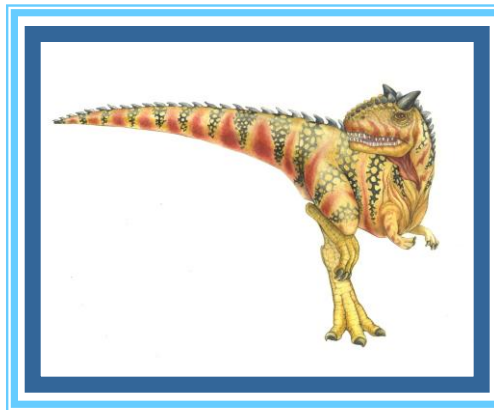


# Chapter 3: Processes

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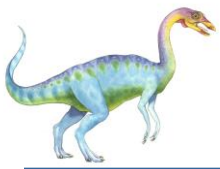


# Topics to be Covered

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Week 1	Introduction
Week 2	Operating System Structures
Week 3	Processes
Week 4	Threads
Week 5	Threads
Week 6	Synchronization
Week 7	Synchronization
Week 8	Midterm
Week 9	Classical Problems
Week 10	CPU Scheduling
Week 11	CPU Scheduling
Week 12	Deadlocks
Week 13	Memory Management
Week 14	Virtual Memory



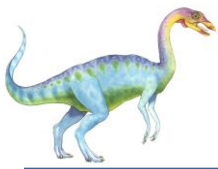


# Chapter 3: Processes

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- 3.1 Process Concept
- 3.2 Process Scheduling
- 3.3 Operations on Processes
- 3.4 Interprocess Communication
- 3.5 Examples of IPC Systems
- 3.6 Communication in Client-Server Systems





# Objectives

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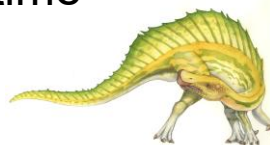
- To introduce the notion of a process -- a program in execution, which forms the basis of all computation
- To describe the various features of processes, including scheduling, creation and termination, and communication
- To explore interprocess communication using shared memory and message passing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



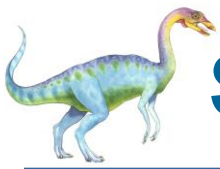


# Process Concept (Cont.)

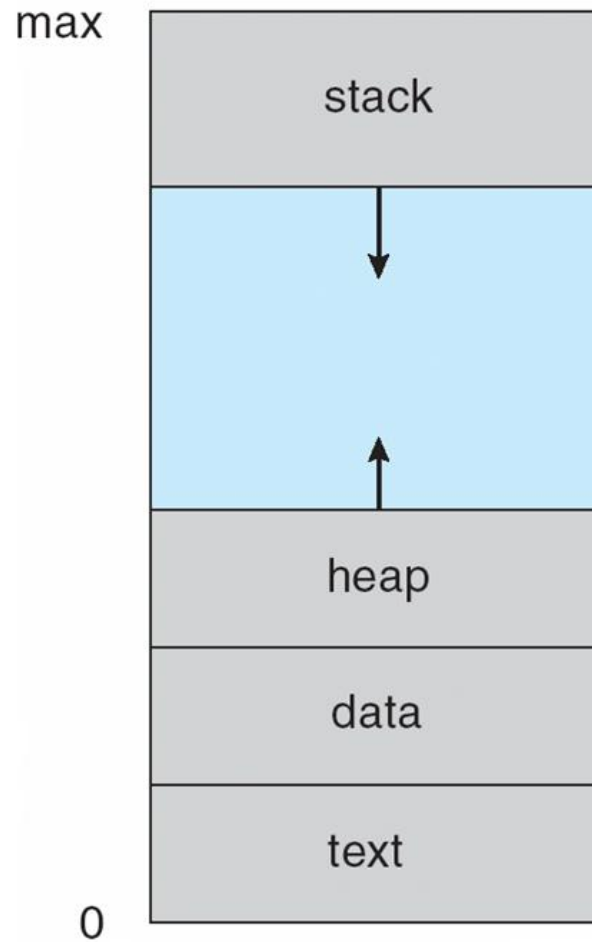
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- Program is **passive** entity stored on disk (**executable file**), process is **active**
  - Program becomes process when executable file loaded into memory
- Execution of program started via GUI mouse clicks, command line entry of its name, etc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





