulty is to avoid cycles as new links are added to the structure. How do we know when a new link will complete a cycle? There are algorithms to detect cycles in graphs; however, they are computationally expensive, especially when the graph is on disk storage. A simpler algorithm in the special case of directories and links is to bypass links during directory traversal. Cycles are avoided, and no extra overhead is incurred.

Check your Progress

1. How to create a File?
2. How to write a file?
3. How to read a file?
4. How to delete a file?
5. What truncating a file?

10.5. ANSWERS TO CHECK YOUR PROGRESS

1. Two steps are necessary to create a file. First, space in the file system must be found for the file. We discuss how to allocate space for the file in Chapter 12. Second, an entry for the new file must be made in the directory.

2. To write a file, we make a system call specifying both the name of the file and the information to be written to the file. Given the name

of the file, the system searches the directory to find the file's location. The system must keep a write pointer to the location in the file Self-Instructional Material NOTES 136 where the next write is to take place. The write pointer must be updated whenever a write occurs.

3. To read from a file, we use a system call that specifies the name of the file and where (in memory) the next block of the file should be put. Again, the directory is searched for the associated entry, and the system needs to keep a read pointer to the location in the file where the next read is to take place. Once the read has taken place, the read pointer is updated. Because a process is usually either reading from or writing to a file, the current operation location can be kept as a per-process current fileposition pointer. Both the read and write operations use this same pointer, saving space and reducing system complexity.

4. To delete a file, we search the directory for the named file. Having found the associated directory entry, we release all file space, so that it can be reused by other files, and erase the directory entry.

5. The user may want to erase the contents of a file but keep its attributes. Rather than forcing the user to delete the file and then recreate it, this function allows all attributes to remain unchanged—except for file length—but lets the file be reset to length zero and its file space released

10.6. SUMMARY

- Files are the important storage structures in which data can be easily stores and access.
- To write a file, we make a system call specifying both the name of the file and the information to be written to the file.
- Direct-access files are of great use for immediate access to large amounts of information. Databases are often of this type.
- A shared directory or file exists in the file system in two (or more) places at once.
- A single-level directory has significant limitations, however, when the number of files increases or when the system has more than one user.

10.7. KEYWORDS

- **File:** A file is a named collection of related information that is recorded on secondary storage such as magnetic disks, magnetic tapes and optical disks.
- **Sequential access:** Information in the file is processed in order, one record after the other.

- **Directory:** The directory can be viewed as a symbol table that translates file names into their directory entries.
- **Single level dictionary:** The simplest directory structure is the single-level directory. All files are contained in the same directory, which is easy to support and understand
- **Protection**. Access-control information determines who can do reading, writing, executing, and so on.

10.8. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is Sequential Access?
2. What is Direct Access?
3. What is Single Level Directory?
4. What is Two Level Directory?
5. What is Acyclic Graph Directory?

Long Answer questions:

1. Explain File Operations?
2. Explain File Attributes?

10.9. FURTHER READINGS

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UNIT XI STRUCTURES

Structure

11.0 Introduction
11.1Objective
11.2 File-System Mounting
11.3 File Sharing
11.4 Protection
11.5 Answers to Check Your Progress Questions
11.6 Summary
11.7 Key Words
11.8 Self Assessment Questions and Exercises
11.9 Further Readings

11.0 INTRODUCTION

This unit describes the file system mounting and the various ways the file system can be shared. Mounting is a process by which the operating system makes files and directories on a storage device (such as hard drive, CD-ROM, or network share) available for users to access via the computer's file system. In general, the process of mounting comprises operating system acquiring access to the storage medium; recognizing, reading, processing file system structure and metadata on it; before registering them to the virtual file system (VFS) component. The location in VFS that the newly-mounted medium was registered is called mount point; when the mounting process is completed, the user can access files and directories on the medium from there. Once the file us created it also needs to protect. The file protection method helps to safeguard the file information and view it more protectively.

11.1 OBJECTIVE

This unit explores and helps to understand the user with the following concepts such as

- File system Mounting
- File sharing
- Protection

11.2 FILE-SYSTEM MOUNTING

Just as a file must be opened before it is used, a file system must be mounted before it can be available to processes on the system. More specifically, the directory structure may be built out of multiple volumes, which must be mounted to make them available within the file-system name space. The mount procedure is straightforward. The operating system is given the name of the device and the mount point—the location within the file structure where the file system is to be attached. Some operating systems require that a file system type be provided, while others inspect

the structures of the device and determine the type of file system. Typically, a mount point is an empty directory. For instance, on a UNIX system, a file system containing a user's home directories might be mounted as /home; then, to access the directory structure within that file system, we could precede the directory names with /home, as in /home/jane. Mounting that file system under /users would result in the path name /users/jane, which we could use to reach the same directory.

Next, the operating system verifies that the device contains a valid file system. It does so by asking the device driver to read the device directory and verifying that the directory has the expected format. Finally, the operating system notes in its directory structure that a file system is mounted at the specified mount point. This scheme enables the operating system to traverse its directory structure, switching among file systems, and even file systems of varying types, as appropriate.

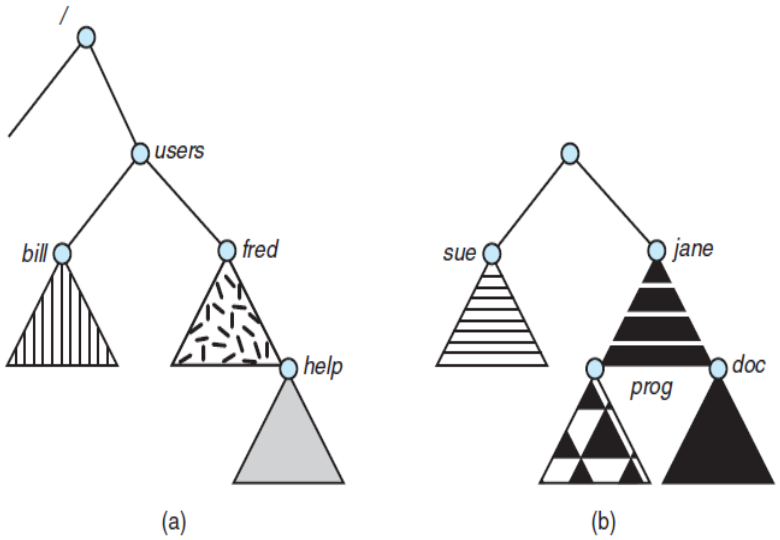

Figure 11.1 File system. (a) Existing system. (b) Unmounted volume.

To illustrate file mounting, consider the file system depicted in Figure 11.14, where the triangles represent subtrees of directories that are of interest. Figure 11.14(a) shows an existing file system, while Figure 11.14(b) shows an unmounted volume residing on /device/dsk. At this point, only the files on the existing file system can be accessed. Figure 11.15 shows the effects of mounting the volume residing on /device/dsk over /users. If the volume is unmounted, the file system is restored to the situation depicted in Figure 11.14. Systems impose semantics to clarify functionality. For example, a system may disallow a mount over a directory that contains files; or it may make the mounted file system available at that directory and obscure the directory's existing files until the file system is unmounted, terminating the use of the file system and allowing access to the original files in that directory. As another example, a

system may allow the same file system to be mounted repeatedly, at different mount points; or it may only allow one mount per file system.

Consider the actions of the Mac OS X operating system. Whenever the system encounters a disk for the first time (either at boot time or while the system is running), the Mac OS X operating system searches for a file system on the device. If it finds one, it automatically mounts the file system under m the /Volumes directory, adding a folder icon labeled with the name of the file system (as stored in the device directory). The user is then able to click on the icon and thus display the newly mounted file

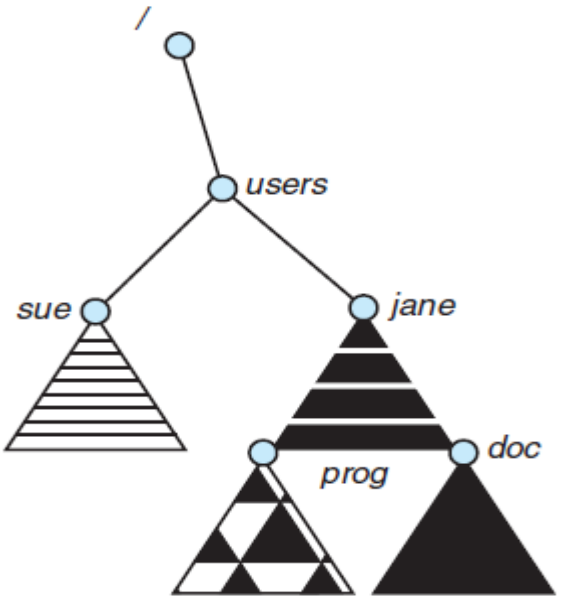

Figure 11.2 Mount point.

The Microsoft Windows family of operating systems maintains an extended two-level directory structure, with devices and volumes assigned drive letters. Volumes have a general graph directory structure associated with the drive letter. The path to a specific file takes the form of drive-letter:\path\to\file. The more recent versions of Windows allow a file system to be mounted anywhere in the directory tree, just as UNIX does. Windows operating systems automatically discover all devices and mount all located file systems at boot time. In some systems, like UNIX, the mount commands are explicit. A system configuration file contains a list of devices and mount points for automatic mounting at boot time, but other mounts may be executed manually.

11.3 FILE SHARING

In this section, we examine more aspects of file sharing. We begin by discussing general issues that arise when multiple users share files. Once multiple users are allowed to share files, the challenge is to extend sharing to multiple file systems, including remote file systems; we discuss that

challenge as well. Finally, we consider what to do about conflicting actions occurring on shared files.

11.3.1 MULTIPLE USERS

When an operating system accommodates multiple users, the issues of file sharing, file naming, and file protection become preeminent. Given a directory structure that allows files to be shared by users, the system must mediate the file sharing. The system can either allow a user to access the files of other users by default or require that a user specifically grant access to the files. These are the issues of access control and protection, which are covered in Section 11.6. To implement sharing and protection, the system must maintain more file and directory attributes than are needed on a single-user system. Although many approaches have been taken to meet this requirement, most systems have evolved to use the concepts of file (or directory) owner (or user) and group. The owner is the user who can change attributes and grant access and who has the most control over the file. The group attribute defines a subset of users who can share access to the file. For example, the owner of a file on a UNIX system can issue all operations on a file, while members of the file's group can execute one subset of those operations, and all other users can execute another subset of operations. Exactly which operations can be executed by group members and other users is definable by the file's owner. More details on permission attributes are included in the next section.

The owner and group IDs of a given file (or directory) are stored with the other file attributes. When a user requests an operation on a file, the user ID can be compared with the owner attribute to determine if the requesting user is the owner of the file. Likewise, the group IDs can be compared. The result indicates which permissions are applicable. The system then applies those permissions to the requested operation and allows or denies it. Many systems have multiple local file systems, including volumes of a single disk or multiple volumes on multiple attached disks. In these cases, the ID checking and permission matching are straightforward, once the file systems are mounted.

11.3.2 Remote File Systems

With the advent of networks communication among remote computers became possible. Networking allows the sharing of resources spread across a campus or even around the world. One obvious resource to share is data in the form of files. Through the evolution of network and file technology, remote file-sharing methods have changed. The first implemented method involves manually transferring files between machines via programs like ftp. The second major method uses a distributed file system (DFS) in which remote directories are visible from a local machine. In some ways, the third method, the WorldWide

Web, is a reversion to the first. A browser is needed to gain access to the remote files, and separate operations (essentially a wrapper for ftp) are used to transfer files. Increasingly, cloud computing is being used for file

sharing as well. ftp is used for both anonymous and authenticated access. Anonymous access allows a user to transfer files without having an account on the remote system. The WorldWideWeb uses anonymous file exchange almost exclusively. DFS involves a much tighter integration between the machine that is accessing the remote files and the machine providing the files. This integration adds complexity, as we describe in this section.

11.3.3 The Client–Server Model

Remote file systems allow a computer to mount one or more file systems from one or more remote machines. In this case, the machine containing the files is the server, and the machine seeking access to the files is the client. The client–server relationship is common with networked machines. Generally, the server declares that a resource is available to clients and specifies exactly which resource (in this case, which files) and exactly which clients. A server can serve multiple clients, and a client can use multiple servers, depending on the implementation details of a given client–server facility. The server usually specifies the available files on a volume or directory level. Client identification is more difficult. A client can be specified by a network name or other identifier, such as an IP address, but these can be spoofed, or imitated. As a result of spoofing, an unauthorized client could be allowed access to the server. More secure solutions include secure authentication of the client via encrypted keys. Unfortunately, with security come many challenges, including ensuring compatibility of the client and server (they must use the same encryption algorithms) and security of key exchanges (intercepted keys could again allow unauthorized access). Because of the difficulty of solving these problems, unsecure authentication methods are most commonly used.

In the case of UNIX and its network file system (NFS), authentication takes place via the client networking information, by default. In this scheme, the user's IDs on the client and server must match. If they do not, the server will be unable to determine access rights to files. Consider the example of a user who has an ID of 1000 on the client and 2000 on the server. A request from the client to the server for a specific file will not be handled appropriately, as the server will determine if user 1000 has access to the file rather than basing the determination on the real user ID of 2000. Access is thus granted or denied based on incorrect authentication information. The server must trust the client to present the correct user ID. Note that the NFS protocols allow many-to-many relationships. That is, many servers can provide files to many clients. In fact, a given machine can be both a server to some NFS clients and a client of other NFS servers.

Once the remote file system is mounted, file operation requests are sent on behalf of the user across the network to the server via the DFS protocol. Typically, a file-open request is sent along with the ID of the requesting user. The server then applies the standard access checks to determine if the user has credentials to access the file in the mode requested. The request is either allowed or denied. If it is allowed, a file handle is returned to the client application, and the application then can perform read, write, and

other operations on the file. The client closes the file when access is completed. The operating system may apply semantics similar to those for a local file-system mount or may use different semantics.

