2.1 Processes:

- Multiprocessors have two or more CPUs sharing the same physical memory
- **Process Model:**
    - Rapid switching back and forth is known as multiprogramming
    - there is only one program counter so when the process is running the logical program counter is loaded into the real program counter
        - then saved in the process' stored logical program counter in memory

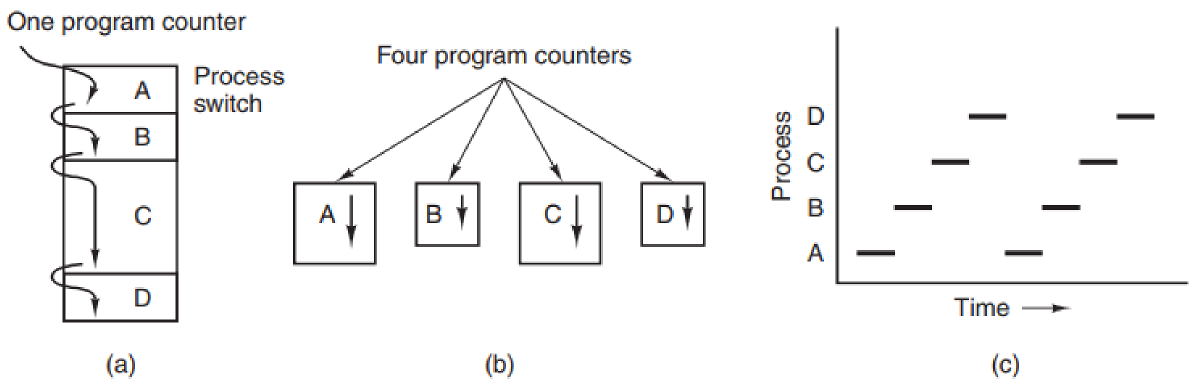


Figure 2-1. (a) Multiprogramming four programs. (b) Conceptual model of four independent, sequential processes. (c) Only one program is active at once.

- processes must not be programmed with built in assumptions about timing
- processes have a program, input, output and a state, whereas a program is something that may be stored on a disk
- If a program is running twice, it counts as two processes… meaning if there are two documents that you would like to print and two printers available and done at the same time, it is two processes

- **Process Creation:**
    - Four principal events cause processes to be created:
        - System initialization
        - execution of a process-creation system call by a running process
        - Aa user request to create new process
        - initiation of a batch job
    - Daemons: processes that stay in the background to handle some activity such as email, web pages, news, and printing
    - fork creates an exact clone of the calling process
        - they have the same memory image
        - changing the memory image of the child fork must be done with execve
    - in both unix and windows, after a process is created, the parent and child have their own distinct address space, if a process changes a word the other process is unaware of the change
        - no writable memory is shared between these processes
        - child may share all of the parent's memory but the memory is shared copy-on-write meaning that whenever either of the two wants to modify part of the memory, that chuck is explicitly copied first to make sure the modification occurs in a private memory area
- **Process Termination:**

- **Processes will terminate due to the given conditions:**
    - normal exit (voluntary)
    - error exit (voluntary)
    - fatal error (involuntary) - often due to a program bug
    - killed by another process (involuntary) - kill call in unix and the process killing must have authorization to do so
- **Process Hierarchies:**
    - child processes can only have one parent
    - the parents and children for a process group and this allows for the processes to individually catch signals, ignore, or take default action (killed)
    - init - the root process of all processes
    - parents are given special tokens, known as handles, that are used to control the child
- **Process States:**
    - processes may generate some output that another process will use as input:
      cat chapter 1 chapter2 chapter3 | grep tree
      concatenates and outputs three files, and running grep selects all lines containing the word "tree"
        - grep maybe ready to run but there is no input waiting for it which results in a block
            - blocking: cannot logically continue, waiting for input that is not available yet OR the process is stopped to allocate for another process
    - **Three process states:**
        - Running (actually using CPU)
        - Ready (runnable; temporarily stopped to let another process run)
        - Blocked (unable to run until some external even happens

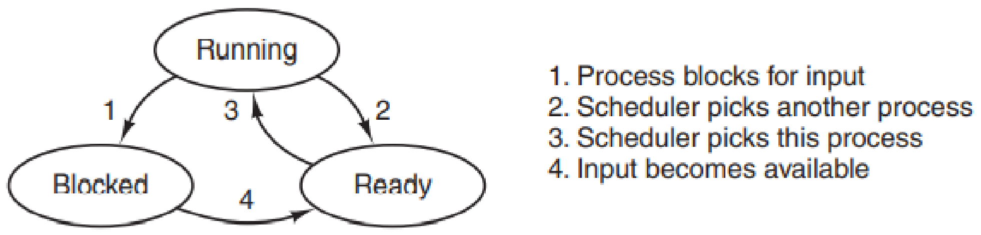

Running
Blocked
Ready
1
2
3
4
1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

Figure 2-2. A process can be in running, blocked, or ready state. Transitions between these states are as shown.

- Process scheduler: part of the operating system without the process even knowing about them

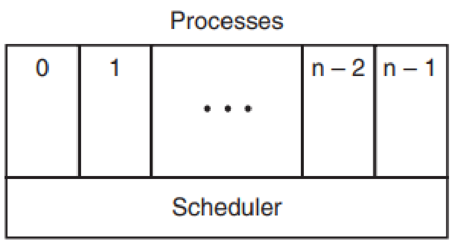
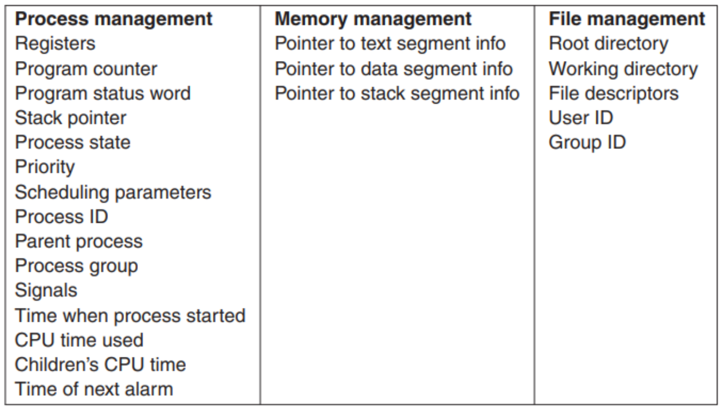


Figure 2-3. The lowest layer of a process-structured operating system handles interrupts and scheduling. Above that layer are sequential processes.

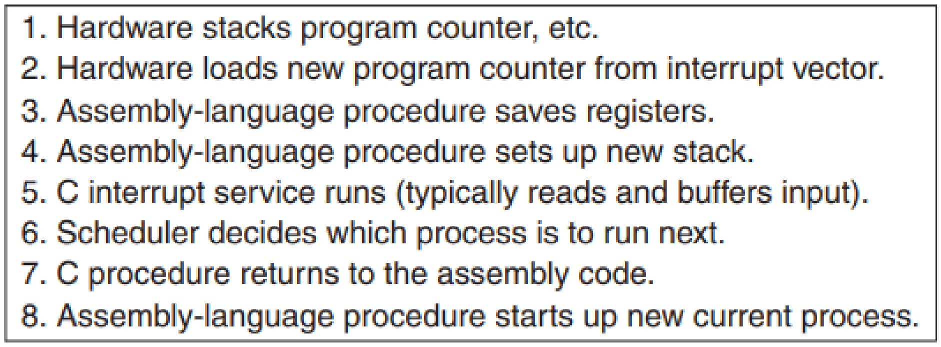
- **Implementation of Processes**
    - Process table: an array of structures with one entry per process
        - contains important information like process' state, program counter, stack pointer, memory allocation, status of its open files, account and scheduling, important registers, and anything else and is switched to either running, blocked, or ready



Process management	Memory management	File management
Registers	Pointer to text segment info	Root directory
Program counter	Pointer to data segment info	Working directory
Program status word	Pointer to stack segment info	File descriptors
Stack pointer		User ID
Process state		Group ID
Priority		
Scheduling parameters		
Process ID		
Parent process		
Process group		
Signals		
Time when process started		
CPU time used		
Children's CPU time		
Time of next alarm		

Figure 2-4. Some of the fields of a typical process-table entry.