# Structure of a Process in Memory



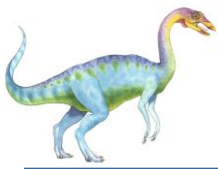


# Process States

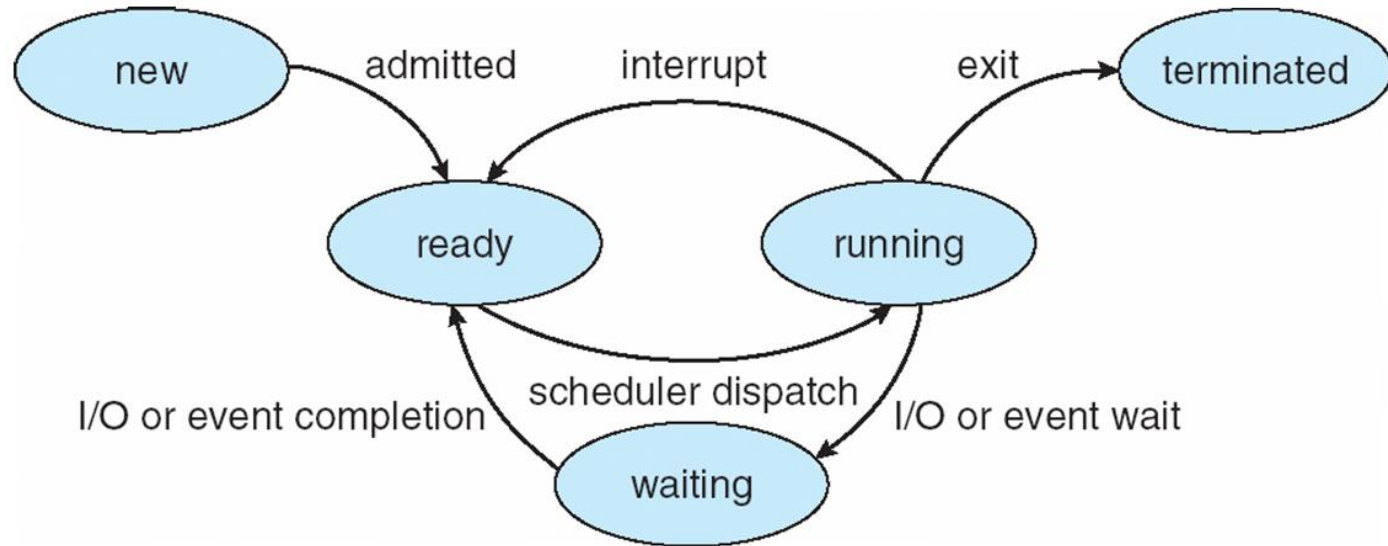
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- As a process executes, it changes **state**
  - **new**: The process is being created
  - **running**: Instructions are being executed
  - **waiting**: The process is waiting for some event to occur
  - **ready**: The process is waiting to be assigned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





