Introduction

Practice Exercises

1.1 What are the three main purposes of an operating system?

Answer:
The three main purposes are:

- To provide an environment for a computer user to execute programs on computer hardware in a convenient and efficient manner.
- To allocate the separate resources of the computer as needed to perform the required tasks. The allocation process should be as fair and efficient as possible.
- As a control program, it serves two major functions: (1) supervision of the execution of user programs to prevent errors and improper use of the computer, and (2) management of the operation and control of I/O devices.

1.2 We have stressed the need for an operating system to make efficient use of the computing hardware. When is it appropriate for the operating system to forsake this principle and to "waste" resources? Why is such a system not really wasteful?

Answer:
Single-user systems should maximize use of the system for the user. A GUI might "waste" CPU cycles, but it optimizes the user's interaction with the system.

1.3 What is the main difficulty that a programmer must overcome in writing an operating system for a real-time environment?

Answer:
The main difficulty is keeping the operating system within the fixed time constraints of a real-time system. If the system does not complete a task in a certain time frame, it may cause a breakdown of the entire system. Therefore, when writing an operating system for a real-time system, the

writer must be sure that his scheduling schemes don't allow response time to exceed the time constraint.

1.4 Keeping in mind the various definitions of ***operating system,*** consider whether the operating system should include applications such as web browsers and mail programs. Argue both that it should and that it should not, and support your answers.

Answer:
An argument in favor of including popular applications in the operating system is that if the application is embedded within the operating system, it is likely to be better able to take advantage of features in the kernel and therefore have performance advantages over an application that runs outside of the kernel. Arguments against embedding applications within the operating system typically dominate, however: (1) the applications are applications—not part of an operating system, (2) any performance benefits of running within the kernel are offset by security vulnerabilities, and (3) inclusion of applications leads to a bloated operating system.

1.5 How does the distinction between kernel mode and user mode function as a rudimentary form of protection (security)?

Answer:
The distinction between kernel mode and user mode provides a rudimentary form of protection in the following manner. Certain instructions can be executed only when the CPU is in kernel mode. Similarly, hardware devices can be accessed only when the program is in kernel mode, and interrupts can be enabled or disabled only when the CPU is in kernel mode. Consequently, the CPU has very limited capability when executing in user mode, thereby enforcing protection of critical resources.

1.6 Which of the following instructions should be privileged?

a. Set value of timer.
b. Read the clock.
c. Clear memory.
d. Issue a trap instruction.
e. Turn off interrupts.
f. Modify entries in device-status table.
g. Switch from user to kernel mode.
h. Access I/O device.

Answer:
The following operations need to be privileged: set value of timer, clear memory, turn off interrupts, modify entries in device-status table, access I/O device. The rest can be performed in user mode.

1.7 Some early computers protected the operating system by placing it in a memory partition that could not be modified by either the user job or the operating system itself. Describe two difficulties that you think could arise with such a scheme.

Answer:
The data required by the operating system (passwords, access controls, accounting information, and so on) would have to be stored in or passed through unprotected memory and thus be accessible to unauthorized users.

1.8 Some CPUs provide for more than two modes of operation. What are two possible uses of these multiple modes?

Answer:
Although most systems only distinguish between user and kernel modes, some CPUs have supported multiple modes. Multiple modes could be used to provide a finer-grained security policy. For example, rather than distinguishing between just user and kernel mode, you could distinguish between different types of user mode. Perhaps users belonging to the same group could execute each other's code. The machine would go into a specified mode when one of these users was running code. When the machine was in this mode, a member of the group could run code belonging to anyone else in the group.

Another possibility would be to provide different distinctions within kernel code. For example, a specific mode could allow USB device drivers to run. This would mean that USB devices could be serviced without having to switch to kernel mode, thereby essentially allowing USB device drivers to run in a quasi-user/kernel mode.

1.9 Timers could be used to compute the current time. Provide a short description of how this could be accomplished.

Answer:
A program could use the following approach to compute the current time using timer interrupts. The program could set a timer for some time in the future and go to sleep. When awakened by the interrupt, it could update its local state, which it uses to keep track of the number of interrupts it has received thus far. It could then repeat this process of continually setting timer interrupts and updating its local state when the interrupts are actually raised.

1.10 Give two reasons why caches are useful. What problems do they solve? What problems do they cause? If a cache can be made as large as the device for which it is caching (for instance, a cache as large as a disk), why not make it that large and eliminate the device?

Answer:
Caches are useful when two or more components need to exchange data, and the components perform transfers at differing speeds. Caches solve the transfer problem by providing a buffer of intermediate speed between the components. If the fast device finds the data it needs in the cache, it need not wait for the slower device. The data in the cache must be kept consistent with the data in the components. If a component has

a data value change, and the datum is also in the cache, the cache must also be updated. This is especially a problem on multiprocessor systems, where more than one process may be accessing a datum. A component may be eliminated by an equal-sized cache, but only if: (a) the cache and the component have equivalent state-saving capacity (that is, if the component retains its data when electricity is removed, the cache must retain data as well), and (b) the cache is affordable, because faster storage tends to be more expensive.