- Interrupt vector: contains the address of the interrupt service procedure, when a procedure is interrupted all the information associated at the time is pushed onto this



1. Hardware stacks program counter, etc.
2. Hardware loads new program counter from interrupt vector.
3. Assembly-language procedure saves registers.
4. Assembly-language procedure sets up new stack.
5. C interrupt service runs (typically reads and buffers input).
6. Scheduler decides which process is to run next.
7. C procedure returns to the assembly code.
8. Assembly-language procedure starts up new current process.

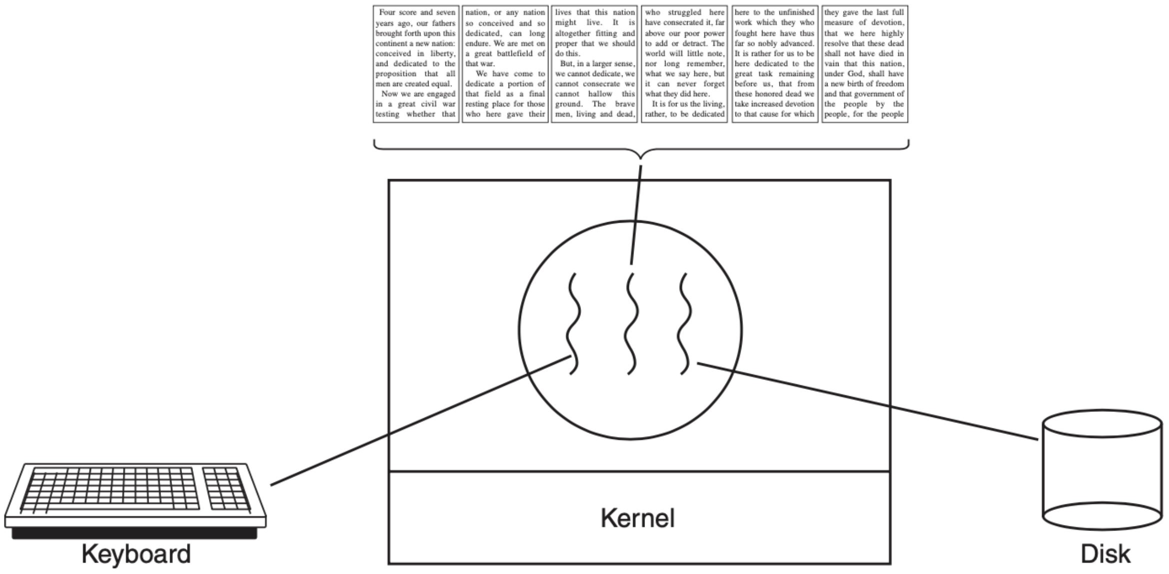
Figure 2-5. Skeleton of what the lowest level of the operating system does when an interrupt occurs.

- **Modeling Multiprogramming:**
    - lets processes use the CPU when it would otherwise become idle
    - example: a computer has 8gb of memory, and os and tables take up two and user programs take up 2gb. This allows for three user programs to be in memory at once, with an 80% average I/O wait, meaning our CPU utilization is 1-0.8^3 which is roughly 49% usage, more gb would allow us to have a larger utilization figure. say 8gb added, this jumps it to 79% utilization

<u>**2.2 Threads**</u>

- **Thread Usage:**
    - threads are known as microprocesses
    - threads have the ability for the parallel entities to share an address space and all of its data among themselves

- easier and faster to create and destroy that a regular process
- when there is substantial computing and also substantial I/O, having threads allows these activities to overlap, speeding up the application
- useful on systems with multiple CPUs



Four score and seven years ago, our fathers brought forth upon this continent a new nation: conceived in liberty, and dedicated to the proposition that all men are created equal.

Now we are engaged in a great civil war testing whether that nation, or any nation so conceived and so dedicated, can long endure. We are met on a great battlefield of that war.

We have come to dedicate a portion of that field as a final resting place for those who here gave their lives that this nation might live. It is altogether fitting and proper that we should do this.

But, in a larger sense, we cannot dedicate, we cannot consecrate we cannot hallow this ground. The brave men, living and dead, who struggled here have consecrated it, far above our poor power to add or detract. The world will little note, nor long remember, what we say here, but it can never forget what they did here.

It is for us the living, rather, to be dedicated here to the unfinished work which they who fought here have thus far so nobly advanced. It is rather for us to be here dedicated to the great task remaining before us, that from these honored dead we take increased devotion to that cause for which they gave the last full measure of devotion, that we here highly resolve that these dead shall not have died in vain that this nation, under God, shall have a new birth of freedom and that government of the people by the people, for the people

Figure 2-7. A word processor with three threads.

- If this were a single thread, any time a backup was created on the disk it would block any other process until it was finished appearing sluggish
- These three threads all share common memory and have access to the document being edited
- Caches store data that is heavily used in main memory rather than disk memory for faster retrieval
- **Web server example:**
    - dispatcher thread: reads incoming requests for work from the network
    - worker thread is used and writes a pointer to the message into a special word associated with that thread
        - dispatcher wakes up sleeping working and moves it from blocked to ready state

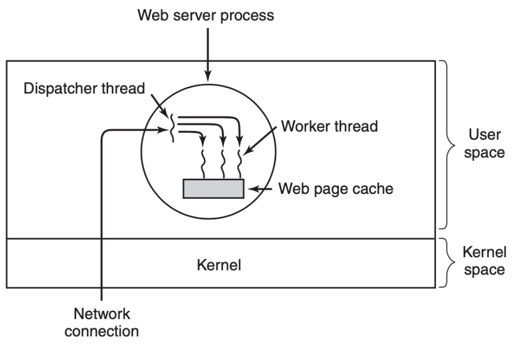


Figure 2-8. A multithreaded Web server.

        - Worker checks to see if the webpage was cached, if not a read operation to get the page from the disk is done

Model	Characteristics
Threads	Parallelism, blocking system calls
Single Threaded process	No parallelism, blocking system calls
Finite-State Machine	Parallelism, non blocking system calls, interrupts

Example of what a thread would look like :

```
while(TRUE){
        get_next_request(&buf);
        handoff_work(&buf);
}
```

```
while(TRUE){
        wait_for_work(&buf);
        look_for_page_in_cache(&buf, &page);
        if(page_not_in_cache(&page){
                read_page_from_disk(&buf,
                &page);
        }
        return_page(&page);
}
```

- **Classical Thread Model:**
    - Based on two independent concepts: resource grouping and execution
    - Processes group related resources together
    - Threads belong to a process and execute tasks
        - contains a program counter, registers, stack.
    - Processes are used to group resources together; threads are the entities scheduled for execution on the CPU

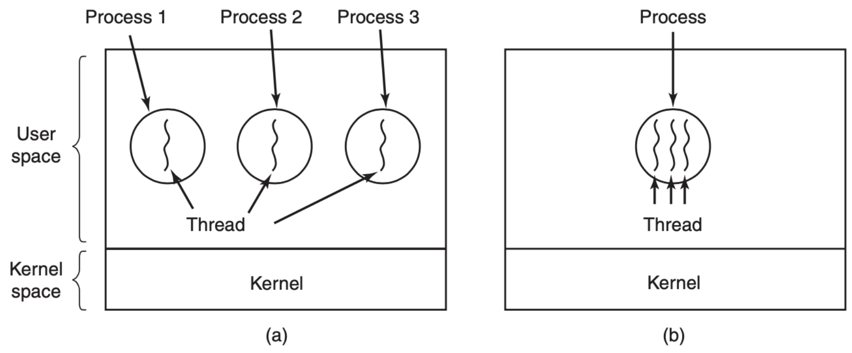


Figure 2-11. (a) Three processes each with one thread. (b) One process with three threads.

