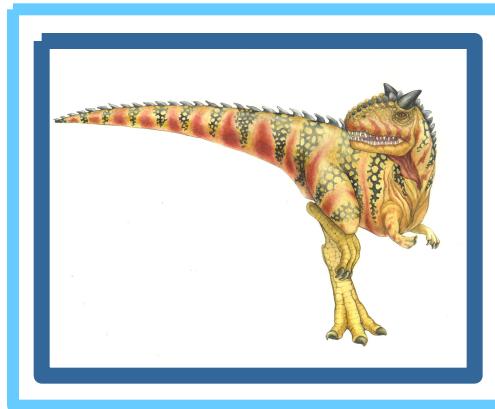


# Chapter 3: Processes



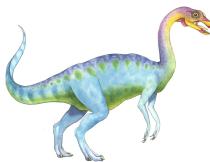


# Chapter 3: Processes

---

- n Process Concept
- n Process Scheduling
- n Operations on Processes
- n Interprocess Communication
- n Examples of IPC Systems
- n Communication in Client-Server Systems





# Objectives

---

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





# Process Concept

- n An operating system executes a variety of programs:
  - | Batch system – **jobs**
  - | Time-shared systems – **user programs** or **tasks**
- n Textbook uses the terms **job** and **process** almost interchangeably
- n **Process** – a program in execution; process execution must progress in sequential fashion
- n 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.)

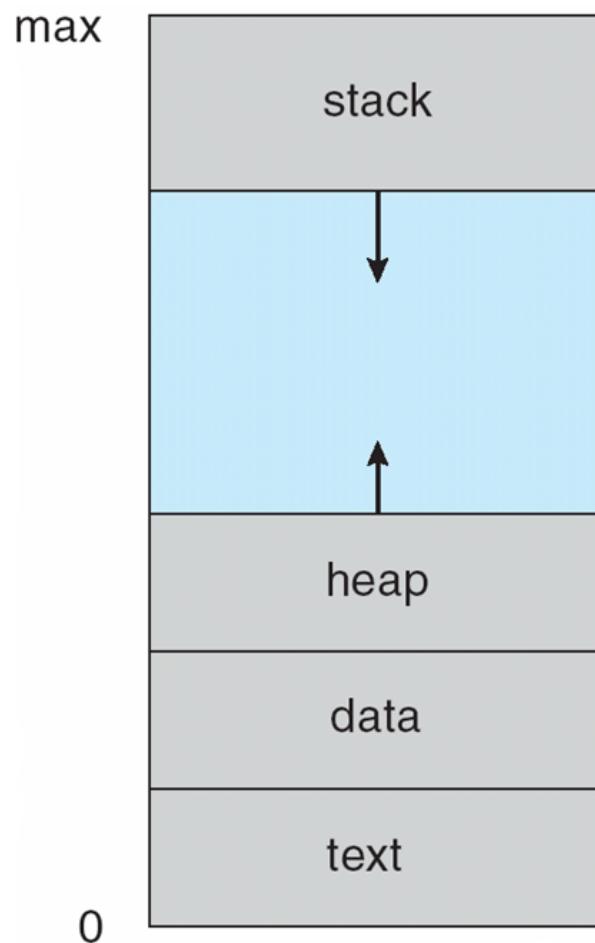
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- n Program is **passive** entity stored on disk (**executable file**), process is **active**
  - | Program becomes process when executable file loaded into memory
- n Execution of program started via GUI mouse clicks, command line entry of its name,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





