Process Creation

Events which cause process creation:

- System initialization.
- Execution of a process creation system call by a running process.
  - In Linux/UNIX: fork()
  - In Windows CreateProcess()
- A user request to create a new process.
- Initiation of a batch job.

Process Termination

Events which cause process termination:

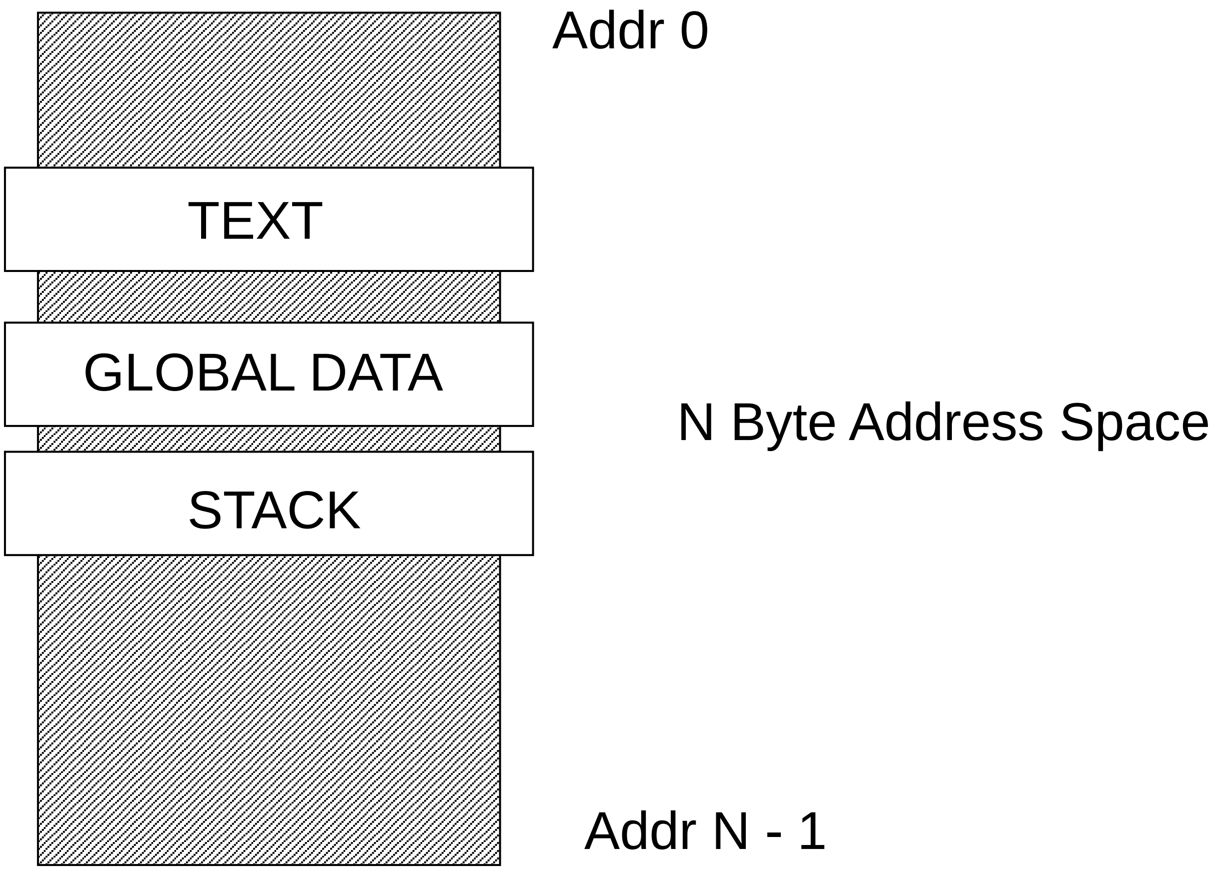
- Normal exit (voluntary).
  - Using C call exit(0);
- Error exit (voluntary).
  - Using C call exit(N); where 0 < N < 256 in Linux
- Fatal error (involuntary).
  - Process receives a signal in Linux/UNIX
- Killed by another process (involuntary).
  - Process receives a signal in Linux/UNIX

Process Components

Major Components of a Linux/UNIX Process

- PID
- PPID
- UID RUID and EUID
- GID RGID and EGID
- Address Space (Minimum: TEXT, GLOBAL DATA, STACK)
- Executable Program
- One or more Threads
- Default (Initial Thread) Scheduling Policy and Priority
- Current Working Directory
- Open Channel Table
- Signal Table

Address Space Model



Implementation of Processes

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		

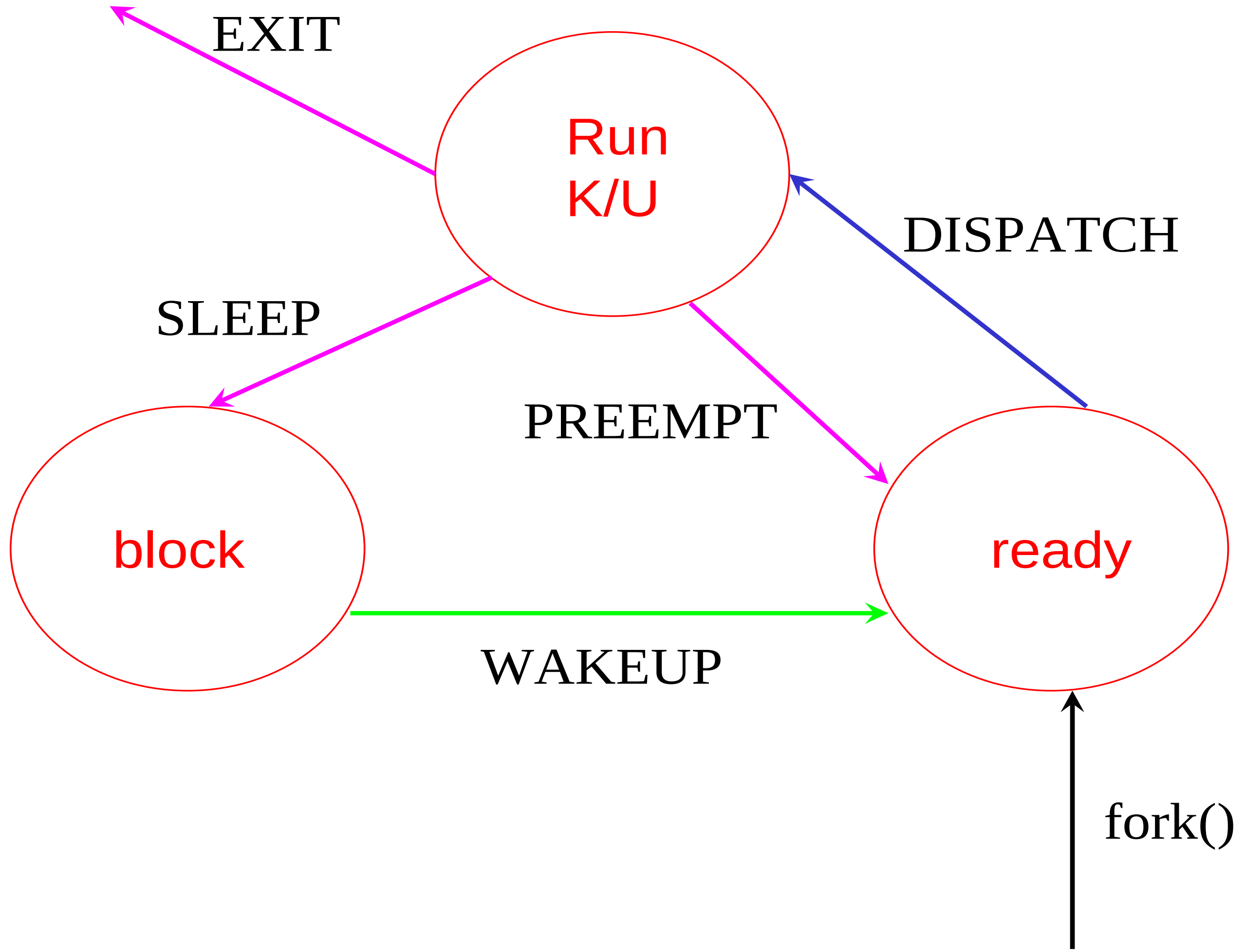
Figure 2-4. Some of the fields of a typical process table entry.