- threads within the same process share and access all the memory within the process' address space, meaning one can read, write, or wipe out another thread's stack

Per-process items (shared by threads in a process)	Per-thread items (items private to each thread)
Address Space Global variables Open files Child Processes Pending alarms Signals and signal handlers Accounting information	Program Counter Registers Stack State

- Thread's have one of several states: running, blocked, ready, or terminated

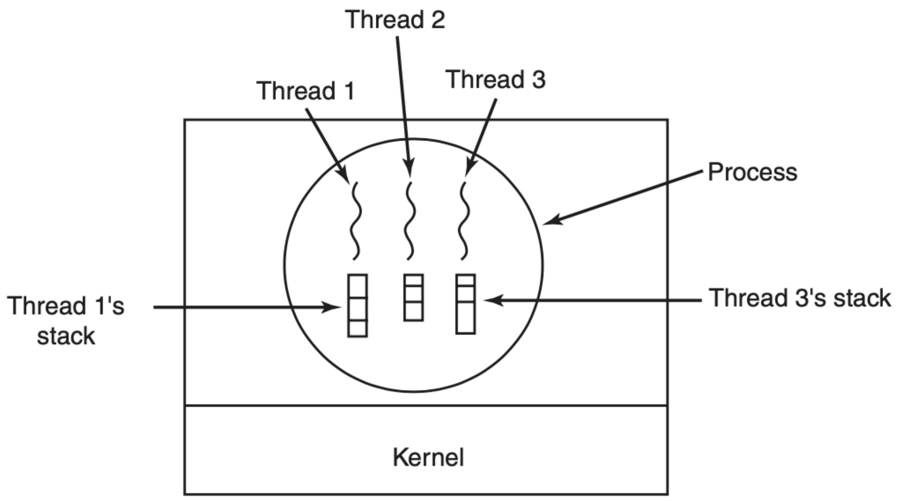


Figure 2-13. Each thread has its own stack.

- Initializing a thread with thread_create() begins the thread process
- We can use thread_exit() to exit a thread, and thread_join() to have a thread wait for a (specific) thread to exit
- thread_yield(): allows a thread to voluntarily give up the CPU to let another thread run (no clock interrupt)

- **POSIX Threads:**
    - Pthreads: package that allows you to use threads and contains 60 function calls
    - Important ones to know:

Thread Call	Description
Pthread_create	Create a new thread
Pthread_exit	Terminate the calling thread
Pthread_join	Wait for a specific thread to exit
Pthread_yield	Release the CPU to let another thread run

Pthread_attr_init	Create and initialize a thread’s attribute structure
Pthread_attr_destroy	Remove a thread’s attribute structure

- Threads that are waiting for another to terminate use pthread_join() to join the two together, this means whichever one is waiting for the other to finish will call for the join
- Pthread_attr_init: creates the attribute structure associated with a thread and initializes it to the default values, values (such as priority) can be changed by manipulating fields in the attribute structure
- Pthread_attr_destroy: removes a thread’s attribute structure, freeing up its memory

Example Code:

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>

#define NUMBER_OF_THREADS 10

void *print_hello_world(void *tid){
      /*function prints thread’s identifier and then exits*/
      printf(“Hello world. Greetings from thread %d\n”, tid);
      pthread_exit(NULL);
}

int main(int argc, char *argv[]){
      /*the main program creates 10 threads and then exits*/
      pthread_t threads[NUMBER_OF_THREADS];
      int status, i;

      for(i = 0; i < NUMBER_OF_THREADS; i++){
            printf(“Main here. Creating thread %d\n”, i);
            status = pthread_create(&threads[i], NULL,
            print_hello_world, (void *)i);