11.3.4 Distributed Information Systems

To make client–server systems easier to manage, distributed information systems, also known as distributed naming services, provide unified access to the information needed for remote computing. The domain name system (DNS) provides host-name-to-network-address translations for the entire Internet. Before DNS became widespread, files containing the same information were sent via e-mail or ftp between all networked hosts. Obviously, this methodology was not scalable. Other distributed information systems provide user name/password/user ID/group ID space for a distributed facility. UNIX systems have employed a wide variety of distributed information methods. Sun Microsystems (now part of Oracle Corporation) introduced yellow pages (since renamed network information service, or NIS), and most of the industry adopted its use. It centralizes storage of user names, host names, printer information, and the like.

Unfortunately, it uses unsecure authentication methods, including sending user passwords unencrypted (in clear text) and identifying hosts by IP address. Sun's NIS+ was a much more secure replacement for NIS but was much more complicated and was not widely adopted. In the case of Microsoft's common Internet file system (CIFS), network information is used in conjunction with user authentication (user name and password) to create a network login that the server uses to decide whether to allow or deny access to a requested file system. For this authentication to be valid, the user names must match from machine to machine (as with NFS). Microsoft uses active directory as a distributed naming structure to provide a single name space for users. Once established, the distributed naming facility is used by all clients and servers to authenticate users.

The industry is moving toward use of the lightweight directory-access protocol (LDAP) as a secure distributed naming mechanism. In fact, active directory is based on LDAP. Oracle Solaris and most other major operating systems include LDAP and allow it to be employed for user authentication as well as system-wide retrieval of information, such as availability of printers. Conceivably, one distributed LDAP directory could be used by an organization to store all user and resource information for all the organization's computers. The result would be secure single sign-on for users, who would enter their authentication information once for access to all computers within the organization. It would also ease system-administration efforts by combining, in one location, information that is currently scattered in various files on each system or in different distributed information services.

11.3.5 Failure Modes

Local file systems can fail for a variety of reasons, including failure of the disk containing the file system, corruption of the directory structure or

other disk-management information (collectively called metadata), disk-controller failure, cable failure, and host-adapter failure. User or system-administrator failure can also cause files to be lost or entire directories or volumes to be deleted. Many of these failures will cause a host to crash and an error condition to be displayed, and human intervention will be required to repair the damage. Remote file systems have even more failure modes. Because of the complexity of network systems and the required interactions between remote machines, many more problems can interfere with the proper operation of remote file systems. In the case of networks, the network can be interrupted between two hosts. Such interruptions can result from hardware failure, poor hardware configuration, or networking implementation issues. Although some networks have built-in resiliency, including multiple paths between hosts, many do not. Any single failure can thus interrupt the flow of DFS commands.

Consider a client in the midst of using a remote file system. It has files open from the remote host; among other activities, it may be performing directory lookups to open files, reading or writing data to files, and closing files. Now consider a partitioning of the network, a crash of the server, or even a scheduled shutdown of the server. Suddenly, the remote file system is no longer reachable. This scenario is rather common, so it would not be appropriate for the client system to act as it would if a local file system were lost. Rather, the system can either terminate all operations to the lost server or delay operations until the server is again reachable. These failure semantics are defined and implemented as part of the remote-file-system protocol. Termination of all operations can result in users' losing data—and patience. Thus, most DFS protocols either enforce or allow delaying of file-system operations to remote hosts, with the hope that the remote host will become available again.

To implement this kind of recovery from failure, some kind of state information may be maintained on both the client and the server. If both server and client maintain knowledge of their current activities and open files, then they can seamlessly recover from a failure. In the situation where the server crashes but must recognize that it has remotely mounted exported file systems and opened files, NFS takes a simple approach, implementing a stateless DFS.

In essence, it assumes that a client request for a file read or write would not have occurred unless the file system had been remotely mounted and the file had been previously open. The NFS protocol carries all the information needed to locate the appropriate file and perform the requested operation. Similarly, it does not track which clients have the exported volumes mounted, again assuming that if a request comes in, it must be legitimate. While this stateless approach makes NFS resilient and rather easy to implement, it also makes it unsecure. For example, forged read or write requests could be allowed by an NFS server. These issues are addressed in the industry standard NFS Version 4, in which NFS is made stateful to improve its security, performance, and functionality.

11.3.6 Consistency Semantics

Consistency semantics represent an important criterion for evaluating any file system that supports file sharing. These semantics specify how multiple users of a system are to access a shared file simultaneously. In particular, they specify when modifications of data by one user will be observable by other users. These semantics are typically implemented as code with the file system.

Consistency semantics are directly related to the process synchronization algorithms of Chapter 5. However, the complex algorithms of that chapter tend not to be implemented in the case of file I/O because of the great latencies and slow transfer rates of disks and networks. For example, performing an atomic transaction to a remote disk could involve several network communications, several disk reads and writes, or both. Systems that attempt such a full set of functionalities tend to perform poorly. A successful implementation of complex sharing semantics can be found in the Andrew file system. For the following discussion, we assume that a series of file accesses (that is, reads and writes) attempted by a user to the same file is always enclosed between the open() and close() operations. The series of accesses between the open() and close() operations makes up a file session. To illustrate the concept, we sketch several prominent examples of consistency semantics.

11.3.7 Immutable-Shared-Files Semantics

A unique approach is that of immutable shared files. Once a file is declared as shared by its creator, it cannot be modified. An immutable file has two key properties: its name may not be reused, and its contents may not be altered. Thus, the name of an immutable file signifies that the contents of the file are fixed.

11.4 PROTECTION

When information is stored in a computer system, we want to keep it safe from physical damage (the issue of reliability) and improper access (the issue of protection). Reliability is generally provided by duplicate copies of files. Many computers have systems programs that automatically (or through computer-operator intervention) copy disk files to tape at regular intervals (once per day or week or month) to maintain a copy should a file system be accidentally destroyed.

File systems can be damaged by hardware problems (such as errors in reading or writing), power surges or failures, head crashes, dirt, temperature extremes, and vandalism. Files may be deleted accidentally. Bugs in the file-system software can also cause file contents to be lost. Reliability is covered in more detail in Chapter 10.

Protection can be provided in many ways. For a single-user laptop system, we might provide protection by locking the computer in a desk drawer or file cabinet. In a larger multiuser system, however, other mechanisms are needed.

11.4.1 Types of Access

The need to protect files is a direct result of the ability to access files. Systems that do not permit access to the files of other users do not need protection. Thus, we could provide complete protection by prohibiting access. Alternatively, we could provide free access with no protection. Both approaches are too extreme for general use. What is needed is controlled access. Protection mechanisms provide controlled access by limiting the types of file access that can be made. Access is permitted or denied depending on several factors, one of which is the type of access requested. Several different types of operations may be controlled:

• Read. Read from the file.

• Write.Write or rewrite the file.

• Execute. Load the file into memory and execute it.

• Append.Write new information at the end of the file.

• Delete. Delete the file and free its space for possible reuse.

• List. List the name and attributes of the file.

Other operations, such as renaming, copying, and editing the file, may also be controlled. For many systems, however, these higher-level functions may be implemented by a system program that makes lower-level system calls. Protection is provided at only the lower level. For instance, copying a file maybe implemented simply by a sequence of read requests. In this case, a user with read access can also cause the file to be copied, printed, and so on.

Many protection mechanisms have been proposed. Each has advantages and disadvantages and must be appropriate for its intended application. A small computer system that is used by only a few members of a research group, for example, may not need the same types of protection as a large corporate computer that is used for research, finance, and personnel operations.

11.4.2 Access Control

The most common approach to the protection problem is to make access dependent on the identity of the user. Different users may need different types of access to a file or directory. The most general scheme to implement identity dependent access is to associate with each file and directory an access-control list (ACL) specifying user names and the types of access allowed for each user. When a user requests access to a particular file, the operating system checks the access list associated with that file. If that user is listed for the requested access, the access is allowed. Otherwise, a protection violation occurs, and the user job is denied access to the file.

This approach has the advantage of enabling complex access methodologies. The main problem with access lists is their length. If we want to allow everyone to read a file, we must list all users with read access. This technique has two undesirable consequences:

• Constructing such a list may be a tedious and unrewarding task, especially if we do not know in advance the list of users in the system.

• The directory entry, previously of fixed size, now must be of variable size, resulting in more complicated space management.

These problems can be resolved by use of a condensed version of the access list. To condense the length of the access-control list, many systems recognize three classifications of users in connection with each file:

• Owner. The user who created the file is the owner.

• Group. A set of users who are sharing the file and need similar access is a group, or work group.

• Universe. All other users in the system constitute the universe.

The most common recent approach is to combine access-control lists with the more general (and easier to implement) owner, group, and universe access control scheme just described. For example, Solaris uses the three categories of access by default but allows access-control lists to be added to specific files and directories when more fine-grained access control is desired. To illustrate, consider a person, Sara, who is writing a new book. She has hired three graduate students (Jim, Dawn, and Jill) to help with the project. The text of the book is kept in a file named book.tex. The protection associated with this file is as follows:

• Sara should be able to invoke all operations on the file.

• Jim, Dawn, and Jill should be able only to read and write the file; they should not be allowed to delete the file.

Figure11.3 windows 7 access control

• All other users should be able to read, but not write, the file. (Sara is interested in letting as many people as possible read the text so that she can obtain feedback.)

To achieve such protection, we must create a new group—say, text— with members Jim, Dawn, and Jill. The name of the group, text, must then be associated with the file book.tex, and the access rights must be set in accordance with the policy we have outlined. Now consider a visitor to whom Sara would like to grant temporary access to Chapter 1. The visitor cannot be added to the text group because that would give him access to all chapters. Because a file can be in only one group.

Check your Progress

1. What is Access Control?
2. What is Read, Write and Execute access?
3. What is Immutable-Shared-Files Semantics?
4. What is a client and server?
5. What is Remote File System?

11.5. ANSWERS TO CHECK YOUR PROGRESS

1. The goal of access control is to minimize the risk of unauthorized access to physical and logical systems. Access control is a fundamental component of security compliance programs that ensures security technology and access control policies are in place to protect confidential information, such as customer data.

2. Read. Read from the file.
   Write.Write or rewrite the file.
   Execute. Load the file into memory and execute it.

3. When a file is declared as shared by its creator, it becomes immutable and the name cannot be re-used for any other resource. Hence it becomes read-only, and shared access is simple.

4. The machine containing the files is the server, and the machine seeking access to the files is the client.

5. The RFS (Remote File System) is a file system that allows the user to "share" a directory on a PC with remote PC over a serial connection. Remote PC will be able to access files on the shared PC directory just as they were local files; they can be opened, read, written, closed and so on.

11.6. SUMMARY

- Once multiple users are allowed to share files, the challenge is to extend sharing to multiple file systems, including remote file systems
- Networking allows the sharing of resources spread across a campus or even around the world.
- Remote file systems allow a computer to mount one or more file systems from one or more remote machines.
- Local file systems can fail for a variety of reasons, including failure of the disk containing the file system, corruption of the directory structure or other disk-management information, and so on.
- The most common approach to the protection problem is to make access dependent on the identity of the user.

11.7. KEYWORDS

- **Distributed information system:** To make client–server systems easier to manage, distributed information systems, also known as distributed naming services, provide unified access to the information needed for remote computing.
- **DNS:** The domain name system (DNS) provides host-name-to-network-address translations for the entire Internet.
- **Consistency semantics:** Consistency semantics represent an important criterion for evaluating any file system that supports file sharing.

11.8. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is Client server model?
2. What is Distributed Information system?
3. What is Failure modes?
4. What is Consistency Semantics?
5. What are types of Access?

Long Answer questions:

1. Explain File System Mounting?
2. Explain File Sharing?
3. Explain Protection?

11.9. FURTHER READINGS

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UNIT XII
IMPLEMENTING FILE SYSTEMS

Structure

12.0 Introduction
12.1 Objectives
12.2 File-System Structure
12.3 File-System Implementation
12.4 Answers to Check Your Progress Questions
12.5 Summary
12.6 Key Words
12.7 Self Assessment Questions and Exercises
12.8 Further Readings

12.0 INTRODUCTION

This unit briefs the file system implementation and how it is structured. Disks offer the massive amount of secondary storage where a file system can be maintained. They have two characteristics which make them a suitable medium for storing various files. A disk can be used to rewrite in place; it is possible to read a chunk from the disk, modify the chunk and write it back there in the same place. A disk can access directly any given block of data it contains. Hence, it is easy to access any file either in sequence or at random and switching from one single file to another need only to move the read-write heads and wait for the disk to rotate to that specific location. This also explains the free space management on how the files can be allocated and retrieved. The file system basic operations and implementation are illustrated.

12.1 OBJECTIVES

The user can understand the following concepts when they go through this unit such as

- Structure of the File system
- Implementation of file system

12.2 FILE-SYSTEM STRUCTURE

Disks provide most of the secondary storage on which file systems are maintained. Two characteristics make them convenient for this purpose:

1. A disk can be rewritten in place; it is possible to read a block from the disk, modify the block, and write it back into the same place.

2. A disk can access directly any block of information it contains. Thus, it is simple to access any file either sequentially or randomly, and switching from one file to another requires only moving the read–write heads and waiting for the disk to rotate.

To improve I/O efficiency, I/O transfers between memory and disk are performed in units of blocks. Each block has one or more sectors. Depending on the disk drive, sector size varies from 32 bytes to 4,096 bytes; the usual size is 512 bytes.

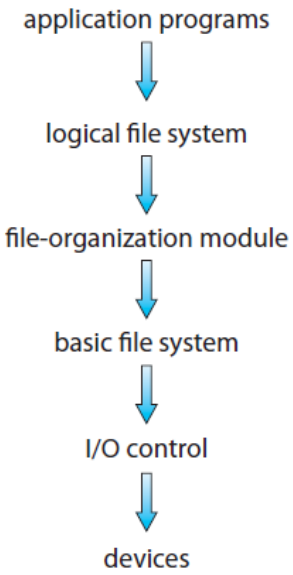


Figure12.1 Layered Structure

File systems provide efficient and convenient access to the disk by allowing data to be stored, located, and retrieved easily. A file system poses two quite different design problems. The first problem is defining how the file system should look to the user. This task involves defining a file and its attributes, the operations allowed on a file, and the directory structure for organizing files. The second problem is creating algorithms and data structures to map the logical file system onto the physical secondary-storage devices. The file system itself is generally composed of many different levels. The structure shown in Figure 12.1 is an example of a layered design. Each level in the design uses the features of lower levels to create new features for use by higher levels.

