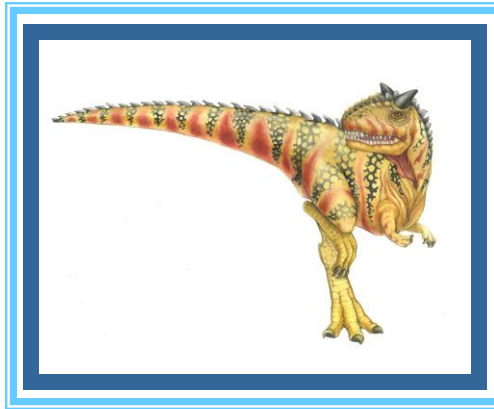


# Chapter 3: Processes

---





# Chapter 3: Processes

---

- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication





# Objectives

---

- ❑ To introduce the notion of a process -- a program in execution, which forms the basis of all computation
- ❑ To describe the various features of processes, including scheduling, creation and termination, and communication
- ❑ To explore interprocess communication using shared memory and message passing

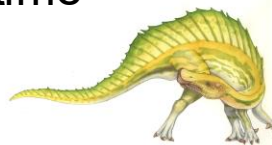




# Process Concept

---

- ❑ 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
- ❑ Multiple parts
  - ❑ The program code, also called **text section**
  - ❑ Current activity including **program counter**, processor registers
  - ❑ **Stack** containing temporary data
    - ▶ Function parameters, return addresses, local variables
  - ❑ **Data section** containing global variables
  - ❑ **Heap** containing memory dynamically allocated during run time





# Process Concept (Cont.)

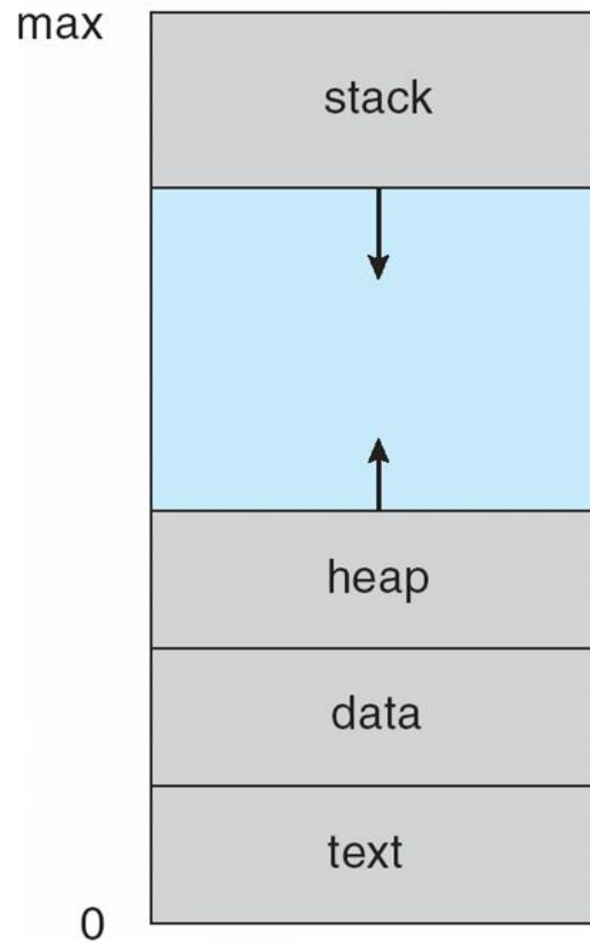
---

- Program is **passive** entity stored on disk (**executable file**), process is **active**
  - Program becomes process when executable file loaded into memory
- Execution of program started via GUI mouse clicks, command line entry of its name, etc
- One program can be several processes
  - Consider multiple users executing the same program