            if(status != 0){
                  printf(“Oops. pthread_create returned error code
                  %d\n”, status);
                  exit(-1);
            }
      }
      exit(NULL);
}
```

- **Implementing Threads in User Space:**

- Threads can be implemented in user space or kernel
- Threads can be placed entirely in the user space without kernel knowledge
    - threads are implemented through a library and is beneficial for machines that do not have multithreading

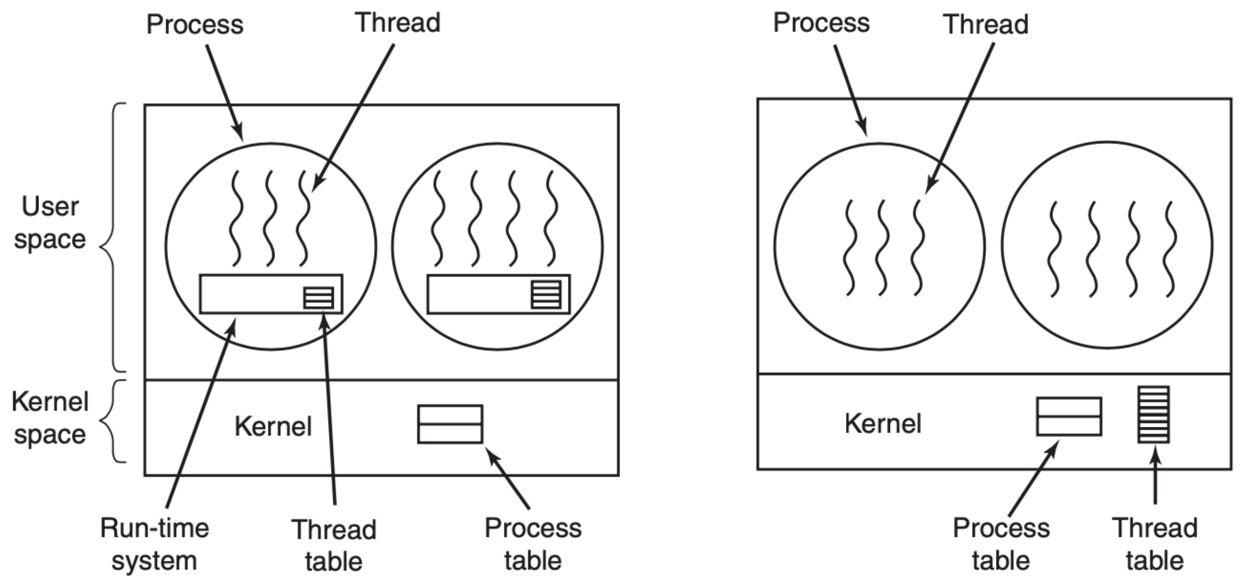


Figure 2-16. (a) A user-level threads package. (b) A threads package managed by the kernel.

    - Each process needs its own thread table to keep track of the threads in that process
    - this method is faster than trapping into the kernel
    - allow for customized scheduling algorithms
    - scale better
    - Issues:
        - blocking system call implementation
        - Select in unix allows the caller to tell whether a prospective read will block, read can be replaced with a new one that first does a select call and then does read only if safe
        - if a thread starts running, no other thread will process unless the first voluntarily gives up CPU time
- If a program calls or jumps to an instruction that is not in memory, a page fault occurs and the operating system will go and get the missing instruction

- **Implementing threads in the Kernel:**
    - No run-time system is needed
    - no thread table in each process (kernel tracks thread information)
    - All calls that might block a thread are implemented as system calls
    - Sometimes threads are recycled by being marked as not runnable, leaving the kernel data structure unaffected, and once a new one is needed it is reactivated
    - Issues:

    - when a multi threaded forks, we need to consider what will be done within that fork
    - Signals, which thread will handle the signal
- **Hybrid Implementations:**
  - Use Kernel level threads to multiplex user-level threads onto some or all of them

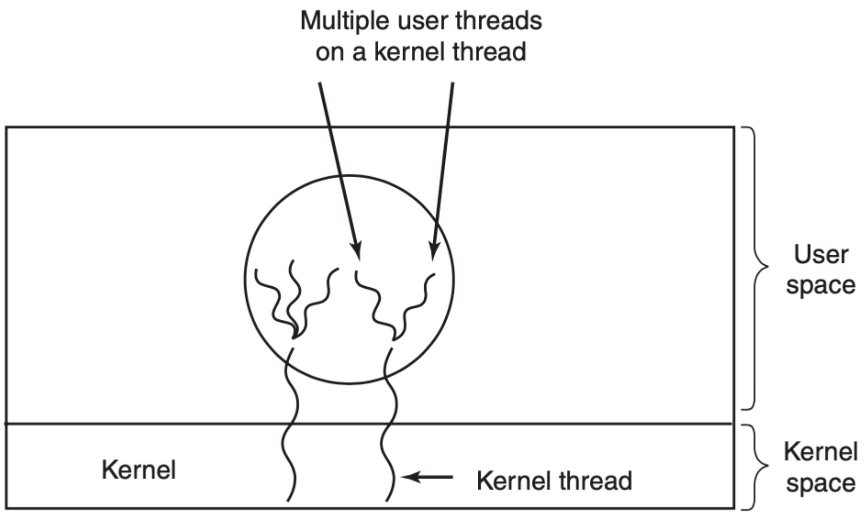


Figure 2-17. Multiplexing user-level threads onto kernel-level threads.

- **Scheduler Activations:**
  - Goal: mimic the functionality of kernel threads, but with the better performance and greater flexibility usually associated with threads packages implemented in user space
  - Upcall: Kernel notifies process' run-time system, passing as parameters on the stack the number of the thread in question and a description of the event that occurred, and the kernel activates the run-time system at a known starting address
- **Pop-Up Threads:**
  - When a message causes the system to create a new thread to handle a message
  - latency between message arrival and the start of processing can be made very short

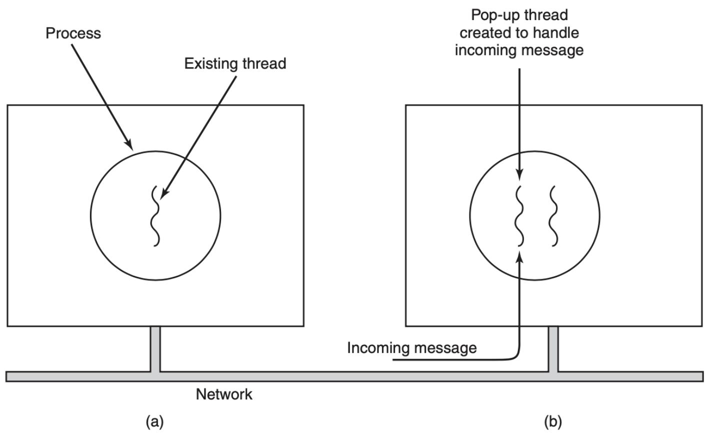


Figure 2-18. Creation of a new thread when a message arrives. (a) Before the message arrives. (b) After the message arrives.

- Usually ran in kernel space, rather than user space because it is faster

- **Making Single Threaded Code Multithreaded:**
  - Can result in us reading data incorrectly because of the timing of execution

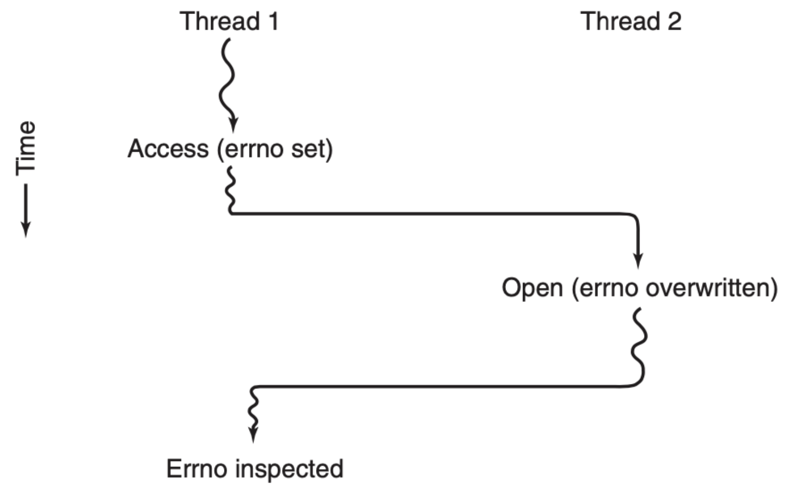


Figure 2-19. Conflicts between threads over the use of a global variable.

- **Solutions:**
  - prohibit global variables
  - assign each thread its own private global variables, allows for each thread to have private access to global variables

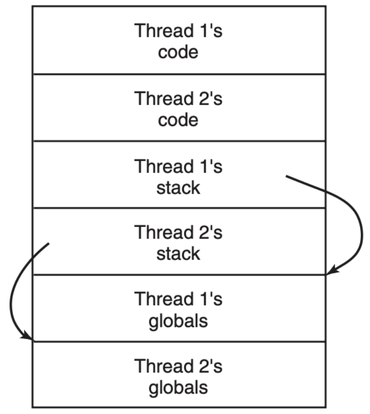


Figure 2-20. Threads can have private global variables.

- New library procedures can be introduced to create, set, and read these threadwide, global variables: create_global("bufptr");

                - allocates storage for a pointer called bufptr on the heap or in special storage
                - only calling thread may access this global
                - Two calls are needed to access global variables, one to read, the other to write
                    - reading: set_global("bufptr", &buf);
                    - writing: bufptr = read_global("bufptr"); returns address
        - Library procedures are not reentrant, meaning that once a function is called another is not supposed to be called until the first is finished
        - Memory allocation can be impacted as well, like malloc which uses crucial tables about memory
        - Handling signals appropriately is of great difficulty as well, we are not sure which thread something may need to go to
        - Stacks are not dynamic because the kernel is aware and cannot provide them with more memory if needed

<u>2.3 Interprocess Communication</u>

- **Three issues:**
    - how one process can pass information to another
    - two or more processes do not get in each other's way
    - proper sequencing when dependencies are present
- **Race conditions:**

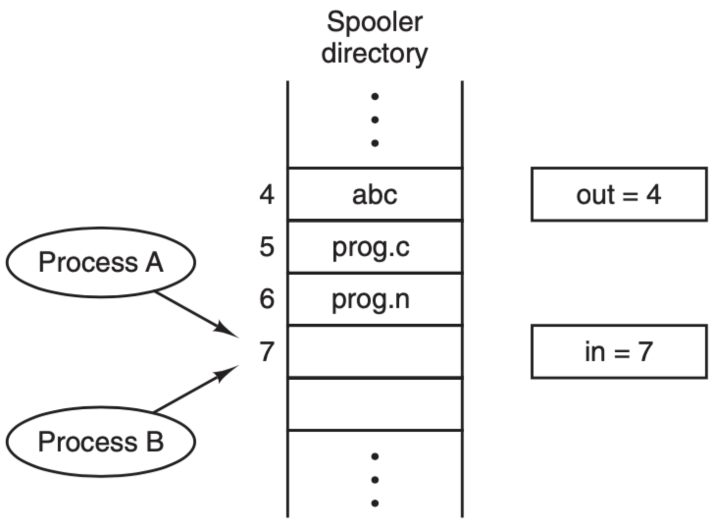


Figure 2-21. Two processes want to access shared memory at the same time.

    - Both processes think that 7 is a free spot and are unaware of each other, Process B continues and says 8 is the next free slot, but when A runs again it will overwrite the data in 7 and that information will be lost
    - Race conditions: where two or more processes are reading or writing some shared data and the final result depends on who runs precisely when

- **Critical Regions:**

- Mutual exclusion: some way of making sure that if one process is using a shared variable or file, the other process will be excluded from doing the same thing
- Critical region: place where shared memory is accessed
- Four conditions to hold:
    - No two processes may be simultaneously inside their critical regions
    - No assumptions may be made about speeds or the number of CPUs
    - No process running outside its critical region may block any process
    - No process should have to wait forever to enter its critical region

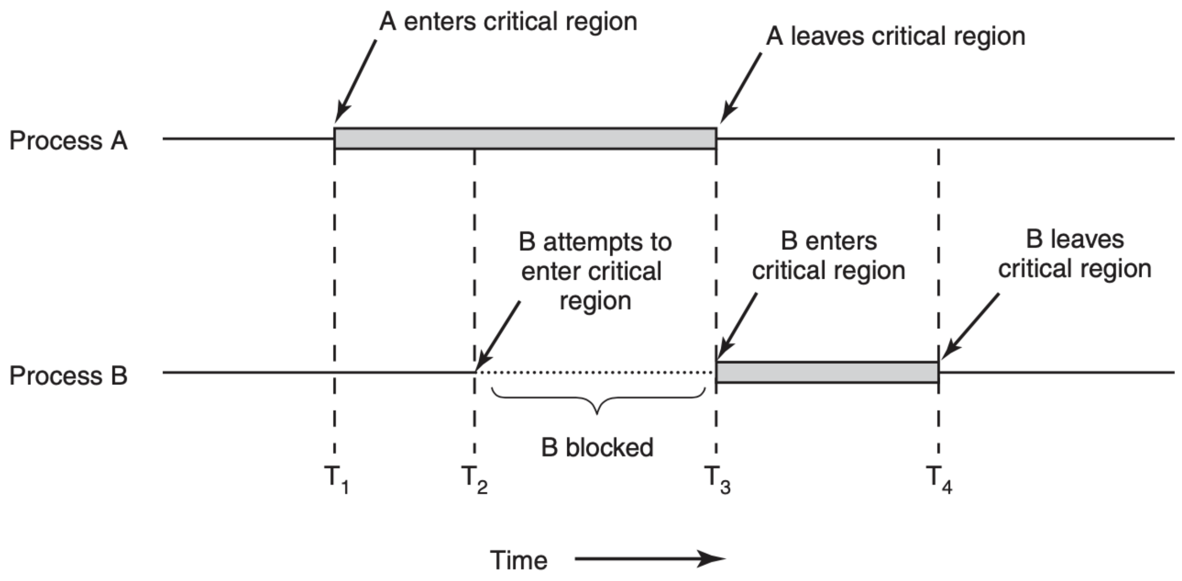


Figure 2-22. Mutual exclusion using critical regions.

- **Mutual Exclusion with Busy Waiting:**
    - **Disabling interrupts:**
        - simplest solution is to have each process disable all interrupts just after entering its critical region and re-enable them just before leaving it
            - Not a great idea, because we shouldn't give user processes this type of power
    - **Lock Variables:**
        - Uses a single shared lock variable that is initially 0
        - if a process wants to enter it has to check the lock first
            - if 0 the process enters and marks the variable as 1 (locked)
        - 0 means no process, 1 means process is in critical region
        - This method has its own race condition and could possibly override data
    - **Strict Alternation:**