The I/O control level consists of device drivers and interrupt handlers to transfer information between the main memory and the disk system. A device driver can be thought of as a translator. Its input consists of high-level commands such as "retrieve block 123." Its output consists of low-level, hardware-specific instructions that are used by the hardware controller, which interfaces the I/O device to the rest of the system. The device driver usually writes specific bit patterns to special locations in the

I/O controller's memory to tell the controller which device location to act on and what actions to take.

The basic file system needs only to issue generic commands to the appropriate device driver to read and write physical blocks on the disk. Each physical block is identified by its numeric disk address (for example, drive 1, cylinder 73, track 2, sector 10). This layer also manages the memory buffers and caches that hold various file-system, directory, and data blocks. A block in the buffer is allocated before the transfer of a disk block can occur. When the buffer is full, the buffer manager must find more buffer memory or free up buffer space to allow a requested I/O to complete. Caches are used to hold frequently used file-system metadata to improve performance, so managing their contents is critical for optimum system performance.

The file-organization module knows about files and their logical blocks, as well as physical blocks. By knowing the type of file allocation used and the location of the file, the file-organization module can translate logical block addresses to physical block addresses for the basic file system to transfer. Each file's logical blocks are numbered from 0 (or 1) through N. Since the physical blocks containing the data usually do not match the logical numbers, a translation is needed to locate each block.

The file-organization module also includes the free-space manager, which tracks unallocated blocks and provides these blocks to the file-organization module when requested. Finally, the logical file system manages metadata information. Metadata includes all of the file-system structure except the actual data (or contents of the files). The logical file system manages the directory structure to provide the file-organization module with the information the latter needs, given a symbolic file name. It maintains file structure via file-control blocks. A file control block (FCB) (an inode in UNIX file systems) contains information about the file, including ownership, permissions, and location of the file contents.

When a layered structure is used for file-system implementation, duplication of code is minimized. The I/O control and sometimes the basic file-system code can be used by multiple file systems. Each file system can then have its own logical file-system and file-organization modules. Unfortunately, layering can introduce more operating-system overhead, which may result in decreased performance. The use of layering, including the decision about how many layers to use and what each layer should do, is a major challenge in designing new systems.

Many file systems are in use today, and most operating systems support more than one. For example, most CD-ROMs are written in the ISO 9660 format, a standard format agreed on by CD-ROM manufacturers. In addition to removable-media file systems, each operating system has one or more disk based file systems. UNIX uses the UNIX file system (UFS), which is based on the Berkeley Fast File System (FFS). Windows supports disk file-system formats of FAT, FAT32, and NTFS (or Windows NT File System), as well as CD-ROM and DVD file-system formats. Although

Linux supports over forty different file systems, the standard Linux file system is known as the extended file system, with the most common versions being ext3 and ext4. There are also distributed file systems in which a file system on a server is mounted by one or more client computers across a network.

File-system research continues to be an active area of operating-system design and implementation. Google created its own file system to meet the company's specific storage and retrieval needs, which include high performance access from many clients across a very large number of disks. Another interesting project is the FUSE file system, which provides flexibility in file-system development and use by implementing and executing file systems as user-level rather than kernel-level code. Using FUSE, a user can add a new file system to a variety of operating systems and can use that file system to manage her files.

12.3 FILE-SYSTEM IMPLEMENTATION

As was described in Section 11.1.2, operating systems implement open() and close() systems calls for processes to request access to file contents. In this section, we delve into the structures and operations used to implement file-system operations.

12.3.1 Overview

Several on-disk and in-memory structures are used to implement a file system. These structures vary depending on the operating system and the file system, but some general principles apply. On disk, the file system may contain information about how to boot an operating system stored there, the total number of blocks, the number and location of free blocks, the directory structure, and individual files. Many of these structures are detailed throughout the remainder of this chapter. Here, we describe them briefly:

• A boot control block (per volume) can contain information needed by the system to boot an operating system from that volume. If the disk does not contain an operating system, this block can be empty. It is typically the first block of a volume. In UFS, it is called the boot block. In NTFS, it is the partition boot sector.

• A volume control block (per volume) contains volume (or partition) details, such as the number of blocks in the partition, the size of the blocks, a free-block count and free-block pointers, and a free-FCB count and FCB pointers. In UFS, this is called a superblock. In NTFS, it is stored in the master file table.

• A directory structure (per file system) is used to organize the files. In UFS, this includes file names and associated in node numbers. In NTFS, it is stored in the master file table.

• A per-file FCB contains many details about the file. It has a unique identifier number to allow association with a directory entry. In NTFS, this

information is actually stored within the master file table, which uses a relational database structure, with a row per file.

The in-memory information is used for both file-system management and performance improvement via caching. The data are loaded at mount time, updated during file-system operations, and discarded at dismount. Several types of structures may be included.

• An in-memory mount table contains information about each mounted volume.

• An in-memory directory-structure cache holds the directory information of recently accessed directories. (For directories at which volumes are mounted, it can contain a pointer to the volume table.)

• The system-wide open-file table contains a copy of the FCB of each open file, as well as other

The per-process open-file table contains a pointer to the appropriate entry in the system-wide open-file table, as well as other information.

• Buffers hold file-system blocks when they are being read from disk or written to disk.

To create a new file, an application program calls the logical file system. The logical file system knows the format of the directory structures. To create a new file, it allocates a new FCB. (Alternatively, if the file-system implementation creates all FCBs at file-system creation time, an FCB is allocated from the set of free FCBs.) The system then reads the appropriate directory into memory, updates it with the new file name and FCB, and writes it back to the disk. Atypical FCB is shown in Figure 12.2.

12.3.2 Partitions and Mounting

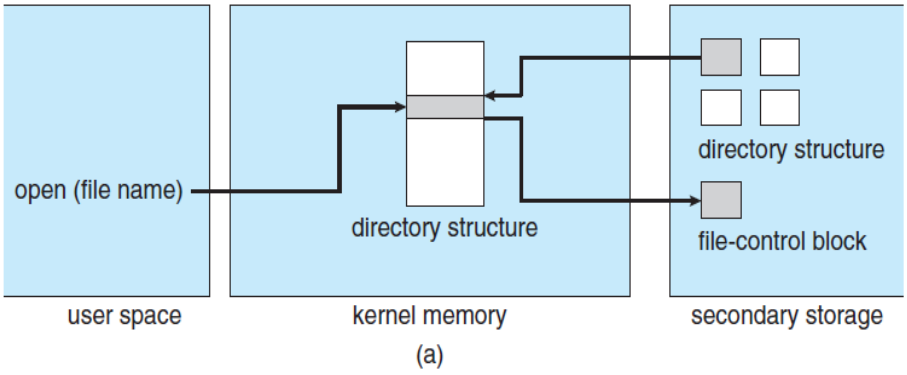
The layout of a disk can have many variations, depending on the operating system. A disk can be sliced into multiple partitions, or a volume can span multiple partitions on multiple disks. Each partition can be either "raw," containing no file system, or "cooked," containing a file system. Raw disk is used where no file system is appropriate. UNIX swap space can use a raw partition, for example, since it uses its own format on disk and does not use a file system. Likewise, some databases use raw disk and format the data to suit their needs. Raw disk can also hold information needed by disk RAID systems, such as bit maps indicating which blocks are mirrored and which have changed and need to be mirrored. Similarly, raw disk can contain a miniature database holding RAID configuration information, such as which disks are members of each RAID set. Raw disk use is discussed in Section 10.5.1.

Boot information can be stored in a separate partition, as described in Section 10.5.2. Again, it has its own format, because at boot time the system does not have the file-system code loaded and therefore cannot interpret the file-system format. Rather, boot information is usually a

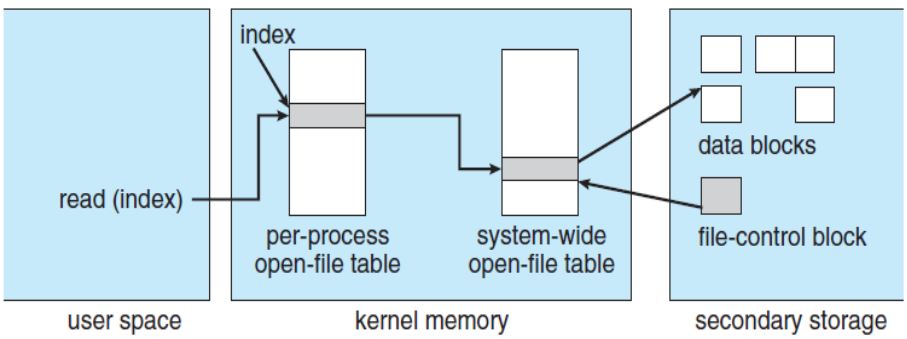
sequential series of blocks, loaded as an image into memory. Execution of the image starts at a predefined location, such as the first byte. This boot loader in turn knows enough about the file-system structure to be able to find and load the kernel and start it executing.

It can contain more than the instructions for how to boot a specific operating system. For instance, many systems can be dual-booted, allowing us to install multiple operating systems on a single system. How does the system know which one to boot? A boot loader that understands multiple file systems and multiple operating systems can occupy the boot space. Once loaded, it can boot one of the operating systems available on the disk. The disk can have multiple partitions, each containing a different type of file system and a different operating system.

The root partition, which contains the operating-system kernel and sometimes other system files, is mounted at boot time. Other volumes can be automatically mounted at boot or manually mounted later, depending on the operating system. As part of a successful mount operation, the operating system verifies that the device contains a valid file system. It does so by asking the device driver to read the device directory and verifying that the directory has the expected format. If the format is invalid, the partition must have its consistency checked and possibly corrected, either with or without user intervention. Finally, the operating system notes in its in-memory mount table that a file system is mounted, along with the type of the file system. The details of this function depend on the operating system.



(a)



(b)

Figure12.2 in memory file structures

Microsoft Windows–based systems mount each volume in a separate name space, denoted by a letter and a colon. To record that a file system is mounted at F:, for example, the operating system places a pointer to the file system in a field of the device structure corresponding to F:. When a process specifies the driver letter, the operating system finds the appropriate file-system pointe rand traverses the directory structures on that device to find the specified file or directory. Later versions of Windows can mount a file system at any point within the existing directory structure.

On UNIX, file systems can be mounted at any directory. Mounting is implemented by setting a flag in the in-memory copy of the inode for that directory. The flag indicates that the directory is a mount point. A field then points to an entry in the mount table, indicating which device is mounted there. The mount table entry contains a pointer to the superblock of the file system on that device. This scheme enables the operating system to traverse its directory structure, switching seamlessly among file systems of varying types.

12.3.3 Virtual File Systems

The previous section makes it clear that modern operating systems must concurrently support multiple types of file systems. But how does an operating system allow multiple types of file systems to be integrated into a directory structure? And how can users seamlessly move between file-system types as they navigate the file-system space? We now discuss some of these implementation details. An obvious but suboptimal method of implementing multiple types of file systems is to write directory and file routines for each type. Instead, however, most operating systems, including UNIX, use object-oriented techniques to simplify, organize, and modularize the implementation. The use of these methods allows very dissimilar file-system types to be implemented within the same structure, including network file systems, such as NFS. Users can access files contained within multiple file systems on the local disk or even on file systems available across the network.

Data structures and procedures are used to isolate the basic system call functionality from the implementation details. Thus, the file-system implementation consists of three major layers, as depicted schematically in Figure 12.4. The first layer is the file-system interface, based on the open(), read(), write(), and close() calls and on file descriptors. The second layer is called the virtual file system (VFS) layer. The VFS layer serves two important functions:

1. It separates file-system-generic operations from their implementation by defining a clean VFS interface. Several implementations for the VFS interface may coexist on the same machine, allowing transparent access to different types of file systems mounted locally.

2. It provides a mechanism for uniquely representing a file throughout a network. The VFS is based on a file-representation structure, called a vnode, that contains a numerical designator for a network-wide unique file. (UNIX inodes are unique within only a single file system.) This network-wide uniqueness is required for support of network file systems.

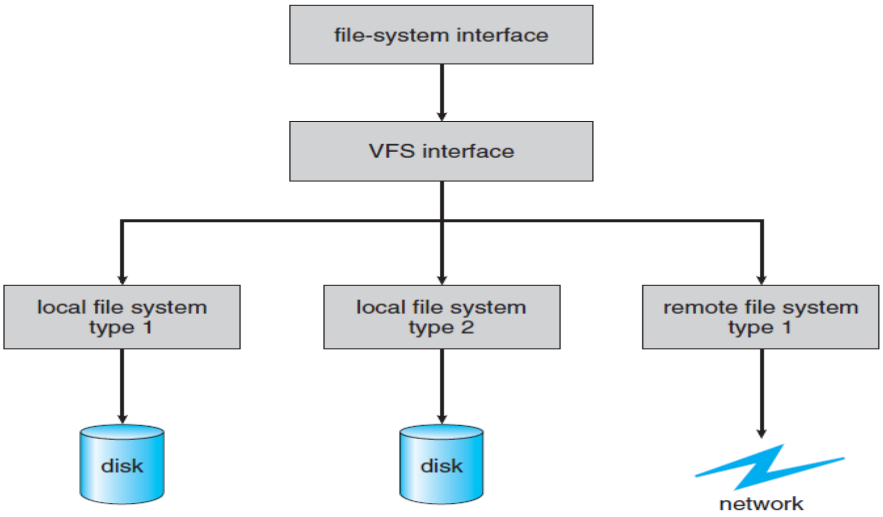


Figure12.3 view of virtual Files

The kernel maintains one vnode structure for each active node (file or directory). Thus, the VFS distinguishes local files from remote ones, and local files are further distinguished according to their file-system types.

