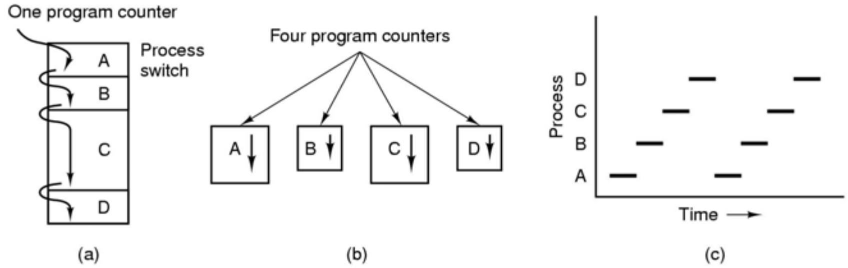
Processes

- What are they? How do we represent them?
- Scheduling
- Something smaller than a process? Threads
- Synchronizing and Communicating
- Classic IPC problems

Processes
The Process Model



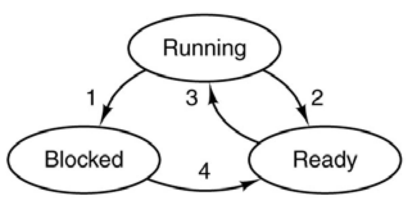
a) Multiprogramming of four processes
b) *Conceptual* model of 4 independent, sequential processes
c) Only one process active at any instant on *each* processor.

From Tanenbaum's *Modern Operating System*

Process Life Cyle

- Processes are “created”
- They run for a while
- They wait
- They run for a while…
- They die

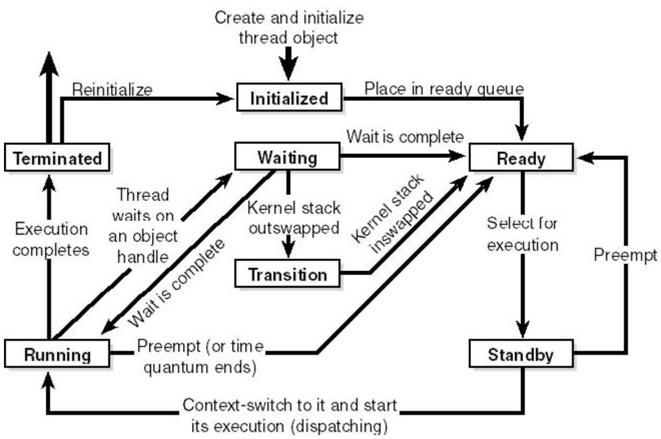
Process States



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

From Tanenbaum’s *Modern Operating System*

NT States



Picture from *Inside Windows 2000*

So what's a Process?

- What from the OS point of view, is a process?
- A struct. Sitting on a batch of queues.

Implementation of Processes

Process management	Memory management	File management
Registers Program counter Program status word Stack pointer Process state 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	Pointer to text segment Pointer to data segment Pointer to stack segment	Root directory Working directory File descriptors User ID Group ID

Fields of a process table entry

From Tanenbaum's *Modern Operating System*

Process Creation

Principal events that cause process creation

A. System start-up
B. Started from a GUI
C. Started from a command line
D. Started by another process

Process Termination

Conditions which terminate processes

1. Normal exit (voluntary)
2. Error exit (voluntary)
3. Fatal error (involuntary)
4. Killed by another process (involuntary)

From Tanenbaum's *Modern Operating System*

Process Hierarchies

- A Process can creates one (or more) child process.
- Each child can create its own children.
- Forms a hierarchy through ancestry
- Parents have control of their children
- NT processes can give away their children.

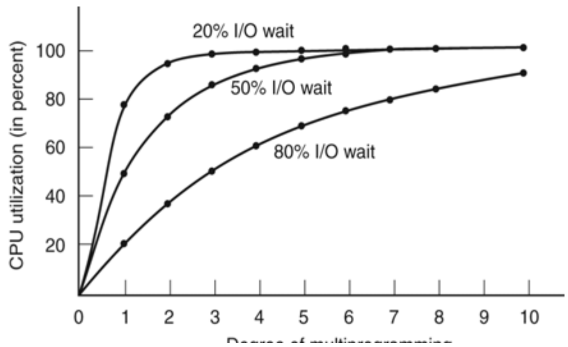
Switching from Running one Process to another

- Known as a “Context Switch”
- Requires
  - Saving and loading registers
  - Saving and loading memory maps
  - Updating Ready List
  - Flushing and reloading the memory caches
  - Etc.

Handling Interrupts
Who does what?

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.

Need for Multiprogrammng



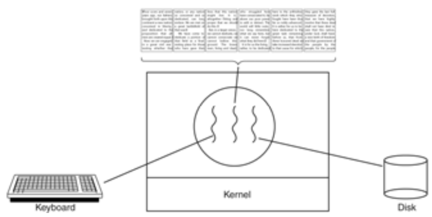
- How many processes does the computer need in order to stay “busy”?