# Process in Memory



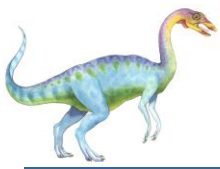


# Process State

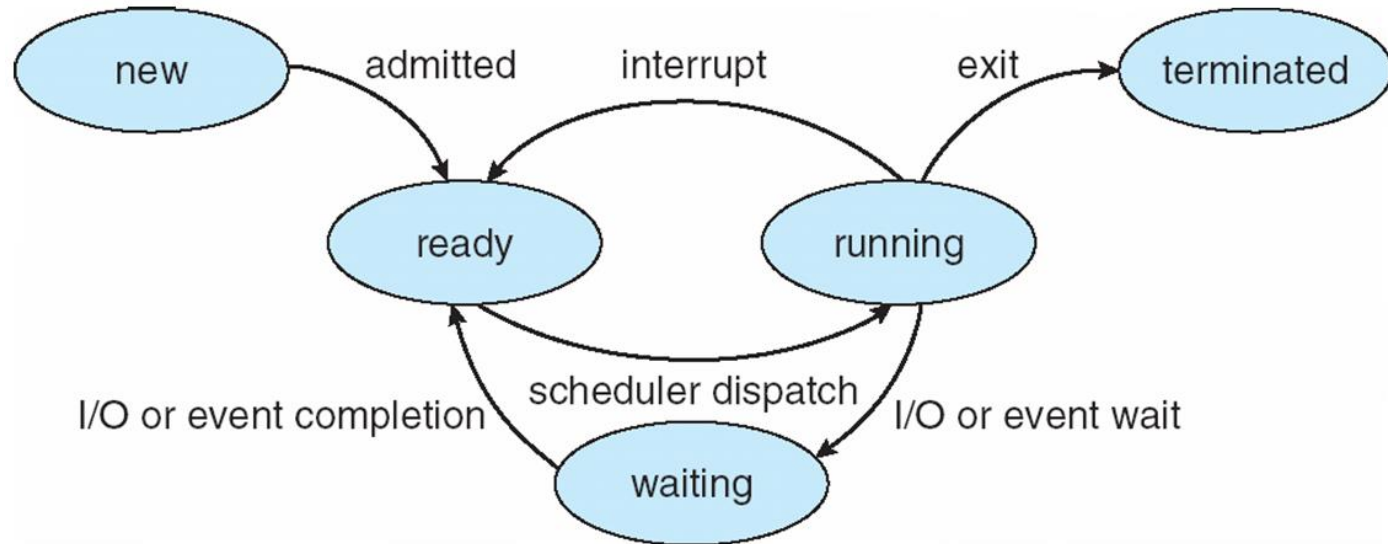
---

- 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 processor
  - **terminated**: The process has finished execution