Check your Progress

1. What is a File System?
2. What is a boot control block?
3. What is a Volume control block?
4. What is a directory?
5. What is a directory structure?

12.4. ANSWERS TO CHECK YOUR PROGRESS

1. A file system or file system (often abbreviated to fs), controls how data is stored and retrieved. Without a file system, information placed in a storage medium would be one large body of data with no way to tell where one piece of information stops and the next begins.
2. A boot control block (per volume) can contain information needed by the system to boot an operating system from that volume. If the disk does not contain an operating system, this block can be empty. It is typically the first block of a volume. In UFS, it is called the boot block. In NTFS, it is the partition boot sector.

3. A volume control block (per volume) contains volume (or partition) details, such as the number of blocks in the partition, the size of the blocks, a free-block count and free-block pointers, and a free-FCB count and FCB pointers. In UFS, this is called a superblock. In NTFS, it is stored in the master file table.
4. A directory is a file system cataloging structure which contains references to other computer files, and possibly other directories. On many computers, directories are known as folders, or drawers, analogous to a workbench or the traditional office filing cabinet.
5. The directory structure is the organization of files into a hierarchy of folders. Computers have used the folder metaphor for decades as a way to help users keep track of where something can be found.

12.5. SUMMARY

- A disk can access directly any block of information it contains. Thus, it is simple to access any file either sequentially or randomly, and switching from one file to another requires only moving the read–write heads and waiting for the disk to rotate.
- The I/O control level consists of device drivers and interrupt handlers to transfer information between the main memory and the disk system.
- The basic file system needs only to issue generic commands to the appropriate device driver to read and write physical blocks on the disk.
- A disk can be sliced into multiple partitions, or a volume can span multiple partitions on multiple disks.
- Data structures and procedures are used to isolate the basic system call functionality from the implementation details.

12.6. KEYWORDS

- **Directory structure:** It is used to organize the files. In UFS, this includes file names and associated in node numbers. In NTFS, it is stored in the master file table.
- **In-memory directory-structure**: The cache holds the directory information of recently accessed directories. (For directories at which volumes are mounted, it can contain a pointer to the volume table.)
- **VFS:** The VFS is based on a file-representation structure, called a vnode, that contains a numerical designator for a network-wide unique file.
- **Booting:** Boot information is usually a sequential series of blocks, loaded as an image into memory.

12.7. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is a disk?
2. What is the purpose of the disk?
3. What are partitions?
4. What is mounting?
5. What is VFS?

Long Answer questions:

1. Explain File system structure?
2. Explain File System Implementation?

12.8. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

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Stallings, W., 2012. Operating systems: internals and design principles. Boston: Prentice Hall,.

UNIT XIII
IMPLEMENTING FILE SYSTEMS

Structure

13.0 Introduction
13.1 Objective
13.2 Directory Implementation
13.3 Allocation Methods
13.4 Free-Space Management
13.5 Answers to Check Your Progress Questions
13.6 Summary
13.7 Key Words
13.8 Self Assessment Questions and Exercises
13.9 Further Readings

13.0 INTRODUCTION

This unit explains the implementation of directories and the methods in which means they can be accessed and the free space management allocation are illustrated. There is the number of algorithms by using which, the directories can be implemented. However, the selection of an appropriate directory implementation algorithm may significantly affect the performance of the system. The directory implementation algorithms are classified according to the data structure they are using. The directories path and access method are explained with the different types of allocation methods.

13.1 OBJECTIVE

This unit covers the following

- Understand the implementation of directories
- Learn free space management
- Study the allocation methods

13.2 DIRECTORY IMPLEMENTATION

The selection of directory-allocation and directory-management algorithms significantly affects the efficiency, performance, and reliability of the file system. In this section, we discuss the trade-offs involved in choosing one of these algorithms.

13.2.1 Linear List

The simplest method of implementing a directory is to use a linear list of file names with pointers to the data blocks. This method is simple to program but time-consuming to execute. To create a new file, we must first search the directory to be sure that no existing file has the same name.

Then, we add a new entry at the end of the directory. To delete a file,we search the directory for the named file and then release the space allocated to it. To reuse the directory entry, we can do one of several things. We can mark the entry as unused (by assigning it a special name, such as an all-blank name, or by including a used– unused bit in each entry), or we can attach it to a list of free directory entries. A third alternative is to copy the last entry in the directory into the freed location and to decrease the length of the directory. A linked list can also be used to decrease the time required to delete a file.

The real disadvantage of a linear list of directory entries is that finding a file requires a linear search. Directory information is used frequently, and users will notice if access to it is slow. In fact, many operating systems implement a software cache to store the most recently used directory information. A cache hit avoids the need to constantly reread the information from disk. A sorted list allows a binary search and decreases the average search time. However, the requirement that the list be kept sorted may complicate creating and deleting files, since we may have to move substantial amounts of directory information to maintain a sorted directory. A more sophisticated tree data structure, such as a balanced tree, might help here. An advantage of the sorted list is that a sorted directory listing can be produced without a separate sort step.

13.2.1 Hash Table

Another data structure used for a file directory is a hash table. Here, a linear list stores the directory entries, but a hash data structure is also used. The hash table takes a value computed from the file name and returns a pointer to the file name in the linear list. Therefore, it can greatly decrease the directory search time. Insertion and deletion are also fairly straightforward, although some provision must be made for collisions—situations in which two file names hash to the same location. The major difficulties with a hash table are its generally fixed size and the dependence of the hash function on that size. For example, assume that we make a linear-probing hash table that holds 64 entries. The hash function converts file names into integers from 0 to 63 (for instance, by using the remainder of a division by 64). If we later try to create a 65th file, we must enlarge the directory hash table—say, to 128 entries. As a result, we need a new hash function that must map file names to the range 0 to 127, and we must reorganize the existing directory entries to reflect their new hash-function values.

Alternatively, we can use a chained-overflow hash table. Each hash entry can be a linked list instead of an individual value, and we can resolve collisions by adding the new entry to the linked list. Lookups may be somewhat slowed, because searching for a name might require stepping through a linked list of colliding table entries. Still, this method is likely to be much faster than a linear each through the entire directory.

Notes

13.3 ALLOCATION METHODS

The direct-access nature of disks gives us flexibility in the implementation of files. In almost every case, many files are stored on the same disk. The main problem is how to allocate space to these files so that disk space is utilized effectively and files can be accessed quickly. Three major methods of allocating disk space are in wide use: contiguous, linked, and indexed. Each method has advantages and disadvantages. Although some systems support all three, it is more common for a system to use one method for all files within a file-system type.

13.3.1 Contiguous Allocation

Contiguous allocation requires that each file occupy a set of contiguous blocks on the disk. Disk addresses define a linear ordering on the disk. With this ordering, assuming that only one job is accessing the disk, accessing block b +1 after block b normally requires no head movement. When head movement is needed (from the last sector of one cylinder to the first sector of the next cylinder), the head need only move from one track to the next. Thus, the number of disk seeks required for accessing contiguously allocated files is minimal, as is seek time when a seek is finally needed. Contiguous allocation of a file is defined by the disk address and length (in block units) of the first block. If the file is n blocks long and starts at location b, then it occupies blocks b, b + 1, b + 2, ..., b + n − 1. The directory entry for each file indicates the address of the starting block and the length of the area allocated for this file (Figure 12.5).

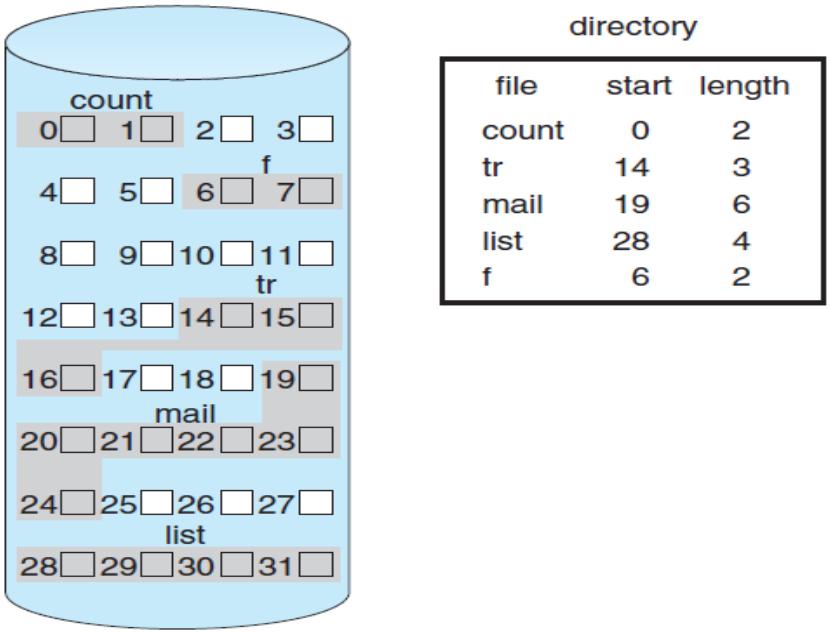

Figure 13.1 Contiguous Memory Allocation

Accessing a file that has been allocated contiguously is easy. For sequential access, the file system remembers the disk address of the last block referenced and, when necessary, reads the next block. For direct

access to block i of a file that starts at block b, we can immediately access block b + i. Thus, both sequential and direct access can be supported by contiguous allocation.

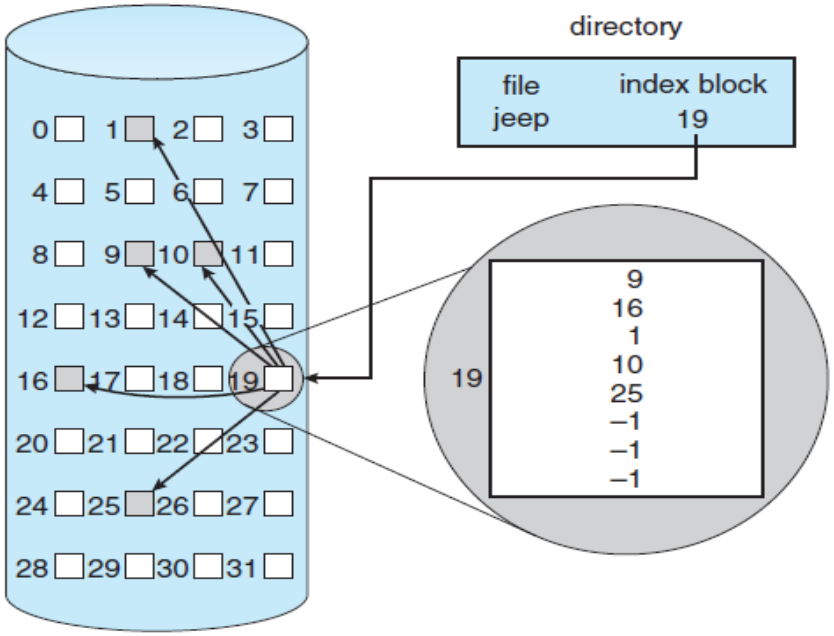

Figure13.2 Index Allocation

13.3.2 Linked Allocation

Linked allocation solves all problems of contiguous allocation. With linked allocation, each file is a linked list of disk blocks; the disk blocks may be scattered anywhere on the disk. The directory contains a pointer to the first and last blocks of the file. For example, a file of five blocks might start at block 9 and continue at block 16, then block 1, then block 10, and finally block 25 (Figure 12.6). Each block contains a pointer to the next block. These pointers

are not made available to the user. Thus, if each block is 512 bytes in size, and a disk address (the pointer) requires 4 bytes, then the user sees blocks of 508 bytes. To create a new file, we simply create a new entry in the directory. With linked allocation, each directory entry has a pointer to the first disk block of the file. This pointer is initialized to null (the end-of-list pointer value) to signify an empty file. The size field is also set to 0. A write to the file causes the free-space management system to find a free block, and this new block is written to and is linked to the end of the file. To read a file, we simply read blocks by following the pointers from block to block. There is no external fragmentation with linked allocation, and any free block on the free-space list can be used to satisfy a request. The size of a file need not be declared when the file is created. A file can continue to grow as long as free blocks are available. Consequently, it is never necessary to compact disk space

13.3.3 Indexed Allocation

Linked allocation solves the external-fragmentation and size-declaration problems of contiguous allocation. However, in the absence of a FAT, linked allocation cannot support efficient direct access, since the pointers to the blocks are scattered with the blocks themselves all over the disk and must be retrieved in order. Indexed allocation solves this problem by bringing all the pointers together into one location: the index block. Each file has its own index block, which is an array of disk-block addresses. The ith entry in the index block points to the ith block of the file. The directory contains the address of the index block (Figure 12.8). To find and read the ith block, we use the pointer in the ith index-block entry. This scheme is similar to the paging scheme described in Section 8.5. When the file is created, all pointers in the index block are set to null. When the ith block is first written, a block is obtained from the free-space manager, and its address is put in the ith index-block entry. Indexed allocation supports direct access, without suffering from external fragmentation, because any free block on the disk can satisfy a request for more space. Indexed allocation does suffer from wasted space, however. The pointer overhead of the index block is generally greater than the pointer overhead of linked allocation. Consider a common case in which we have a file of only one or two blocks. With linked allocation, we lose the space of only one pointer per block. With indexed allocation, an entire index block must be allocated, even if only one or two pointers will be non-null.