Interrupts on a Process Thread

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.

Thread States



Thread Usage (1)

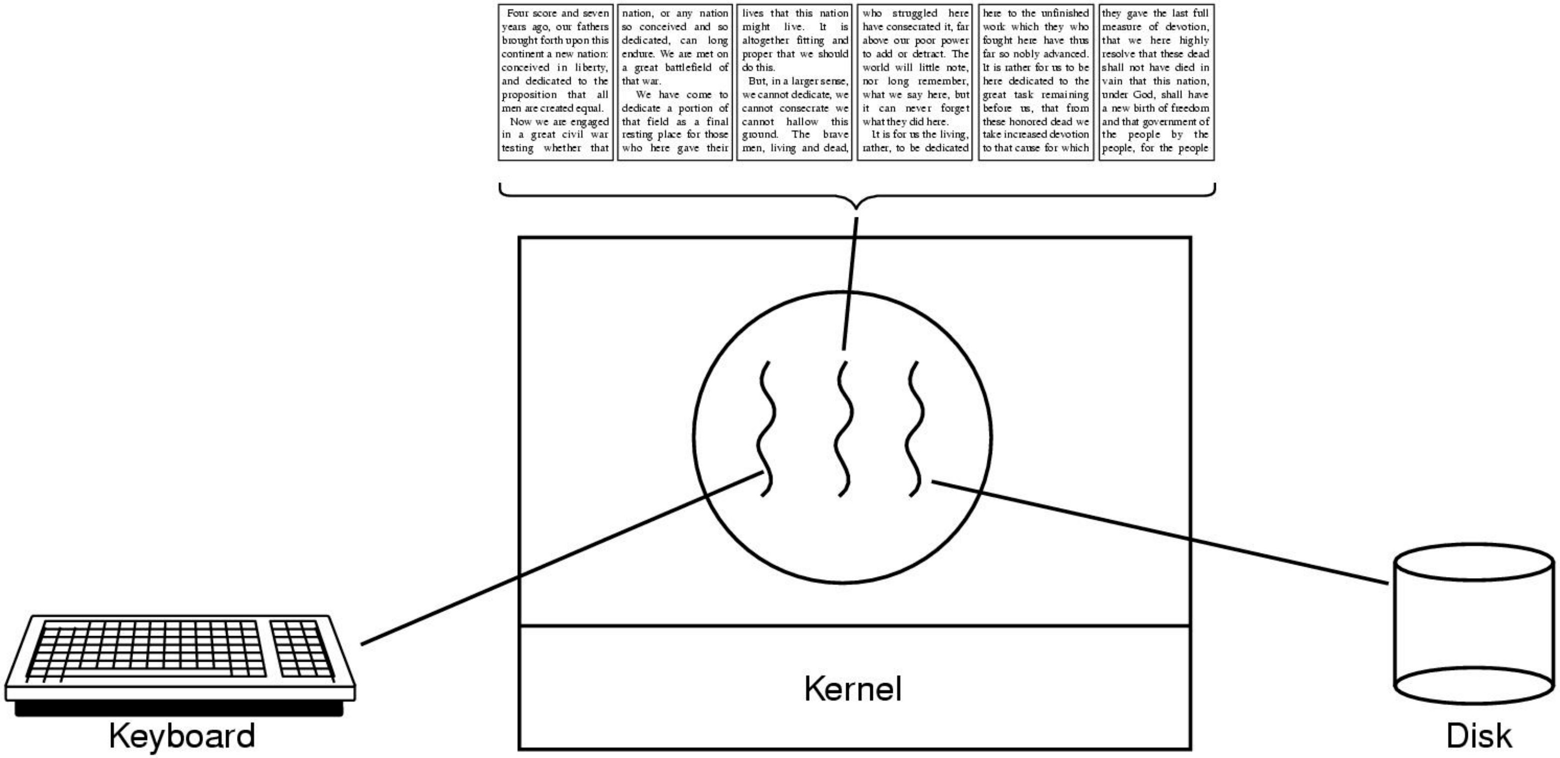


Figure 2-7. A word processor with three threads.

The Classical Thread Model (1)

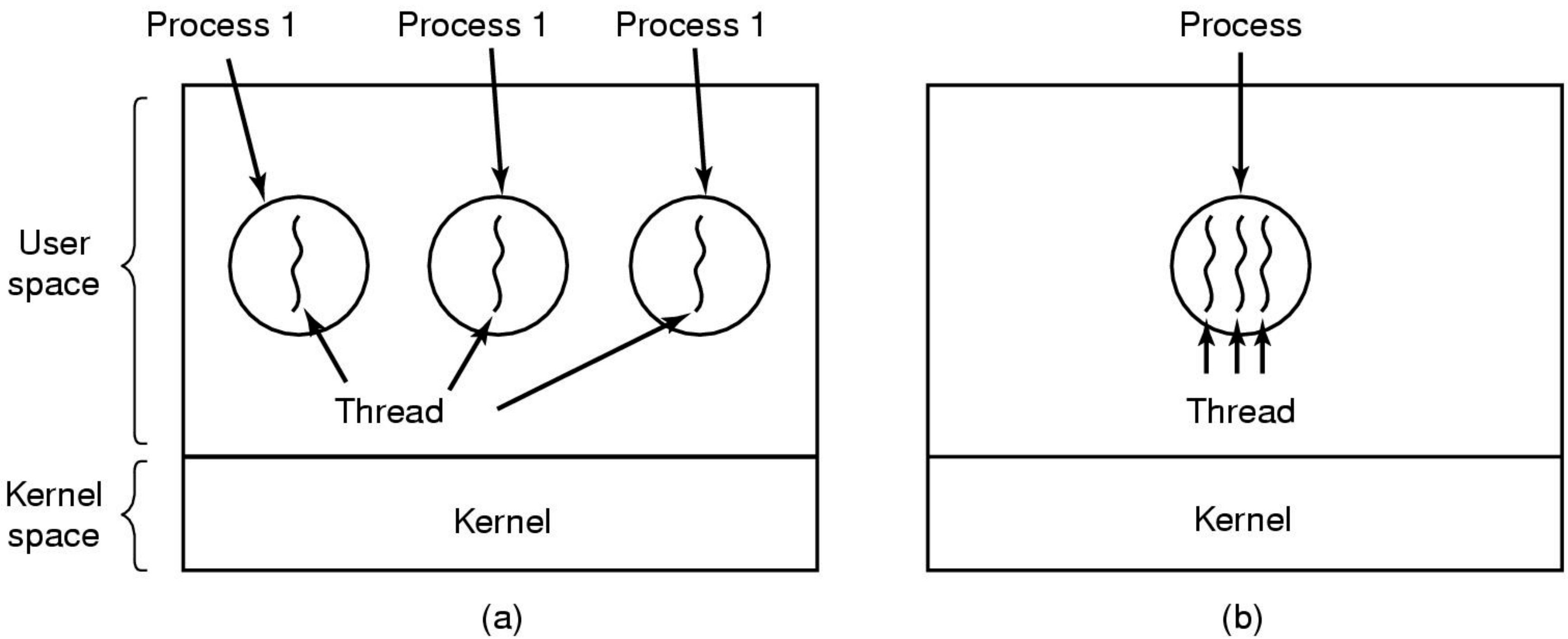


Figure 2-11. (a) Three processes each with one thread. (b) One process with three threads.

The Classical Thread Model (2)

Per process items	Per thread items
Address space	Program counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	
Signals and signal handlers	
Accounting information	

Figure 2-12. The first column lists some items shared by all threads in a process. The second one lists some items private to each thread.