# Diagram of Process State

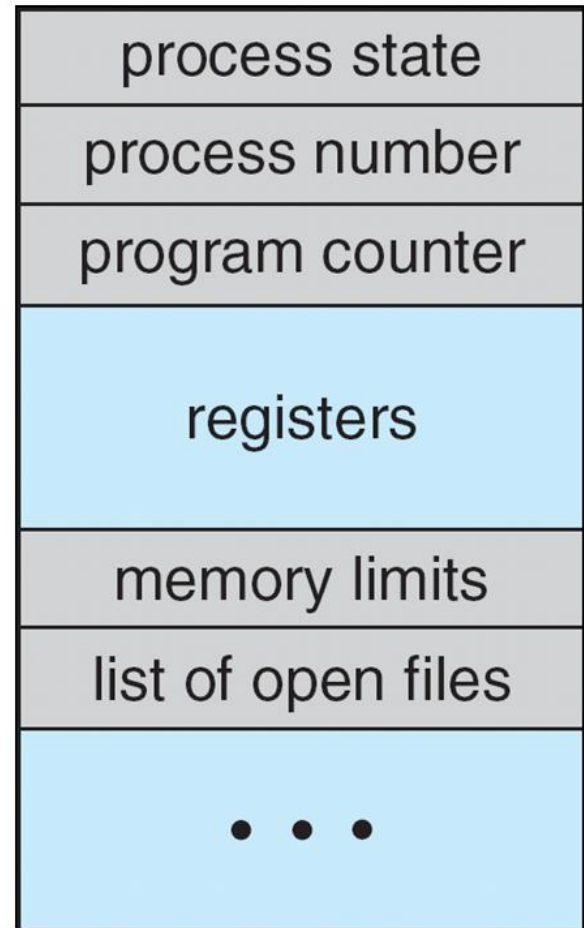


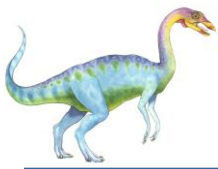


# Process Control Block (PCB)

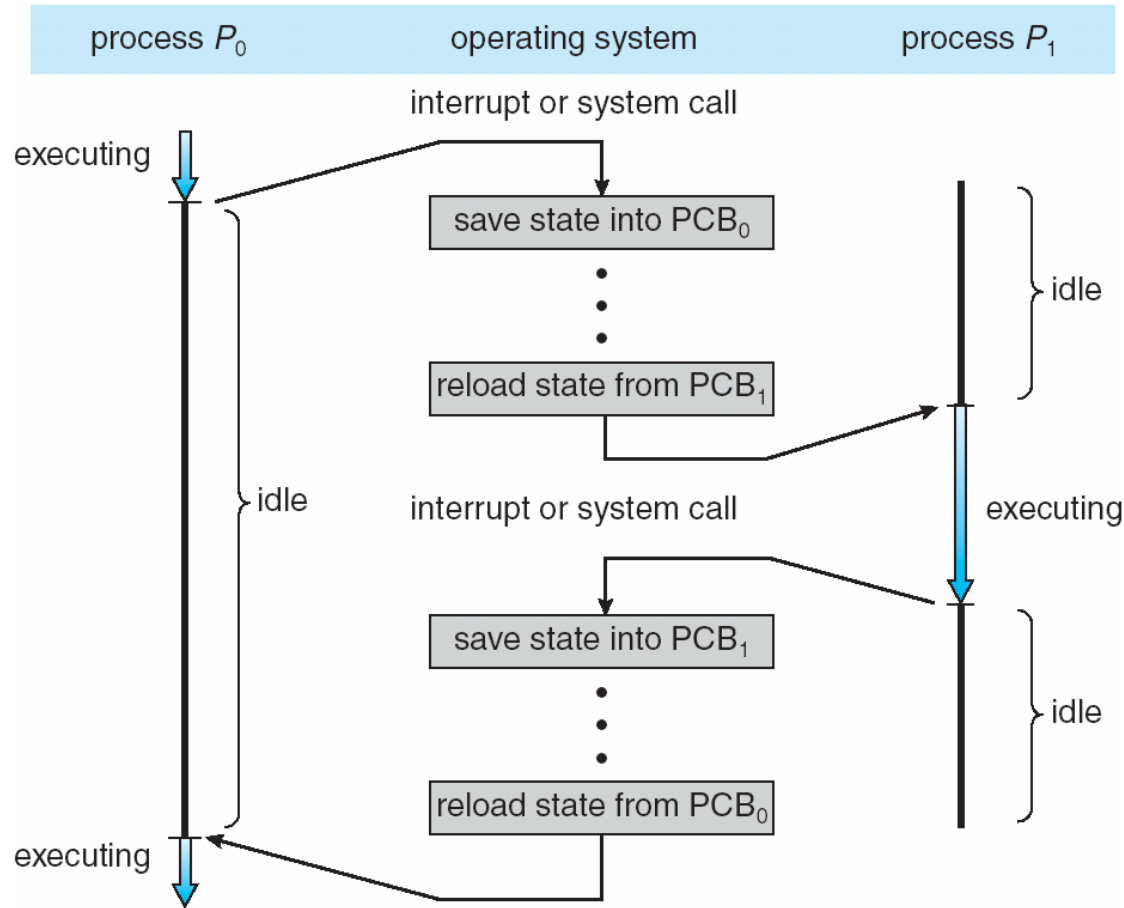
Information associated with each process  
(also called **task control block**)

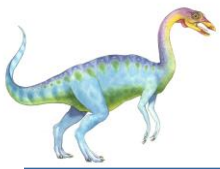
- ❑ Process state – running, waiting, etc
- ❑ Program counter – location of instruction to next execute
- ❑ CPU registers – contents of all process-centric registers
- ❑ CPU scheduling information- priorities, scheduling queue pointers
- ❑ Memory-management information – memory allocated to the process
- ❑ 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

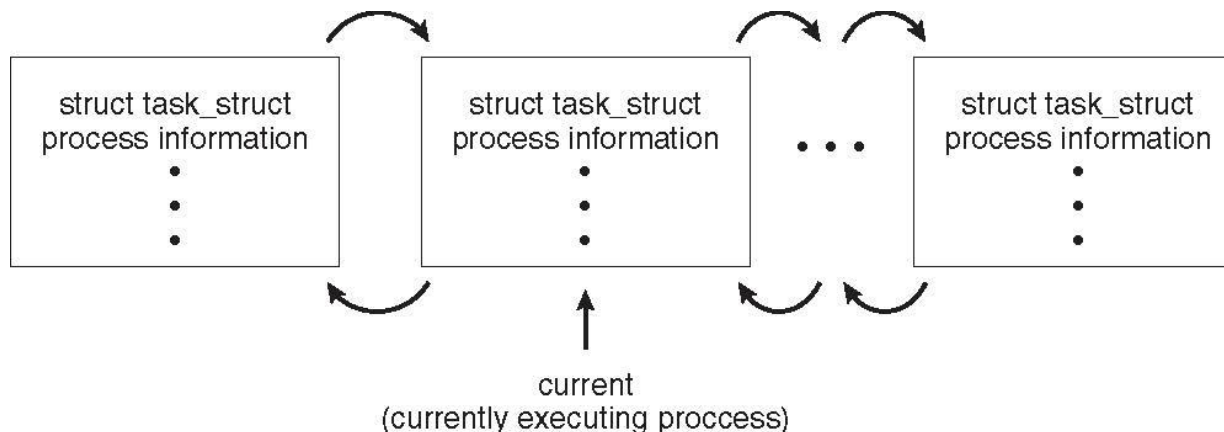




# Process Representation in Linux

Represented by the C structure `task_struct`

```
pid t_pid; /* process identifier */
long state; /* state of the process */
unsigned int time_slice /* scheduling information */
struct task_struct *parent; /* this process's parent */
struct list_head children; /* this process's children */
struct files_struct *files; /* list of open files */
struct mm_struct *mm; /* address space of this process */
```