```
while(TRUE){                            while(TRUE){
      while (turn ≠ 0){                       while(turn ≠ 1){
            critical_region();                      critical_region();
            turn = 1;                               turn = 0;
            noncritical_region();                   noncritical_region();
      }                                       }
}                                    }
```

- This is considered busy waiting because we are constantly testing a variable
    - known as a spin lock
    - Not a good approach because if one process is faster than another it may set the turn to 1 and get stuck

- **Peterson's solution:**
    - Consists of two procedures written in ANSI C, which means that function prototypes should be supplied for all the functions defined and used

Peterson's solution in code:

```
#define FALSE 0
#define TRUE 1
#define N 2             /*number of processes*/

int turn;               /*who's turn is it?*/
int interested[N];      /*all values initially 0*/

void enter_region(int process){     /*process is 0 or 1*/
      int other;                    /*number of the other process */

      other = 1 - process;          /*the opposite of process */
      interested[process] = TRUE;   /*show that you are interested*/
      turn = process;               /*set flag*/
      /*null statement*/
      while (turn == process && interested[other] == true);
void leave_region(int process){     /*process: who is leaving*/
      /* indicate departure from critical region*/
      interested[process] = FALSE;
}
```

- How does this work?:
    - process 0 calls enter_region -> indicates it is interested and sets turn to 0 -> process 1 not interested, return immediately. IF process one calls enter_region, it will just stay there until interested[0] goes to FALSE

- **TSL Instruction:**
    - Test and Set Lock reads contents from the memory word lock into register RX and then stores a nonzero value at the memory address lock (TSL RX, LOCK)
    - CPU executing the TSL instruction locks the memory bus to prohibit other CPUs from accessing memory until it is done
    - When lock is 0, any process may set it to 1 using the TSL instruction and then read or write the shared memory, when done the process sets the lock back to 0, this effectively locks the bus from other processes

Example with TSL in Assembly:
```
enter_region:
      TSL REGISTER, LOCK        |copy lock to register and set lock to 1
      CMP REGISTER, #0          |was lock zero?
      JNE enter_region          |if it was not zero, lock was set, so loop
      RET                       |return to caller; critical region entered

leave_region:
      MOVE LOCK, #-             |store a 0 in lock
      RET                       |return to caller
```

- XCHG may be used alternatively which exchanges the contents of two locations atomically

Example with XCHG in Assembly:
```
enter_region:
      MOVE REGISTER, #1         |put a 1 in the register
      XCHG REGISTER, LOCK       |swap the contents of the reg and lock variable
      CMP REGISTER, #0          |was lock zero?
      JNE enter_region          |if it was non zero, lock was set, so loop
      RET                       |return to caller; critical region entered

leave_region:
      MOVE LOCK, #0             |store a 0 in lock
      RET                       |return to caller
```

- **Sleep and Wakeup:**
    - Priority inversion problem: Some low priority process may be in its critical region and one that is high priority may be busy waiting, but since the low priority process is never scheduled while high is running, low never gets the chance to leave its critical region and high loops forever
    - sleep: causes caller to block, until another process wakes it up
    - Producer-Consumer Problem:

Example Code:
```
#define N 100
int count = 0;

void producer(void){
      int item;

      while(TRUE){                              /*repeat forever*/
            item = produce_item();              /*generate next item*/
            if(count == N) sleep();             /*if buffer is full, sleep*/
            insert_item(item);                  /*put item in buffer*/
            count = count + 1;                  /*increment count in buffer*/
            if(count == 1) wakeup(consumer);    /*was buffer empty?*/
      }
}

void consumer(void){
      int item;

      while(TRUE){                              /*repeat forever*/
            if(count == 0) sleep();             /*if buffer is empty, sleep*/
            item = remove_item();               /*take an item out*/
            count = count + 1;                  /*decrement count of items*/
            if(count == N - 1) wakeup(producer);/*was buffer full? */
            consumer_item(item);                /*print item*/
      }
}
```

            - to avoid any issues that may arise we can use wakeup waiting bit, which is flagged if a process is still awake

- **Semaphores:**
    - Semaphores tracked wakeup calls, it would be 0, meaning no wakeups were saves, or some positive value if one or more wakeups were pending
    - semaphores use generalizations of sleep and wakeup, known as down and up
        - down: checks to see if the value is greater than 0
            - if so decrement the value and continue
            - if value is 0, process is put to sleep without completing the down for the moment
        - up: increments the value of the semaphore addressed
            - if one or more processes were sleeping on that semaphore, unable to complete an earlier down, one of them is chosen by the system and is allows to complete its down
            - no process ever blocks an up

- **Solving Producer-Consumer Problem Using Semaphores:**
    - The semaphore method has fewer clock cycles than the other methods previously stated, making it faster and efficient

Semaphore Example Code:

```
#define N 100                           /*number of slots in buffer*/
typedef int semaphore;                  /*semaphores are a special int*/
semaphore mutex = 1;                    /*controls access to cr*/
semaphore empty = N;                    /*counts empty buffer slots*/
semaphore full = 0;                     /*counts full buffer slots*/

void producer(void){
      int item;

      while(TRUE){                        /*TRUE is the constant 1*/
            item = produce_item();        /*generate something for buffer*/
            down(&empty);                 /*decrement empty count*/
            down(&mutex);                 /*enter critical region*/
            insert_item(item);            /*put new item in buffer*/
            up(&mutex);                   /*leave critical region*/
            up(&full);                    /*increment count of full slots*/
      }
}

void consumer(void){
      int item;

