

## The Big Picture So Far

HW Abstraction	Example OS Services	User level Abstractions
Processor	Process management, protection, synchronization	Process
Memory	Memory Protection, management, VM	Address space
IO devices	Interrupt handling, concurrency with CPU	Mouse, keyboard, IO related system calls
File system	Management, Persistence	Files
Distributed systems	Security, distrib. file system, communication	RPC calls, sharing files,...

## Chapter 4: Processes

- Process Concept
- Process Scheduling
- Operations on Processes
- Cooperating Processes
- Interprocess Communication
- Communication in Client-Server Systems

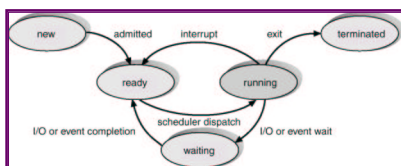
## Process Concept

- An operating system executes a variety of programs:
  - ◆ Batch system – jobs
  - ◆ Time-shared systems – user programs or tasks
- Textbook uses the terms *job* and *process* almost interchangeably.
- Process – a program in execution; process execution must progress in sequential fashion.
- A process includes:
  - ◆ program counter
  - ◆ stack
  - ◆ data section

## Process State

- As a process executes, it changes *state*
  - ◆ **new**: The process is being created.
  - ◆ **running**: Instructions are being executed.
  - ◆ **waiting**: The process is waiting for some event to occur.
  - ◆ **ready**: The process is waiting to be assigned to a process.
  - ◆ **terminated**: The process has finished execution.

## Diagram of Process State

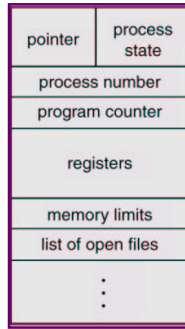


## Process Control Block (PCB)

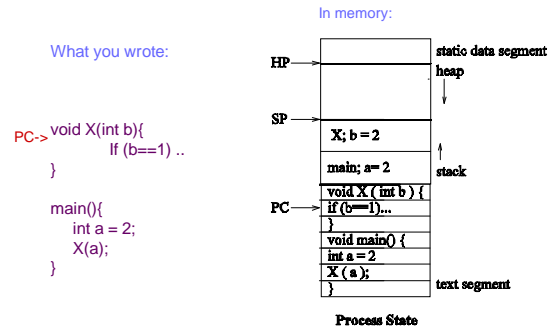
Information associated with each process in the OS, i.e., the process related data structure.  
The PCB contains:

- Process state (running, waiting, ...)
- Program counter (value of PC)
- Stack pointer, General purpose CPU registers
- CPU scheduling information (e.g., priority)
- Memory-management information
- Username of owner
- I/O status information
- Pointer to state queues, ..

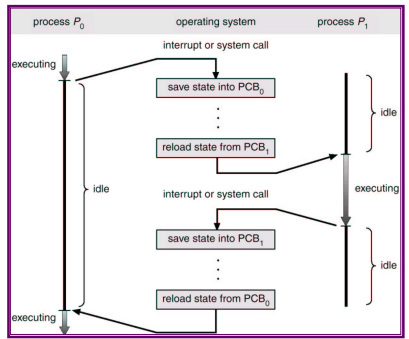
## Process Control Block (PCB)



## Example Process State in Memory



## CPU Switch From Process to Process



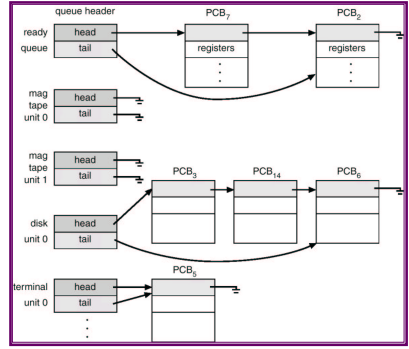
## PCBs and Hardware State

- The OS starts executing a process by loading hardware registers from its PCB
- While the process is running the CPU modifies the hw registers (PC, SP, ..)
- When the process stops a process it saves the current values into the PCB
- Going from one process to another is the context switch
  - ◆ 100 to 1000 switches per second
  - ◆ Cost of CSW is related to the time period

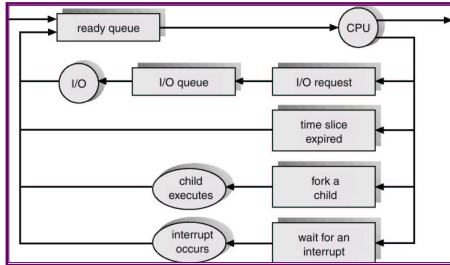
## Process Scheduling Queues

- Queues related to process scheduling:
- Job queue – set of all processes in the system.
  - Ready queue – set of all processes residing in main memory, ready and waiting to execute.
  - Device queues – set of processes waiting for an I/O device.
  - Process migration between the various queues managed by the OS.