Threads
Overview

- Usage
- Model
- Implementation
- Conversions

Thread Usage

- Makes it *easier* to write programs that have to be ready to do more than one thing at a time using the same data.



Thread Model

- A process consists of
  - Open files
  - Memory management
  - Code
  - Global data

  - Call Stack (includes local data)
  - Hardware Context:
    - Instruction pointer, stack pointer, general registers

Thread Model
(continued)

- Each thread has its own
  - Stack (includes local variables)
  - Program counter
  - General registers (copies)
- A process can have many threads

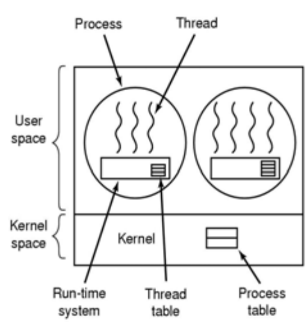
Thread Implementations
User level thread package

- Implemented as a library in user mode
  - Includes code for creating, destroying, switching…
- Often faster for thread creation, destruction and switching
- Doesn’t require modification of the OS
- If one thread in a process blocks then the whole process blocks.
- Can only use one processor.

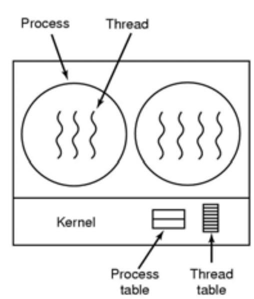
Thread Implementations
In the Kernel

- An application can have one thread blocked and still have another thread running.
- The threads can be running on different processors allowing for true parallelism.

Thread Implementations



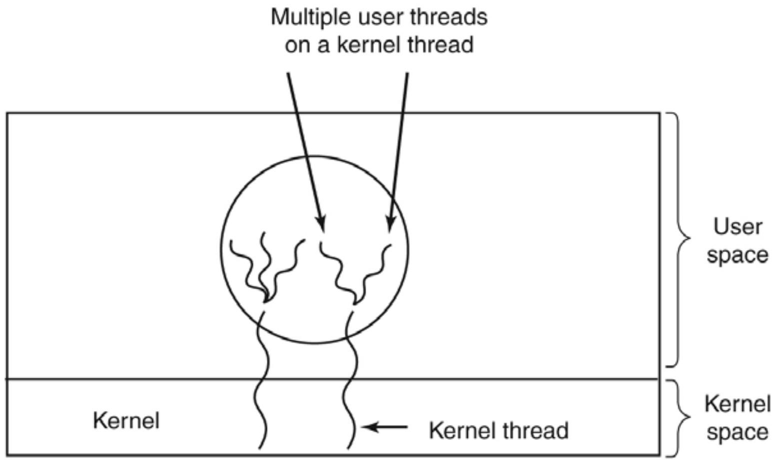
User Mode Library



In the kernel

From Tanenbaum's *Modern Operating System*

Hybrid Implementation



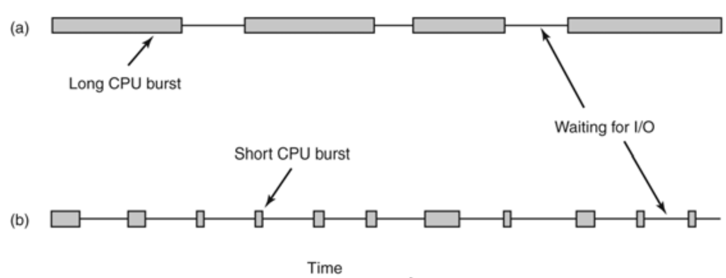
Converting Single-threaded to multi-threaded (!!!)

- Not for faint of heart
- Not all libraries are “thread-safe”.
- There may be “global” variables than need to be “local” to a thread.

Scheduling Overview

- Scheduling issues
  - What to optimize. Price of a context switch.
- Preemptive vs. non-preemptive
- Three-level scheduling
  - Short-term / cpu scheduler
  - medium-term / memory scheduler
  - long-term / admission scheduler
- Batch vs. Interactive
- General Algorithms
  - FCFS
  - SJF
  - SRTN
  - Round Robin
  - Priority
  - Multiple Queue
  - Guaranteed scheduling
  - Lottery scheduling
  - Fair share
- Examples: CTSS, NT, Unix and Linux

CPU Burst



- Processes with long cpu bursts are called compute-bound
- Processes that do a lot of I/O are called I/O-bound

Who’s in Charge?