# Diagram of Process State



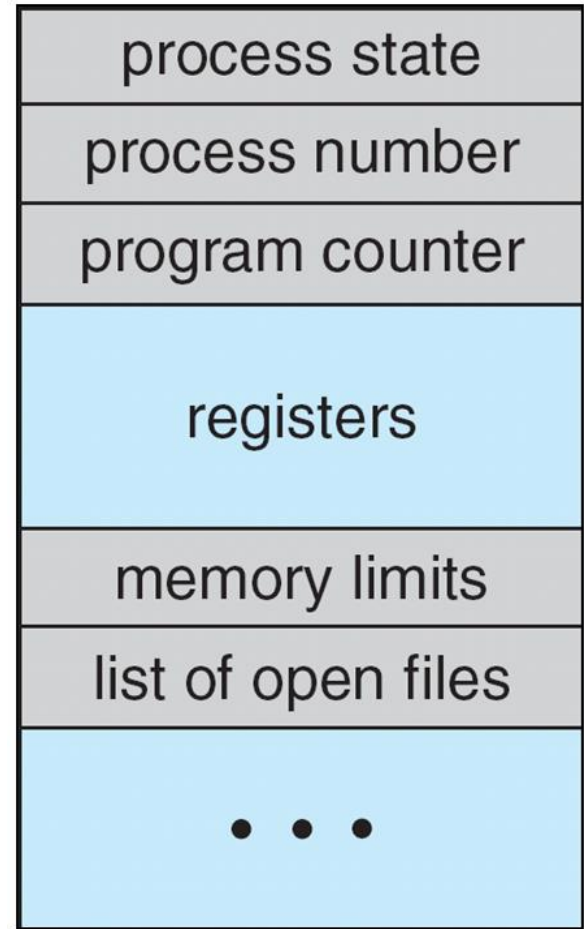


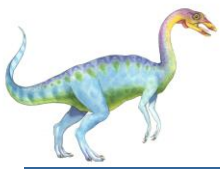


# Process Control Block (PCB)

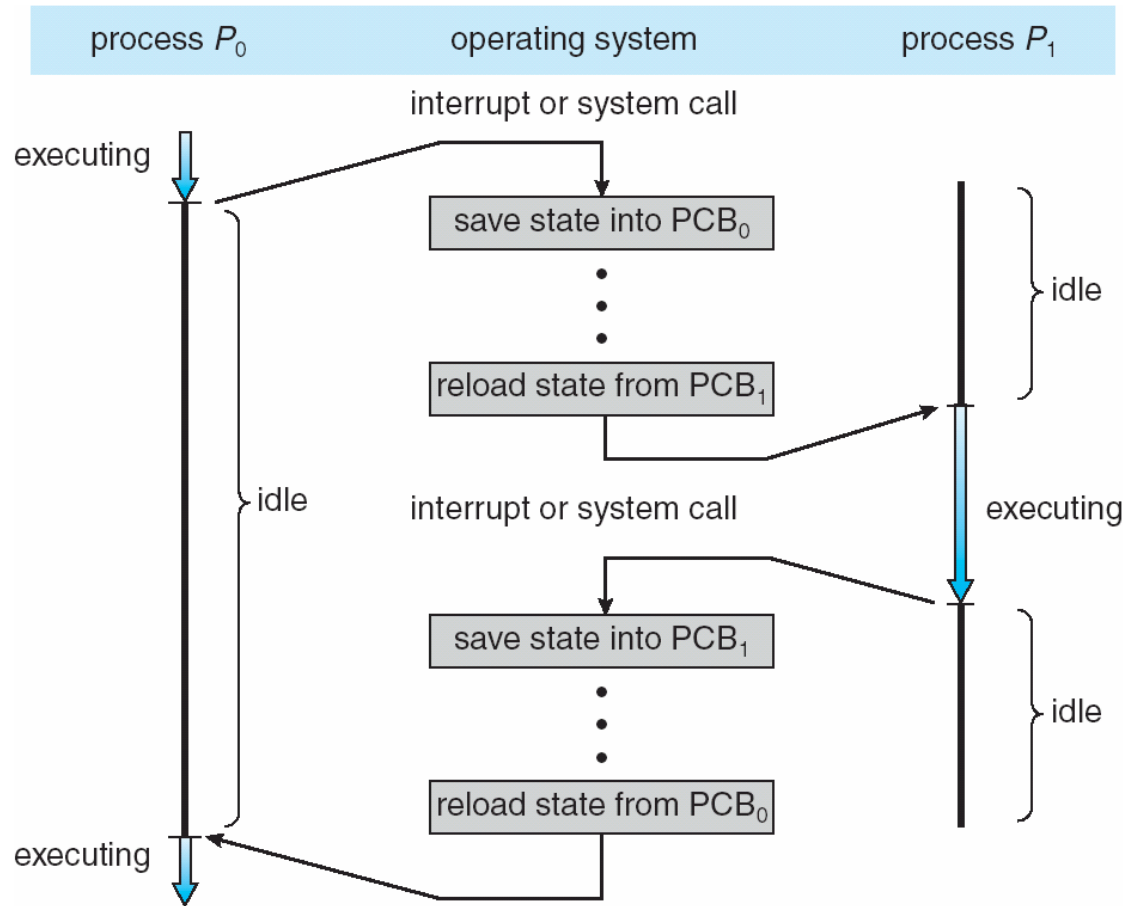
Information associated with each process  
(also called **task control block**)

- ❑ Process state – running, waiting, etc
- ❑ Program counter – location of instruction to next execute
- ❑ CPU registers – contents of all process-centric registers
- ❑ CPU scheduling information- priorities, scheduling queue pointers
- ❑ Memory-management information – memory allocated to the process
- ❑ Accounting information – CPU used, clock time elapsed since start, time limits
- ❑ I/O status information – I/O devices allocated to process, list of open files





# CPU Switch From Process to Process





# Threads

---

- ❑ So far, process has a single thread of execution
- ❑ Consider having multiple program counters per process
  - ❑ Multiple locations can execute at once
    - ▶ Multiple threads of control -> **threads**
- ❑ Must then have storage for thread details, multiple program counters in PCB