# Process Scheduling

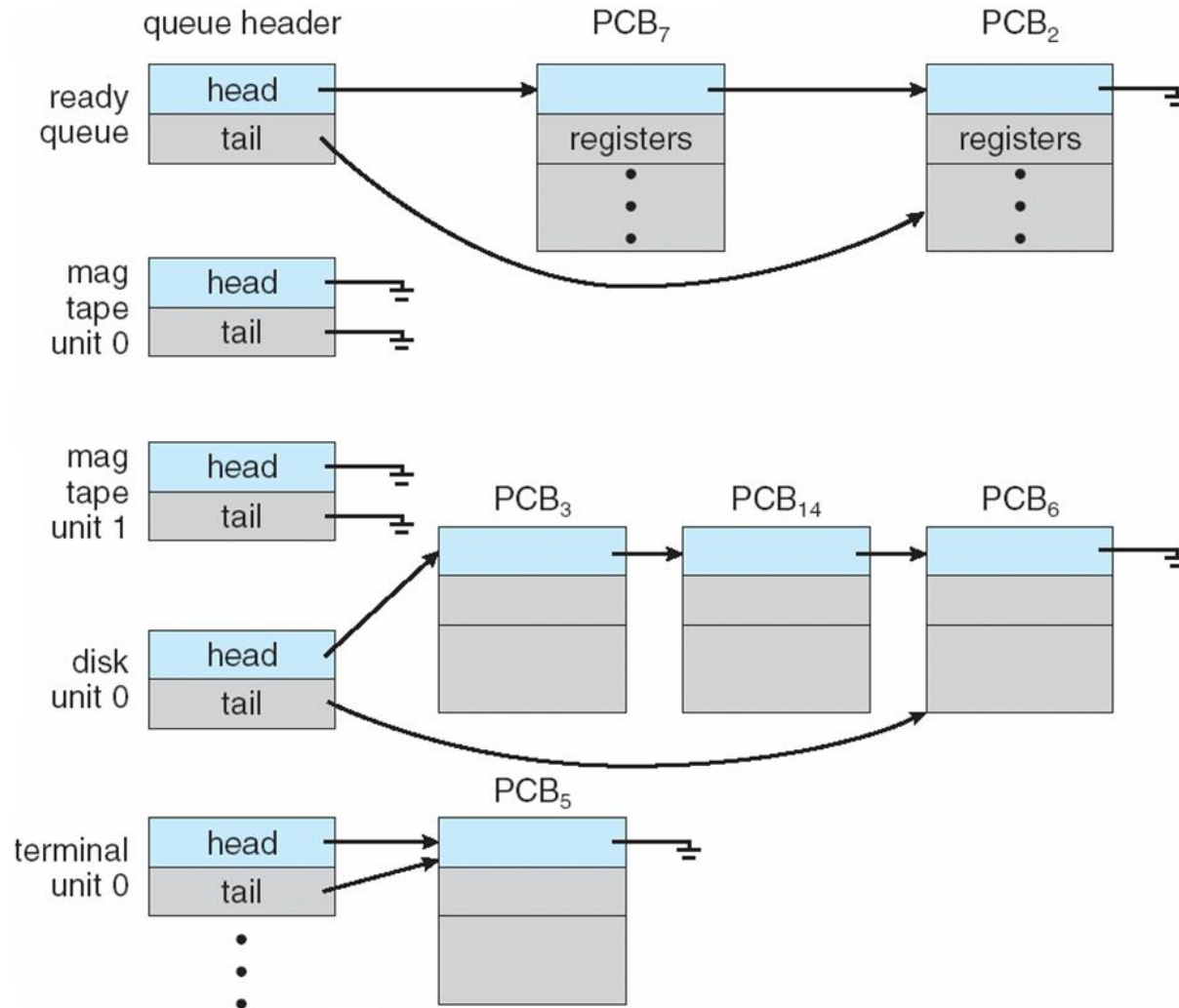
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- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the 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