- Who gets to decide when it is time to schedule the next process to run?
- If the OS allows the currently running process to get to a good “stopping spot”, the scheduler is **non-preemptive**.
- If, instead, the OS can switch processes even while a process is in the middle of its cpu-burst, then the scheduler is **preemptive**

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

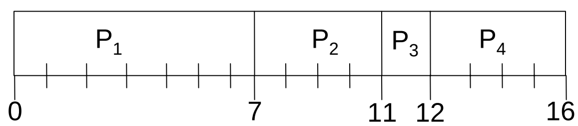
Real-time systems
Meeting deadlines - avoid losing data
Predictability - avoid quality degradation in multimedia systems

From Tanenbaum’s *Modern Operating System*

First-Come, First-Served (FCFS)

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- Non-preemptive



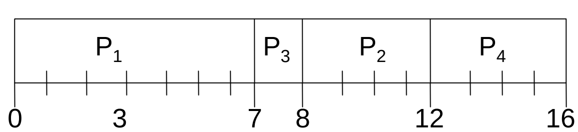
- Average waiting time = (0 + 5 + 7 + 7) / 4 = 4.75
- Average turnaround time = (7 + 9 + 8 + 11) / 4 = 8.75

From Silberchatz' Operating System Concepts

Shortest Job First (SJF)

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- Non-preemptive



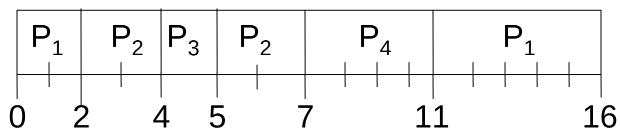
- Average waiting time = (0 + 6 + 3 + 7) / 4 = 4
- Average turnaround time = (7 + 10 + 4 + 11) / 4 = 8

Adapted from Silberchatz' Operating System Concepts

Shortest Remaining Time Next (SRTN)

Process	Arrival Time	Burst Time
P_1	0	7
P_2	2	4
P_3	4	1
P_4	5	4

- Preemptive



- Average waiting time = (9 + 1 + 0 + 2) / 4 = 3
- Average turnaround time = (16 + 5 + 1 + 6) / 4 = 7

From Silberchatz' Operating System Concepts

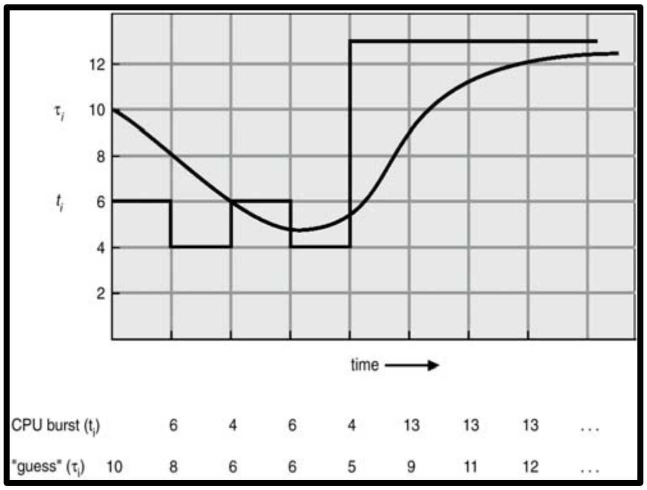
Using "Aging" to Estimate Length of Next CPU Burst

- Useful for both batch or interactive processes.
- Provides an estimate of the next length.
- Can be done by using the length of previous CPU bursts, using exponential averaging.

1. t_n = actual length of n^{th} CPU burst
2. τ_{n+1} = predicted value for the next CPU burst
3. $\alpha, 0 \le \alpha \le 1$
4. Define:

$$\tau_{n+1} = \alpha\, t_n + (1 - \alpha)\tau_n .$$

Prediction of the Length of the Next CPU Burst



From Silberchatz' Operating System Concepts

Round Robin

- Each process gets a small unit of CPU time (*time quantum*), usually 10-100 milliseconds. After this time has elapsed, the process is preempted and added to the end of the ready queue.
- If there are *n* processes in the ready queue and the time quantum is *q*, then each process gets 1/*n* of the CPU time in chunks of at most *q* time units at once. No process waits more than (*n*-1)*q* time units.
- Performance
  - *q* large ⇒ FIFO
  - *q* small ⇒ *q* must be large with respect to context switch, otherwise overhead is too high.

From Silberchatz' Operating System Concepts

Example of RR with Time Quantum = 20

Process	Burst Time
P_1	53
P_2	17
P_3	68
P_4	24

- The Gantt chart is:

P_1	P_2	P_3	P_4	P_1	P_3	P_4	P_1	P_3	P_3

0 20 37 57 77 97 117 121 134 154 162

- Typically, higher average turnaround than SJF, but better *response*.

From Silberchatz' Operating System Concepts

Priority Scheduling

- Each process is *explicitly* assigned a priority.
- Each queue may have its own scheduling strategy.
- No process in a lower priority queue will run so long as there is a ready process in a higher priority queue.