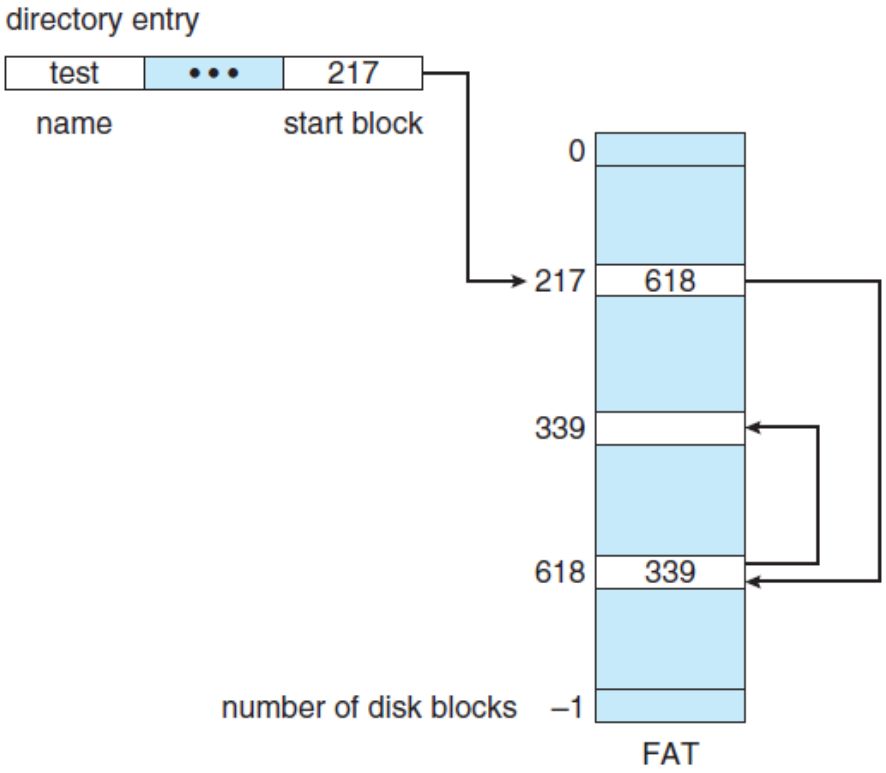

Figure 13.3 File Allocation Table

Notes

13.4 FREE-SPACE MANAGEMENT

Since disk space is limited, we need to reuse the space from deleted files for new files, if possible. (Write-once optical disks allow only one write to any given sector, and thus reuse is not physically possible.) To keep track of free disk space, the system maintains a free-space list. The free-space list records all free disk blocks—those not allocated to some file or directory. To create a file, we search the free-space list for the required amount of space and allocate that space to the new file. This space is then removed from the free-space list. When a file is deleted, its disk space is added to the free-space list. The free-space list, despite its name, may not be implemented as a list, as we discuss next.

13.4.1 Bit Vector

Frequently, the free-space list is implemented as a bit map or bit vector. Each block is represented by 1 bit. If the block is free, the bit is 1; if the block is allocated, the bit is 0. For example, consider a disk where blocks 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 17, 18, 25, 26, and 27 are free and the rest of the blocks are allocated. The free-space bit map would be

0011110011111100011000000011100000 ...

The main advantage of this approach is its relative simplicity and its efficiency in finding the first free block or n consecutive free blocks on the disk. Indeed, many computers supply bit-manipulation instructions that can be used effectively for that purpose. One technique for finding the first free block on a system that uses a bit-vector to allocate disk space is to sequentially check each word in the bit map to see whether that value is not 0, since a 562 0-valued word contains only 0 bits and represents a set of allocated blocks. The first non-0 word is scanned for the first 1 bit, which is the location of the first free block. The calculation of the block number is(number of bits per word) × (number of 0-value words) + offset of first 1 bit.

Again, we see hardware features driving software functionality. Unfortunately, bit vectors are inefficient unless the entire vector is kept in main memory (and is written to disk occasionally for recovery needs). Keeping it in main memory is possible for smaller disks but not necessarily for larger ones. A 1.3-GB disk with 512-byte blocks would need a bit map of over 332 KB to track its free blocks, although clustering the blocks in groups of four reduces this number to around 83 KB per disk. A1-TB disk with 4-KB blocks requires 256 MB to store its bit map. Given that disk size constantly increases, the problem with bit vectors will continue to escalate as well.

13.4.2 Linked List

Another approach to free-space management is to link together all the free disk blocks, keeping a pointer to the first free block in a special location on the disk and caching it in memory. This first block contains a pointer to the next free disk block, and so on. Recall our earlier example (Section

12.5.1), in which blocks 2, 3, 4, 5, 8, 9, 10, 11, 12, 13, 17, 18, 25, 26, and 27 were free and the rest of the blocks were allocated. In this situation, we would keep a pointer to block 2 as the first free block. Block 2 would contain a pointer to block 3, which would point to block 4, which would point to block 5, which would point to block 8, and so on (Figure 12.10). This scheme is not efficient; to traverse the list, we must read each block, which requires substantial I/O time. Fortunately, however, traversing the free list is not a frequent action. Usually, the operating system simply needs a free block so that it can allocate that block to a file, so the first block in the free list is used. The FAT method incorporates free-block accounting into the allocation data structure. No separate method is needed.

13.4.3 Grouping

A modification of the free-list approach stores the addresses of n free blocks in the first free block. The first n−1 of these blocks are actually free. The last block contains the addresses of another n free blocks, and so on. The addresses of a large number of free blocks can now be found quickly, unlike the situation when the standard linked-list approach is used.

13.4.4 Counting

Another approach takes advantage of the fact that, generally, several contiguous blocks may be allocated or freed simultaneously, particularly when space is allocated with the contiguous-allocation algorithm or through clustering. Thus, rather than keeping a list of n free disk addresses, we can keep the address of the first free block and the number (n) of free contiguous blocks that follow the first block. Each entry in the free-space list then consists of a disk address and a count. Although each entry requires more space than would a simple disk address, the overall list is shorter, as long as the count is generally greater than 1. Note that this method of tracking free space is similar to the extent method of allocating blocks. These entries can be stored in a balanced tree, rather than a linked list, for efficient lookup, insertion, and deletion.

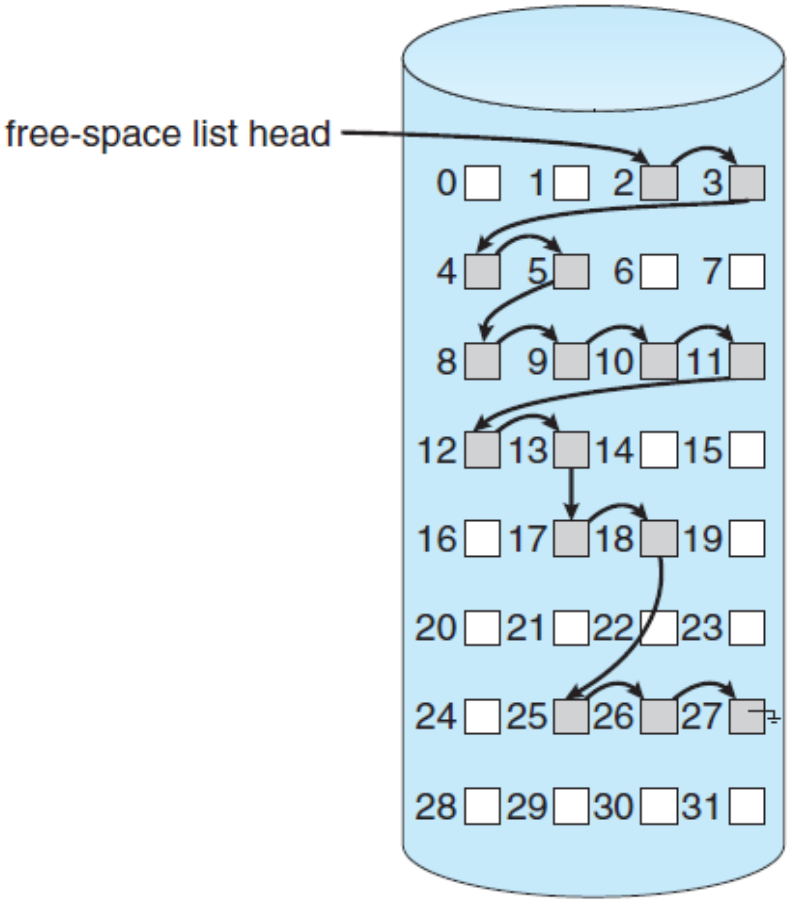

Figure13.4 Linked Free space

13.4.5 Space Maps

Oracle's ZFS file system (found in Solaris and other operating systems) was designed to encompass huge numbers of files, directories, and even file systems (in ZFS, we can create file-system hierarchies). On these scales, metadata I/O can have a large performance impact. Consider, for example, that if the free-space list is implemented as a bit map, bit maps must be modified both when blocks are allocated and when they are freed. Freeing 1 GB of data on a 1-TB disk could cause thousands of blocks of bit maps to be updated, because those data blocks could be scattered over the entire disk. Clearly, the data structures for such a system could be large and inefficient.

In its management of free space, ZFS uses a combination of techniques to control the size of data structures and minimize the I/O needed to manage those structures. First, ZFS creates metaslabs to divide the space on the device into chunks of manageable size. A given volume may contain hundreds of metaslabs. Each metaslab has an associated space map. ZFS uses the counting algorithm to store information about free blocks. Rather than write counting structures to disk, it uses log-structured file-system techniques to record them. The space map is a log of all block activity (allocating and freeing), in time order, in counting format. When ZFS

decides to allocate or free space from a metaslab, it loads the associated space map into memory in a balanced-tree structure (for very efficient operation), indexed by offset, and replays the log into that structure. The in-memory spacemap is then an accurate representation of the allocated and free space in the metaslab. ZFS also condenses the map as much as possible by combining contiguous free blocks into a single entry.

Finally, the free-space list is updated on disk as part of the transaction-oriented operations of ZFS. During the collection and sorting phase, block requests can still occur, and ZFS satisfies these requests from the log. In essence, the log plus the balanced tree is the free list.

Check your Progress

1. What is a bit vector?
2. What is Grouping?
3. What is Space Maps?
4. Name the Allocation methods?
5. What is Hash table?

13.5. ANSWERS TO CHECK YOUR PROGRESS

1. A bit vector is a vector in which each element is a bit (so its value is either 0 or 1). In most vectors, each element has a different address in memory and can be manipulated separately from the other elements, but we also hope to be able to perform "vector operations" that treat all elements uniformly.
2. A modification of the free-list approach stores the addresses of n free blocks in the first free block. The first n−1 of these blocks are actually free. The last block contains the addresses of another n free blocks, and so on.
3. Oracle's ZFS file system (found in Solaris and other operating systems) was designed to encompass huge numbers of files, directories, and even file systems (in ZFS, we can create file-system hierarchies).
4. Contiguous Allocation, Linked Allocation and Indexed Allocation.
5. A hash table (hash map) is a data structure that implements an associative array abstract data type, a structure that can map keys to values. A hash table uses a hash function to compute an index into an array of buckets or slots, from which the desired value can be found.

13.6. SUMMARY

- The simplest method of implementing a directory is to use a linear list of file names with pointers to the data blocks.
- Three major methods of allocating disk space are in wide use: contiguous, linked, and indexed.

- Contiguous allocation requires that each file occupy a set of contiguous blocks on the disk.
- Linked allocation solves all problems of contiguous allocation. With linked allocation, each file is a linked list of disk blocks; the disk blocks may be scattered anywhere on the disk.
- Since disk space is limited, we need to reuse the space from deleted files for new files, if possible.
- For sequential access, the file system remembers the disk address of the last block referenced and, when necessary, reads the next block.

13.7. KEYWORDS

- **ZFS:** ZFS uses a combination of techniques to control the size of data structures and minimize the I/O needed to manage those structures.
- **Linked list:** Another approach to free-space management is to link together all the free disk blocks, keeping a pointer to the first free block in a special location on the disk and caching it in memory.
- **Linked allocation:** Linked allocation solves all problems of contiguous allocation. With linked allocation, each file is a linked list of disk blocks; the disk blocks may be scattered anywhere on the disk.

13.8. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is Linear List?
2. What is Contiguous Allocation?
3. What is Linked Allocation?
4. What is Indexed Allocation?
5. What is Linked List?

Long Answer questions:

1. Explain free space management?
2. Explain Allocation methods?
3. Explain Directory Implementation?

13.9. FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

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UNIT XIV
SECONDARY STORAGE STRUCTURE

Structure

14.0Introduction
14.1Objective
14.2 Overview of Mass-Storage Structure
14.3 Disk Structure
14.4 Disk Attachment
14.5 Overview of Mass-Storage Structure-Disk Attachment-Disk Scheduling-Disk Management
14.6 Disk Management
14.7 Answers to Check Your Progress Questions
14.8 Summary
14.9 Key Words
14.10 Self Assessment Questions and Exercises
14.11 Further Readings

14.0 INTRODUCTION

The storage structure helps to store the data from the Operating System to the system. There are many storage devices; this unit covers the secondary storage structure on how the data is stored and retrieved. As we know, a process needs two types of time, CPU time and IO time. For I/O, it requests the Operating system to access the disk. However, the operating system must be fair enough to satisfy each request and at the same time, operating system must maintain the efficiency and speed of process execution. The technique that operating system uses to determine the request which is to be satisfied next is called disk scheduling. The disk scheduling and disk management on the devices are explored.

14.1 OBJECTIVE

This unit helps the user to learn and understand the

- Disk Scheduling
- Disk Management
- Overview of storage structures

14.2 OVERVIEW OF MASS-STORAGE STRUCTURE

In this section, we present a general overview of the physical structure of secondary and tertiary storage devices.

14.2.1 Magnetic Disks

Magnetic disks provide the bulk of secondary storage for modern computer systems. Conceptually, disks are relatively simple. Each disk platter has a flat circular shape, like a CD. Common platter diameters range from 1.8 to 3.5 inches. The two surfaces of a platter are covered with a magnetic material. We store information by recording it magnetically on the platters.

A read–write head "flies" just above each surface of every platter. The heads are attached to a disk arm that moves all the heads as a unit. The surface of a platter is logically divided into circular tracks, which are subdivided into sectors. The set of tracks that are at one arm position makes up a cylinder. There may be thousands of concentric cylinders in a disk drive, and each track may contain hundreds of sectors. The storage capacity of common disk drives is measured in gigabytes.