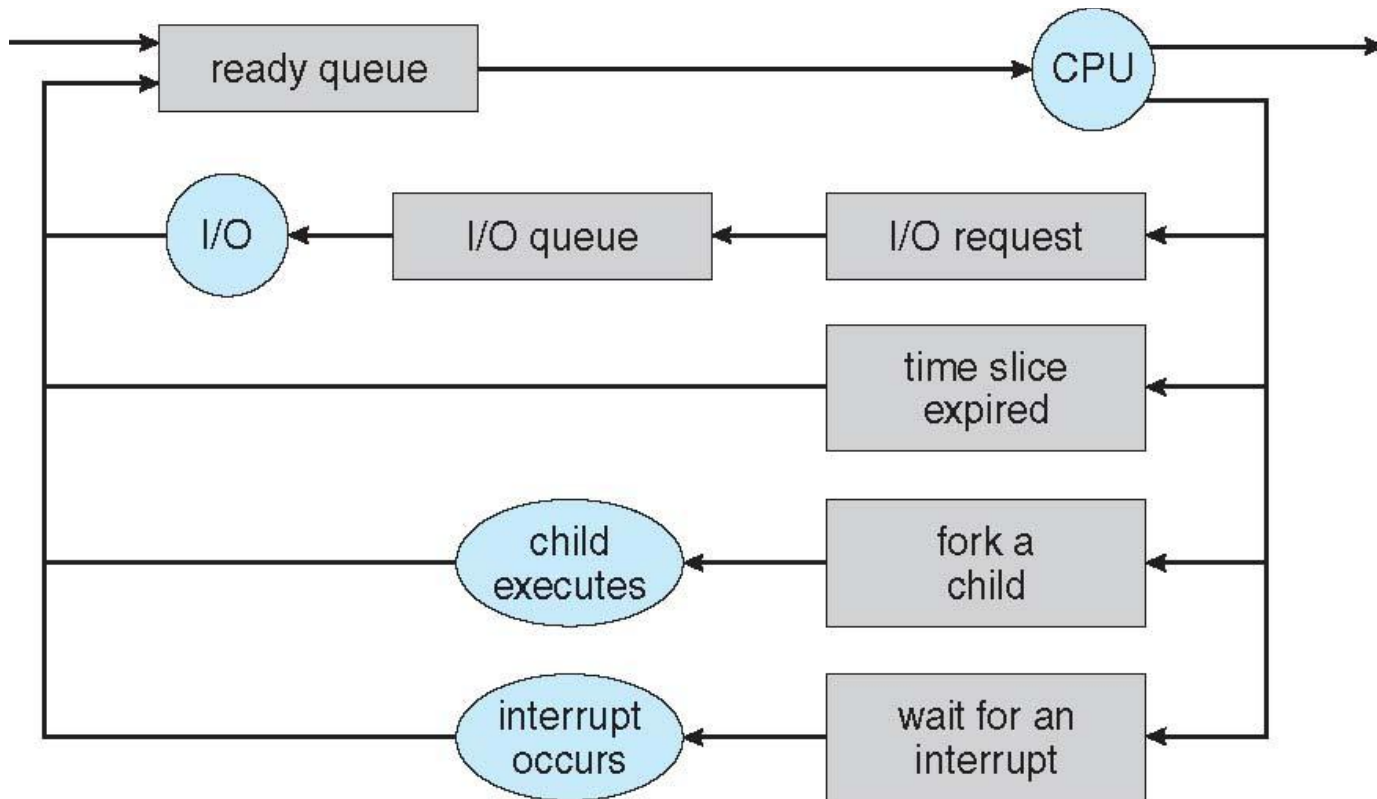
# Ready Queue And Various I/O Device Queues





# Representation of Process Scheduling

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





# Schedulers

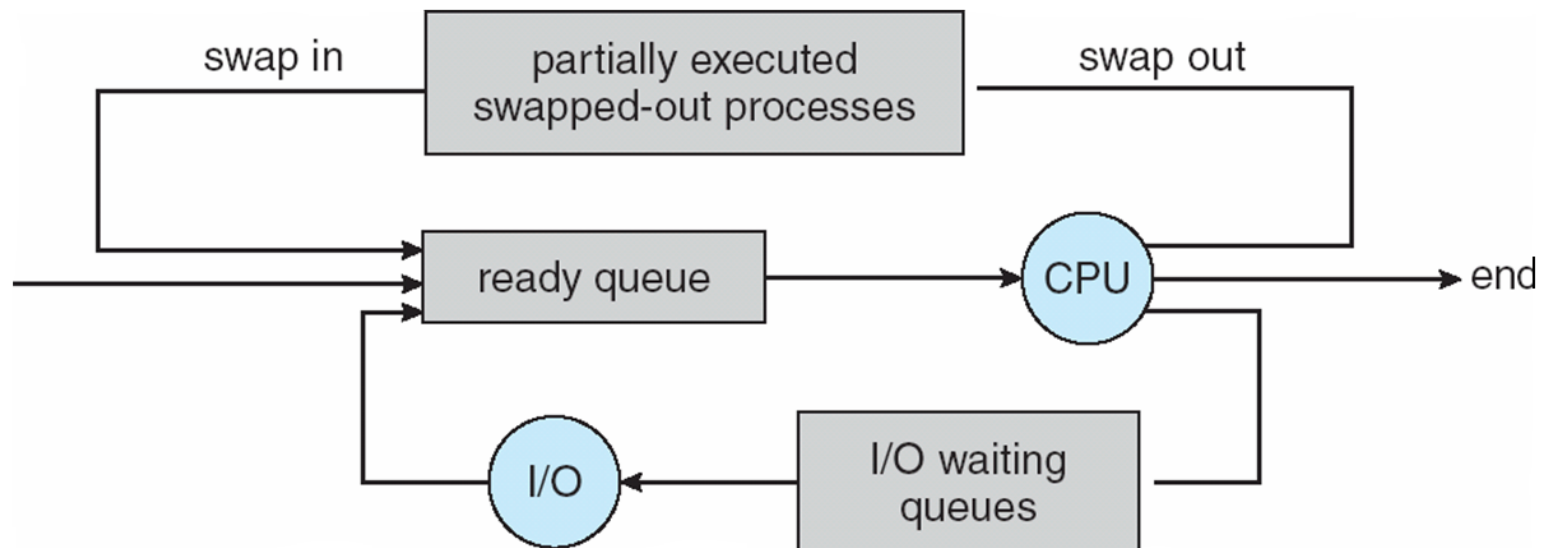
- ❑ **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - ❑ Sometimes the only scheduler in a system
  - ❑ Short-term scheduler is invoked frequently (milliseconds)  $\Rightarrow$  (must be fast), TDM
  - ❑ UNIX and Windows (self-adjusting nature of human users)
- ❑ **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**
    - ▶ **degree of multiprogramming** : the number of processes in memory.
- ❑ 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