Multi-Queue with Feedback

- Different queues, possibly with different scheduling algorithms.
- Could use a RR queue for “foreground” processes and a FCFS queue for “background”.
- Example: CTSS had a multilevel queue
  - Each lower priority had a quantum twice as long as the one above.
  - You moved down in priority if you used up your quantum.
  - Receiving a carriage-return at the process’s keyboard moved the process to the highest priority.

Guaranteed Scheduling

- What if we want to *guarantee* that a process get x% of the CPU? How do we write the scheduler?
- Scheduling algorithm would compute the ratio of
  a) The fraction of CPU time a process has used since the process began
  b) The fraction of CPU time it is supposed to have.
- The process with the lowest ratio would run next.

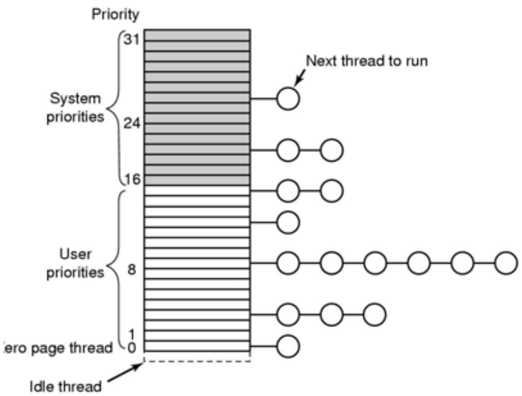
Lottery

- Issue lottery tickets.
- The more lottery tickets you have, the better your chance of “winning”.
- Processes can give (or lend) their tickets to their children or to other processes.

Fair Share

- If there are 2 users on the machine, how much of the CPU time should each get?
- In Unix or NT it would depend on who has more processes (or threads).
- Dividing the time based on the number of users instead, would be called “a fair share”

NT Scheduling

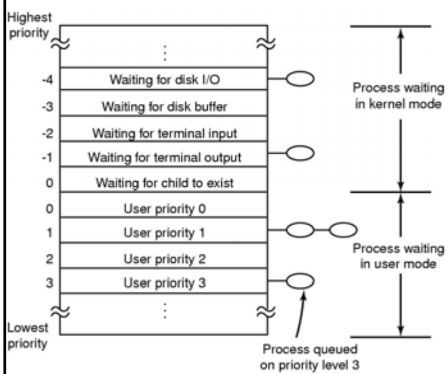


From Tanenbaum's *Modern Operating System*

Priority Inversion

- **Priority Inversion**:
  When a high priority process is prevented from making progress due to a lower priority process.
- High Priority process waits on a resource held by a Low Priority process. [By itself this does **not** constitute a problem.]
- But the low priority process can't release the resource because a Medium Priority process is running.
- Here we have one process (medium priority) blocking a higher priority process.
- How do unix and NT handle this?

UNIX Scheduler



- Fixed quantum size.
- The running process's cpu_usage count is incremented when the clock ticks
- Once per second the cpu_usage is "aged" and priorities are recomputed
- Priority ≈ base + cpu_usage + nice
- Processes waiting *inside* the kernel for i/o to complete have negative (high) priorities, but these drop to "normal" when they return to user space.

From Tanenbaum's *Modern Operating System*

Linux 2.4 Scheduler

- Processes are assigned CPU time once each **epoch**. A new epoch begins when no ready-to-run job has any cpu time left.
- A process can carry over half its unused CPU time from the last epoch.
- Priority (known as **goodness**) is recalculated each time the scheduler runs.
- Goodness is largely determined by the unused cpu time.
- Preference is given to a process if it uses the same memory space as the last process (so the memory management cache doesn't need to be cleared).
- Preference is given in a multiprocessor machine to a process if it last ran on the current processor. This improves cache hits.

Linux 2.6 Scheduler

- 140 levels.
  - First 100 are “real time”. Last 40 for “user”
  - Allows a 5-word bit map to identify occupied levels.
- *Active* vs. *expired* arrays. Active array of levels holds processes to be scheduled
- When user process uses up its quantum it moves to the expired array.
  - Priority is then recalculated based on “interactivity”:
  - ratio of how much it executed compared to how much it slept.
  - adjusts priority ±5.
  - Quantum is based on priority. Better priority has longer quantum.
    - (Note: different sources quote different ranges… have to check real source)
- Queues are swapped when no active user process left.
  - Like the 2.4 scheduler this allows low priority processes to get a chance.
- Separate structures for each cpu, but migration is possible.

Issues for Multi-level Round Robin Queues

- Quantum
  - Fixed size or variable
  - When / how is it “used up”
- Priority
  - How is it determined
  - When is it modified

IPC Overview

- IPC (InterProcess Communication)
  - Allows processes to exchange data and synchronize execution
- Issues
  - Race Condition
  - Critical Region / Mutual Exclusion
- Guaranteeing Mutual Exclusion with
  - Pure software solutions
  - Hardware assistance
  - Common abtractions
    - Semaphore
    - Monitor
- Other forms of communication.