      while(TRUE){
            down(&full);                  /*decrement full count*/
            down(&mutex);                 /*enter critical region*/
            item = remove_item();         /*take item from buffer*/
            up(&mutex);                   /*leave critical region*/
            up(&empty);                   /*increment count of empty slots*/
            consume_item(item);           /*do something with the item*/
      }
}
```

        - Binary semaphores: semaphores that are initialized to 1 and used by two or more processes to ensure that only one of them can enter its critical region at the same time
        - Can hide interrupts by initially setting semaphore to 0 associate with each I/O device
            - after starting, the managing process does a down on the associated semaphore
            - when the interrupt handler comes, up is applied to the associated semaphore
        - mutex semaphore is used for mutual exclusion and guarantees one process will be reading or writing the buffer
        - Synchronization: producer ensures to stop when buffer is full, consumer when buffer is empty

    - **Mutexes:**
        - shared variable that can be in one of two states: locked or unlocked
        - mutex_lock: a thread or process needs to access a critical region
        - mutex_unlock: a thread or process leaves a critical region
        - when mutex_lock fails to acquire a lock, it calls thread_yield giving up CPU time to another thread, there is no busy waiting
    - **Futexes:**
        - "Fast user space mutex", a feature that implements basic locking but avoid dropping into the kernel unless it really has to
    - **Mutexes in Pthreads:**

Thread Call	Description
Pthread_mutex_init	Create a mutex
Pthread_mutex_destroy	destroy an existing mutex
Pthread_mutex_lock	Acquire a lock or block
Pthread_mutex_trylock	Acquire a lock or fail
Pthread_mutex_unlock	Release a lock

- Condition Variables: allow threads to block due to some condition not being met
    - in producer-consumer we use condition variables to let the producer block and be awakened later
    - do not have memory like semaphores do, meaning that if a signal is sent to a condition variable on which no thread is waiting the signal is lost

Thread Call	Description
Pthread_cond_init	Create a condition variable
Pthread_cond_destroy	Destroy a condition variable
Pthread_cond_wait	block waiting for a signal
Pthread_cond_signal	Signal another thread and wake it up
Pthread_cond_broadcast	Signal multiple threads and wake them all up

- the statement that puts a thread to sleep should always check the condition to make sure it is satisfied before continuing

- **Monitors:**
    - collection of procedures, variables, and data structures that are all grouped together in a special kind of module or package

Example of threads to solve producer-consumer problem:
```
#include <stdio.h>
#include <pthread.h>

#define MAX 1000000000              /*how many numbers to produce*/
pthread_mutex_t the_mutex;
pthread_cond_t condc, condp;        /*used for signaling */
int buffer = 0;                     /*buffer used between p and c*/
```

```
void *producer(void *ptr){
      int i;

      for(i = 1; i <=MAX; i++){
            pthread_mutex_lock(&the_mutex);     /*get exclusive access to
                                                buffer*/
            while(buffer != 0)pthread_cond_wait(&condp, &the_mutex);
            buffer = i;                         /*put item in buffer*/
            pthread_cond_signal(&condc);        /*wake up consumer*/
            pthread_mutex_unlock(&the_mutex);   /*release access to buffer*/
      }
      pthread_exit(0);
}

void *consumer(void *ptr){
      int i;

      for(i = 1; i <= MAX; i++){
            pthread_mutex_lock(&the_mutex);     /*get exclusive access to
                                                buffer*/
            while(buffer ==0)pthread_cond_wait(&condc, &the_mutex);
            buffer = 0;                         /*take item out of buffer*/
            pthread_cond_signal(&condp);        /*wake up producer*/
            pthread_mutex_unlcok(&the_mutex);   /*release access to buffer*/
      }
      pthread_exit(0);
}

int main(int argc, char **argv){
      pthread_t pro, con;
      pthread_mutex_init(&the_mutex, 0);
      pthread_cond_init(&condc, 0);
      pthread_cond_init(&condp, 0);
      pthread_create(&con, 0, consumer, 0);
      pthread_create(&pro, 0, producer, 0);
      pthread_join(pro, 0);
      pthread_join(con,0);
      pthread_cond_destroy(&condc);
      pthread_cond_destroy(&condp);
      pthread_mutex_destroy(&the_mutex);
}
```

- Conditional variables can also use wait and signal

                - when the buffer may be full, it does a wait on some condition variable and causes the calling process to block
                - consumer can wake up its sleeping partner by doing a signal on the condition variable that its partner is waiting on
                    - signal must exit the monitor immediately leaving it to be the last statement in a monitor procedure

- **Message Passing:**
    - interprocess communication that uses two primitives, send and receive, which like semaphores and unlike monitors, are system calls rather than language constructs
        - send(destination, &message);
        - receive(source, &message);
        - **The Procedure-Consumer Problem with Message Passing:**
            - Mailbox: place to buffer a certain number of messages, typically specified when the mailbox is created

Example Producer Consumer Problem with Message Passing

```
#define N 100

void producer(void){
        int item;
        message m;

        while(TRUE){
                item = produce_item();          /*generate something to put in buffer*/
                receive(consumer, &m);          /*wait for an empty to arrive*/
                build_message(&m, item);        /*construct a message to send*/
                send(consumer, &m);             /*send item to consumer*/
        }
}

void consumer(void){
        int item, i;
        message m;