The Classical Thread Model (3)

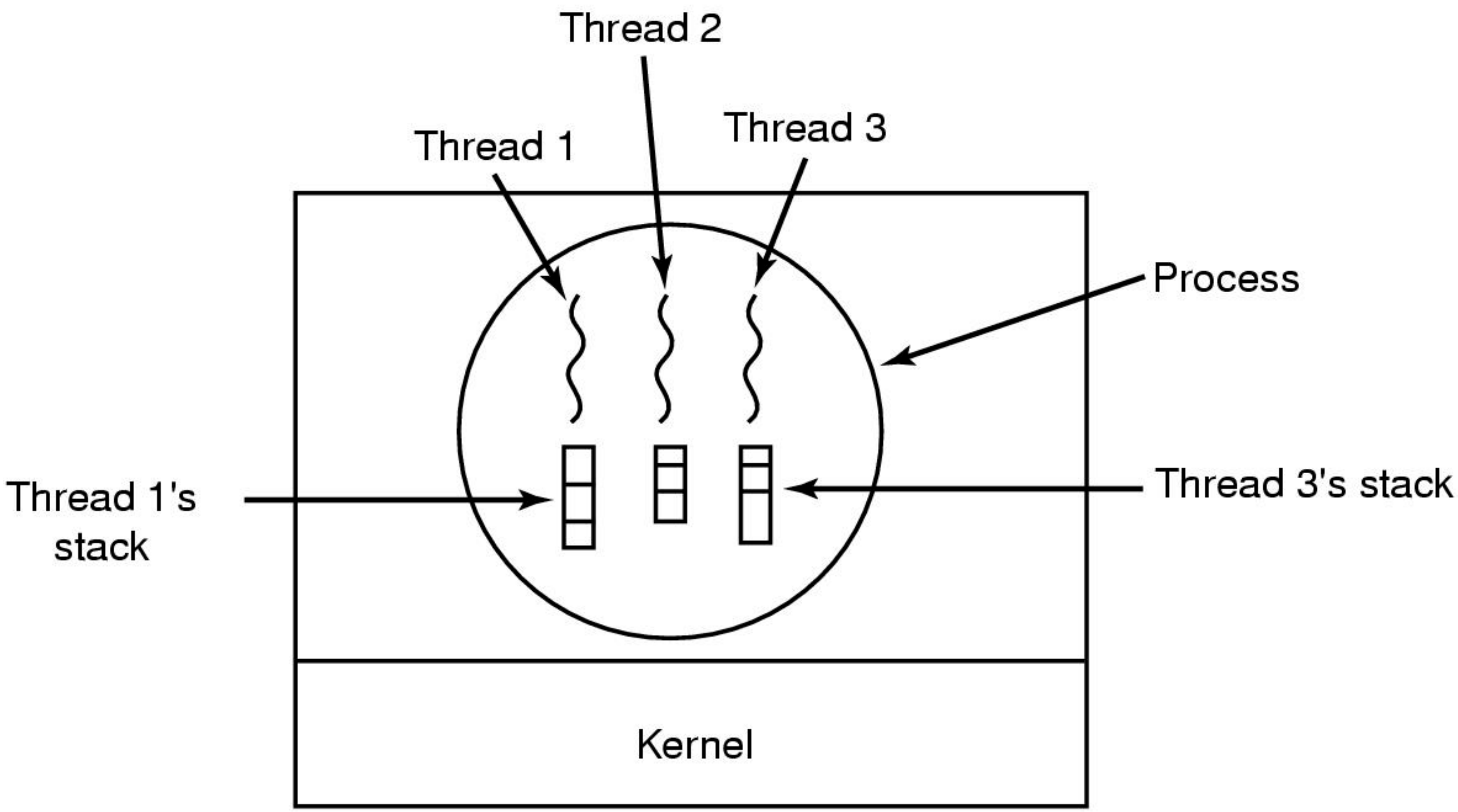


Figure 2-13. Each thread has its own stack.

Critical Regions (1)

Conditions required to avoid race condition:

- No two threads may be simultaneously inside their critical regions. (Mutex Requirement)
- No assumptions may be made about speeds or the number of CPUs.
- No thread running outside its critical region may block other thread. (Progress Requirement)
- No thread should have to wait forever to enter its critical region. (Bounded Waiting Requirement)

Critical Regions (2)

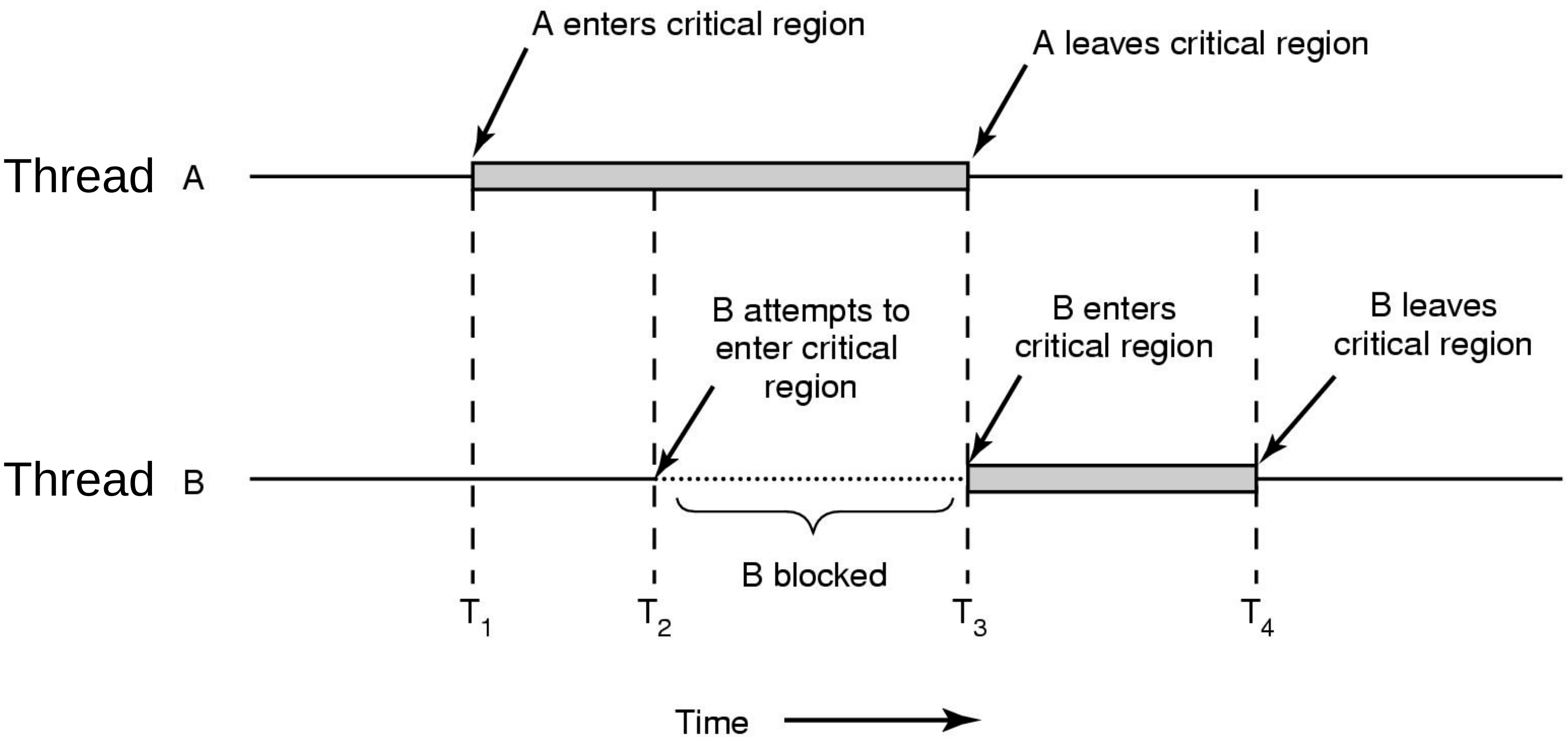


Figure 2-22. Mutual exclusion using critical regions.

Mutual Exclusion with Busy Waiting

Proposals for achieving mutual exclusion:

- Disabling interrupts
- Lock variables
- Strict alternation
- Peterson's solution
- The TSL instruction

Strict Alternation

```
while (TRUE) {
    while (turn != 0)        /* loop */ ;
    critical_region( );
    turn = 1;
    noncritical_region( );
}
```

(a)

```
while (TRUE) {
    while (turn != 1)        /* loop */ ;
    critical_region( );
    turn = 0;
    noncritical_region( );
}
```

(b)

Figure 2-23. A proposed solution to the critical region problem. (a) Process 0. (b) Process 1. In both cases, be sure to note the semicolons terminating the while statements.