Race Condition

```
x = 0;  // Shared memory
```

```
//Process A
//x = x + 1;
MOV EAX, x // line 1
INC EAX    // line 2
MOV x, EAX // line 3
```

```
// Process B
//x = x - 1;
MOV EAX, x // line 1
DEC EAX    // line 2
MOV x, EAX // line 3
```

<u>Scenario 1</u>
Proc A – line 1
Proc B – line 1,2,3
Proc A – line 2,3

Result: 1

<u>Scenario 2</u>
Proc A – line 1
Proc B – line 1
Proc A – line 2,3
Proc B – line 2,3

Result: -1

Critical Region

- **Any section of code where shared memory is accessed or modified**
- Conditions for a *good* solution for avoiding races:
  - No two processes may be in their corresponding critical regions simultaneously (**mutual exclusion**)
  - No assumptions to be made about speed or number of processes
  - No process running *outside* a critical region may block another process from entering
  - No process should have to wait forever.

Easy Solution: Disable Interupts

- Eeek!
- Obviously this can only be done in kernel mode.
- And even in kernel mode it's not great.
- Especially inefficient and difficult with multiple processors.
- But sometimes it may be the right (or simplest) answer.

Software Solution: Using a “lock”

int lock = 0; // lock is a shared variable

```
// Call this BEFORE
// beginning the
// critical region

void enterRegion()
{
  // bit spin waiting
  // for lock
  while (lock == 1)
    yield();
  lock = 1;
}
```

```
// Call this AFTER
// finishing the
// critical region

void leaveRegion()
{
   lock = 0;
}
```

Software Solution: Taking Turns

```
// Call this before
// beginning the
// critical region

void enterRegion(int
  proc)
{
  // bit spin waiting
  // for turn
  while (turn != proc)
    yield();
}
```

```
// Call this after
// finishing the
// critical region

void leaveRegion(int
  proc)
{
  turn = 1 - proc;
}
```

Software Solution:
Taking Turns

<u>Process 0</u>

```
while (TRUE) {
   enterRegion(0);
   criticalRegion();
   leaveRegion(0);
   nonCriticalRegion();
}
```

<u>Process 1</u>

```
while (TRUE) {
   enterRegion(1);
   criticalRegion();
   leaveRegion(1);
   nonCriticalRegion();
}
```

Software Solution:
Peterson’s Solution

```
int turn;                // Will be set before first use
bool interested[2];      // Initialized to false

void enter_region  (int process) {
    int other = 1 -  process;
    interested[process] = true;
    turn = process;
    while (turn == process && interested[other] == true)
          ;    // NOTE: Loop does nothing but check state
}

void exit_region (int process) {
    interested[process] = false;
}
```

Hardware Solution: Disable Interupts

- Eeek!
- Obviously this can only be done in kernel mode.
- And even in kernel mode it's not great.
- Especially inefficient and difficult with multiple processors.
- But sometimes it may be the right (or simplest) answer.

Hardware Solution: Atomic Machine Instruction

- Atomic machine instruction
  - Instruction that cannot be interrupted
- Test and Set Lock (TSL)
  - Test a memory location and set it.
  - Motorolla 680x0
  - Usage: TSL register, memory
  - Enter_region:
```
    TSL reg, LOCK// Copy LOCK to the register
          // and set LOCK = 1
    CMP reg, 0    // Compare the register with zero.
    BNE Enter_region     // If it wasn't zero, try again.
```
  - Exit_region:
```
    MOVE LOCK, 0
```
- Swap
  - Exchanges register with memory.
  - Intel x86

Busy Wait and Priority Inversion

- Busy wait can lead to priority inversion.
- If a high-priority process busy-waits on a resource held by a low-priority process then the low-priority process will never get to execute.
- Effectively, the low priority process is blocking the busy-waiting high priority process from ever proceeding.
- Moral: busy-waiting must be used with caution.

Producer / Consumer Problem

- A problem involving two kinds of processes, producers and consumers, and a shared <u>fixed-sized</u> queue.
- Producers produce things and place them in the queue.
- Consumers take things out of the queue and consume them.
- What should happen if
  - the queue is full when the producer wants to put something in?
  - The queue is empty when the consumer goes to take something out?
- *How* do we block the producer / consumer until the right time and then make sure they get back to work?

Sleep and Wakeup

```
#define N 100                              /* number of slots in the buffer */
int count = 0;                             /* number of items in the buffer */

void producer(void)
{
     int item;

     while (TRUE) {                        /* repeat forever */
          item = produce_item( );          /* generate next item */
          if (count == N) sleep( );        /* if buffer is full, go to sleep */
          insert_item(item);               /* put item in buffer */
          count = count + 1;               /* increment count of items 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, got to sleep */
          item = remove_item( );           /* take item out of buffer */
          count = count − 1;               /* decrement count of items in buffer */
          if (count == N − 1) wakeup(producer); /* was buffer full? */
          consume_item(item);              /* print item */
     }
}
```

Producer-consumer problem with fatal race condition

From Tanenbaum's *Modern Operating System*

Semaphores

- A *very* widely used primitive for synchronization.
- Think of it as an abstract data type with just three operations:
  - Constructor / initializer
  - `P()`. Attempts to "lock" the semaphore.
  - `V()`. Frees the semaphore.
- **NEVER** access the "value" of a semaphore directly. Only access it through the provided operations.
- `P()` and `V()` are **atomic**.
- Tannenbaum uses "`down()`" and "`up()`" instead.
- Semaphores come in two flavors:
  - Binary. Also called **Mutex**.
  - Counting. Allows more than one process to "own the lock" simultaneously.