# Process Scheduling

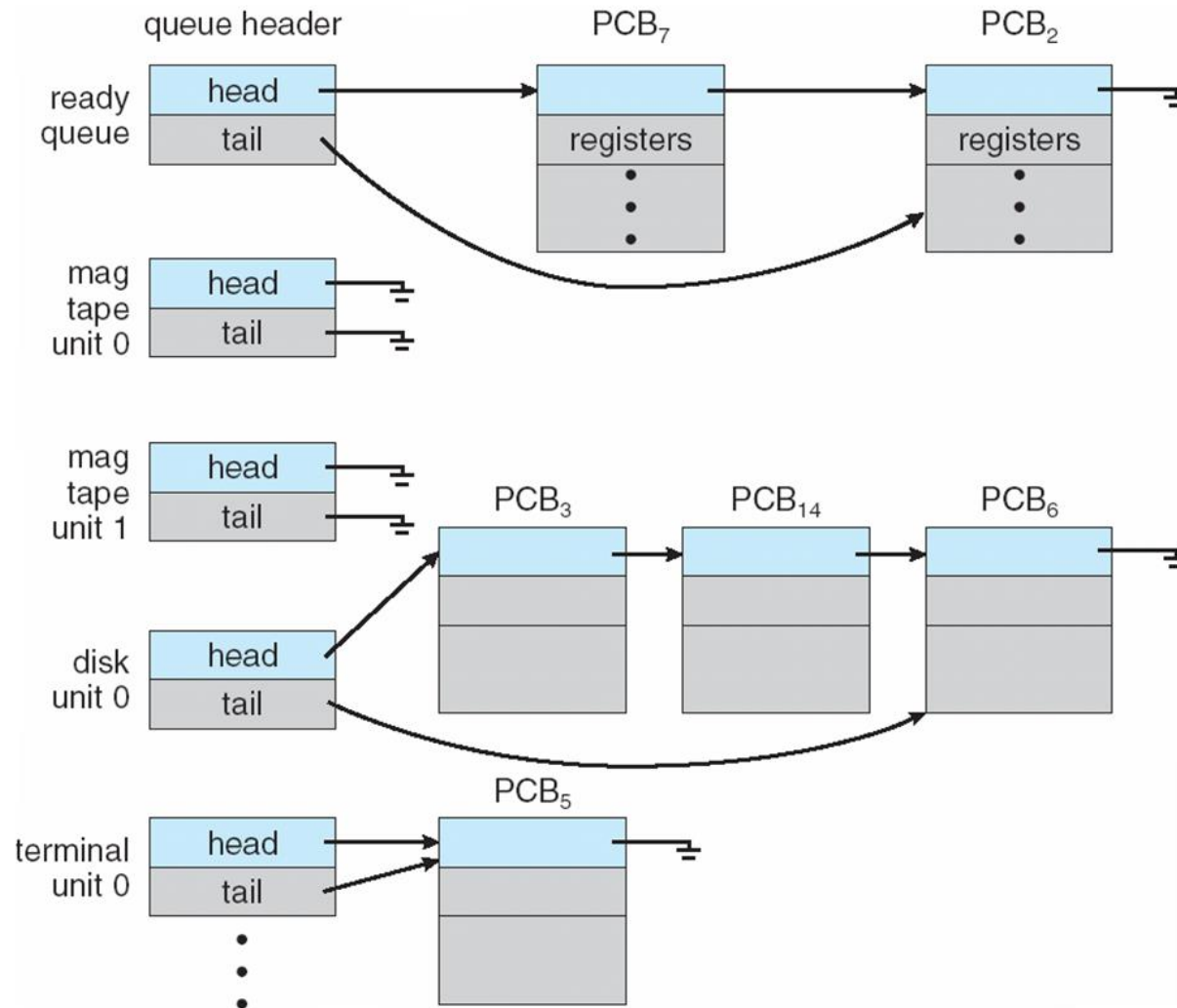
---

- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **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
  - Processes migrate among the various queues





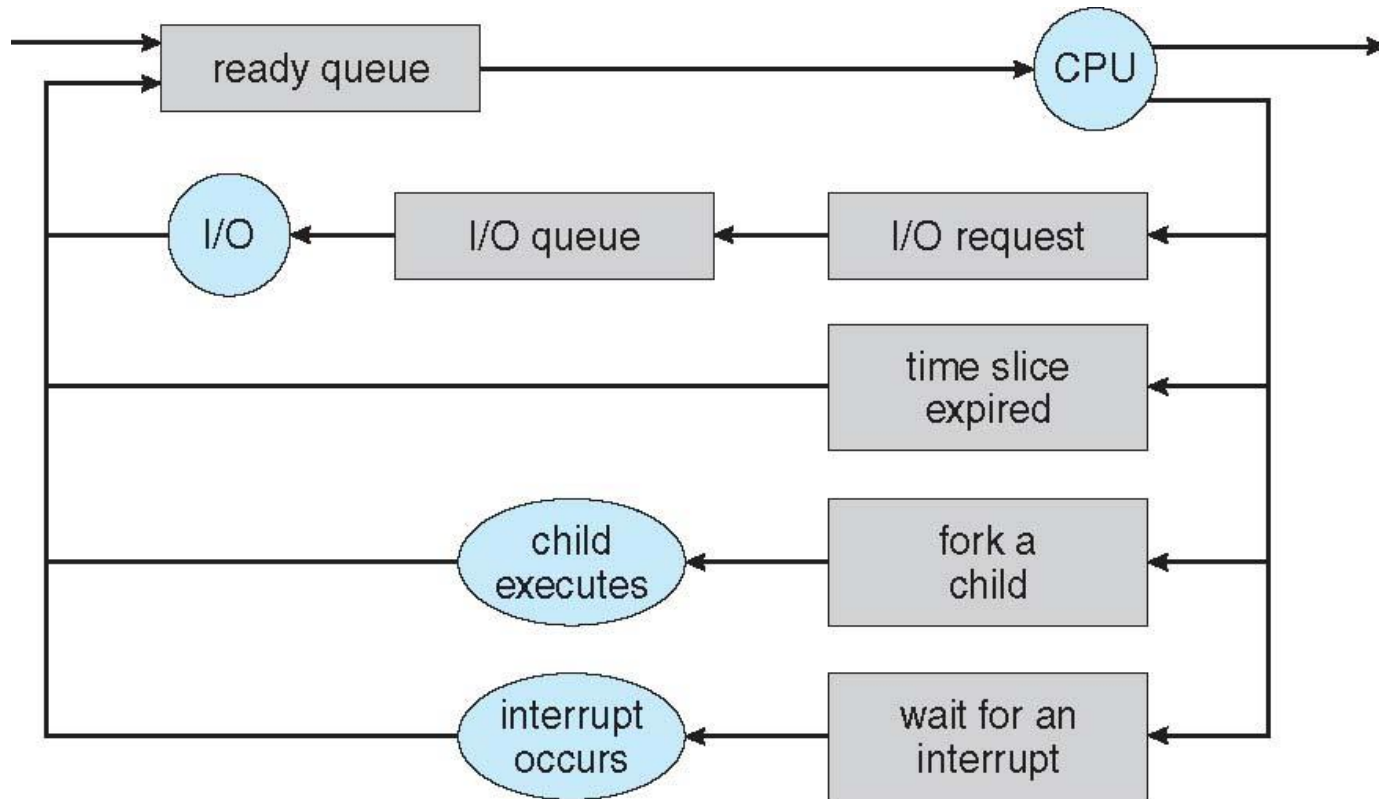
# Ready Queue And Various I/O Device Queues