1.11 Distinguish between the client–server and peer-to-peer models of distributed systems.

Answer:
The client-server model firmly distinguishes the roles of the client and server. Under this model, the client requests services that are provided by the server. The peer-to-peer model doesn't have such strict roles. In fact, all nodes in the system are considered peers and thus may act as *either* clients or servers—or both. A node may request a service from another peer, or the node may in fact provide such a service to other peers in the system.

For example, let's consider a system of nodes that share cooking recipes. Under the client-server model, all recipes are stored with the server. If a client wishes to access a recipe, it must request the recipe from the specified server. Using the peer-to-peer model, a peer node could ask other peer nodes for the specified recipe. The node (or perhaps nodes) with the requested recipe could provide it to the requesting node. Notice how each peer may act as both a client (it may request recipes) and as a server (it may provide recipes).

Operating-System Structures

CHAPTER 2

Practice Exercises

2.1 What is the purpose of system calls?

Answer:
System calls allow user-level processes to request services of the operating system.

2.2 What is the purpose of the command interpreter? Why is it usually separate from the kernel?

Answer:
It reads commands from the user or from a file of commands and executes them, usually by turning them into one or more system calls. It is usually not part of the kernel because the command interpreter is subject to changes.

2.3 What system calls have to be executed by a command interpreter or shell in order to start a new process on a UNIX system?

Answer: A `fork()` system call and an `exec()` system call need to be performed to start a new process. The `fork()` call clones the currently executing process, while the `exec()` call overlays a new process based on a different executable over the calling process.

2.4 What is the purpose of system programs?

Answer:
System programs can be thought of as bundles of useful system calls. They provide basic functionality to users so that users do not need to write their own programs to solve common problems.

2.5 What is the main advantage of the layered approach to system design? What are the disadvantages of the layered approach?

Answer:
As in all cases of modular design, designing an operating system in a modular way has several advantages. The system is easier to debug and modify because changes affect only limited sections of the system rather

than touching all sections. Information is kept only where it is needed and is accessible only within a defined and restricted area, so any bugs affecting that data must be limited to a specific module or layer. The primary disadvantage to the layered approach is th apoor performance due to the overhead of traversing through the different layers to obtain a service provided by the operating system.

2.6 List five services provided by an operating system, and explain how each creates convenience for users. In which cases would it be impossible for user-level programs to provide these services? Explain your answer.

Answer:
The five services are:

a. **Program execution**. The operating system loads the contents (or sections) of a file into memory and begins its execution. A user-level program could not be trusted to properly allocate CPU time.

b. **I/O operations**. It is necessary to communicate with disks, tapes, and other devices at a very low level. The user need only specify the device and the operation to perform on it, and the system converts that request into device- or controller-specific commands. User-level programs cannot be trusted to access only devices they should have access to and to access them only when they are otherwise unused.

c. **File-system manipulation**. There are many details in file creation, deletion, allocation, and naming that users should not have to perform. Blocks of disk space are used by files and must be tracked. Deleting a file requires removing the name file information and freeing the allocated blocks. Protections must also be checked to assure proper file access. User programs could neither ensure adherence to protection methods nor be trusted to allocate only free blocks and deallocate blocks on file deletion.

d. **Communications**. Message passing between systems requires messages to be turned into packets of information, sent to the network controller, transmitted across a communications medium, and reassembled by the destination system. Packet ordering and data correction must take place. Again, user programs might not coordinate access to the network device, or they might receive packets destined for other processes.

e. **Error detection**. Error detection occurs at both the hardware and software levels. At the hardware level, all data transfers must be inspected to ensure that data have not been corrupted in transit. All data on media must be checked to be sure they have not changed since they were written to the media. At the software level, media must be checked for data consistency—for instance, whether the number of allocated and unallocated blocks of storage match the total number on the device. There, errors are frequently process-independent (for instance, the corruption of data on a disk), so there must be a global program (the operating system) that handles all types of errors. Also, when errors are processed by the operating system, processes need not contain code to catch and correct all the errors possible on a system.

2.7 Why do some systems store the operating system in firmware, while others store it on disk?

Answer:
For certain devices, such as embedded systems, a disk with a file system may be not be available for the device. In this situation, the operating system must be stored in firmware.

2.8 How could a system be designed to allow a choice of operating systems from which to boot? What would the bootstrap program need to do?

Answer:
Consider a system that would like to run both Windows and three different distributions of Linux (for example, RedHat, Debian, and Ubuntu). Each operating system will be stored on disk. During system boot, a special program (which we will call the **boot manager**) will determine which operating system to boot into. This means that rather than initially booting to an operating system, the boot manager will first run during system startup. It is this boot manager that is responsible for determining which system to boot into. Typically, boot managers must be stored at certain locations on the hard disk to be recognized during system startup. Boot managers often provide the user with a selection of systems to boot into; boot managers are also typically designed to boot into a default operating system if no choice is selected by the user.