When the disk is in use, a drive motor spins it at high speed. Most drives rotate 60 to 250 times per second, specified in terms of rotations per minute (RPM). Common drives spin at 5,400, 7,200, 10,000, and 15,000 RPM. Disk speed has two parts. The transfer rate is the rate at which data flow between the drive and the computer. The positioning time, or random-access time, consists of two parts: the time necessary to move the disk arm to the desired cylinder, called the seek time, and the time necessary for the desired sector to rotate to the disk head, called the rotational latency. Typical disks can transfer several megabytes of data per second, and they have seek times and rotational latencies of several milliseconds.

Because the disk head flies on an extremely thin cushion of air (measured in microns), there is a danger that the head will make contact with the disk surface. Although the disk platters are coated with a thin protective layer, the head will sometimes damage the magnetic surface. This accident is called a head crash. A head crash normally cannot be repaired; the entire disk must be replaced. A disk can be removable, allowing different disks to be mounted as needed. Removable magnetic disks generally consist of one platter, held in a plastic case to prevent damage while not in the disk drive. Other forms of removable disks include CDs, DVDs, and Blu-ray discs as well as removable flash-memory devices known as flash drives (which are a type of solid-state drive).

A disk drive is attached to a computer by a set of wires called an I/O bus. Several kinds of buses are available, including advanced technology attachment (ATA), serial ATA (SATA), eSATA, universal serial bus (USB), and fibre channel (FC). The data transfers on a bus are carried out by special electronic processors called controllers. The host controller is the controller at the computer end of the bus. The host controller then sends the command via messages to the disk controller, and the disk controller operates the disk-drive hardware to carry out the command. Disk controllers usually have a built-in cache. Data transfer at the disk drive happens between the cache and the disk surface, and data transfer to the host, at fast electronic speeds, occurs between the cache and the host controller.

14.2.2 Solid-State Disks

Sometimes old technologies are used in new ways as economics change or the technologies evolve. An example is the growing importance of solid-state disks, or SSDs. Simply described, an SSD is nonvolatile memory that is used like a hard drive. There are many variations of this technology, from DRAM with a battery to allow it to maintain its state in a power failure through flash-memory technologies like single-level cell (SLC) and multilevel cell (MLC) chips.

SSDs have the same characteristics as traditional hard disks but can be more reliable because they have no moving parts and faster because they have no seek time or latency. In addition, they consume less power. However, they are more expensive per megabyte than traditional hard disks, have less capacity than the larger hard disks, and may have shorter life spans than hard disks, so their uses are somewhat limited. One use for SSDs is in storage arrays, where they hold file-system metadata that require high performance. SSDs are also used in some laptop computers to make them smaller, faster, and more energy-efficient.

Because SSDs can be much faster than magnetic disk drives, standard bus interfaces can cause a major limit on throughput. Some SSDs are designed to connect directly to the system bus (PCI, for example). SSDs are changing other traditional aspects of computer design as well. Some systems use them as a direct replacement for disk drives, while others use them as a new cache tier, moving data between magnetic disks, SSDs, and memory to optimize performance.

In the remainder of this chapter, some sections pertain to SSDs, while others do not. For example, because SSDs have no disk head, disk-scheduling algorithms largely do not apply. Throughput and formatting, however, do apply.

14.2.3 Magnetic Tapes

Magnetic tape was used as an early secondary-storage medium. Although it is relatively permanent and can hold large quantities of data, its access time is slow compared with that of main memory and magnetic disk. In addition, random access to magnetic tape is about a thousand times slower than random access to magnetic disk, so tapes are not very useful for secondary storage.

14.2.4 Disk Transfer Rates

As with many aspects of computing, published performance numbers for disks are not the same as real-world performance numbers. Stated transfer rates are always lower than effective transfer rates, for example. The transfer rate may be the rate at which bits can be read from the magnetic media by the disk head, but that is different from the rate at which blocks are delivered to the operating system.

Tapes are used mainly for backup, for storage of infrequently used information, and as a medium for transferring information from one system to another. A tape is kept in a spool and is wound or rewound past a read–write head. Moving to the correct spot on a tape can take minutes, but once positioned, tape drives can write data at speeds comparable to disk drives. Tape capacities vary greatly, depending on the particular kind of tape drive, with current capacities exceeding several terabytes. Some tapes have built-in compression that can more than double the effective storage. Tapes and their drivers are usually categorized by width, including 4, 8, and 19 millimeters and 1/4 and 1/2 inch. Some are named according to technology, such as LTO-5 and SDLT.

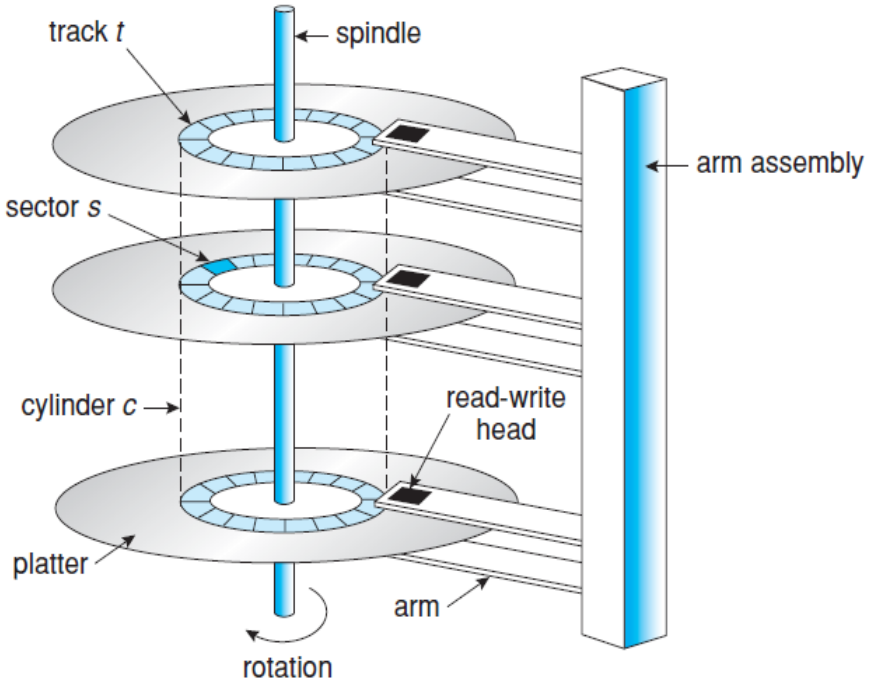

Figure 14.1 Moving of Magnetic Tapes

14.3 DISK STRUCTURE

odern magnetic disk drives are addressed as large one-dimensional arrays of logical blocks, where the logical block is the smallest unit of transfer. The size of a logical block is usually 512 bytes, although some disks can be low-level formatted to have a different logical block size, such as 1,024 bytes. This option is described in Section 10.5.1. The one-dimensional array of logical blocks is mapped onto the sectors of the disk sequentially. Sector 0 is the first sector of the first track on the outermost cylinder. The mapping proceeds in order through that track, then through the rest of the

tracks in that cylinder, and then through the rest of the cylinders from outermost to innermost.

By using this mapping, we can—at least in theory—convert a logical block number into an old-style disk address that consists of a cylinder number, a track number within that cylinder, and a sector number within that track. In practice, it is difficult to perform this translation, for two reasons. First, most disks have some defective sectors, but the mapping hides this by substituting spare sectors from elsewhere on the disk. Second, the number of sectors per track is not a constant on some drives. Let's look more closely at the second reason. On media that use constant linear velocity (CLV), the density of bits per track is uniform. The farther a track is from the center of the disk, the greater its length, so the more sectors it can hold. As we move from outer zones to inner zones, the number of sectors per track decreases. Tracks in the outermost zone typically hold 40 percent more sectors than do tracks in the innermost zone. The drive increases its rotation speed as the head moves from the outer to the inner tracks to keep the same rate of data moving under the head. This method is used in CD-ROM and DVD-ROM drives. Alternatively, the disk rotation speed can stay constant; in this case, the density of bits decreases from inner tracks to outer tracks to keep the data rate constant. This method is used in hard disks and is known as constant angular velocity (CAV).

The number of sectors per track has been increasing as disk technology improves, and the outer zone of a disk usually has several hundred sectors per track. Similarly, the number of cylinders per disk has been increasing; large disks have tens of thousands of cylinders.

14.4 DISK ATTACHMENT

Computers access disk storage in two ways. One way is via I/O ports (or host-attached storage); this is common on small systems. The other way is via a remote host in a distributed file system; this is referred to as network-attached storage.

14.4.1 Host-Attached Storage

Host-attached storage is storage accessed through local I/O ports. These ports use several technologies. The typical desktop PC uses an I/O bus architecture called IDE or ATA. This architecture supports a maximum of two drives per I/O bus. A newer, similar protocol that has simplified cabling is SATA. High-end workstations and servers generally use more sophisticated I/O architectures such as fibre channel (FC), a high-speed serial architecture that can operate over optical fiber or over a four-conductor copper cable. It has two variants. One is a large switched fabric having a 24-bit address space. This variant is expected to dominate in the future and is the basis of storage-area networks (SANs), discussed in Section 10.3.3. Because of the large address space and the switched nature of the communication, multiple hosts and storage devices can attach to the fabric, allowing great flexibility in I/O communication.

The other FC variant is an arbitrated loop (FC-AL) that can address 126 devices (drives and controllers). A wide variety of storage devices are suitable for use as host-attached storage. Among these are hard disk drives, RAID arrays, and CD, DVD, and tape drives. The I/O commands that initiate data transfers to a host-attached storage device are reads and writes of logical data blocks directed to specifically identified storage units (such as bus ID or target logical unit).

14.4.2 Network-Attached Storage

A network-attached storage (NAS) device is a special-purpose storage system that is accessed remotely over a data network (Figure 10.2). Clients access network-attached storage via a remote-procedure-call interface such as NFS for UNIX systems or CIFS for Windows machines. The remote procedure calls(RPCs) are carried via TCP or UDP over an IP network—usually the same local area network (LAN) that carries all data traffic to the clients. Thus, it may be easiest to think of NAS as simply another storage-access protocol. The network attached storage unit is usually implemented as a RAID array with software that implements the RPC interface.

Network-attached storage provides a convenient way for all the computers on a LAN to share a pool of storage with the same ease of naming and access enjoyed with local host-attached storage. However, it tends to be less efficient and have lower performance than some direct-attached storage options. iSCSI is the latest network-attached storage protocol. In essence, it uses the IP network protocol to carry the SCSI protocol. Thus, networks—rather than SCSI cables—can be used as the interconnects between hosts and their storage. As a result, hosts can treat their storage as if it were directly attached, even if the storage is distant from the host.

14.4.3 Storage-Area Network

One drawback of network-attached storage systems is that the storage I/O operations consume bandwidth on the data network, thereby increasing the latency of network communication. This problem can be particularly acute in large client–server installations—the communication between servers and clients competes for bandwidth with the communication among servers and storage devices.

A storage-area network (SAN) is a private network (using storage protocols rather than networking protocols) connecting servers and storage units, as shown in Figure 10.3. The power of a SAN lies in its flexibility. Multiple hosts and multiple storage arrays can attach to the same SAN, and storage can be dynamically allocated to hosts. A SAN switch allows or prohibits access between the hosts and the storage. As one example, if a host is running low on disk space, the SAN can be configured to allocate more storage to that host. SANs make it possible for clusters of servers to share the same storage and for storage arrays to include multiple direct host connections. SANs typically have more ports—as well as more expensive ports—than storage arrays. FC is the most common SAN interconnect,

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although the simplicity of iSCSI is increasing its use. Another SAN interconnect is InfiniBand — a special-purpose bus architecture that provides hardware and software support for high-speed interconnection networks for servers and storage units.

14.5 DISK SCHEDULING

One of the responsibilities of the operating system is to use the hardware efficiently. For the disk drives, meeting this responsibility entails having fast access time and large disk bandwidth. For magnetic disks, the access time has two major components, as mentioned in Section 10.1.1. The seek time is the time for the disk arm to move the heads to the cylinder containing the desired sector. The rotational latency is the additional time for the disk to rotate the desired sector to the disk head. The disk bandwidth is the total number of bytes transferred, divided by the total time between the first request for service and the completion of the last transfer. We can improve both the access time and the bandwidth by managing the order in which disk I/O requests are serviced.

Whenever a process needs I/O to or from the disk, it issues a system call to the operating system. The request specifies several pieces of information:

- Whether this operation is input or output
- What the disk address for the transfer is
- What the memory address for the transfer is
- What the number of sectors to be transferred is

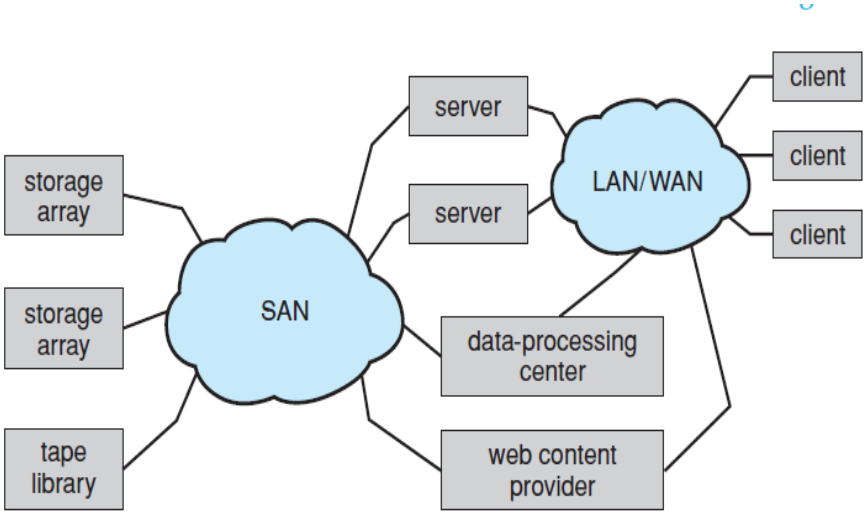

Figure 14.2 Storage Area Network

If the desired disk drive and controller are available, the request can be serviced immediately. If the drive or controller is busy, any new requests

for service will be placed in the queue of pending requests for that drive. For a multiprogramming system with many processes, the disk queue may often have several pending requests. Thus, when one request is completed, the operating system chooses which pending request to service next. How does the operating system make this choice? Any one of several disk-scheduling algorithms can be used, and we discuss them next.