# Process in Memory





# Process State

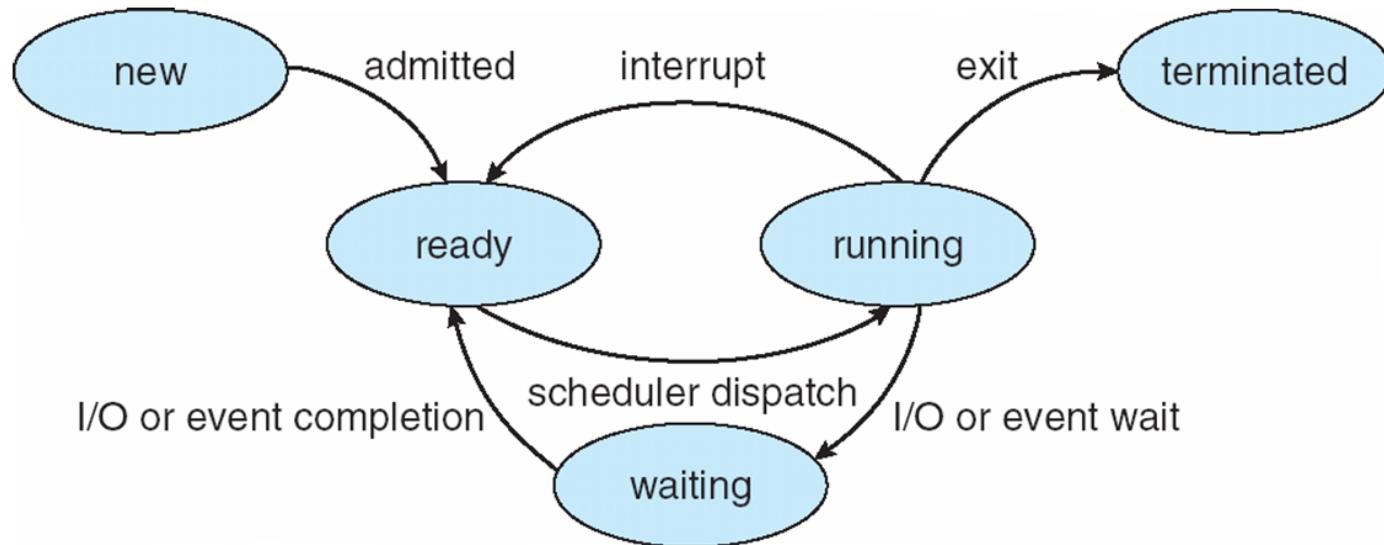
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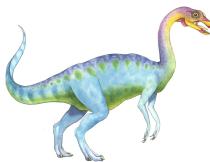
- n As a process executes, it changes **state**
  - | **new**: The process is being created
  - | **running**: Instructions are being executed
  - | **waiting**: The process is waiting for some event to occur
  - | **ready**: The process is waiting to be assigned to a processor
  - | **terminated**: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