Peterson's Solution

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

int turn;                                 /* whose turn is it? */
int interested[N];                        /* all values initially 0 (FALSE) */

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 */
     while (turn == process && interested[other] == TRUE) /* null statement */ ;
}

void leave_region(int process)            /* process: who is leaving */
{
     interested[process] = FALSE;         /* indicate departure from critical region */
}
```

Figure 2-24. Peterson’s solution for achieving mutual exclusion.

The TSL Instruction (2)

```
enter_region:
        MOVE REGISTER,#1              | put a 1 in the register
        XCHG REGISTER,LOCK            | swap the contents of the register 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
```

Figure 2-26. Entering and leaving a critical region using the x-86 XCHG instruction.

Semaphores

- Basically an unsigned counter and a queue
- Two basic operations defined:
  - wait(sem_object); also down(), p()
  - signal(sem_object); also up(), v()
- A wait call is a conditional decrement
  - If sem counter is +, decrement and return
  - If sem counter is 0, block caller
- A signal call is a conditional increment
  - If no waiters, increment counter
  - If waiters, move one waiter to ready Q

MULTIPLE PRODUCER, MULTIPLE CONSUMER RING BUFFER EXAMPLE

GLOBAL TO PRODUCER AND CONSUMER THREADS:

sem_t prod = 10; **sem_t cons = 0;**
sem_t iptr = 1; **sem_t optr = 1;**

int buf[10], in=0, out=0;
void p (sem_t *);
void v (sem_t *);

PRODUCER FUNCTION

```
void producer(){
while(1){
  p(&prod);
  p(&iptr);
  buf[in] = random();
  in = (in + 1) % 10;
  v(&iptr);
  v(&cons);
}
```

CONSUMER FUNCTION

```
void consumer(){
int val;
while(1){
  p(&cons);
  p(&optr);
  val = buf[out];
  // print val somewhere
  out = (out + 1) % 10;
  v(&optr);
  v(&prod);
}
```

Event Counters and Sequencers

- Semaphores may provide more functionality than needed to resolve certain kinds of synchronization requirements
  - Total order problems like the multiple producer / multiple consumer problem need the power of semaphores
  - Partial order problems like the single producer / single consumer problem do not need all of the functionality of a semaphore
- Event Counters can solve partial order problems more efficiently than semaphores
- Event Counters in conjunction with Sequencers can solve total order problems as efficiently as semaphores, and can provide additional functionality

Event Counters

- Basically an unsigned counter and a queue
- Two basic operations defined:
  - await(EventCounter, value);
  - advance (EventCounter);
- An await call is a test between EC and value
  - If value is =< EC return to caller
  - If value is > EC block caller
- An advance call is an unconditional EC increment
  - If any waiter has value =< EC after increment, then move such waiter(s) to ready Q

ONE PRODUCER, ONE CONSUMER RING BUFFER EXAMPLE

GLOBAL TO PRODUCER AND CONSUMER THREADS:

```
ec_t pEC, cEC;
int ring_buf[10];
unsigned  in=0, out=0;
void await    (ec_t * , int);
void advance  (ec_t *);
```

PRODUCER FUNCTION

```
void producer(){
while(1){
  await(&pEC, in – 10 + 1);
  ring_buf[in % 10] = random();
  in = (in + 1);
  advance(&cEC)
}
```

CONSUMER FUNCTION

```
void consumer(){
int val;
while(1){
  await(&cEC, out + 1);
  val = ring_buf[out % 10];
  // print val somewhere
  out = (out + 1);
  advance(&pEC);
}
```

Sequencers

- Basically an unsigned atomic counter
- One operation defined:
  - ticket(Sequencer);
- A ticket call atomically returns the next Sequencer value, and this value is generally used in an await(EC, ticket(Seq)) form of call
- Sequencers, in conjunction with Event Counters provide all of the synchronization capabilities of semaphores

MULTIPLE PRODUCER, MULTIPLE CONSUMER RING BUFFER EXAMPLE

GLOBAL TO PRODUCER AND CONSUMER THREADS:

```
ec_t  pEC, cEC;
seq_t ps,  cs;
int ring_buf[10];
unsigned  in=0, out=0;
void await   (ec_t * , int);
void advance (ec_t *);
int  ticket  (seq_t *);
```

PRODUCER FUNCTION

```
void producer(){
int t;  // local to each pro
while(1){
  t = ticket(&ps);
  await(&cEC, t);
  await(&pEC, t – 10 + 1);
  ring_buf[t % 10] = random();
  advance(&cEC)
}
```

CONSUMER FUNCTION

```
void consumer(){
int u, val; // local to each con
while(1){
  u = ticket(&cs);
  await(&pEC, u);
  await(&cEC, u + 1);
  val = ring_buf[u % 10];
  // print val somewhere
  advance(&pEC);
}
```

Monitors (1)

```
monitor example
        integer i;
        condition c;

        procedure producer( );
        .
        .
        .
        end;

        procedure consumer( );
        .       .       .
        end;
end monitor;
```

Figure 2-33. A monitor.

Monitors (2)

```
monitor ProducerConsumer
        condition full, empty;
        integer count;

        procedure insert(item: integer);
        begin
                if count = N then wait(full);
                insert_item(item);
                count := count + 1;
                if count = 1 then signal(empty)
        end;

        function remove: integer;
        begin
                if count = 0 then wait(empty);
                remove = remove_item;
                count := count − 1;
                if count = N − 1 then signal(full)
        end;

        count := 0;
end monitor;

procedure producer;
begin
        while true do
        begin
                item = produce_item;
                ProducerConsumer.insert(item)
        end
end;

procedure consumer;
begin
        while true do
        begin
                item = ProducerConsumer.remove;
                consume_item(item)
        end
end;
```

Figure 2-34. An outline of the producer-consumer problem with monitors.

MULTIPLE PRODUCER, MULTIPLE CONSUMER RING BUFFER EXAMPLE USING A MONITOR IN THE LANGUAGE CSP/k

```
CIRCULARBUFFER: PROCEDURE OPTIONS (CONCURRENT);

   CIRCULARBUFFERMONITOR: MONITOR;
      DECLARE (BUFFERS (100)) CHARACTER (80) VARYING;
      DECLARE (FIRSTBUFFER, LASTBUFFER) FIXED;
      DECLARE (TOTALBUFFERS, FULLBUFFERS) FIXED;
      DECLARE (ABUFFERISEMPTY) CONDITION;
      DECLARE (ABUFFERISFULL) CONDITION;

      DO;
         FIRSTBUFFER = 1;
         LASTBUFFER = 1;
         TOTALBUFFERS = 100;
         FULLBUFFERS = 0;
      END;

   SPOOLER: ENTRY (IMAGE);
      DECLARE (IMAGE) CHARACTER (*) VARYING;
      IF FULLBUFFERS = TOTALBUFFERS THEN
         WAIT (ABUFFERISEMPTY);
      BUFFERS (LASTBUFFER) = IMAGE;
      LASTBUFFER = MOD (LASTBUFFER, TOTALBUFFERS) + 1;
      FULLBUFFERS = FULLBUFFERS + 1;
      SIGNAL(ABUFFERISFULL);
   END;

   DESPOOLER: ENTRY (IMAGE);
      DECLARE (IMAGE) CHARACTER (*) VARYING;
      IF FULLBUFFERS = 0 THEN
         WAIT (ABUFFERISFULL);
      IMAGE = BUFFERS (FIRSTBUFFER);
      FIRSTBUFFER = MOD(FIRSTBUFFER, TOTALBUFFERS) + 1;
      FULLBUFFERS = FULLBUFFERS - 1;
      SIGNAL (ABUFFERISEMPTY);
   END;

END;
```

MULTIPLE PRODUCER, MULTIPLE CONSUMER RING BUFFER EXAMPLE USING A MONITOR IN THE LANGUAGE CSP/k (cont'd)

```
     READCARDS: PROCESS;
         DECLARE (CARDIMAGE) CHARACTER (80) VARYING;
         CARDIMAGE = 'MORECARDS';
         DO WHILE (CARDIMAGE <> 'ENDOFFILE');
             GET SKIP EDIT (CARDIMAGE) (A(80));
             CALL SPOOLER (CARDIMAGE);
         END;
     END;