Mutex *roughly* implemented using TSL

```
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 later
ok:   RET | return to caller; critical region entered

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

Note that in a real implementation, failing to get the lock on a mutex would put the process on a wait queue. Tanenbaum likes this version because it can be done in user mode.

From Tanenbaum's *Modern Operating System*

Counting Semaphores

Can be used to allocating N things. Declare a semaphore S:

```
int S = N;
```

Simple *conceptual* implementation of the operations:

```
P(S): {
    --S;
    if  (S < 0)
        sleep();
}

V(S): {
    ++S;
    wake(); // Wake one of the waiting processes
}
```

These functions ***must*** be "atomic".
And ***never*** access the value of the semaphore directly.

Semaphores can be tricky…

Process A	**Process B**
P(*S*);	*P*(*Q*);
P(*Q*);	*P*(*S*);
⋮	⋮
V(*Q*);	*V*(*S*);
V(*S*);	*V*(*Q*)

•Above is one source of error, two processes requesting to lock a pair of semaphores, but in reverse order.

•Or suppose a programmer fails to use the V operation…

•Or even the P operation!

Using Semaphores

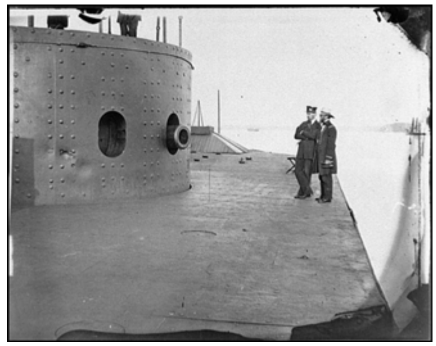
```
#define N 100                       /* number of slots in the buffer */
typedef int semaphore;              /* semaphores are a special kind of int */
semaphore mutex = 1;                /* controls access to critical region */
semaphore empty = N;                /* counts empty buffer slots */
semaphore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

void producer(void)
{
    int item;

    while (TRUE) {                  /* TRUE is the constant 1 */
        item = produce_item( );     /* generate something to put in 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) {                  /* infinite loop */
        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 */
    }
}
```

The producer-consumer problem using semaphores

From Tanenbaum's *Modern Operating System*

Monitor

- High-level synchronization primitive. Must be provided by the language.
- Collection of data and procedures collected together. (like an OOP class)
- Only one procedure in a monitor can be active at a time.
- A process that is running in a monitor procedure can block itself by waiting on a condition variable.



Monitors

```
monitor example
        integer i;
        condition c;

        procedure producer( );
        .
        .
        .
        end;

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

From Tanenbaum's *Modern Operating System*

Condition Variables

- To allow a process to wait within the monitor, a **condition variable** must be declared.

  condition x;
- Condition variables can only be used with the operations **wait** and **signal**.
  - The operation

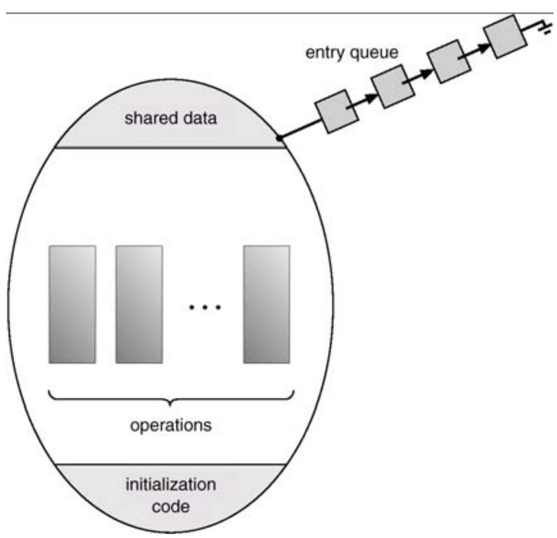
    wait(x);