# Diagram of Process State

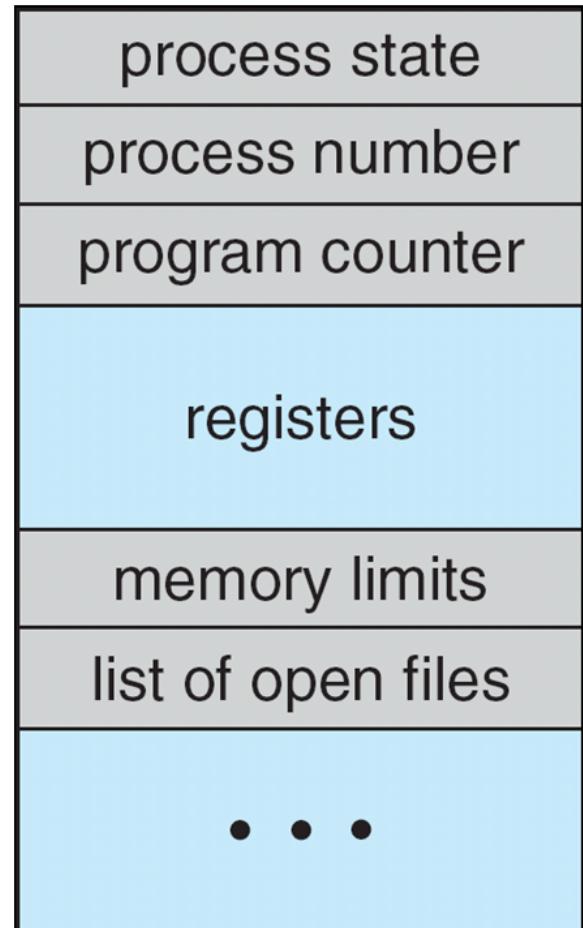




# Process Control Block (PCB)

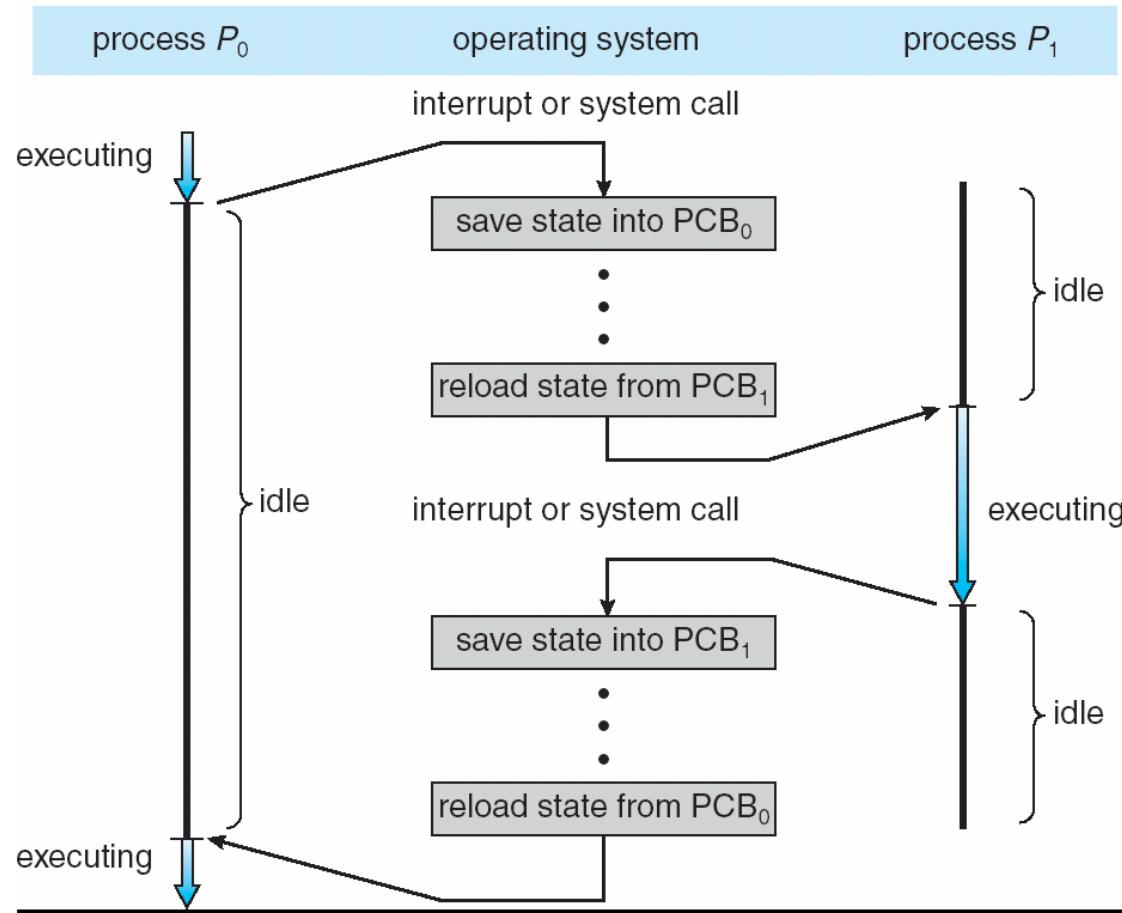
Information associated with each process  
(also called **task control block**)