     PRINTLINES: PROCESS;
         DECLARE (LINEIMAGE) CHARACTER (80) VARYING;
         LINEIMAGE = 'MORECARDS';
         DO WHILE (LINEIMAGE <> 'ENDOFFILE');
             CALL DESPOOLER (LINEIMAGE);
             PUT SKIP EDIT (LINEIMAGE) (A(80));
         END;
     END;

END;
```

CSP/k program for managing a circular buffer.

Mutexes

```
mutex_lock:
        TSL REGISTER,MUTEX           | copy mutex to register and set mutex to 1
        CMP REGISTER,#0              | was mutex zero?
        JZE ok                       | if it was zero, mutex was unlocked, so return
        CALL thread_yield            | mutex is busy; schedule another thread
        JMP mutex_lock               | try again
ok:     RET                          | return to caller; critical region entered

mutex_unlock:
        MOVE MUTEX,#0                | store a 0 in mutex
        RET                          | return to caller
```

Figure 2-29. Implementation of mutex lock and mutex unlock.

Mutexes in Pthreads (1)

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

Figure 2-30. Some of the Pthreads calls relating to mutexes.

Mutexes in Pthreads (2)

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 all of them

Figure 2-31. Some of the Pthreads calls relating to condition variables.

Mutexes in Pthreads (3)

```
#include <stdio.h>
#include <pthread.h>
#define MAX 1000000000                    /* how many numbers to produce */
pthread_mutex_t the_mutex;
pthread_cond_t condc, condp;
int buffer = 0;                           /* buffer used between producer and consumer */