Processes

Practice Exercises

3.1 Using the program shown in Figure 3.30, explain what the output will be at LINE A.

```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

int value = 5;

int main()
{
pid_t pid;

  pid = fork();

  if (pid == 0) { /* child process */
     value += 15;
     return 0;
  }
  else if (pid > 0) { /* parent process */
     wait(NULL);
     printf("PARENT: value = %d",value); /* LINE A */
     return 0;
  }
}
```

Figure 3.30 What output will be at Line A?

Answer:
The result is still 5, as the child updates its copy of value. When control returns to the parent, its value remains at 5.

3.2 Including the initial parent process, how many processes are created by the program shown in Figure 3.31?

Answer:
Eight processes are created.

3.3 Original versions of Apple's mobile iOS operating system provided no means of concurrent processing. Discuss three major complications that concurrent processing adds to an operating system.

Answer:

a. The CPU scheduler must be aware of the different concurrent processes and must choose an appropriate algorithm that schedules the concurrent processes.

b. Concurrent processes may need to communicate with one another, and the operating system must therefore develop one or more methods for providing interprocess communication.

c. Because mobile devices often have limited memory, a process that manages memory poorly will have an overall negative impact on other concurrent processes. The operating system must therefore manage memory to support multiple concurrent processes.

3.4 Some computer systems provide multiple register sets. Describe what happens when a context switch occurs if the new context is already loaded into one of the register sets. What happens if the new context is in memory rather than in a register set and all the register sets are in use?

Answer:
The CPU current-register-set pointer is changed to point to the set containing the new context, which takes very little time. If the context is in memory, one of the contexts in a register set must be chosen and be moved to memory, and the new context must be loaded from memory into the set. This process takes a little more time than on systems with one set of registers, depending on how a replacement victim is selected.

3.5 When a process creates a new process using the `fork()` operation, which of the following states is shared between the parent process and the child process?

a. Stack

b. Heap

c. Shared memory segments

Answer:
Only the shared memory segments are shared between the parent process and the newly forked child process. Copies of the stack and the heap are made for the newly created process.

3.6 Consider the "exactly once"semantic with respect to the RPC mechanism. Does the algorithm for implementing this semantic execute correctly even if the ACK message sent back to the client is lost due to a network problem? Describe the sequence of messages, and discuss whether "exactly once" is still preserved.

Answer:
The "exactly once" semantics ensure that a remore procedure will be executed exactly once and only once. The general algorithm for ensuring this combines an acknowledgment (ACK) scheme combined with timestamps (or some other incremental counter that allows the server to distinguish between duplicate messages).

The general strategy is for the client to send the RPC to the server along with a timestamp. The client will also start a timeout clock. The client will then wait for one of two occurrences: (1) it will receive an ACK from the server indicating that the remote procedure was performed, or (2) it will time out. If the client times out, it assumes the server was unable to perform the remote procedure, so the client invokes the RPC a second time, sending a later timestamp. The client may not receive the ACK for one of two reasons: (1) the original RPC was never received by the server, or (2) the RPC was correctly received—and performed—by the server but the ACK was lost. In situation (1), the use of ACKs allows the server ultimately to receive and perform the RPC. In situation (2), the server will receive a duplicate RPC, and it will use the timestamp to identify it as a duplicate so as not to perform the RPC a second time. It is important to note that the server must send a second ACK back to the client to inform the client the RPC has been performed.

3.7 Assume that a distributed system is susceptible to server failure. What mechanisms would be required to guarantee the "exactly once" semantic for execution of RPCs?

Answer:
The server should keep track in stable storage (such as a disk log) of information regarding what RPC operations were received, whether they were successfully performed, and the results associated with the operations. When a server crash takes place and an RPC message is received, the server can check whether the RPC has been previously performed and therefore guarantee "exactly once" semantics for the execution of RPCs.

```
#include <stdio.h>
#include <unistd.h>

int main()
{
   /* fork a child process */
   fork();

   /* fork another child process */
   fork();

   /* and fork another */
   fork();

   return 0;
}
```

Figure 3.31 How many processes are created?

Threads & Concurrency

Practice Exercises

4.1 Provide three programming examples in which multithreading provides better performance than a single-threaded solution.

Answer:

a. A web server that services each request in a separate thread

b. A parallelized application such as matrix multiplication where various parts of the matrix can be worked on in parallel

c. An interactive GUI program such as a debugger where one thread is used to monitor user input, another thread represents the running application, and a third thread monitors performance

4.2 Using Amdahl's Law, calculate the speedup gain of an application that has a 60 percent parallel component for (a) two processing cores and (b) four processing cores.

Answer:

a. With two processing cores we get a speedup of 1.42 times.

b. With four processing cores, we get a speedup of 1.82 times.

4.3 Does the multithreaded web server described in Section 4.1 exhibit task or data parallelism?

Answer:
Data parallelism. Each thread is performing the same task, but on different data.

4.4 What are two differences between user-level threads and kernel-level threads? Under what circumstances is one type better than the other?

Answer:

a. User-level threads are unknown by the kernel, whereas the kernel is aware of kernel threads.

b. On systems using either many-to-one or many-to-many model mapping, user threads are scheduled by the thread library, and the kernel schedules kernel threads.

c. Kernel threads need not be associated with a process, whereas every user thread belongs to a process. Kernel threads are generally more expensive to maintain than user threads, as they must be represented with a kernel data structure.