# 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**





# 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 (state save, state restore)**
- **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





# Multitasking in Mobile Systems

- ❑ Some mobile systems (e.g., early version of iOS < 4) allow only one process to run, others suspended
- ❑ Due to screen real estate, 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





# Operations on Processes

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- System must provide mechanisms for:
  - process creation,
  - process termination,
  - and so on as detailed next





# Process Creation

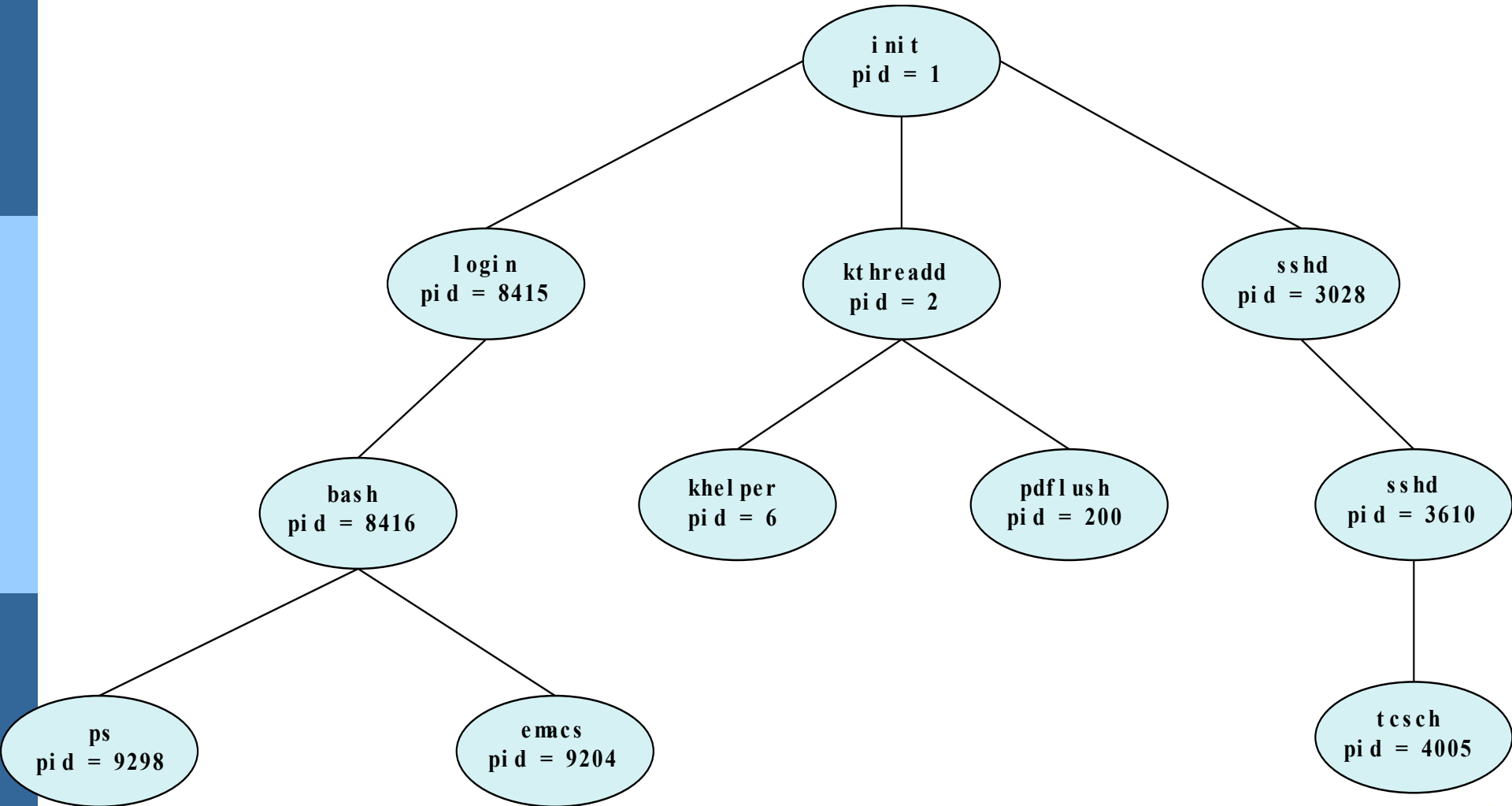
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- ❑ **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- ❑ Generally, process identified and managed via a **process identifier (pid)**
- ❑ Resource sharing options
  - ❑ Parent 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