# Representation of Process Scheduling

- **Queueing diagram** represents queues, resources, flows

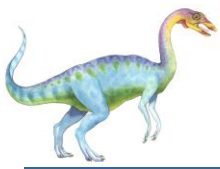




# Schedulers

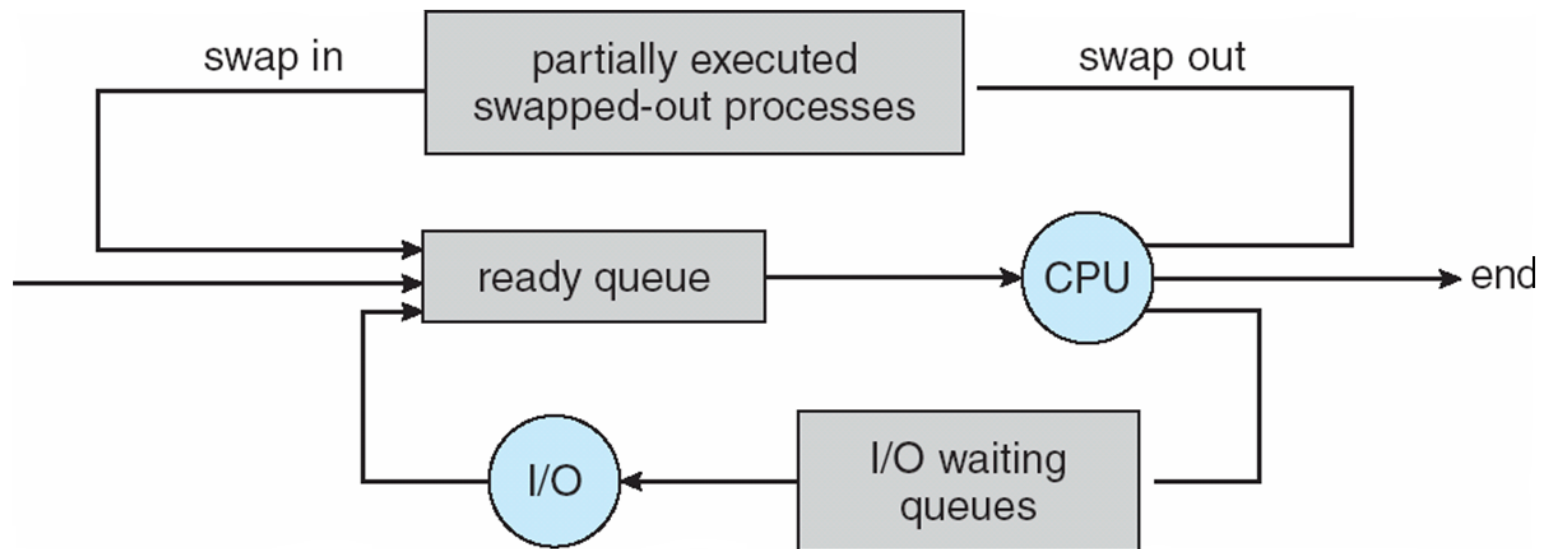
- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - Sometimes the only scheduler in a system
  - Short-term scheduler is invoked frequently (milliseconds)  $\Rightarrow$  (must be fast)
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  - Long-term scheduler is invoked infrequently (seconds, minutes)  $\Rightarrow$  (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
- Long-term scheduler strives for good ***process mix***