## Ready Queue And Various I/O Device Queues



## Representation of Process Scheduling

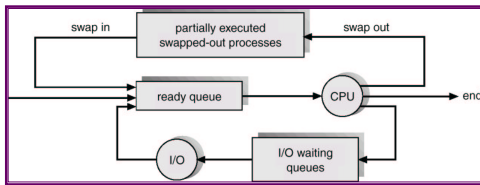


## Schedulers

Different schedulers in the OS:

- Long-term scheduler (or job scheduler) – selects which processes should be brought into the ready queue.
- Short-term scheduler (or CPU scheduler) – selects which process should be executed next and allocates CPU.

## Addition of Medium Term Scheduling



## Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) ⇒ (must be fast).
- Long-term scheduler is invoked very infrequently (seconds, minutes) ⇒ (may be slow).
- The long-term scheduler controls the *degree of multiprogramming*.
- Processes can be described as either:
  - ◆ *I/O-bound process* – spends more time doing I/O than computations, many short CPU bursts.
  - ◆ *CPU-bound process* – spends more time doing computations; few very long CPU bursts.

## Context Switch

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process.
- Context-switch time is overhead; the system does no useful work while switching.
- Time dependent on hardware support.

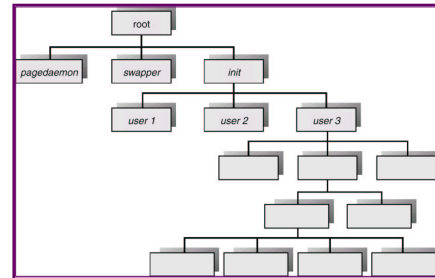
## Process Creation

- Parent process create children processes, which, in turn create other processes, forming a tree of processes.
- Resource sharing
  - ◆ Parent and children share all resources.
  - ◆ Children share subset of parent's resources.
  - ◆ Parent and child share no resources.
- Execution
  - ◆ Parent and children execute concurrently.
  - ◆ Parent waits until children terminate.

## Process Creation (Cont.)

- Address space
  - ✦ Child duplicate of parent.
  - ✦ Child has a program loaded into it.
- UNIX examples
  - ✦ **fork** system call creates new process
  - ✦ **exec** system call used after a **fork** to replace the process' memory space with a new program.

## Processes Tree on a UNIX System



## Process Termination

- Process executes last statement and asks the operating system to decide it (**exit**).
  - ✦ Output data from child to parent (via **wait**).
  - ✦ Process' resources are deallocated by operating system.
- Parent may terminate execution of children processes (**abort**).
  - ✦ Child has exceeded allocated resources.
  - ✦ Task assigned to child is no longer required.
  - ✦ Parent is exiting.
    - ✓ Operating system does not allow child to continue if its parent terminates.
    - ✓ Cascading termination.

## Cooperating Processes

- *Independent* process cannot affect or be affected by the execution of another process.
- *Cooperating* process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - ✦ Information sharing
  - ✦ Computation speed-up
  - ✦ Modularity
  - ✦ Convenience

## Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process.
  - ✦ *unbounded-buffer* places no practical limit on the size of the buffer.
  - ✦ *bounded-buffer* assumes that there is a fixed buffer size.

## Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
    ...
} item;
item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```
- Solution is correct, but can only use `BUFFER_SIZE-1` elements

### Bounded-Buffer – Producer Process

```
item nextProduced;

while (1) {
    while (((in + 1) % BUFFER_SIZE) ==
out)
        ; /* do nothing */
    buffer[in] = nextProduced;
    in = (in + 1) % BUFFER_SIZE;
}
```

### Bounded-Buffer – Consumer Process

```
item nextConsumed;

while (1) {
    while (in == out)
        ; /* do nothing */
    nextConsumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
}
```

### Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions.
- Message system – processes communicate with each other without resorting to shared variables.
- IPC facility provides two operations:
  - ◆ **send**(*message*) – message size fixed or variable
  - ◆ **receive**(*message*)
- If *P* and *Q* wish to communicate, they need to:
  - ◆ establish a *communication link* between them
  - ◆ exchange messages via send/receive
- Implementation of communication link
  - ◆ physical (e.g., shared memory, hardware bus)
  - ◆ logical (e.g., logical properties)

### Implementation Questions

- How are links established?
- Can a link be associated with more than two processes?
- How many links can there be between every pair of communicating processes?
- What is the capacity of a link?
- Is the size of a message that the link can accommodate fixed or variable?
- Is a link unidirectional or bi-directional?