void *producer(void *ptr)                 /* produce data */
{     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)                 /* consume data */
{     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_unlock(&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);
}
```

. . .

Figure 2-32. Using threads to solve the producer-consumer problem.

Scheduling – Thread Behavior

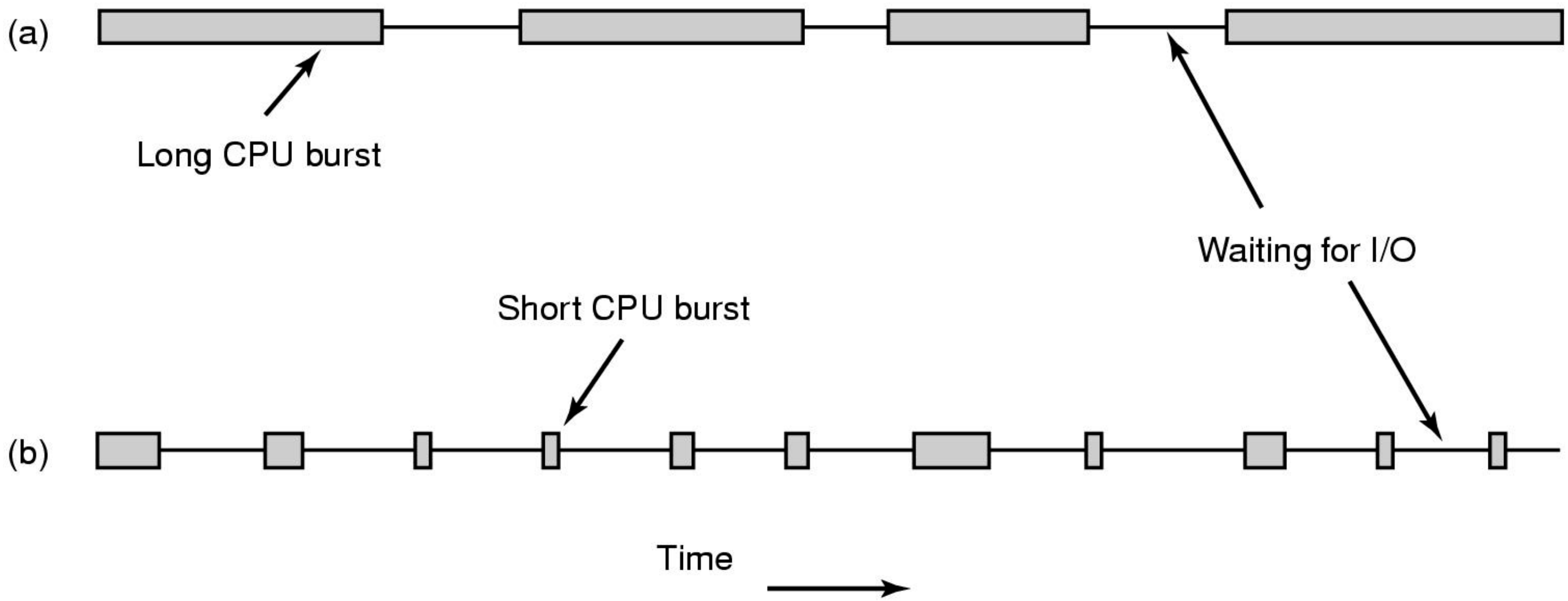


Figure 2-38. Bursts of CPU usage alternate with periods of waiting for I/O. (a) A CPU-bound process. (b) An I/O-bound process.

Categories of Scheduling Algorithms

- Batch
- Interactive
- Real time

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

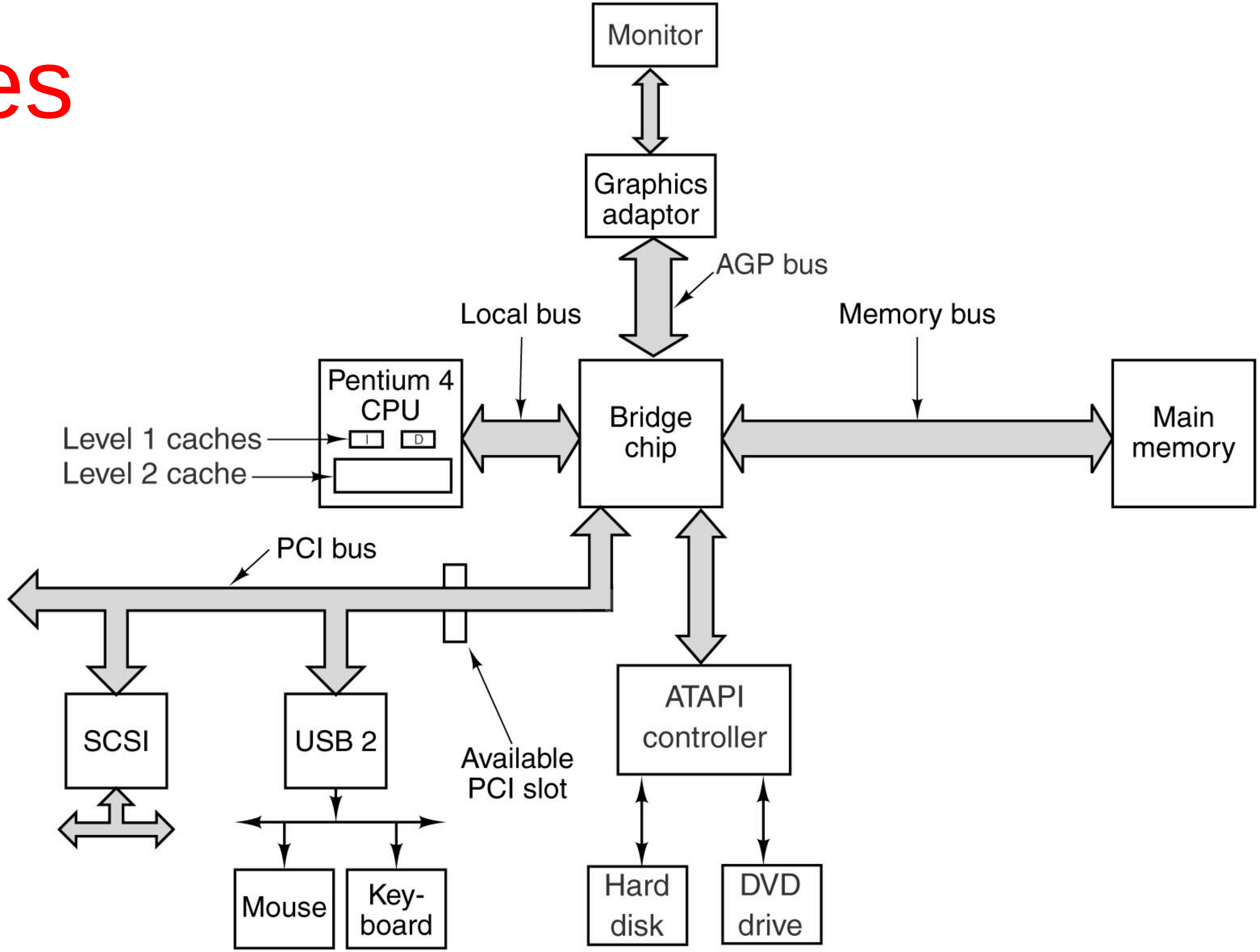
Meeting deadlines - avoid losing data
Predictability - avoid quality degradation in multimedia systems

Figure 2-39. Some goals of the scheduling algorithm under different circumstances.

Scheduling Parameters

- When a thread is created it is allocated a set of scheduling parameters
  - A scheduling policy
    - Batch, timeshare, real-time
  - A priority within that policy
    - Batch priorities are low, timeshare intermediate, real-time high
  - A possible time-slice (quantum)
    - Timeshare and real-time round robin use timeouts
  - Possible processor (core) affinity
    - A thread can be connected to one or a set of cores
  - Possible memory affinity
    - In NUMA systems, a thread can be connected to one or a set of cores that are closer to some specific part of RAM
  - Possible IO (bridge) affiinity
    - In NUMA systems, a thread can be connected to one or a set of cores that are closer to some specific IO bridge

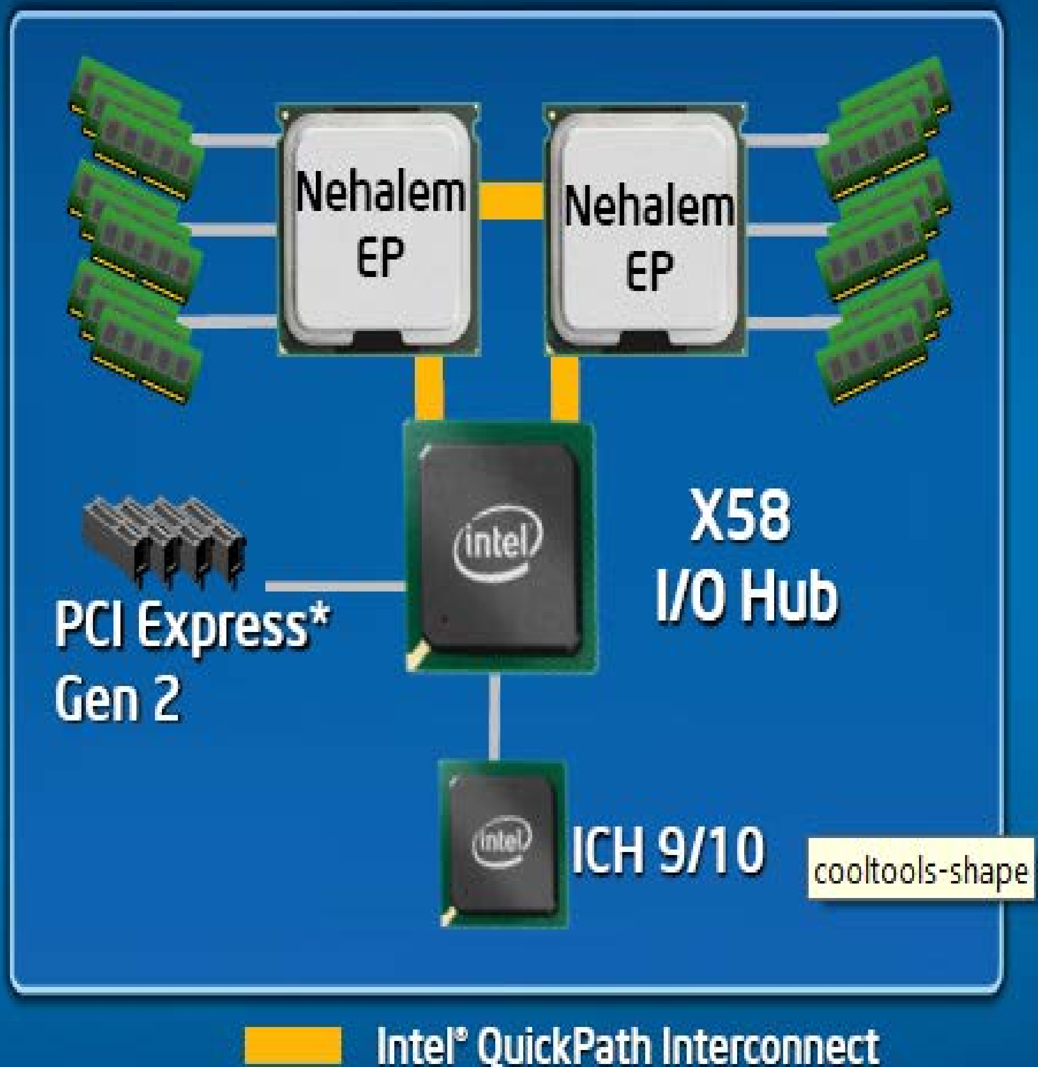
Buses



The bus structure of a pre-Nehalem Pentium 4

Enterprise: 2008 Nehalem Based

Two Socket System Architecture

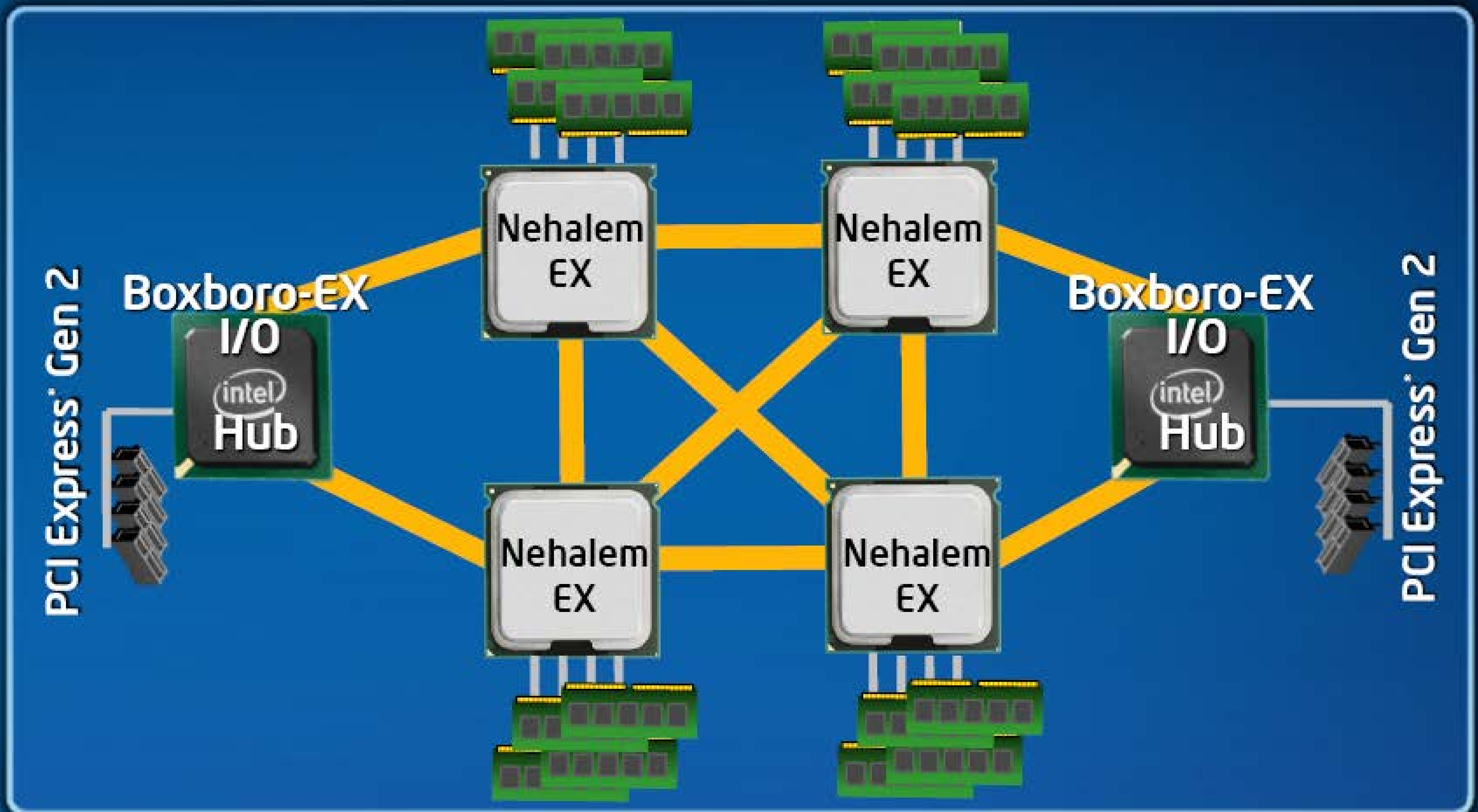


Nehalem-EP Platform:

- Two sockets each with Integrated Memory Controller
- Turbo mode operation
- Intel® QuickPath Architecture
- DDR3 Memory: 3 Channel, 3 DIMMs per channel
- Intel® Virtualization Technology
- PCI Express* Gen 2

Enterprise: 2009 Nehalem Based

Four Socket System Architecture



Boxboro-EX Platform:

Intel® QuickPath Interconnect

Four processors with Intel* QuickPath Interconnects

PCI Express* Gen 2, Integrated Memory Controller

POSIX Scheduling Policies as Used in Linux/UNIX Systems

sched_setscheduler() sets both the scheduling policy and the associated parameters for the thread whose ID is specified in arg tid. If tid equals zero, the scheduling policy and parameters of the calling thread will be set. The interpretation of the argument param depends on the selected policy. Currently, Linux supports the following "normal" (i.e., non-real-time) scheduling policies:

SCHED_OTHER the standard round-robin time-sharing policy;

SCHED_BATCH for "batch" style execution of processes; and

SCHED_IDLE for running very low priority background jobs.

The following "real-time" policies are also supported, for special time-critical applications that need precise control over the way in which runnable threads are selected for execution:

SCHED_FIFO a first-in, first-out policy; and

SCHED_RR a round-robin policy.

http://www.kernel.org/doc/man-pages/online/pages/man2/sched_setscheduler.2.html

Scheduling in Interactive Systems

- Round-robin scheduling
- Priority scheduling
- Multiple queues
- Shortest process next
- Guaranteed scheduling
- Lottery scheduling
- Fair-share scheduling

Round-Robin Scheduling

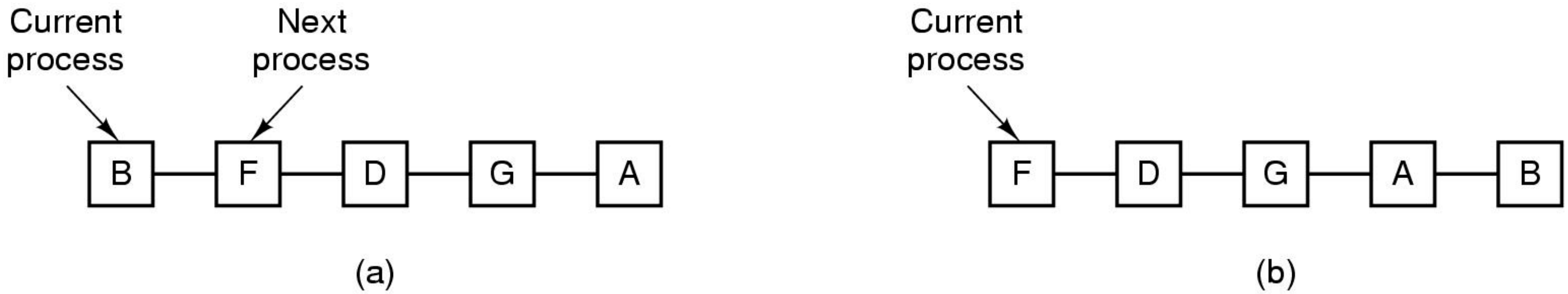


Figure 2-41. Round-robin scheduling. (a) The list of runnable processes. (b) The list of runnable processes after B uses up its quantum.

Priority Scheduling

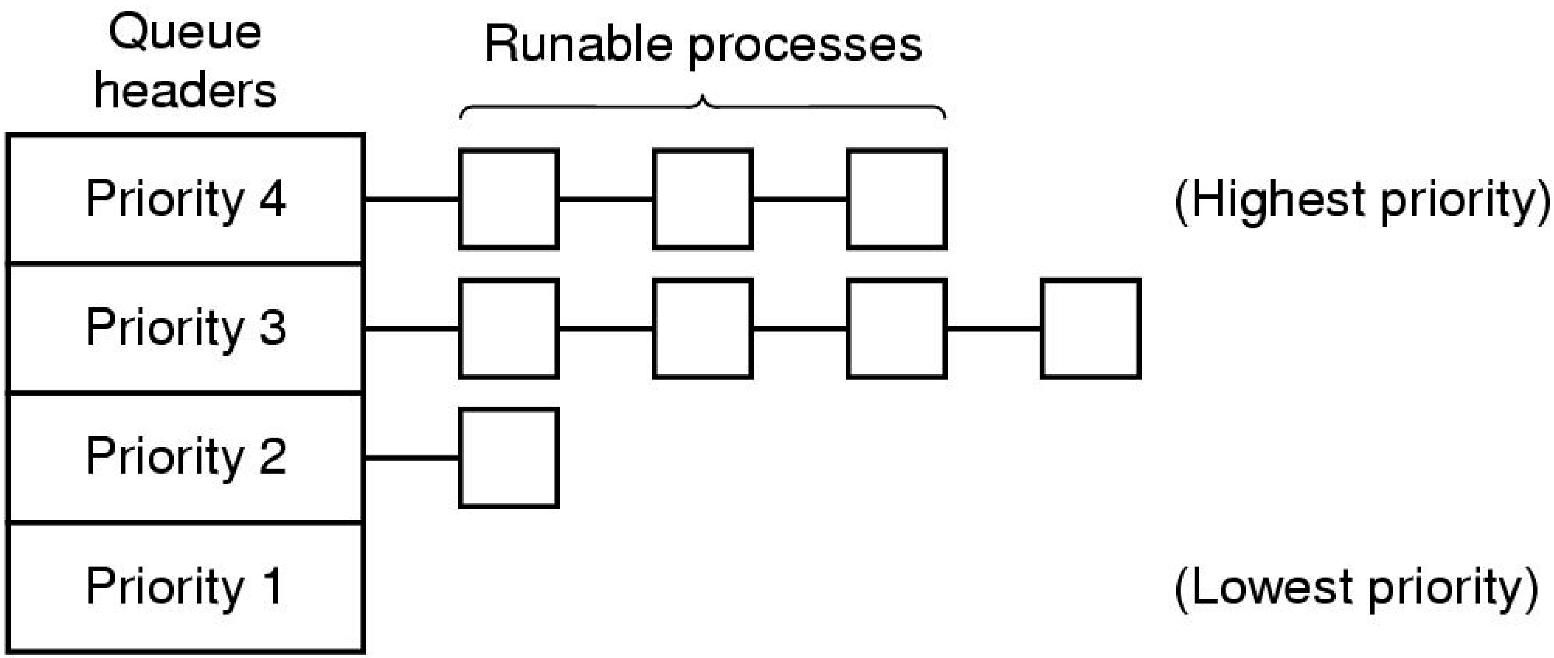


Figure 2-42. A scheduling algorithm with four priority classes.