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

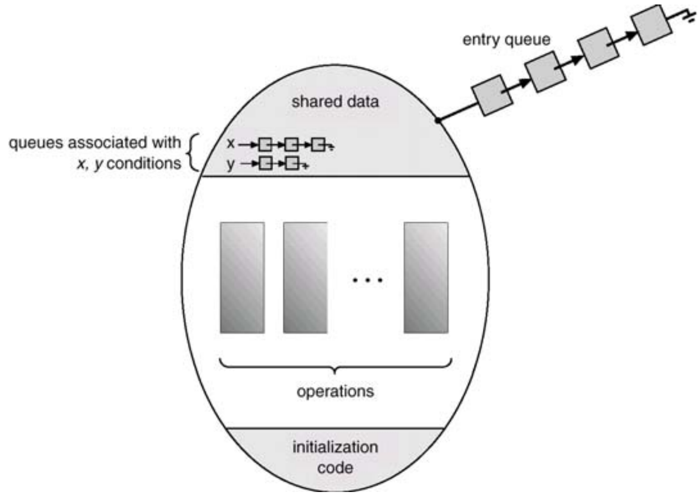
    signal(x);
  - The **signal** operation resumes exactly one suspended process. If no process is suspended, then the **signal** operation has no effect.

- Note that condition variables are also commonly provided with Mutex libraries.

Schematic View of a Monitor



Monitor With Condition Variables



Monitors

```
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;
```

- Outline of producer-consumer problem with monitors
  - only one monitor procedure active at one time
  - buffer has *N* slots

From Tanenbaum's *Modern Operating System*

Monitors

```
public class ProducerConsumer {
      static final int N = 100;                     // constant giving the buffer size
      static producer p = new producer( );     // instantiate a new producer thread
      static consumer c = new consumer( );// instantiate a new consumer thread
      static our_monitor mon = new our_monitor( );  // instantiate a new monitor
      public static void main(String args[ ]) {
         p.start( );                                // start the producer thread
         c.start( );                                // start the consumer thread
      }
      static class producer extends Thread {
         public void run( )  {                     // run method contains the thread code
            int item;
            while (true) {                          // producer loop
               item = produce_item( );
               mon.insert(item);
            }
         }
         private int produce_item( ) { ... }     // actually produce
      }
      static class consumer extends Thread {
         public void run( )  {                     run method contains the thread code
            int item;
            while (true) {                          // consumer loop
               item = mon.remove( );
               consume_item (item);
            }
         }
         private void consume_item(int item) { ... }     // actually consume
      }
```

Solution to producer-consumer problem in Java

From Tanenbaum's *Modern Operating System*

Monitors

```
   static class our_monitor {                 // this is a monitor
      private int buffer[ ] = new int[N];
      private int count = 0, lo = 0, hi = 0; // counters and indices
      public synchronized void insert(int val) {
         if (count == N) go_to_sleep( );   // if the buffer is full, go to sleep
         buffer [hi] = val;                  // insert an item into the buffer
         hi = (hi + 1) % N;                  // slot to place next item in
         count = count + 1;                  // one more item in the buffer now
         if (count == 1) notify( );          // if consumer was sleeping, wake it up
      }
      public synchronized int remove( ) {
         int val;
         if (count == 0) go_to_sleep( );   // if the buffer is empty, go to sleep
         val = buffer [lo];                  // fetch an item from the buffer
         lo = (lo + 1) % N;                  // slot to fetch next item from
         count = count – 1;                  // one few items in the buffer
         if (count == N – 1) notify( );      // if producer was sleeping, wake it up
         return val;
      }
      private void go_to_sleep( ) { try{wait( );} catch(InterruptedException exc) {};}
   }
}
```

Solution to producer-consumer problem in Java (part 2)

From Tanenbaum's *Modern Operating System*

Message Passing

- Widely used IPC technique is for the OS to support sending messages.
  - Less “fragile” than semaphores.
  - Doesn’t require language support (unlike monitors)
- Possible Design Issues:
  - Where do we send
    - to a process or through a “mailbox”?
  - Efficiency
    - How many times will the message be sent?
    - Maximum size of messages?
    - Maximum size of message queue?
  - Portability
    - Does the interface work with different OS’s?
    - Does it work with both single processor and distributed systems?

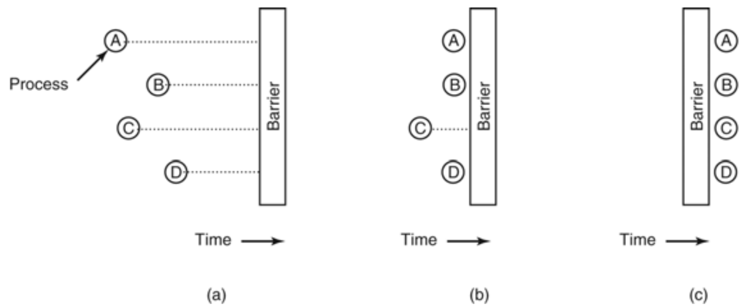
Using Message Passing

```
#define N 100                           /* number of slots in the buffer */

void producer(void)
{
     int item;
     message m;                         /* message buffer */

     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 */
     }
}
```

The producer-consumer problem with N messages

From Tanenbaum’s *Modern Operating System*

Barrier



- Here we have several processes that need to synchronize together.
- High level abstractions, such as a barrier, are often convenient to solve certain types of problems.