### Direct Communication

- Processes must name each other explicitly:
  - ◆ **send**(*P*, *message*) – send a message to process *P*
  - ◆ **receive**(*Q*, *message*) – receive a message from process *Q*
- Properties of communication link
  - ◆ Links are established automatically.
  - ◆ A link is associated with exactly one pair of communicating processes.
  - ◆ Between each pair there exists exactly one link.
  - ◆ The link may be unidirectional, but is usually bi-directional.

### Indirect Communication

- Messages are directed and received from mailboxes (also referred to as ports).
  - ◆ Each mailbox has a unique id.
  - ◆ Processes can communicate only if they share a mailbox.
- Properties of communication link
  - ◆ Link established only if processes share a common mailbox
  - ◆ A link may be associated with many processes.
  - ◆ Each pair of processes may share several communication links.
  - ◆ Link may be unidirectional or bi-directional.

## Indirect Communication

- Operations
  - ✦ create a new mailbox
  - ✦ send and receive messages through mailbox
  - ✦ destroy a mailbox
- Primitives are defined as:
  - send**( $A, message$ ) – send a message to mailbox  $A$
  - receive**( $A, message$ ) – receive a message from mailbox  $A$

## Indirect Communication

- Mailbox sharing
  - ✦  $P_1, P_2,$  and  $P_3$  share mailbox  $A$ .
  - ✦  $P_1$  sends;  $P_2$  and  $P_3$  receive.
  - ✦ Who gets the message?
- Solutions
  - ✦ Allow a link to be associated with at most two processes.
  - ✦ Allow only one process at a time to execute a receive operation.
  - ✦ Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.

## Synchronization

- Message passing may be either blocking or non-blocking.
- **Blocking** is considered **synchronous**
- **Non-blocking** is considered **asynchronous**
- **send** and **receive** primitives may be either blocking or non-blocking.

## Buffering

- Queue of messages attached to the link; implemented in one of three ways.
  1. Zero capacity – 0 messages  
Sender must wait for receiver (rendezvous).
  2. Bounded capacity – finite length of  $n$  messages  
Sender must wait if link full.
  3. Unbounded capacity – infinite length  
Sender never waits.

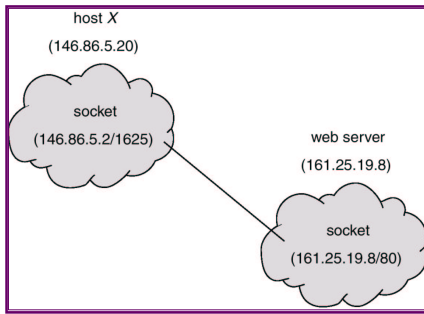
## Client-Server Communication

- Sockets
- Remote Procedure Calls
- Remote Method Invocation (Java)

## Sockets

- A socket is defined as an *endpoint for communication*.
- Concatenation of IP address and port
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- Communication consists between a pair of sockets.

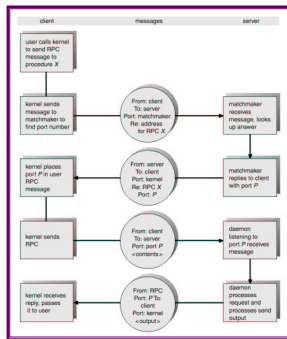
## Socket Communication



## Remote Procedure Calls

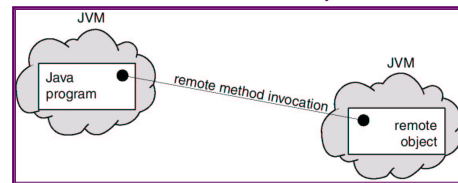
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems.
- Stubs** – client-side proxy for the actual procedure on the server.
- The client-side stub locates the server and *marshalls* the parameters.
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server.

## Execution of RPC



## Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs.
- RMI allows a Java program on one machine to invoke a method on a remote object.



## Marshalling Parameters