# Addition of Medium Term Scheduling

- **Medium-term scheduler** can be added if degree of multiple programming needs to decrease
  - Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**



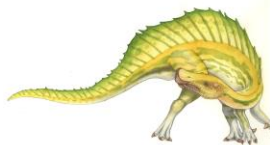




# Multitasking in Mobile Systems

---

- ❑ Some mobile systems (e.g., early version of iOS) allow only one process to run, others suspended
- ❑ user interface limits iOS provides for a
  - ❑ Single **foreground** process- controlled via user interface
  - ❑ Multiple **background** processes– in memory, running, but not on the display, and with limits
  - ❑ Limits include single, short task, receiving notification of events, specific long-running tasks like audio playback
- ❑ Android runs foreground and background, with fewer limits
  - ❑ Background process uses a **service** to perform tasks
  - ❑ Service can keep running even if background process is suspended
  - ❑ Service has no user interface, small memory use





# 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 via a **context switch**
- **Context** of a process represented in the PCB
- Context-switch time is overhead; the system does no useful work while switching
  - The more complex the OS and the PCB → the longer the context switch
- Time dependent on hardware support
  - Some hardware provides multiple sets of registers per CPU → multiple contexts loaded at once





# Operations on Processes

---

- System must provide mechanisms for:
  - process creation,
  - process termination,