Thread Scheduling (1)

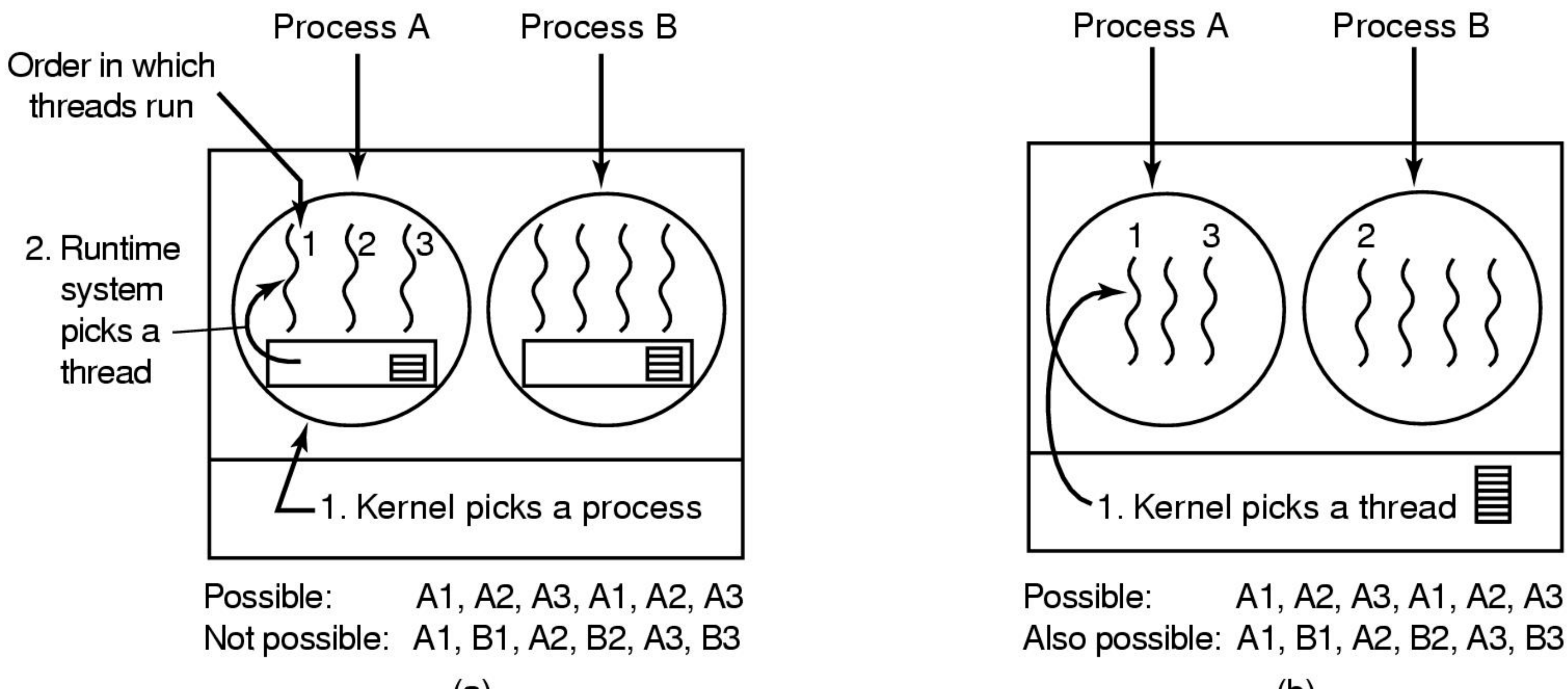


Figure 2-43. (a) Possible scheduling of user-level threads with a 50-msec process quantum and threads that run 5 msec per CPU burst.

Thread Scheduling (2)

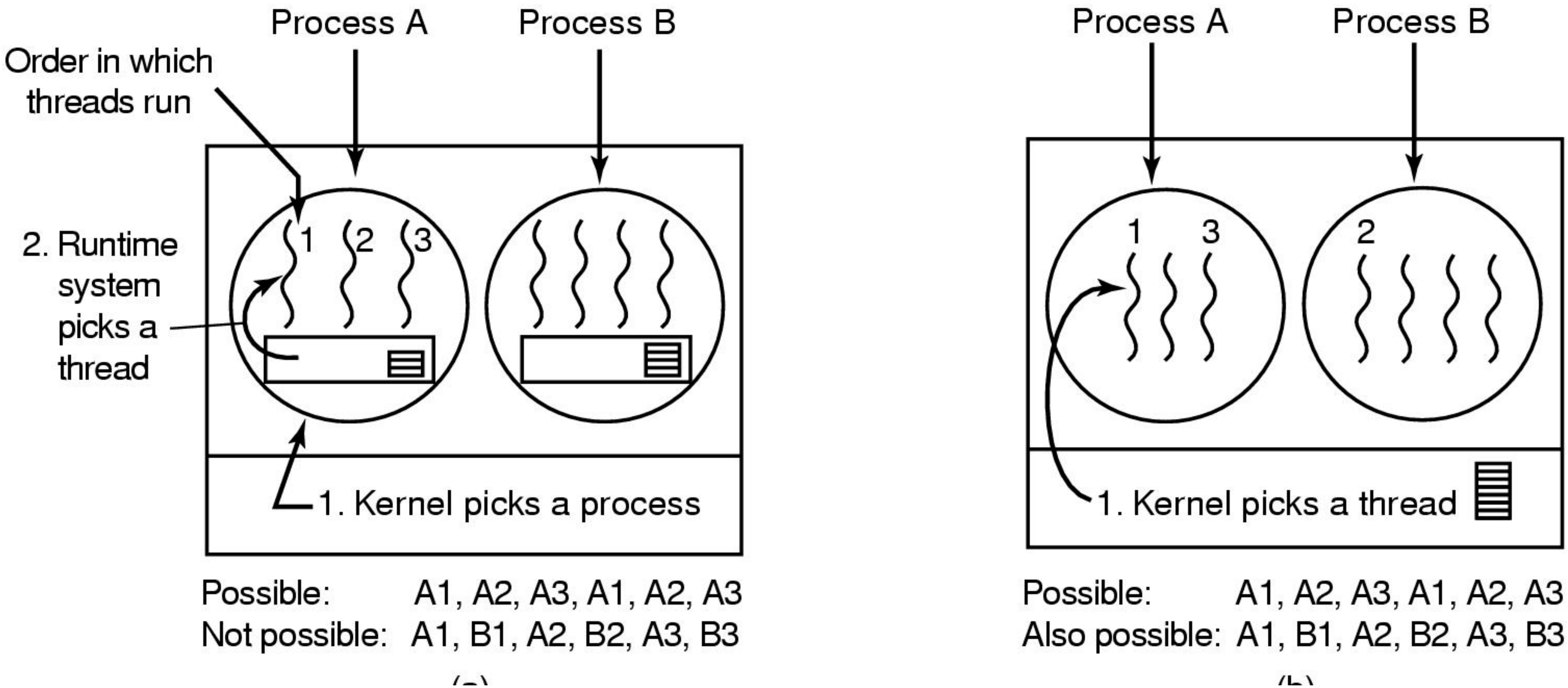


Figure 2-43. (b) Possible scheduling of kernel-level threads with the same characteristics as (a).

Scheduling in Real Time Systems

- Real Time Issues
- FIFO RT
- RR RT
- Deadline Scheduling

Scheduling in Real Time Systems (2)

- Real Time Issues
  - Deterministic latency
    - Policies that can guarantee a minimum time bound from ready state to run state
  - Priority range
    - Generally higher than non RT policies
  - Dynamic priority adjustment
    - Hands-off for all but deadline

FIFO Real Time Policy

- Highest Priority First (no RR)
- Once an HPF thread reaches the run state it cannot be preempted by another thread of the same highest priority
  - Run state is left only by EXIT, BLOCK operation or Priority Preemption (no RR)
  - Another thread of the same priority can only run when the first FIFO thread leaves the run state

Round Robin Real Time Policy

- Highest Priority First with RR
- Once an HPF thread reaches the run state it can be preempted by another thread of the same highest priority when its quantum expires
  - Run state is left by EXIT, BLOCK operation, Quantum Expiration or Priority Preemption
  - Another thread of the same priority can run if first RR thread completes its time slice

Deadline Real Time Policy

- A thread’s priority is dynamically adjusted as the thread approaches a predetermined deadline
- The intent is to make sure that the deadline scheduled thread will reach the run state by the deadline
    - The given thread’s priority will have been dynmically increased so much by the deadline that it will have become the highest priority thread in the system