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





# CPU Switch From Process to Process





# Threads

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

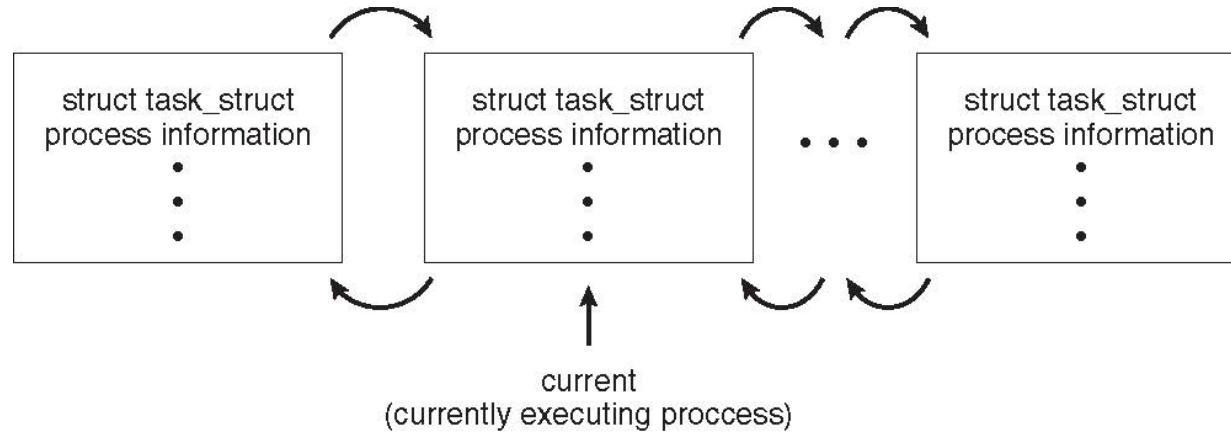




# Process Representation in Linux

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 */
```





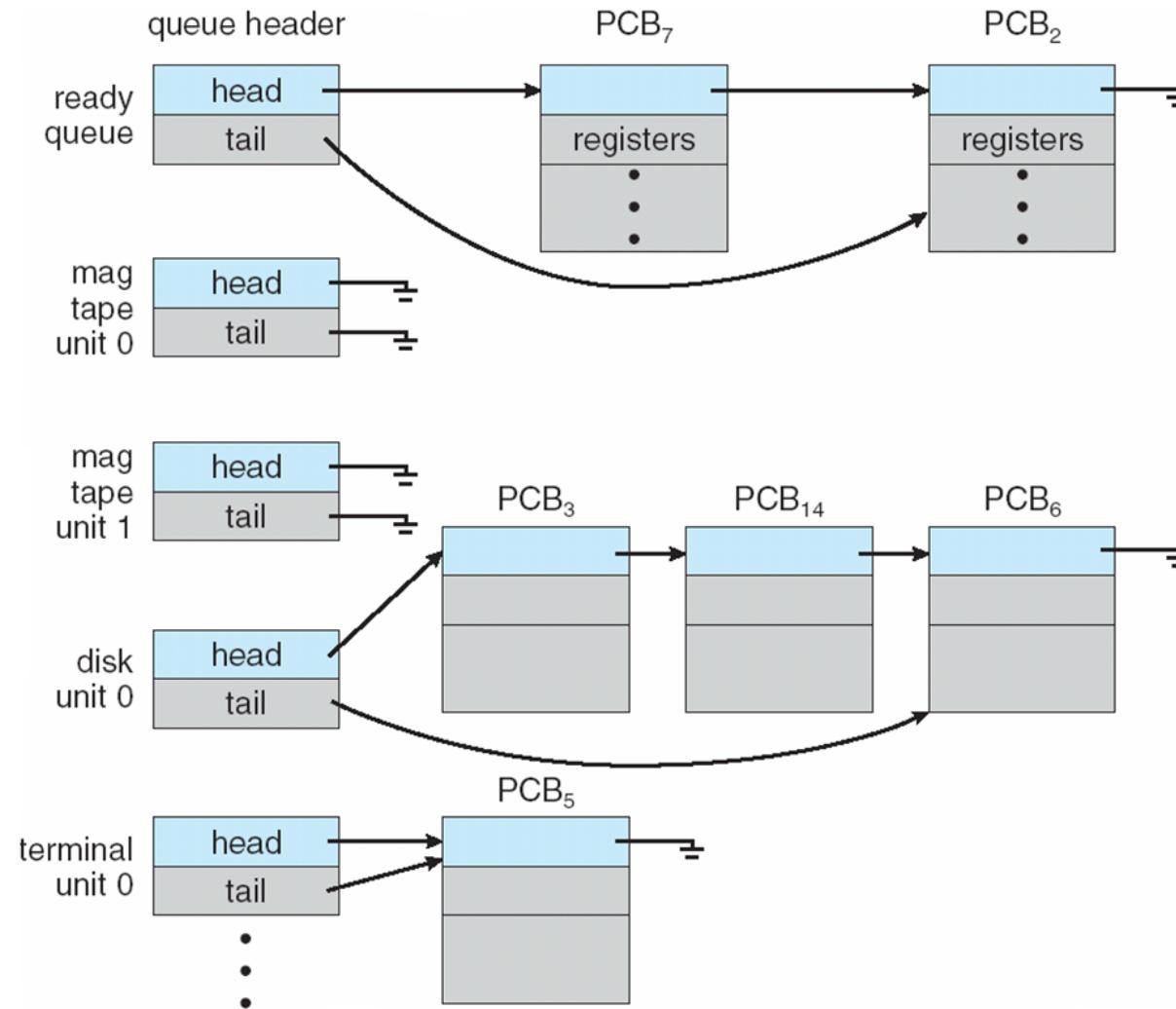
# Process Scheduling

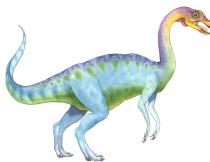
- n Maximize CPU use, quickly switch processes onto CPU for time sharing
- n **Process scheduler** selects among available processes for next execution on CPU
- n Maintains **scheduling queues** of processes
  - | **Job queue** – set of all processes in the system
  - | **Ready queue** – set of all processes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





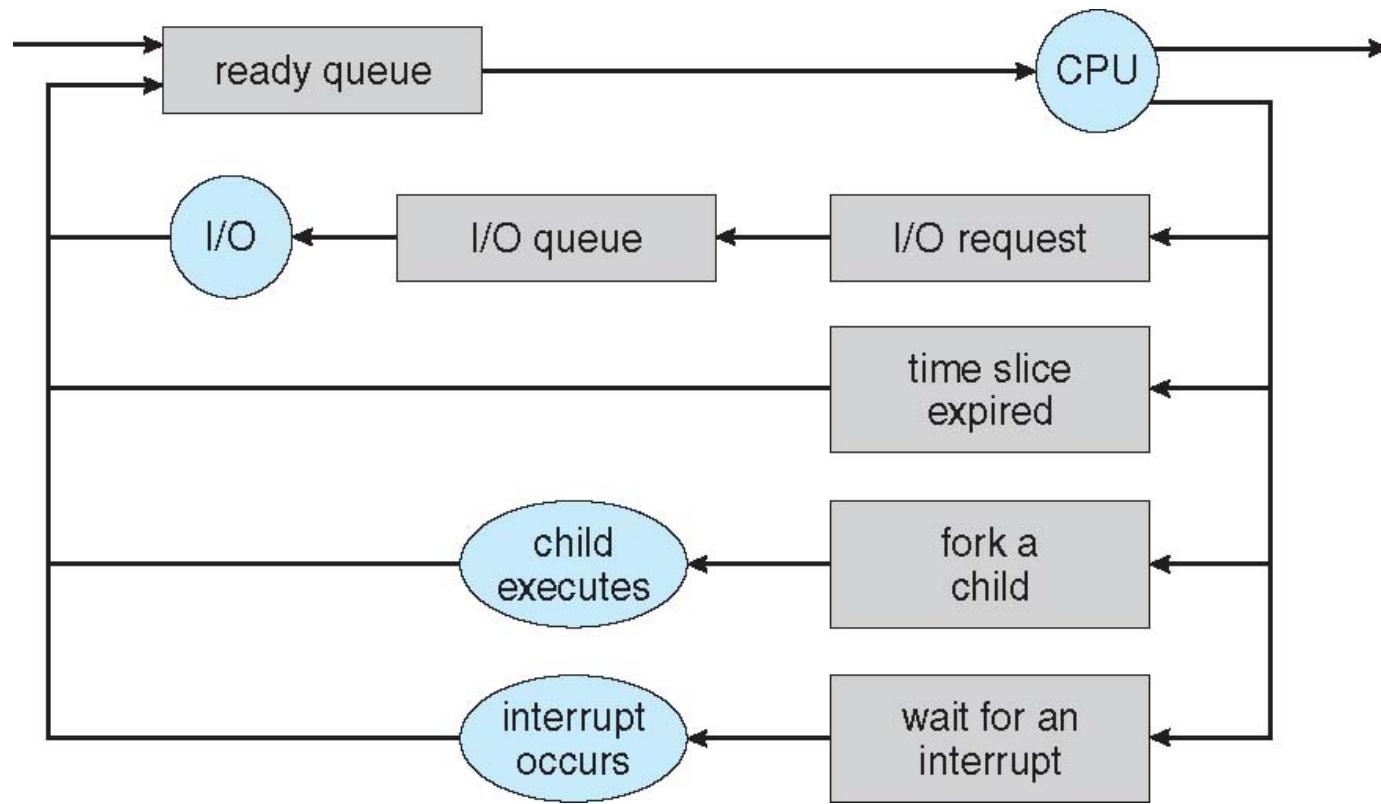