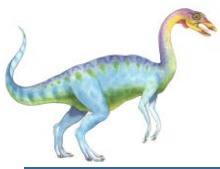




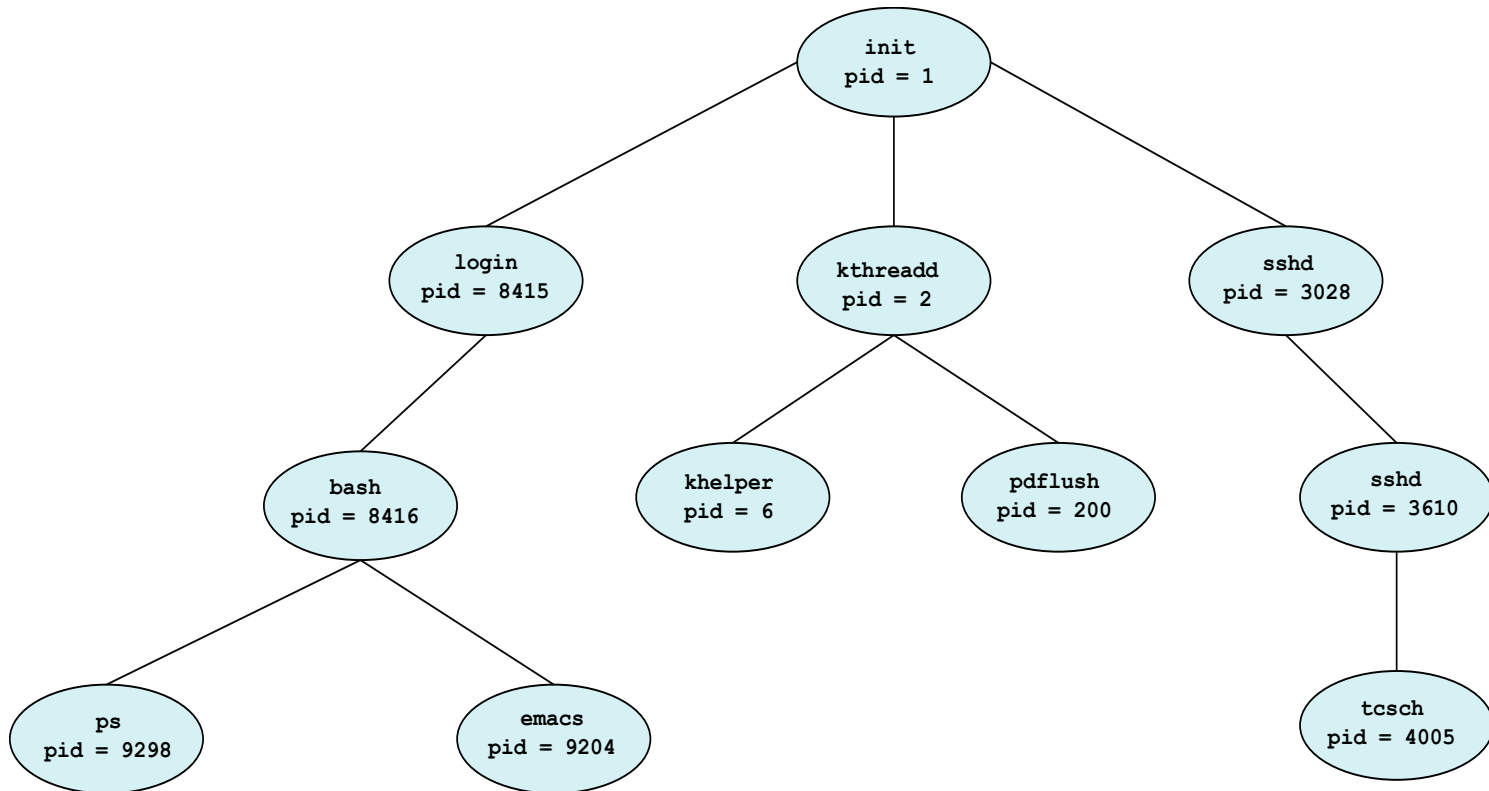
# Process Creation

- ❑ **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- ❑ Generally, process identified and managed via a **process identifier (pid)**
- ❑ Resource sharing options
  - ❑ Parent and children share all resources
  - ❑ Children share subset of parent's resources
  - ❑ Parent and child share no resources
- ❑ Execution options
  - ❑ Parent and children execute concurrently
  - ❑ Parent waits until children terminate





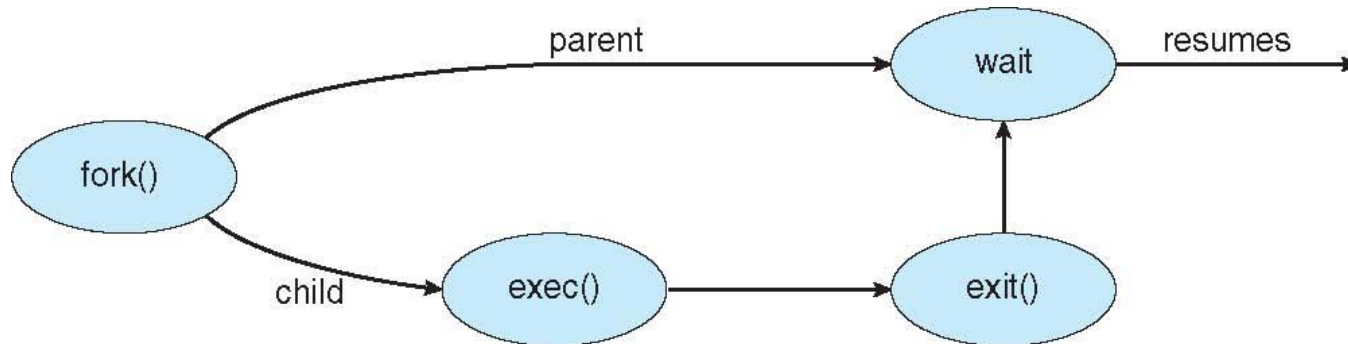
# A Tree of Processes in Linux





# 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





# Process Termination

---

- Process executes last statement and then asks the operating system to delete it using the **exit()** system call.
  - Returns status data from child to parent (via **wait()**)
  - Process' resources are deallocated by operating system
- Parent may terminate the execution of children processes using the **abort()** system call. Some reasons for doing so:
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - The parent is exiting and the operating systems does not allow a child to continue if its parent terminates





# Process Termination

- Some operating systems do not allow child to exist if its parent has terminated. If a process terminates, then all its children must also be terminated.
    - **cascading termination.** All children, grandchildren, etc. are terminated.
    - The termination is initiated by the operating system.
  - The parent process may wait for termination of a child process by using the `wait()` system call. The call returns status information and the pid of the terminated process
- ```
pid = wait(&status);
```
- If no parent waiting (did not invoke `wait()`) process is a **zombie**
  - If parent terminated without invoking `wait`, process is an **orphan**







# Interprocess Communication

---

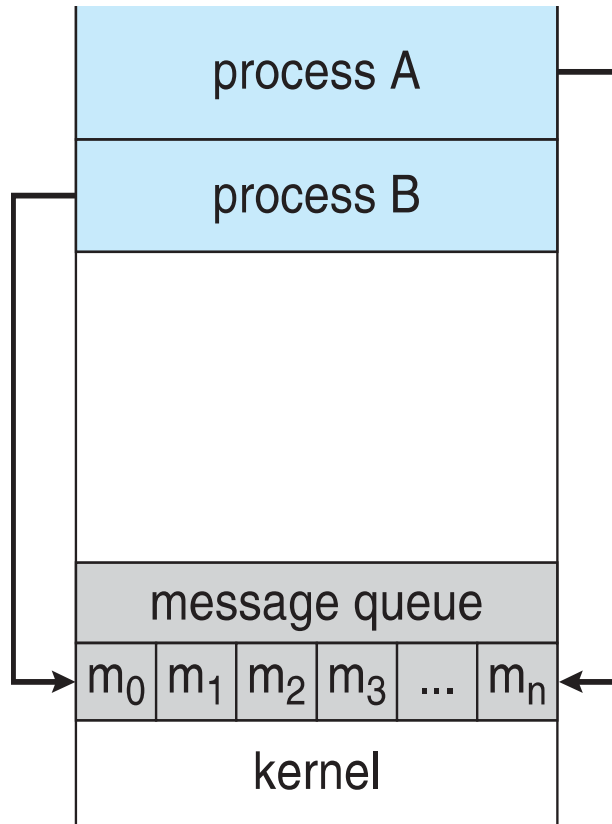
- ❑ Processes within a system may be *independent* or *cooperating*
- ❑ Cooperating process can affect or be affected by other processes, including sharing data
- ❑ Reasons for cooperating processes:
  - ❑ Information sharing
  - ❑ Computation speedup
  - ❑ Modularity
  - ❑ Convenience
- ❑ Cooperating processes need **interprocess communication (IPC)**
- ❑ Two models of IPC
  - ❑ **Shared memory**
  - ❑ **Message passing**