4.5 Describe the actions taken by a kernel to context-switch between kernel-level threads.

Answer:
Context switching between kernel threads typically requires saving the value of the CPU registers from the thread being switched out and restoring the CPU registers of the new thread being scheduled.

4.6 What resources are used when a thread is created? How do they differ from those used when a process is created?

Answer:
Because a thread is smaller than a process, thread creation typically uses fewer resources than process creation. Creating a process requires allocating a process control block (PCB), a rather large data structure. The PCB includes a memory map, a list of open files, and environment variables. Allocating and managing the memory map is typically the most time-consuming activity. Creating either a user thread or a kernel thread involves allocating a small data structure to hold a register set, stack, and priority.

4.7 Assume that an operating system maps user-level threads to the kernel using the many-to-many model and that the mapping is done through LWPs. Furthermore, the system allows developers to create real-time threads for use in real-time systems. Is it necessary to bind a real-time thread to an LWP? Explain.

Answer:
Yes. Timing is crucial to real-time applications. If a thread is marked as real-time but is not bound to an LWP, the thread may have to wait to be attached to an LWP before running. Consider a situation in which a real-time thread is running (is attached to an LWP) and then proceeds to block (must perform I/O, has been preempted by a higher-priority real-time thread, is waiting for a mutual exclusion lock, etc.). While the real-time thread is blocked, the LWP it was attached to is assigned to another thread. When the real-time thread has been scheduled to run again, it must first wait to be attached to an LWP. By binding an LWP to a real-time thread, you are ensuring that the thread will be able to run with minimal delay once it is scheduled.

CHAPTER 5

CPU Scheduling

Practice Exercises

5.1 A CPU-scheduling algorithm determines an order for the execution of its scheduled processes. Given n processes to be scheduled on one processor, how many different schedules are possible? Give a formula in terms of n.

Answer:
$n!$ (n factorial $= n \times n - 1 \times n - 2 \times ... \times 2 \times 1$).

5.2 Explain the difference between preemptive and nonpreemptive scheduling.

Answer:
Preemptive scheduling allows a process to be interrupted in the midst of its execution, taking the CPU away and allocating it to another process. Nonpreemptive scheduling ensures that a process relinquishes control of the CPU only when it finishes with its current CPU burst.

5.3 Suppose that the following processes arrive for execution at the times indicated. Each process will run for the amount of time listed. In answering the questions, use nonpreemptive scheduling, and base all decisions on the information you have at the time the decision must be made.

Process	Arrival Time	Burst Time
P_1	0.0	8
P_2	0.4	4
P_3	1.0	1

a. What is the average turnaround time for these processes with the FCFS scheduling algorithm?

b. What is the average turnaround time for these processes with the SJF scheduling algorithm?

c. The SJF algorithm is supposed to improve performance, but notice that we chose to run process P_1 at time 0 because we did not know that two shorter processes would arrive soon. Compute what the average turnaround time will be if the CPU is left idle for the first 1 unit and then SJF scheduling is used. Remember that processes P_1 and P_2 are waiting during this idle time, so their waiting time may increase. This algorithm could be known as ***future-knowledge scheduling***.

Answer:

a. 10.53

b. 9.53

c. 6.86

Remember that turnaround time is finishing time minus arrival time, so you have to subtract the arrival times to compute the turnaround times. FCFS is 11 if you forget to subtract arrival time.

5.4 Consider the following set of processes, with the length of the CPU burst time given in milliseconds:

Process	Burst Time	Priority
P_1	2	2
P_2	1	1
P_3	8	4
P_4	4	2
P_5	5	3

The processes are assumed to have arrived in the order P_1, P_2, P_3, P_4, P_5, all at time 0.

a. Draw four Gantt charts that illustrate the execution of these processes using the following scheduling algorithms: FCFS, SJF, nonpreemptive priority (a larger priority number implies a higher priority), and RR (quantum = 2).

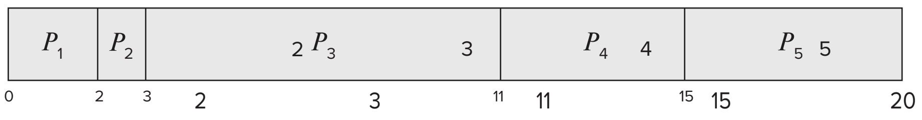
b. What is the turnaround time of each process for each of the scheduling algorithms in part a?

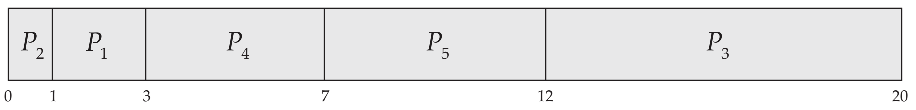
c. What is the waiting time of each process for each of these scheduling algorithms?

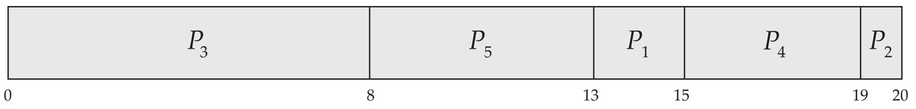
d. Which of the algorithms results in the minimum average waiting time (over all processes)?