Common IPC Mechanisms in Unix and NT

- Semaphores / Mutexes
- Spin Locks
- Signals (unix)
- Pipes. Processes must be related.
- FIFO (aka named pipes). Can be shared by unrelated processes.
- Shared memory.
- Shared Files.
- Message Queues.
- Mail slots (NT) Don't guarantee delivery. Can send to multiple recipients.
- Remote Procedure Call. The ability to invoke a procedure in another process.
- Sockets (intended for network communications)
- MPI (Message Passing Interface)

Spin Lock

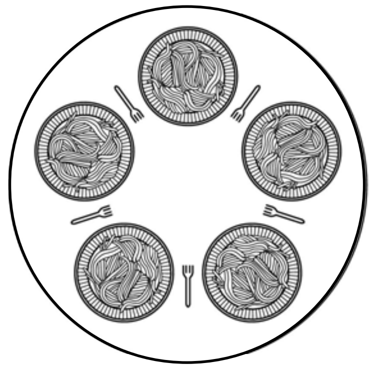
- Suppose when we are trying to get the lock on a resource, we bit spin with the TSL. What's the down side?
  - We are using up cpu cycles.
  - On a single core/cpu possibly no one will get to run and free up resource.
- A *spin lock* is a mechanism where attempting to lock involves bit-spinning till the lock is gained.
  - They may be used when
    - you have more than one core/cpu
    - *and* the lock will only be needed for a very short time.
    - *and t*he one who has the lock will *not* get blocked
  - Some implementations will switch to a more standard semaphore lock
    - If the process/thread that has the lock is currently running
    - If bit-spinning turns out to be taking too long
- An optimization to avoid bus traffic is to use a regular read during the bit spinning and only use the TSL when we believe the lock is free.

Classic IPC Problems

- Producer/Consumer (aka Bounded Buffer)
- Dining Philosophers
- Readers / Writers
- Sleeping Barber

Dining Philosophers

- Philosophers eat/think
- Eating needs 2 forks
- Pick one fork at a time
- How to prevent deadlock



From Tanenbaum's *Modern Operating System*

Dining Philosophers

```
#define N 5                          /* number of philosophers */

void philosopher(int i)              /* i: philosopher number, from 0 to 4 */
{
      while (TRUE) {
            think( );                /* philosopher is thinking */
            take_fork(i);            /* take left fork */
            take_fork((i+1) % N);    /* take right fork; % is modulo operator */
            eat( );                  /* yum-yum, spaghetti */
            put_fork(i);             /* put left fork back on the table */
            put_fork((i+1) % N);     /* put right fork back on the table */
      }
}
```

A <u>non-</u>solution

From Tanenbaum's *Modern Operating System*

Dining Philosophers

```
#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           /* philosopher is thinking */
#define HUNGRY      1           /* philosopher is trying to get forks */
#define EATING      2           /* philosopher is eating */
typedef int semaphore;          /* semaphores are a special kind of int */
int state[N];                   /* array 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: philosopher number, from 0 to N−1 */
{
    while (TRUE) {              /* repeat forever */
        think( );               /* philosopher is thinking */
        take_forks(i);          /* acquire two forks or block */
        eat( );                 /* yum-yum, spaghetti */
        put_forks(i);           /* put both forks back on table */
    }
}
```

From Tanenbaum's *Modern Operating System*

Dining Philosophers

```
void take_forks(int i)          /* i: philosopher number, from 0 to N−1 */
{
    down(&mutex);               /* enter critical region */
    state[i] = HUNGRY;          /* record fact that philosopher i 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(i)               /* i: philosopher number, from 0 to N−1 */
{
    down(&mutex);               /* enter critical region */
    state[i] = THINKING;        /* philosopher has finished eating */
    test(LEFT);                 /* see if left neighbor can now eat */
    test(RIGHT);                /* see if right neighbor can now eat */
    up(&mutex);                 /* exit critical region */
}

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

From Tanenbaum's *Modern Operating System*

The Readers and Writers Problem

```
typedef int semaphore;          /* use your imagination */
semaphore mutex = 1;            /* controls access to 'rc' */
semaphore db = 1;               /* controls access to the database */
int rc = 0;                     /* # of processes reading or wanting to */

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

From Tanenbaum's *Modern Operating System*

```
typedef int semaphore;
semaphore protectCount = 1;  // mutex
semaphore protectDB = 1;     // mutex
int rc = 0
```

```
void beforeReading() {
   P(protectCount);
   if (++rc == 1)
      P(protectDB);
   V(protectCount);
}

void afterReading() {
   P(protectCount);
   if (--rc == 0)
      V(protectDB);
   V(protectCount);
}
```

```
void beforeWriting() {
   P(protectDB);
}

void afterWriting() {
   V(protectDB);
}
```