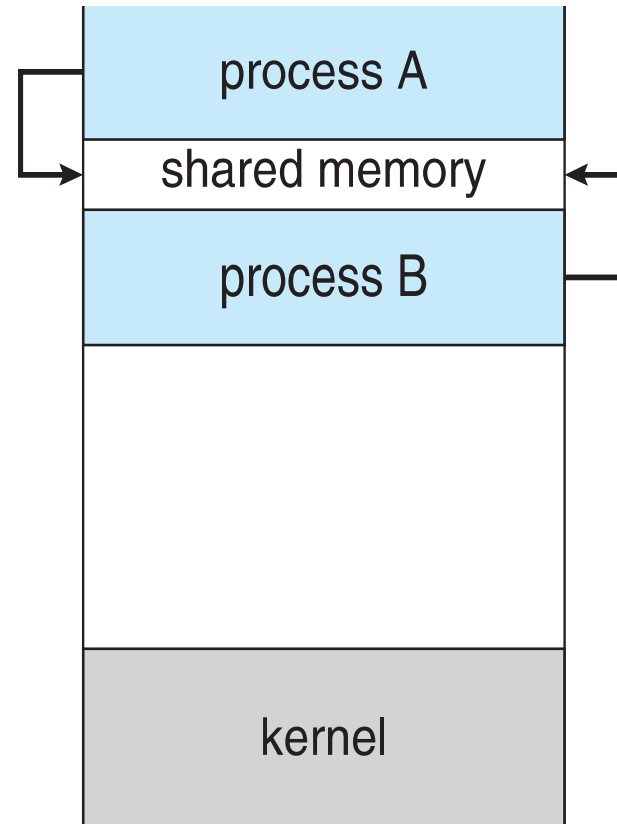


# Communications Models

(a) Message passing. (b) shared memory.



(a)



(b)





# 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





# Interprocess Communication – Shared Memory

---

- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the users processes not the operating system.
- Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.





# Interprocess Communication – Message Passing

---

- 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*)
  - **receive**(*message*)
- The *message* size is either fixed or variable
- PROS and CONS of both





## Message Passing (Cont.)

---

- If processes  $P$  and  $Q$  wish to communicate, they need to:
  - Establish a **communication link** between them
  - Exchange messages via send/receive
- Implementation issues:
  - 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?





# Message Passing (Cont.)

---

- Implementation of communication link
  - Physical:
    - ▶ Shared memory
    - ▶ Hardware bus
    - ▶ Network
  - Logical:
    - ▶ Direct or indirect
    - ▶ Synchronous or asynchronous
    - ▶ Automatic or explicit buffering







# 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 (port)
  - 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**
  - ❑ **Blocking send** -- the sender is blocked until the message is received
  - ❑ **Blocking receive** -- the receiver is blocked until a message is available
- ❑ **Non-blocking** is considered **asynchronous**
  - ❑ **Non-blocking send** -- the sender sends the message and continue
  - ❑ **Non-blocking receive** -- the receiver receives:
    - ❑ A valid message, or
    - ❑ Null message
- ❑ Different combinations possible
  - ❑ If both send and receive are blocking, we have a **rendezvous**





# Synchronization (Cont.)

---

## □ Producer-consumer becomes trivial

```
message next_produced;  
while (true) {  
    /* produce an item in next produced */  
    send(next_produced);  
}
```

```
message next_consumed;  
while (true) {  
    receive(next_consumed);  
  
    /* consume the item in next consumed */  
}
```





# Buffering

---

- Queue of messages attached to the link.
- implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.  
Sender must wait for receiver
  2. Bounded capacity – finite length of  $n$  messages  
Sender must wait if link full
  3. Unbounded capacity – infinite length  
Sender never waits



# End of Chapter 3

---