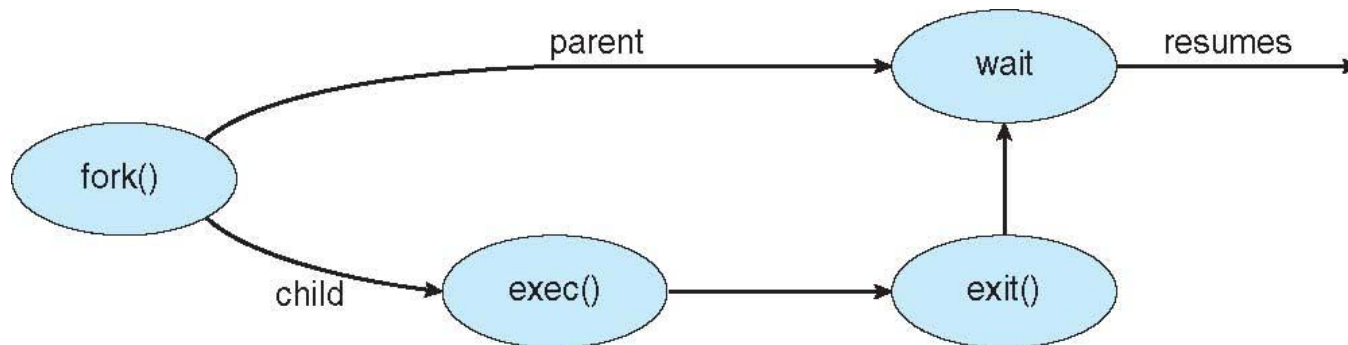
# A Tree of Processes in Linux





# 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





# C Program Forking Separate Process

```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

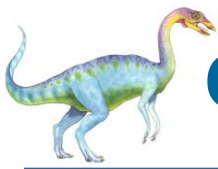
int main()
{
    pid_t pid;

    /* fork a child process */
    pid = fork();

    if (pid < 0) { /* error occurred */
        fprintf(stderr, "Fork Failed");
        return 1;
    }
    else if (pid == 0) { /* child process */
        execlp("/bin/ls", "ls", NULL);
    }
    else { /* parent process */
        /* parent will wait for the child to complete */
        wait(NULL);
        printf("Child Complete");
    }

    return 0;
}
```





# Creating a Separate Process via Windows API

```
#include <stdio.h>
#include <windows.h>

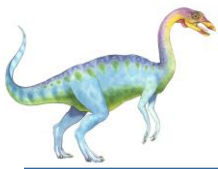
int main(VOID)
{
    STARTUPINFO si;
    PROCESS_INFORMATION pi;

    /* allocate memory */
    ZeroMemory(&si, sizeof(si));
    si.cb = sizeof(si);
    ZeroMemory(&pi, sizeof(pi));

    /* create child process */
    if (!CreateProcess(NULL, /* use command line */
        "C:\\WINDOWS\\system32\\mspaint.exe", /* command */
        NULL, /* don't inherit process handle */
        NULL, /* don't inherit thread handle */
        FALSE, /* disable handle inheritance */
        0, /* no creation flags */
        NULL, /* use parent's environment block */
        NULL, /* use parent's existing directory */
        &si,
        &pi))
    {
        fprintf(stderr, "Create Process Failed");
        return -1;
    }
    /* parent will wait for the child to complete */
    WaitForSingleObject(pi.hProcess, INFINITE);
    printf("Child Complete");

    /* close handles */
    CloseHandle(pi.hProcess);
    CloseHandle(pi.hThread);
}
```





# 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**
  - A process that has terminated, but whose parent has not yet called `wait()`, is known as a **zombie** process
- If parent terminated without invoking `wait`, process is an **orphan**
  - a parent did not invoke `wait()` and instead terminated, thereby leaving its child processes as **orphans**