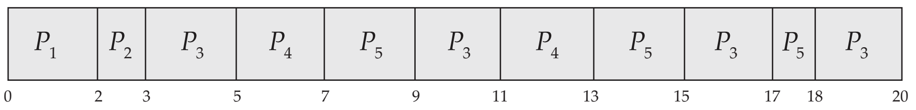
Answer:

a. The four Gantt charts:









b. Turnaround time:

	FCFS	SJF	Priority	RR
P_1	2	3	15	2
P_2	3	1	20	3
P_3	11	20	8	20
P_4	15	7	19	13
P_5	20	12	13	18

c. Waiting time (turnaround time minus burst time):

	FCFS	SJF	Priority	RR
P_1	0	1	13	0
P_2	2	0	19	2
P_3	3	12	0	12
P_4	11	3	15	9
P_5	15	7	8	13

d. SJF has the shortest wait time.

5.5 The following processes are being scheduled using a preemptive, round-robin scheduling algorithm.

Process	Priority	Burst	Arrival
P_1	40	20	0
P_2	30	25	25
P_3	30	25	30
P_4	35	15	60
P_5	5	10	100
P_6	10	10	105

Each process is assigned a numerical priority, with a higher number indicating a higher relative priority. In addition to the processes listed above, the system also has an **idle task** (which consumes no CPU resources and is identified as P_{idle}). This task has priority 0 and is scheduled whenever the system has no other available processes to run. The length of a time quantum is 10 units. If a process is preempted by a higher-priority process, the preempted process is placed at the end of the queue.

a. Show the scheduling order of the processes using a Gantt chart.

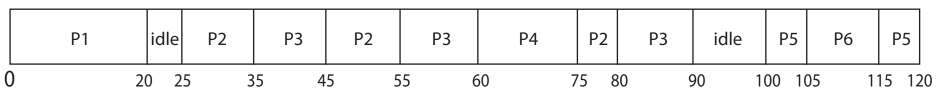
b. What is the turnaround time for each process?

c. What is the waiting time for each process?

d. What is the CPU utilization rate?

Answer:

a. The Gantt chart:



b. P1: 20-0 - 20, P2: 80-25 = 55, P3: 90 - 30 = 60, P4: 75-60 = 15, P5: 120-100 = 20, P6: 115-105 = 10

c. P1: 0, p2: 40, P3: 35, P4: 0, P5: 10, P6: 0

d. 105/120 = 87.5 percent.

5.6 What advantage is there in having different time-quantum sizes at different levels of a multilevel queueing system?

Answer:
Processes that need more frequent servicing—for instance, interactive processes such as editors—can be in a queue with a small time quantum. Processes with no need for frequent servicing can be in a queue with a larger quantum, requiring fewer context switches to complete the processing and thus making more efficient use of the computer.

5.7 Many CPU-scheduling algorithms are parameterized. For example, the RR algorithm requires a parameter to indicate the time slice. Multilevel feedback queues require parameters to define the number of queues, the scheduling algorithms for each queue, the criteria used to move processes between queues, and so on.

These algorithms are thus really sets of algorithms (for example, the set of RR algorithms for all time slices, and so on). One set of algorithms may include another (for example, the FCFS algorithm is the RR algorithm with an infinite time quantum). What (if any) relation holds between the following pairs of algorithm sets?

a. Priority and SJF

b. Multilevel feedback queues and FCFS

c. Priority and FCFS

d. RR and SJF

Answer:

a. The shortest job has the highest priority.

b. The lowest level of MLFQ is FCFS.

c. FCFS gives the highest priority to the job that has been in existence the longest.

d. None.

5.8 Suppose that a CPU scheduling algorithm favors those processes that have used the least processor time in the recent past. Why will this algorithm favor I/O-bound programs and yet not permanently starve CPU-bound programs?

Answer:
It will favor the I/O-bound programs because of the relatively short CPU bursts requested by them; however, the CPU-bound programs will not starve, because the I/O-bound programs will relinquish the CPU relatively often to do their I/O.

5.9 Distinguish between PCS and SCS scheduling.

Answer:
PCS scheduling is local to the process. It is how the thread library schedules threads onto available LWPs. SCS scheduling is used when the operating system schedules kernel threads. On systems using either the many-to-one or the many-to-many model, the two scheduling models are fundamentally different. On systems using the one-to-one model, PCS and SCS are the same.

5.10 The traditional UNIX scheduler enforces an inverse relationship between priority numbers and priorities: the higher the number, the lower the priority. The scheduler recalculates process priorities once per second using the following function:

Priority = (recent CPU usage / 2) + base

where base = 60 and *recent CPU usage* refers to a value indicating how often a process has used the CPU since priorities were last recalculated.

Assume that recent CPU usage for process P_1 is 40, for process P_2 is 18, and for process P_3 is 10. What will be the new priorities for these three processes when priorities are recalculated? Based on this information, does the traditional UNIX scheduler raise or lower the relative priority of a CPU-bound process?