        for(i = 0; i < N; i++) send(producer, &m);      /*send N empties*/
        while(TRUE){
                receive(producer, &m);          /*get message containing item*/
                item = extract_item(&m);        /*extract item from message*/
                send(producer, &m);             /*send back empty reply*/
                consume_item(item);             /*do something with the item */
        }
}
```

- **Barriers:**

- Some applications are divided into phases and have the rule that no process may proceed into the next phase until all processes are ready

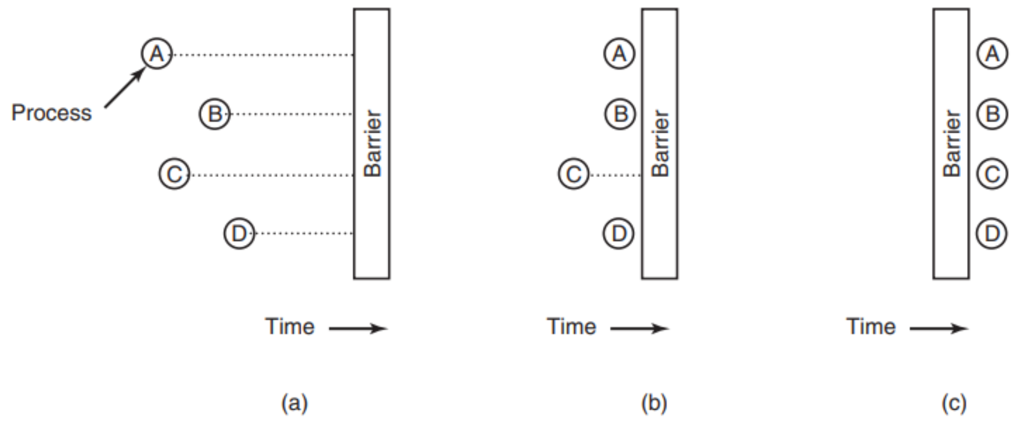


Figure 2-37. Use of a barrier. (a) Processes approaching a barrier. (b) All processes but one blocked at the barrier. (c) When the last process arrives at the barrier, all of them are let through.

- **Avoiding Locks: Read-Copy-Update**
    - We must decide if the reader will read new or old data

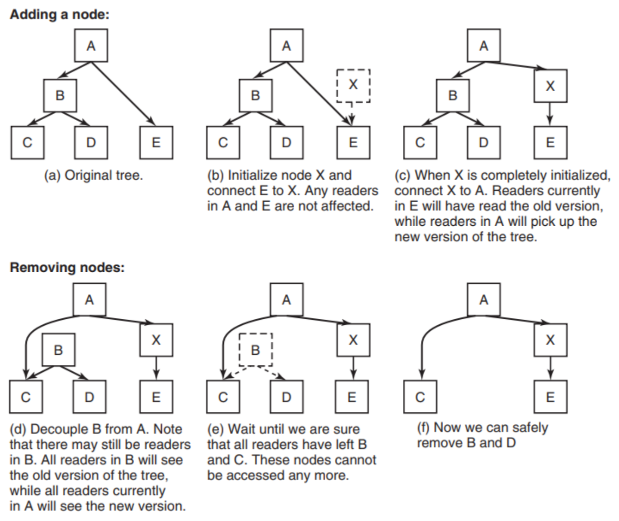

Adding a node:
(a) Original tree.
(b) Initialize node X and connect E to X. Any readers in A and E are not affected.
(c) When X is completely initialized, connect X to A. Readers currently in E will have read the old version, while readers in A will pick up the new version of the tree.
Removing nodes:
(d) Decouple B from A. Note that there may still be readers in B. All readers in B will see the old version of the tree, while all readers currently in A will see the new version.
(e) Wait until we are sure that all readers have left B and C. These nodes cannot be accessed any more.
(f) Now we can safely remove B and D

Figure 2-38. Read-Copy-Update: inserting a node in the tree and then removing a branch—all without locks.

<u>2.4 Scheduling</u>

- Schedulers decide which process will go next when two or more processes are in a ready state using an algorithm
    - **Introduction to Scheduling:**
        - Scheduler has to worry about making efficient use of the CPU because process switching is expensive
    - **Process Behavior:**
        - Nearly all processes alternate bursts of computing with I/O requests

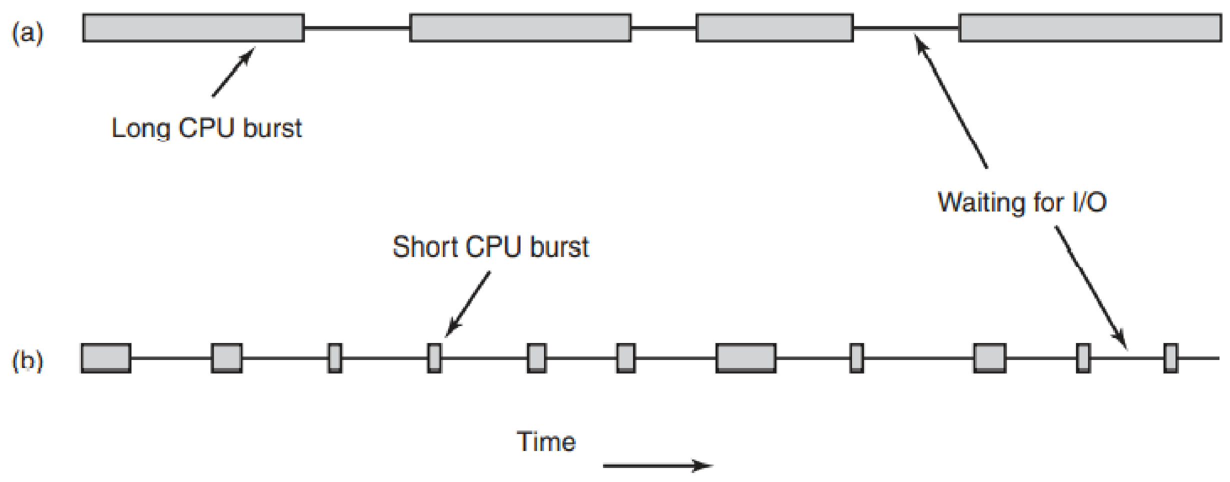


Figure 2-39. Bursts of CPU usage alternate with periods of waiting for I/O. (a) A CPU-bound process. (b) An I/O-bound process.

- Compute bound (CPU bound): when a process spends most of its time computing
  - Long CPU bursts
- I/O bound: When a process is spending time waiting for I/O
- If an I/O bound process wants to run, it should get a chance quickly so that it can issue its disk request and keep the disk busy

- **When to Schedule:**
  - When a new process is created, a decision needs to be made whether to run the child or the parent
  - Scheduling decision must be made when a process exits
  - When a process blocks on I/O, on a semaphore, or for some other reason, another process has to be selected to run
  - When an I/O interrupt occurs, a scheduling decision may be made
  - Scheduling algorithms can be classified in two ways:
    - Nonpreemptive: picks a process to run and then just lets it run until it blocks or voluntarily releases CPU
    - Preemptive: picks a process and lets it run for a maximum of some fixed time
      - requires having a clock interrupt occur at the end of a time interval
- **Categories of Scheduling Algorithms:**
  - Different environments determine the algorithm and there are three:
    - Batch: no users impatiently waiting at terminals for a quick response to a short request, and both preemptive and nonpreemptive work
    - Interactive: preemption is essential to keep one process from hogging CPU and denying service to the others
    - Real time: preemption but sometimes not needed because the processes know that they may not run for long periods of time and usually do their work and block quickly
- **Scheduling Algorithm Goals:**

- All Systems:
    - Fairness - giving each process a fair share of the CPU
    - Policy enforcement - seeing that stated policy is carried out
    - Balance - keeping all parts of the system busy
- Batch Systems:
    - Throughput - maximize jobs per hour
    - Turnaround time - minimize time between submission and termination
    - CPU utilization - keep the CPU busy all the time
- Interactive Systems:
    - Response time - Respond to requests quickly
    - Proportionality - meet users' expectations
- Real-Time Systems:
    - Meeting deadlines - avoiding losing data
    - Predictability - avoid quality degradation in multimedia systems

- Throughput: number of jobs per hour that a system completes
- Turnaround Time: statistically average time from the moment that a batch job is submitted until the moment it is completed
- Response time: time between issuing a command and getting the result
- Proportionality: What users idea of how long a process should take

- **Scheduling in Batch Systems:**
    - First Come First Served:
        - non preemptive algorithm where a process is assigned the CPU in the order they have requested (queue)
        - Uses a single linked list to track all processes
        - Is not very flexible and may have other processes take much longer than they should
    - Shortest Job First:
        - Scheduler picks the shortest job first

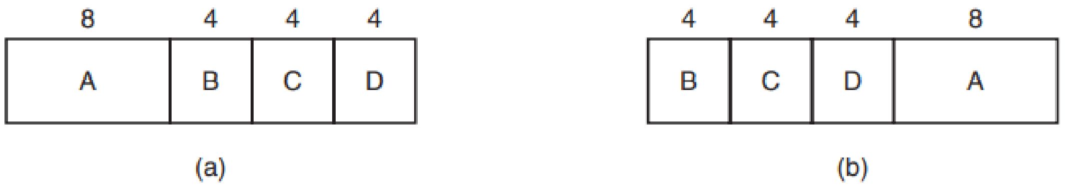


Figure 2-41. An example of shortest-job-first scheduling. (a) Running four jobs in the original order. (b) Running them in shortest job first order.

- A will take 8 minutes to process, meaning B takes 12, C 16, and D 20, where shortest first does B C and D in 12 and leaves A last. The averages are lower 14 minutes vs 11 minutes.
- Only optimal when all the jobs are available simultaneously

- Shortest Remaining Time Next:
    - preemptive version of shortest job first

    - When a new job arrives, its total time is compared to the current process' remaining time

- **Scheduling in Interactive Systems:**
  - Round Robin: Each process is assigned a time interval, known as a quantum, during which it is allowed to run, if it is still running at the end of the quantum, the CPU is preempted and given to another process

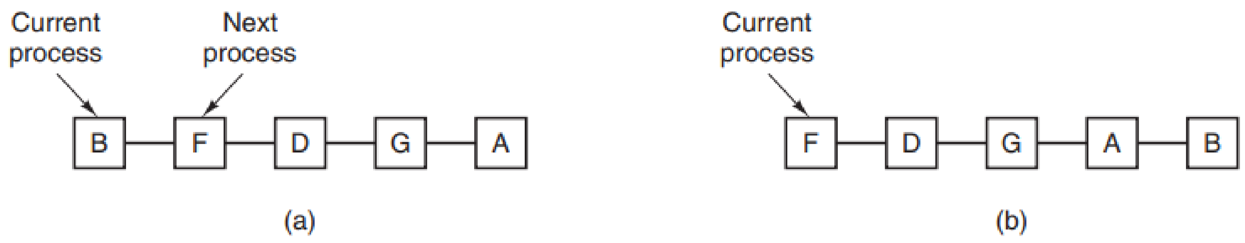


Figure 2-42. Round-robin scheduling. (a) The list of runnable processes. (b) The list of runnable processes after *B* uses up its quantum.

  - Setting quantum too short causes too many process switches and lowers the CPU efficiency, but setting it too long may cause poor response to short interactive requests

- Priority Scheduling:
  - Need to take external factors into account
  - processes are assigned a priority, and the runnable process with highest priority is allowed to run
  - If an action causes a priority to drop below that of the next highest process, a process switch will occur
  - priorities can be assigned to processes statically or dynamically
  - Unix command, "nice", allows a user to voluntarily reduce the priority of his process, in order to be nice to other users

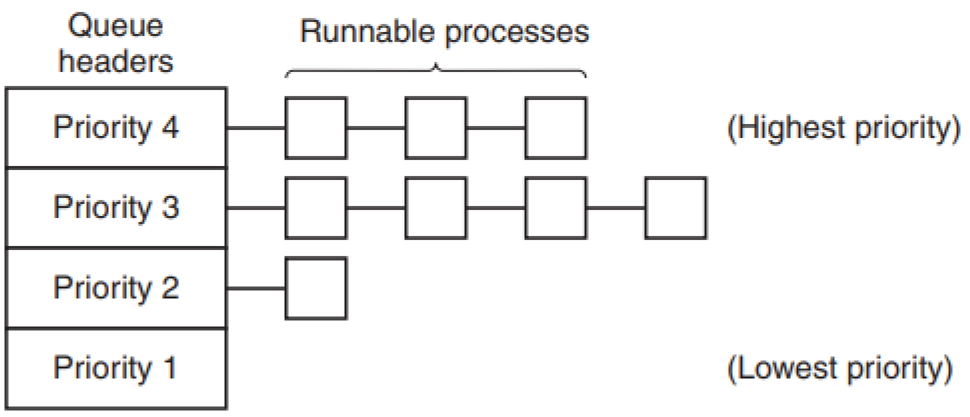
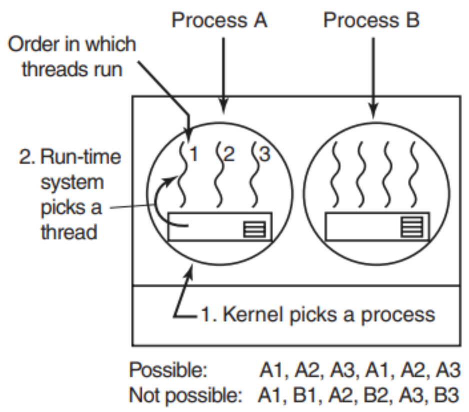
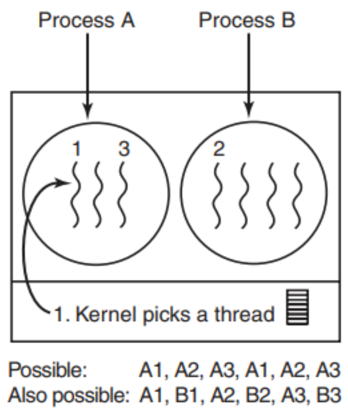


Figure 2-43. A scheduling algorithm with four priority classes.

  - **Shortest Process Next:**

    - Regarding the execution of each command as a separate "job", then we can minimize overall response time by running the shortest one first
    - We can do this by estimating running time based on past behavior
    - aging: technique of estimating the next value in a series by taking the weighted average of the current measured value and the previous estimate
  - **Guaranteed Scheduling:**
    - processes will be given 1/n of CPU cycles for all n processes
    - must keep track of how much CPU each process has had since its creation
    - by doing this a comparison of the ratios is examined and the lowest is given CPU time until the ratio is just above its closest process
  - **Lottery Scheduling:**
    - Similar to guaranteed scheduling but a simpler implementation
    - give processes lottery tickets for various system resources, such as CPU time
    - Tickets are chosen at random and the process holding the ticket gets CPU time
    - More important processes may be given more tickets
    - Cooperating processes may exchange tickets if they wish, to increase the chances of a part of their process being run
  - **Fair Share Scheduling:**
    - Some systems take into account which user owns a process before scheduling it
    - each user is allocated some fraction of CPU and the scheduler picks processes in such a way as to enforce it
      - meaning two users would get 50 percent each
- **Scheduling in Real-Time Systems:**
  - Real-Time: system which time plays an essential role
  - hard real-time: are absolute deadlines that must be met
  - soft real-time: missing an occasional deadline is undesirable but nevertheless tolerable
  - Divides programs into a number of processes, each of whose behavior is predictable and known in advance
  - response times can either be periodic or aperiodic
  - schedulable: where m periodic events and event i occurs with a period of p_i and requires c_i sec of CPU time to handle and satisfies this condition: $\sum_{i=1}^{m} \frac{C_i}{P_i} \leq 1$
    - if a process fails to meet this test it cannot be scheduled
  - static: make their scheduling decisions before the system starts running
  - dynamic: make their scheduling decisions at run time, after execution has started
- **Policy Versus Mechanism:**
  - Separating the Scheduling mechanism from the scheduling policy allows the scheduling algorithm to be parameterized in some way, but the parameters can be filled in by user processes
- **Thread Scheduling:**


Process A
Process B
Order in which threads run
1
2
3
2. Run-time system picks a thread
1. Kernel picks a process
Possible: A1, A2, A3, A1, A2, A3
Not possible: A1, B1, A2, B2, A3, B3


Process A
Process B
1
3
2
1. Kernel picks a thread
Possible: A1, A2, A3, A1, A2, A3
Also possible: A1, B1, A2, B2, A3, B3

        - performance is a key difference between these two methods
        - thread switch with user-level threads takes a handful of machine instructions
        - kernel-level threads require a full context switch changing the memory map and invalidating the cache but block on I/O does not suspend the entire process as it does with user-level threads
        - generally, application-specific thread schedulers can tune an application better than the kernel can

2.5 Classical IPC Problems:

- Dining Philosophers Problem:
    - starvation: all programs continue to run indefinitely but fail to make any progress

Example Solution Code:

```
#define N         5                 /*number of philosophers*/
#define LEFT      (i + N -1) % N    /*number of i's left neighbor*/
#define RIGHT     (i + 1) % N       /*number of i's right neighbor*/
#define THINKING  0                 /*phil thinking*/
#define HUNGRY    1                 /*phil trying to get forks*/
#define EATING    2                 /*phil eating*/

typedef int semaphore;              /*semaphore special kind of int*/
int state[N];                       /*arr to keep track of everyone's state*/
semaphore mutex = 1;                /*mutual exclusion for critical regions*/
semaphore s[N];                     /*one semaphore per philosopher*/

void philosopher(int i){            /*i: philosophers number, 0 to N-1*/
      while(TRUE){
            think();                /*think*/
            take_forks(i);          /*acquire two forks*/
            eat();                  /*enjoy food*/
            put_forks(i);           /*put both forks back on table*/
      }
}

void take_forks(int i){             /*i: phil number from 0 to N-1*/
      down(&mutex);                 /*enter critical region*/
      state[i] = HUNGRY;            /*record that phil is hungry*/
      test(i);                      /*try to acquire 2 forks*/
      up(&mutex);                   /*exit critical region*/
      down(&s[i]);                  /*block if forks were not acquired*/
}

void put_forks(int i){              /*i: phil number from 0 to N-1*/
      down(&mutex);                 /*enter critical region*/
      state[i] = THINKING;          /*phil has finished eating*/
      test(LEFT);                   /*see if left neighbor can eat*/
      test(RIGHT);                  /*see if right neighbor can eat*/
      up(&mutex);                   /*exit critical region*/
}

void test(i)                        /*i: phil number from 0 to N-1*/
{
      if(state[i] == HUNGRY && state[LEFT] ≠ EATING && state[RIGHT] ≠
      EATING){
            state[i] = EATING;
            up(&s[i]);
      }
}
```

Reader and Writers Problem:

```
typedef int semaphore;
semaphore mutex = 1;
semaphore db = 1;
int rc = 0;

void reader(void){
      while(TRUE){
            down(&mutex);           /*get exclusive access to rc*/
            rc = rc + 1;            /*one reader more now*/
            if(rc == 1) down(&db);  /*if this is the first reader…*/
            up(&mutex);             /*release exclusive access to rc*/
            read_data_base();       /*access the data*/
            down(&mutex);           /*get exclusive access to rc*/
            rc = rc - 1;            /*one reader fewer now*/
            if(rc == 0) up(&db);    /*if this is the last reader…*/
            up(&mutex);             /*release exclusive access to rc*/
            use_data_read();        /*noncritical region*/
      }
}

void writer(void){
      while(TRUE){
            think_up_data();        /*noncritical region*/
            down(&db);              /*get exclusive region*/
            write_data_base();      /*update the data*/
            up(&db);                /*release exclusive access*/
      }
}
```