14.5.1 FCFS Scheduling

The simplest form of disk scheduling is, of course, the first-come, first-served (FCFS) algorithm. This algorithm is intrinsically fair, but it generally does not provide the fastest service. Consider, for example, a disk queue with requests for I/O to blocks on cylinders98, 183, 37, 122, 14, 124, 65, 67, in that order. If the disk head is initially at cylinder 53, it will first move from 53 to 98, then to 183, 37, 122, 14, 124, 65, and finally to 67, for a total head movement of 640 cylinders. This schedule is diagrammed in Figure 10.4. The wild swing from 122 to 14 and then back to 124 illustrates the problem with this schedule. If the requests for cylinders 37 and 14 could be serviced together, before or after the requests for 122 and 124, the total head movement could be decreased substantially, and performance could be thereby improved.

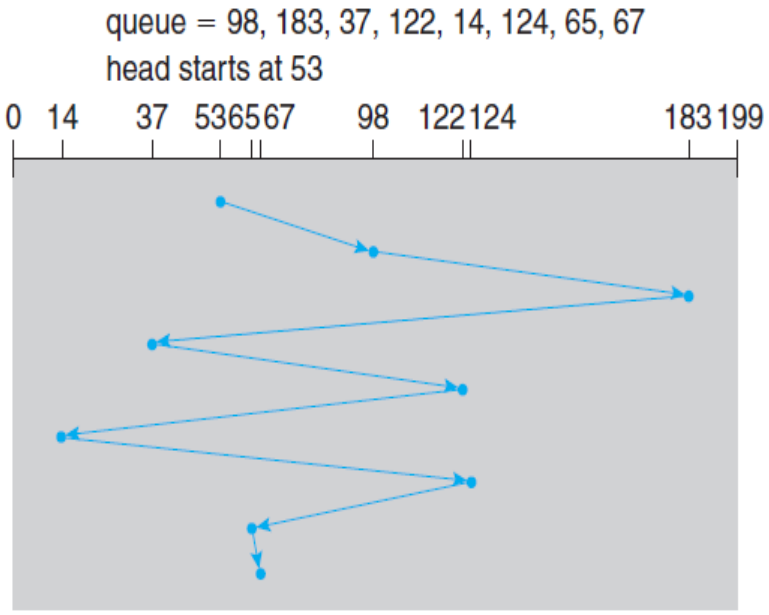

Figure14.3 FCFS Disk Scheduling

14.5.2 SSTF Scheduling

It seems reasonable to service all the requests close to the current head position before moving the head far away to service other requests. This assumption is the basis for the shortest-seek-time-first (SSTF) algorithm. The SSTF algorithm selects the request with the least seek time from the current head position. In other words, SSTF chooses the pending request closest to the current head position.

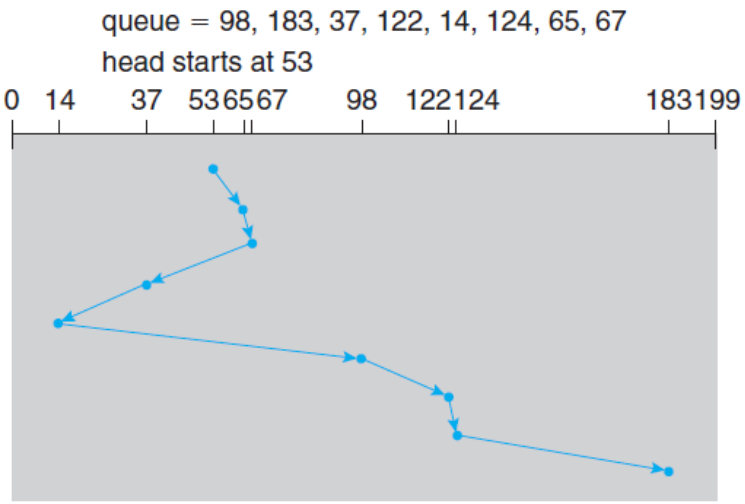

Figure14.4 SSTF Scheduling

For our example request queue, the closest request to the initial head position (53) is at cylinder 65. Once we are at cylinder 65, the next closest request is at cylinder 67. From there, the request at cylinder 37 is closer than the one at 98, so 37 is served next. Continuing, we service the request at cylinder 14, then 98, 122, 124, and finally 183 (Figure 10.5). This scheduling method results in a total head movement of only 236 cylinders—little more than one-third of the distance needed for FCFS scheduling of this request queue. Clearly, this algorithm gives a substantial improvement in performance.

SSTF scheduling is essentially a form of shortest-job-first (SJF) scheduling; and like SJF scheduling, it may cause starvation of some requests. Remember that requests may arrive at any time. Suppose that we have two requests in the queue, for cylinders 14 and 186, and while the request from 14 is being serviced, a new request near 14 arrives. This new request will be serviced next, making the request at 186 wait. While this request is being serviced, another request close to 14 could arrive. In theory, a continual stream of requests near one another could cause the request for cylinder 186 to wait indefinitely. This scenario becomes increasingly likely as the pending-request queue grows longer. Although the SSTF algorithm is a substantial improvement over the FCFS algorithm, it is not optimal. In the example, we can do better by moving the head from 53 to 37, even though the latter is not closest, and then to 14, before turning around to service 65, 67, 98, 122, 124, and 183. This strategy reduces the total head movement to 208 cylinders.

14.5.3 SCAN Scheduling

In the SCAN algorithm, the disk arm starts at one end of the disk and moves toward the other end, servicing requests as it reaches each cylinder, until it gets to the other end of the disk. At the other end, the direction of head movement is reversed, and servicing continues. The head

continuously scans back and forth across the disk. The SCAN algorithm is sometimes called the elevator algorithm, since the disk arm behaves just like an elevator in a building, first servicing all the requests going up and then reversing to service requests the other way.

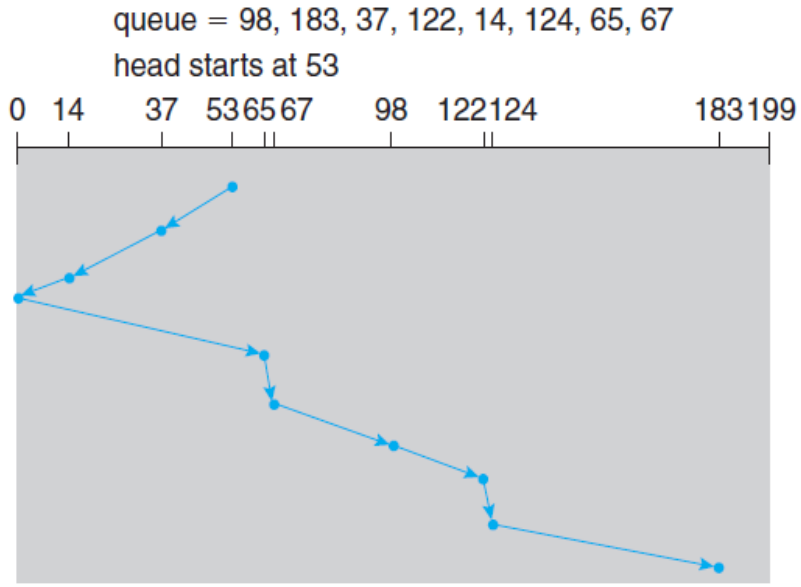

Figure 14.5 SCAN Scheduling

Let's return to our example to illustrate. Before applying SCAN to schedule the requests on cylinders 98, 183, 37, 122, 14, 124, 65, and 67, we need to know the direction of head movement in addition to the head's current position. Assuming that the disk arm is moving toward 0 and that the initial head position is again 53, the head will next service 37 and then 14. At cylinder 0, the arm will reverse and will move toward the other end of the disk, servicing the requests at 65, 67, 98, 122, 124, and 183 (Figure 10.6). If a request arrives in the queue just in front of the head, it will be serviced almost immediately; a request arriving just behind the head will have to wait until the arm moves to the end of the disk, reverses direction, and comes back. Assuming a uniform distribution of requests for cylinders, consider the density of requests when the head reaches one end and reverses direction. At this point, relatively few requests are immediately in front of the head, since these cylinders have recently been serviced. The heaviest density of is at the other end of the disk. These requests have also waited the longest, so why not go there first? That is the idea of the next algorithm.

14.5.4 C-SCAN Scheduling

Circular SCAN (C-SCAN) scheduling is a variant of SCAN designed to provide a more uniform wait time. Like SCAN, C-SCAN moves the head from one end of the disk to the other, servicing requests along the way. When the head reaches the other end, however, it immediately returns to the beginning of the disk without servicing any requests on the return trip

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(Figure 10.7). The C-SCAN scheduling algorithm essentially treats the cylinders as a circular list that wraps around from the final cylinder to the first one.

0 14 37 53 65 67 98 122124 183199

queue = 98, 183, 37, 122, 14, 124,

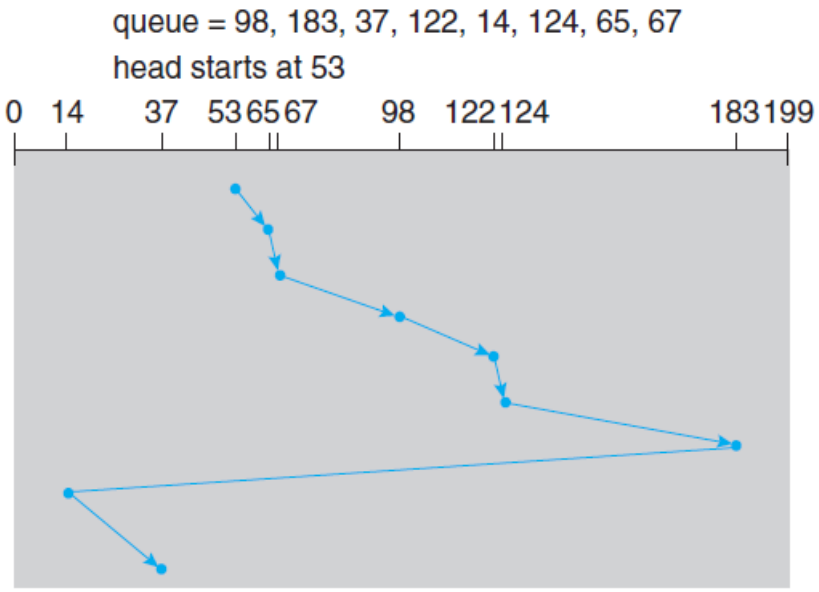

Figure 14.6 C-LOOK Scheduling

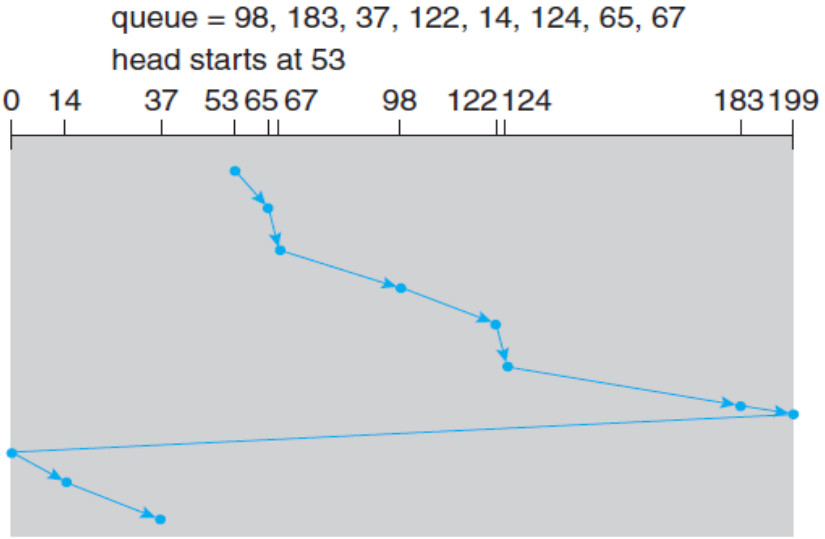

Figure 14.7C SCAN Scheduling

14.5.5 LOOK Scheduling

As we described them, both SCAN and C-SCAN move the disk arm across the full width of the disk. In practice, neither algorithm is often implemented this way. More commonly, the arm goes only as far as the final request in each direction. Then, it reverses direction immediately, without going all the way to the end of the disk. Versions of SCAN and C-SCAN that follow this pattern are called LOOK and C-LOOK scheduling, because they look for a request before continuing to move in a given direction (Figure 10.8).

14.5.6 Selection of a Disk-Scheduling Algorithm

Given so many disk-scheduling algorithms, how do we choose the best one? SSTF is common and has a natural appeal because it increases performance over FCFS. SCAN and C-SCAN perform better for systems that place a heavy load on the disk, because they are less likely to cause a starvation problem. For any particular list of requests, we can define an optimal order of retrieval, but the computation needed to find an optimal schedule may not justify the savings over SSTF or SCAN. With any scheduling algorithm, however, performance depends heavily on the number and types of requests. For instance, suppose that the queue usually has just one outstanding request. Then, all scheduling algorithms behave the same, because they have only one choice of where to move the disk head: they all behave like FCFS scheduling.

Requests for disk service can be greatly influenced by the file-allocation method. A program reading a contiguously allocated file will generate several requests that are close together on the disk, resulting in limited head movement. A linked or indexed file, in contrast, may include blocks that are widely scattered on the disk, resulting in greater head movement.

The location of directories and index blocks is also important. Since every file must be opened to be used, and opening a file requires searching the directory structure, the directories will be accessed frequently. Suppose that a directory entry is on the first cylinder and a file's data are on the final cylinder. In this case, the disk head has to move the entire width of the disk. If the directory

14.6 DISK MANAGEMENT

The operating system is responsible for several other aspects of disk management, too. Here we discuss disk initialization, booting from disk, and bad-block recovery.