Answer:
The priorities assigned to the processes will be 80, 69, and 65, respectively. The scheduler lowers the relative priority of CPU-bound processes.

CHAPTER 6

Synchronization Tools

Practice Exercises

6.1 In Section 6.4, we mentioned that disabling interrupts frequently can affect the system's clock. Explain why this can occur and how such effects can be minimized.

Answer:
The system clock is updated at every clock interrupt. If interrupts were disabled—particularly for a long period of time—the system clock could easily lose the correct time. The system clock is also used for scheduling purposes. For example, the time quantum for a process is expressed as a number of clock ticks. At every clock interrupt, the scheduler determines if the time quantum for the currently running process has expired. If clock interrupts were disabled, the scheduler could not accurately assign time quanta. This effect can be minimized by disabling clock interrupts for only very short periods.

6.2 What is the meaning of the term ***busy waiting***? What other kinds of waiting are there in an operating system? Can busy waiting be avoided altogether? Explain your answer.

Answer:
Busy waiting means that a process is waiting for a condition to be satisfied in a tight loop without relinquishing the processor. One strategy to avoid busy waiting temporarily puts the waiting process to sleep and awakens it when the appropriate program state is reached, but this solution incurs the overhead associated with putting the process to sleep and later waking it up.

6.3 Explain why spinlocks are not appropriate for single-processor systems yet are often used in multiprocessor systems.

Answer:
Spinlocks are not appropriate for single-processor systems because the condition that would break a process out of the spinlock can be obtained only by executing a different process. If the process is not relinquishing the processor, other processes do not get the opportunity to set the

program condition required for the first process to make progress. In a multiprocessor system, other processes execute on other processors and therefore can modify the program state in order to release the first process from the spinlock.

6.4 Show that, if the `wait()` and `signal()` semaphore operations are not executed atomically, then mutual exclusion may be violated.

Answer:
A `wait()` operation atomically decrements the value associated with a semaphore. If two `wait()` operations are executed on a semaphore when its value is 1 and the operations are not performed atomically, then both operations might decrement the semaphore value, thereby violating mutual exclusion.

6.5 Illustrate how a binary semaphore can be used to implement mutual exclusion among n processes.

Answer:
The n processes share a semaphore, `mutex`, initialized to 1. Each process P_i is organized as follows:

```
do {
   wait(mutex);

      /* critical section */

   signal(mutex);

      /* remainder section */
} while (true);
```

6.6 Race conditions are possible in many computer systems. Consider a banking system that maintains an account balance with two functions: `deposit(amount)` and `withdraw(amount)`. These two functions are passed the `amount` that is to be deposited or withdrawn from the bank account balance. Assume that a husband and wife share a bank account. Concurrently, the husband calls the `withdraw()` function, and the wife calls `deposit()`. Describe how a race condition is possible and what might be done to prevent the race condition from occurring.

Answer:
Assume that the balance in the account is $250.00 and that the husband calls `withdraw($50)` and the wife calls `deposit($100)`. Obviously, the correct value should be $300.00. Since these two transactions will be serialized, the local value of the balance for the husband becomes $200.00, but before he can commit the transaction, the `deposit(100)` operation takes place and updates the shared value of the balance to $300.00. We then switch back to the husband, and the value of the shared balance is set to $200.00—obviously an incorrect value.

CHAPTER 7

Synchronization Examples

Practice Exercises

7.1 Explain why Windows and Linux implement multiple locking mechanisms. Describe the circumstances under which they use spinlocks, mutex locks, semaphores, and condition variables. In each case, explain why the mechanism is needed.

Answer:
These operating systems provide different locking mechanisms depending on the application developers' needs. Spinlocks are useful for multiprocessor systems where a thread can run in a busy loop (for a short period of time) rather than incurring the overhead of being put in a sleep queue. Mutexes are useful for locking resources. Solaris 2 uses adaptive mutexes, meaning that the mutex is implemented with a spinlock on multiprocessor machines. Semaphores and condition variables are more appropriate tools for synchronization when a resource must be held for a long period of time, since spinning is inefficient for a long duration.

7.2 Windows provides a lightweight synchronization tool called **slim reader–writer** locks. Whereas most implementations of reader–writer locks favor either readers or writers, or perhaps order waiting threads using a FIFO policy, slim reader–writer locks favor neither readers nor writers, nor are waiting threads ordered in a FIFO queue. Explain the benefits of providing such a synchronization tool.

Answer:
Simplicity. If reader–writer locks provide fairness or favor readers or writers, they involve more overhead. Providing such a simple synchronization mechanism makes access to the lock fast. Use of this lock may be most appropriate for situations where reader–writer locks are needed, but quickly acquiring and releasing them is similarly important.

7.3 Describe what changes would be necessary to the producer and consumer processes in Figure 7.1 and Figure 7.2 so that a mutex lock could be used instead of a binary semaphore.

Answer:

The calls to `wait(mutex)` and `signal(mutex)` need to be replaced so that they are now calls to the API for a mutex lock, such as `acquire(mutex)` and `release()` mutex.