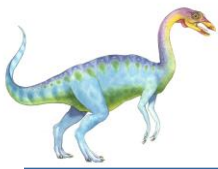




# Multiprocess Architecture – Chrome Browser

- Many web browsers ran as single process (some still do)
  - If one web site causes trouble, entire browser can hang or crash
- Google Chrome Browser is multiprocess with 3 different types of processes:
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    - ▶ Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  - **Plug-in** process for each type of plug-in





# 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**

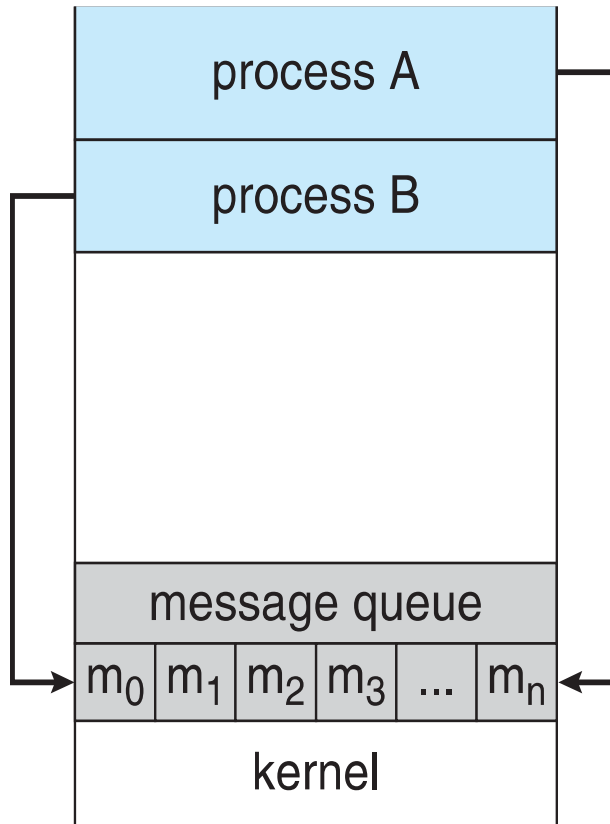




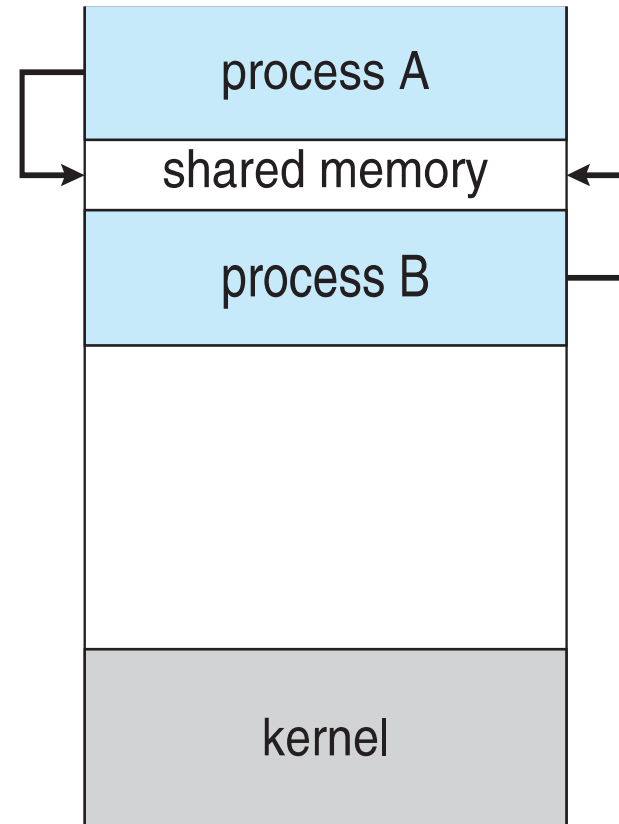
# Communications Models

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

message-passing systems are slow since they typically implemented using system calls and thus require the more **time-consuming task of kernel intervention.**



(a)



(b)

Shared memory can be faster than message passing. Shared memory suffers from **cache coherency** issues, which arise because shared data migrate among the several caches



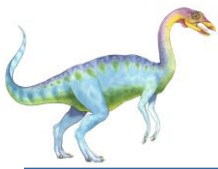


# Cooperating Processes

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- **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;

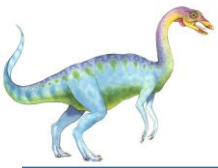
item buffer[BUFFER_SIZE];
int in = 0; // points the next free position
int out = 0; // points the first full position
```

## □ Solution is correct, but can only use BUFFER\_SIZE-1 elements

The buffer is empty when **in == out;**

The buffer is full when **((in + 1) % BUFFER\_SIZE) == out**





# Bounded-Buffer – Producer

---

```
item next_produced;
while (true) {
    /* produce an item in next produced */
    while (((in + 1) % BUFFER_SIZE) == out)
        ; /* do nothing */
    buffer[in] = next_produced;
    in = (in + 1) % BUFFER_SIZE;
}
```





# Bounded Buffer – Consumer

---

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

    /* consume the item in next consumed */
}
```