14.6.1 DISK FORMATTING

A new magnetic disk is a blank slate: it is just a platter of a magnetic recording material. Before a disk can store data, it must be divided into sectors that the disk controller can read and write. This process is called low-level formatting, or physical formatting. Low-level formatting fills the disk with a special data structure for each sector. The data structure for a

sector typically consists of a header, a data area (usually 512 bytes in size), and a trailer. The header and trailer contain information used by the disk controller, such as a sector number and an error-correcting code (ECC). When the controller writes a sector of data during normal I/O, the ECC is updated with a value calculated from all the bytes in the data area. When the sector is read, the ECC is recalculated and compared with the stored value. If the stored and calculated numbers are different, this mismatch indicates that the data area of the sector has become corrupted and that the disk sector may be bad (Section 10.5.3). The ECC is an error-correcting code because it contains enough information, if only a few bits of data have been corrupted, to enable the controller to identify which bits have changed and calculate what their correct values should be. It then reports a recoverable soft error. The controller automatically does the ECC processing whenever a sector is read or written.

Most hard disks are low-level-formatted at the factory as a part of the manufacturing process. This formatting enables the manufacturer to test the disk and to initialize the mapping from logical block numbers to defect-free sectors on the disk. For many hard disks, when the disk controller is instructed to low-level-format the disk, it can also be told how many bytes of data space to leave between the header and trailer of all sectors. It is usually possible to choose among a few sizes, such as 256, 512, and 1,024 bytes. Formatting a disk with a larger sector size means that fewer sectors can fit on each track; but it also means that fewer headers and trailers are written on each track and more space is available for user data. Some operating systems can handle only a sector size of 512 bytes.

Before it can use a disk to hold files, the operating system still needs to record its own data structures on the disk. It does so in two steps. The first step is to partition the disk into one or more groups of cylinders. The operating system can treat each partition as though it were a separate disk. For instance, one partition can hold a copy of the operating system's executable code, while another holds user files. The second step is logical formatting, or creation of a file system. In this step, the operating system stores the initial file-system data structures onto the disk. These data structures may include maps of free and allocated space and an initial empty directory.

To increase efficiency, most file systems group blocks together into larger chunks, frequently called clusters. Disk I/O is done via blocks, but file system I/O is done via clusters, effectively assuring that I/O has more sequential-access and fewer random-access characteristics. Some operating systems give special programs the ability to use a disk partition as a large sequential array of logical blocks, without any file-system data structures. This array is sometimes called the raw disk, and I/O to this array is termed raw I/O. For example, some database systems prefer raw I/O because it enables them to control the exact disk location where each database record is stored. Raw I/O bypasses all the file-system services, such as the buffer cache, file locking, prefetching, space allocation, file names, and directories. We can make certain applications more efficient by allowing

them to implement their own special-purpose storage services on a raw partition, but most applications perform better when they use the regular file-system services.

14.6.2 Boot Block

For a computer to start running—for instance, when it is powered up or rebooted—it must have an initial program to run. This initial bootstrap program tends to be simple. It initializes all aspects of the system, from CPU registers to device controllers and the contents of main memory, and then starts the operating system. To do its job, the bootstrap program finds the operating-system kernel on disk, loads that kernel into memory, and jumps to an initial address to begin the operating-system execution.

For most computers, the bootstrap is stored in read-only memory (ROM). This location is convenient, because ROM needs no initialization and is at a fixed location that the processor can start executing when powered up or reset. And, since ROM is read only, it cannot be infected by a computer virus. The problem is that changing this bootstrap code requires changing the ROM hardware chips. For this reason, most systems store a tiny bootstrap loader program in the boot ROM whose only job is to bring in a full bootstrap program from disk. The full bootstrap program can be changed easily: a new version is simply written onto the disk. The full bootstrap program is stored in the "boot blocks" at a fixed location on the disk. A disk that has a boot partition is called a boot disk or system disk.

The code in the boot ROM instructs the disk controller to read the boot blocks into memory (no device drivers are loaded at this point) and then starts executing that code. The full bootstrap program is more sophisticated than the bootstrap loader in the boot ROM. It is able to load the entire operating system from a non-fixed location on disk and to start the operating system running. Even so, the full bootstrap code may be small. Let's consider as an example the boot process in Windows. First, note that Windows allows a hard disk to be divided into partitions, and one partition —identified as the boot partition—contains the operating system and device drivers. The Windows system places its boot code in the first sector on the hard disk, which it terms the master boot record, or MBR. Booting begins by running code that is resident in the system's ROM memory. This code directs the system to read the boot code from the MBR. In addition to containing boot code, the MBR contains a table listing the partitions for the hard disk and a flag indicating which partition the system is to be booted from, as illustrated in Figure 10.9. Once the system identifies the boot partition, it reads the first sector from that partition (which is called the boot sector) and continues with the remainder of the boot process, which includes loading the various subsystems and system services.

14.6.3 Bad Blocks

Because disks have moving parts and small tolerances (recall that the disk head flies just above the disk surface), they are prone to failure. Sometimes the failure is complete; in this case, the disk needs to be replaced and its

Notes

contents restored from backup media to the new disk. More frequently, one or more sectors become defective. Most disks even come from the factory with bad blocks. Depending on the disk and controller in use, these blocks are handled in a variety of ways.

On simple disks, such as some disks with IDE controllers, bad blocks are handled manually. One strategy is to scan the disk to find bad blocks while the disk is being formatted. Any bad blocks that are discovered are flagged as unusable so that the file system does not allocate them. If blocks go bad during normal operation, a special program (such as the Linux bad blocks command) must be run manually to search for the bad blocks and to lock them away. Data that resided on the bad blocks usually are lost. More sophisticated disks are smarter about bad-block recovery. The controller maintains a list of bad blocks on the disk. The list is initialized during the low-level formatting at the factory and is updated over the life of the disk. Low-level formatting also sets aside spare sectors not visible to the operating system. The controller can be told to replace each bad sector logically with one of the spare sectors. This scheme is known as sector sparing or forwarding. A typical bad-sector transaction might be as follows:

• The operating system tries to read logical block 87.

• The controller calculates the ECC and finds that the sector is bad. It reports this finding to the operating system.

• The next time the system is rebooted, a special command is run to tell the controller to replace the bad sector with a spare.

• After that, whenever the system requests logical block 87, the request is translated into the replacement sector's address by the controller.

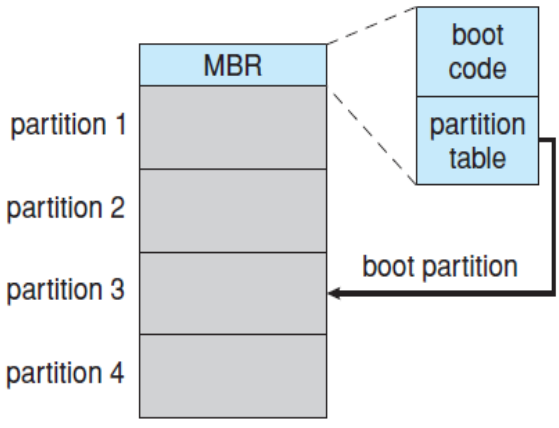

Figure 14.8 Booting from disks

Note that such a redirection by the controller could invalidate any optimization by the operating system's disk-scheduling algorithm! For this reason, most disks are formatted to provide a few spare sectors in each

cylinder and a spare cylinder as well. When a bad block is remapped, the controller uses a spare sector from the same cylinder, if possible.

As an alternative to sector sparing, some controllers can be instructed to replace a bad block by sector slipping. Here is an example: Suppose that logical block 17 becomes defective and the first available spare follows sector 202. Sector slipping then remaps all the sectors from 17 to 202, moving them all down one spot. That is, sector 202 is copied into the spare, then sector 201 into 202, then 200 into 201, and so on, until sector 18 is copied into sector 19.

Slipping the sectors in this way frees up the space of sector 18 so that sector 17 can be mapped to it. The replacement of a bad block generally is not totally automatic, because the data in the bad block are usually lost. Soft errors may trigger a process in which a copy of the block data is made and the block is spared or slipped. An unrecoverable hard error, however, results in lost data. Whatever file was using that block must be repaired

(for instance, by restoration from a backup tape), and that requires manual intervention.

Check your Progress

1. What does Solid State Drive (SSD) mean?
2. What is a Magnetic Tape?
3. What is a Host-Attached Storage?
4. What is a Network-attached storage?
5. What is a Storage Area Network?

14.7. ANSWERS TO CHECK YOUR PROGRESS

1. A solid state drive (SSD) is an electronic storage drive built on solid state architecture. SSDs are built with NAND and NOR flash memory to store non-volatile data and dynamic random access memory (DRAM). A SSD and magnetic hard disk drive (HDD) share a similar purpose.
2. Magnetic tape is a medium for magnetic recording, made of a thin, magnetizable coating on a long, narrow strip of plastic film. It was developed in Germany in 1928, based on magnetic wire recording.
3. Host-attached storage is storage accessed through local I/O ports.
    a. The typical desktop PC uses an I/O bus architecture called IDE or ATA. This architecture supports a maximum of two drives per I/O bus.
    b. A newer, similar protocol that has simplified cabling is SATA.
    c. High-end workstations and servers generally use more sophisticated I/O architectures, such as SCSI and fiber channel (FC).

4. Network-attached storage (NAS) is a file-level storage architecture where 1 or more servers with dedicated disks store data and share it with many clients connected to a network. NAS is 1 of the 3 main storage architectures—along with storage area networks (SAN) and direct-attached storage (DAS)—and is the only 1 that's both inherently networked and fully responsible for an entire network's storage.
5. A storage area network (SAN) is a dedicated high-speed network or subnetwork that interconnects and presents shared pools of storage devices to multiple servers.

14.8. SUMMARY

- The technique that operating system uses to determine the request which is to be satisfied next is called disk scheduling.
- Several kinds of buses are available, including advanced technology attachment (ATA), serial ATA (SATA), eSATA, universal serial bus (USB), and fibre channel (FC).
- Magnetic tape was used as an early secondary-storage medium.
- Host-attached storage is storage accessed through local I/O ports.
-
- Three major methods of allocating disk space are in wide use: contiguous, linked, and indexed.
- Contiguous allocation requires that each file occupy a set of contiguous blocks on the disk.
- Linked allocation solves all problems of contiguous allocation. With linked allocation, each file is a linked list of disk blocks; the disk blocks may be scattered anywhere on the disk.
- Since disk space is limited, we need to reuse the space from deleted files for new files, if possible.
- For sequential access, the file system remembers the disk address of the last block referenced and, when necessary, reads the next block.

14.9. KEYWORDS

- **SAN:** A storage-area network (SAN) is a private network (using storage protocols rather than networking protocols) connecting servers and storage units.
- **SCAN:** In the SCAN algorithm, the disk arm starts at one end of the disk and moves toward the other end, servicing requests as it reaches each cylinder, until it gets to the other end of the disk.
- **C-SCAN:** C-SCAN scheduling is a variant of SCAN designed to provide a more uniform wait time.

14.10. SELF ASSESSMENT QUESTIONS AND EXERCISES

Short Answer questions:

1. What is RPM?
2. What is a Disk Transfer Rates?
3. What is SSTF Scheduling?
4. What is C Scan Scheduling?
5. What Look Scheduling?

Long Answer questions:

1. Explain different types of Disk Scheduling?
2. Explain Disk Management?
3. Explain Over view of Storage structures?

14.11 FURTHER READINGS

Silberschatz, A., Galvin, P.B. and Gagne, G., 2006. Operating system principles. John Wiley & Sons.

Tanenbaum, A.S. and Woodhull, A.S., 1997. Operating systems: design and implementation (Vol. 68). Englewood Cliffs: Prentice Hall.

Deitel, H.M., Deitel, P.J. and Choffnes, D.R., 2004. Operating systems. Delhi.: Pearson Education: Dorling Kindersley.

Stallings, W., 2012. Operating systems: internals and design principles. Boston: Prentice Hall,.

MODEL QUESTION PAPER

SECTION-A (10X2=20 marks)

1. Define Operating System. List the objectives of an operating system.
2. With a neat diagram, explain various states of a process.
3. Give the Peterson's solution to the Critical section problem.
4. Distinguish between Logical and Physical address space.
5. What are the necessary conditions for the occurrence of deadlock?
6. What are the various attributes that are associated with an opened file?
7. Explain how multiprogramming increases the utilization of CPU.
8. What are the advantages of inter-process communication? Also explain various implementations of inter-process communication.
9. What is a Semaphore? Also give the operations for accessing semaphores.
10. What is the purpose of Paging and Page tables?

SECTION-B (5X5=25 marks)

1. With a neat diagram, explain the layered structure of UNIX operating system.

   (OR)

   What are the advantages and disadvantages of using the same system call interface for manipulating both files and devices?

2. What is a process? Explain about various fields of Process Control Block.

   (OR)

   What are the advantages of inter-process communication? How communication takes place in a shared-memory environment? Explain.

3. What is a Critical Section problem? Give the conditions that a solution to the critical section problem must satisfy.

   (OR)

What is Dining Philosophers problem? Discuss the solution to Dining philosopher's problem using monitors.

4. What is a Virtual Memory? Discuss the benefits of virtual memory technique.

(OR)

What is Thrashing? What is the cause of Thrashing? How does the system detect Thrashing? What can the system do to eliminate this problem?

5. What is a deadlock? How deadlocks are detected?

(OR)

Explain the Resource-Allocation-Graph algorithm for deadlock avoidance.

SECTION-C (3X10=30 marks)

(answer any three)

1. Discuss the necessary conditions that cause deadlock situation to occur.
2. Explain and compare the FCFS and SSTF disk scheduling algorithms.
3. Explain the various methods for free-space management.
4. Explain the Round Robin scheduling algorithm with a suitable example.
5. Write about deadlock conditions and bankers algorithm in detail.