7.4 Describe how deadlock is possible with the dining-philosophers problem.

Answer:
If all philosophers simultaneously pick up their left forks, when they turn to pick up their right forks they will realize they are unavailable, and will block while waiting for it to become available. This blocking while waiting for a resource to become available is a deadlocked situation.

7.5 Explain the difference between signaled and non-signaled states with Windows dispatcher objects.

Answer:
An object that is in the signaled state is available, and a thread will not block when it tries to acquire it. When the lock is acquired, it is in the non-signaled state. When the lock is released, it transitions back to the signaled state.

7.6 Assume `val` is an atomic integer in a Linux system. What is the value of `val` after the following operations have been completed?

```
atomic_set(&val,10);
atomic_sub(8,&val);
atomic_inc(&val);
atomic_inc(&val);
atomic_add(6,&val);
atomic_sub(3,&val);
```

Answer:
The final value of `val` is 10 - 8 + 1 + 1 + 6 - 3 = 7

Deadlocks

Practice Exercises

8.1 List three examples of deadlocks that are not related to a computer-system environment.

Answer:

- Two cars crossing a single-lane bridge from opposite directions.
- A person going down a ladder while another person is climbing up the ladder.
- Two trains traveling toward each other on the same track.

8.2 Suppose that a system is in an unsafe state. Show that it is possible for the threads to complete their execution without entering a deadlocked state.

Answer:
An unsafe state may not necessarily lead to deadlock, it just means that we cannot guarantee that deadlock will not occur. Thus, it is possible that a system in an unsafe state may still allow all processes to complete without deadlock occurring. Consider the situation where a system has twelve resources allocated among processes P_0, P_1, and P_2. The resources are allocated according to the following policy:

	Max	Current	Need
P_0	10	5	5
P_1	4	2	2
P_2	9	3	6

Currently, there are two resources available. This system is in an unsafe state. Process P_1 could complete, thereby freeing a total of four resources, but we cannot guarantee that processes P_0 and P_2 can complete. However, it is possible that a process may release resources before requesting any further resources. For example, process P_2 could release a resource, thereby increasing the total number of resources to five. This allows process P_0 to complete, which would free a total of nine resources, thereby allowing process P_2 to complete as well.

8.3 Consider the following snapshot of a system:

	Allocation	*Max*	*Available*
	A B C D	*A B C D*	*A B C D*
T_0	0 0 1 2	0 0 1 2	1 5 2 0
T_1	1 0 0 0	1 7 5 0	
T_2	1 3 5 4	2 3 5 6	
T_3	0 6 3 2	0 6 5 2	
T_4	0 0 1 4	0 6 5 6	

Answer the following questions using the banker's algorithm:

a. What is the content of the matrix ***Need***?

b. Is the system in a safe state?

c. If a request from thread T_1 arrives for (0,4,2,0), can the request be granted immediately?

Answer:

a. The values of ***Need*** for processes P_0 through P_4, respectively, are (0, 0, 0, 0), (0, 7, 5, 0), (1, 0, 0, 2), (0, 0, 2, 0), and (0, 6, 4, 2).

b. The system is in a safe state. With ***Available*** equal to (1, 5, 2, 0), either process P_0 or P_3 could run. Once process P_3 runs, it releases its resources, which allows all other existing processes to run.

c. The request can be granted immediately. The value of ***Available*** is then (1, 1, 0, 0). One ordering of processes that can finish is P_0, P_2, P_3, P_1, and P_4.

8.4 A possible method for preventing deadlocks is to have a single, higher-order resource that must be requested before any other resource. For example, if multiple threads attempt to access the synchronization objects $A \cdots E$, deadlock is possible. (Such synchronization objects may include mutexes, semaphores, condition variables, and the like.) We can prevent deadlock by adding a sixth object F. Whenever a thread wants to acquire the synchronization lock for any object $A \cdots E$, it must first acquire the lock for object F. This solution is known as **containment**: the locks for objects $A \cdots E$ are contained within the lock for object F. Compare this scheme with the circular-wait scheme of Section 8.5.4.

Answer:
This is probably not a good solution because it yields too large a scope. It is better to define a locking policy with as narrow a scope as possible. The circular wait approach is a reasonable approach to avoiding deadlock, and does not increase the scope of holding a lock.

8.5 Prove that the safety algorithm presented in Section 8.6.3 requires an order of $m \times n^2$ operations.

Answer:

The figure below provides Java code that implements the safety algorithm of the banker's algorithm (the complete implementation of the banker's algorithm is available with the source-code download for this text).

```
for (int i = 0; i < n; i++) {
   // first find a thread that can finish
   for (int j = 0; j < n; j++) {
      if (!finish[j]) {
         boolean temp = true;
         for (int k = 0; k < m; k++) {
            if (need[j][k] > work[k])
               temp = false;
         }

         if (temp) { // if this thread can finish
            finish[j] = true;
            for (int x = 0; x < m; x++)
               work[x] += work[j][x];
         }
      }
   }
}
```

As can be seen, the nested outer loops—both of which loop through n times—provide the n^2 performance. Within these outer loops are two sequential inner loops that loop m times. The Big O of this algorithm is therefore $O(m \times n^2)$.

8.6 Consider a computer system that runs 5,000 jobs per month and has no deadlock-prevention or deadlock-avoidance scheme. Deadlocks occur about twice per month, and the operator must terminate and rerun about ten jobs per deadlock. Each job is worth about two dollars (in CPU time), and the jobs terminated tend to be about half done when they are aborted.

A systems programmer has estimated that a deadlock-avoidance algorithm (like the banker's algorithm) could be installed in the system with an increase of about 10 percent in the average execution time per job. Since the machine currently has 30 percent idle time, all 5,000 jobs per month could still be run, although turnaround time would increase by about 20 percent on average.

a. What are the arguments for installing the deadlock-avoidance algorithm?

b. What are the arguments against installing the deadlock-avoidance algorithm?

Answer:

An argument for installing deadlock avoidance in the system is that we could ensure that deadlock would never occur. In addition, despite the increase in turnaround time, all 5,000 jobs could still run.
An argument against installing deadlock-avoidance software is that deadlocks occur infrequently, and they cost little when they do occur.

8.7 Can a system detect that some of its threads are starving? If you answer "yes," explain how it can. If you answer "no," explain how the system can deal with the starvation problem.

Answer:
Starvation is a difficult topic to define, as it may mean different things for different systems. For the purposes of this question, we will define starvation as the situation in which a process must wait beyond a reasonable period of time—perhaps indefinitely—before receiving a requested resource. One way of detecting starvation would be to first identify a period of time—T—that is considered unreasonable. When a process requests a resource, a timer is started. If the elapsed time exceeds T, then the process is considered to be starved.

One strategy for dealing with starvation would be to adopt a policy whereby resources are assigned only to the process that has been waiting the longest. For example, if process P_a has been waiting longer for resource X than process P_b, the request from process P_b would be deferred until process P_a's request has been satisfied.

Another strategy would be less strict. In this scenario, a resource might be granted to a process that had waited less than another process, providing that the other process was not starving. However, if another process was considered to be starving, its request would be satisfied first.

8.8 Consider the following resource-allocation policy. Requests for and releases of resources are allowed at any time. If a request for resources cannot be satisfied because the resources are not available, then we check any threads that are blocked waiting for resources. If a blocked thread has the desired resources, then these resources are taken away from it and are given to the requesting thread. The vector of resources for which the blocked thread is waiting is increased to include the resources that were taken away.

For example, a system has three resource types, and the vector ***Available*** is initialized to (4,2,2). If thread T_0 asks for (2,2,1), it gets them. If T_1 asks for (1,0,1), it gets them. Then, if T_0 asks for (0,0,1), it is blocked (resource not available). If T_2 now asks for (2,0,0), it gets the available one (1,0,0), as well as one that was allocated to T_0 (since T_0 is blocked). T_0's ***Allocation*** vector goes down to (1,2,1), and its ***Need*** vector goes up to (1,0,1).

a. Can deadlock occur? If you answer "yes," give an example. If you answer "no," specify which necessary condition cannot occur.

b. Can indefinite blocking occur? Explain your answer.

Answer:

a. Deadlock cannot occur, because preemption exists.

b. Yes. A process may never acquire all the resources it needs if they are continuously preempted by a series of requests such as those of process *C*.

8.9 Consider the following snapshot of a system:

	Allocation	***Max***
	A B C D	*A B C D*
T_0	3 0 1 4	5 1 1 7
T_1	2 2 1 0	3 2 1 1
T_2	3 1 2 1	3 3 2 1
T_3	0 5 1 0	4 6 1 2
T_4	4 2 1 2	6 3 2 5

Using the banker's algorithm, determine whether or not each of the following states is unsafe. If the state is safe, illustrate the order in which the threads may complete. Otherwise, illustrate why the state is unsafe.

a. ***Available*** $= (0, 3, 0, 1)$

b. ***Available*** $= (1, 0, 0, 2)$

Answer:

a. Not safe. Processes P_2, P_1, and P_3 are able to finish, but no remaining processes can finish.
Safe. Processes P_1, P_2, and P_3 are able to finish. Following this, processes P_0 and P_4 are also able to finish.

8.10 Suppose that you have coded the deadlock-avoidance safety algorithm that determines if a system is in a safe state or not, and now have been asked to implement the deadlock-detection algorithm. Can you do so by simply using the safety algorithm code and redefining $\boldsymbol{Max}_i = \boldsymbol{Waiting}_i + \boldsymbol{Allocation}_i$, where $\boldsymbol{Waiting}_i$ is a vector specifying the resources for which thread *i* is waiting and $\boldsymbol{Allocation}_i$ is as defined in Section 8.6? Explain your answer.

Answer:
Yes. The *Max* vector represents the maximum request a process may make. When calculating the safety algorithm, we use the *Need* matrix, which represents *Max* — *Allocation*. Another way to think of this is *Max* = *Need* + *Allocation*. According to the question, the *Waiting* matrix fulfills a role similar to the *Need* matrix; therefore, *Max* = *Waiting* + *Allocation*.

8.11 Is it possible to have a deadlock involving only one single-threaded process? Explain your answer.

Answer:
No. This follows directly from the hold-and-wait condition.