# Ready Queue And Various I/O Device Queues

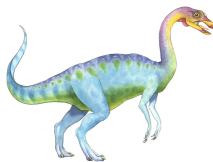




# Representation of Process Scheduling

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





# Schedulers

---

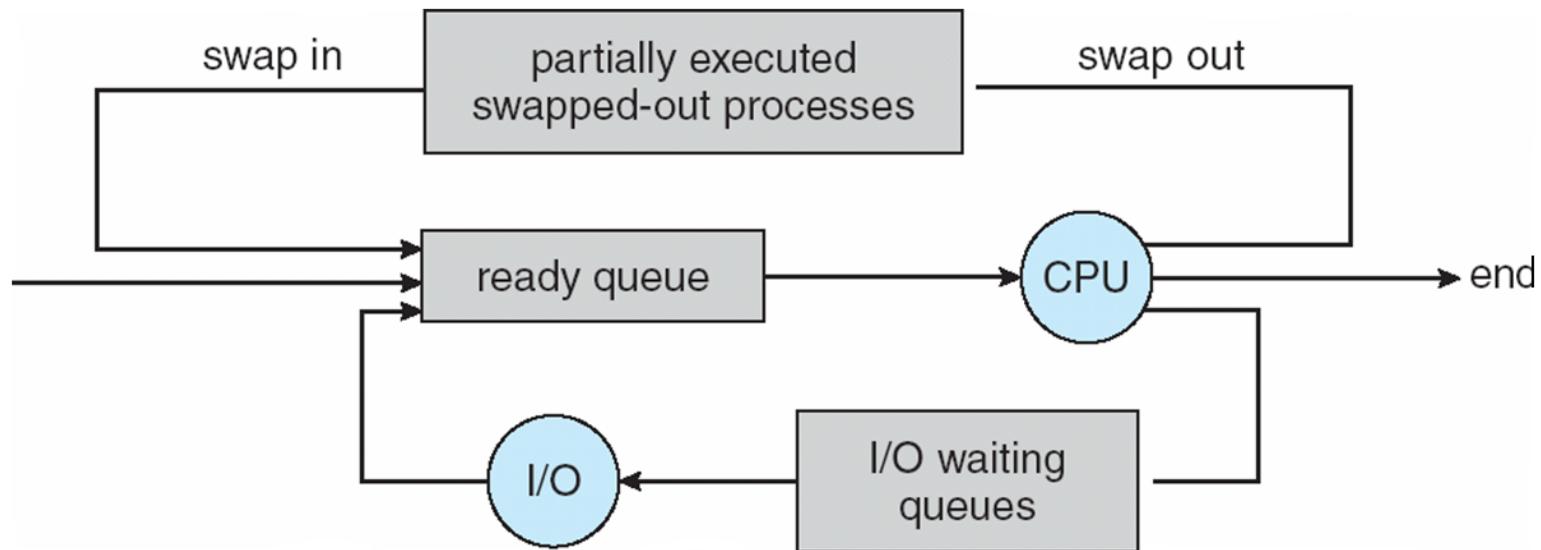
- n **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - | Sometimes the only scheduler in a system
  - | Short-term scheduler is invoked frequently (milliseconds) ⇒ (must be fast)
- n **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  - | Long-term scheduler is invoked infrequently (seconds, minutes) ⇒ (may be slow)
  - | The long-term scheduler controls the **degree of multiprogramming**
- n 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
- n Long-term scheduler strives for good ***process mix***

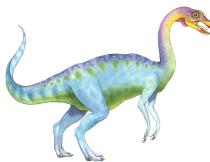




# Addition of Medium Term Scheduling

- n **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

- n Some mobile systems (e.g., early version of iOS) allow only one process to run, others suspended
- n 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
- n 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

- n 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**
- n **Context** of a process represented in the PCB
- n 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
- n Time dependent on hardware support
  - | Some hardware provides multiple sets of registers per CPU → multiple contexts loaded at once





# Operations on Processes

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



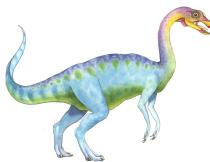


# Process Creation

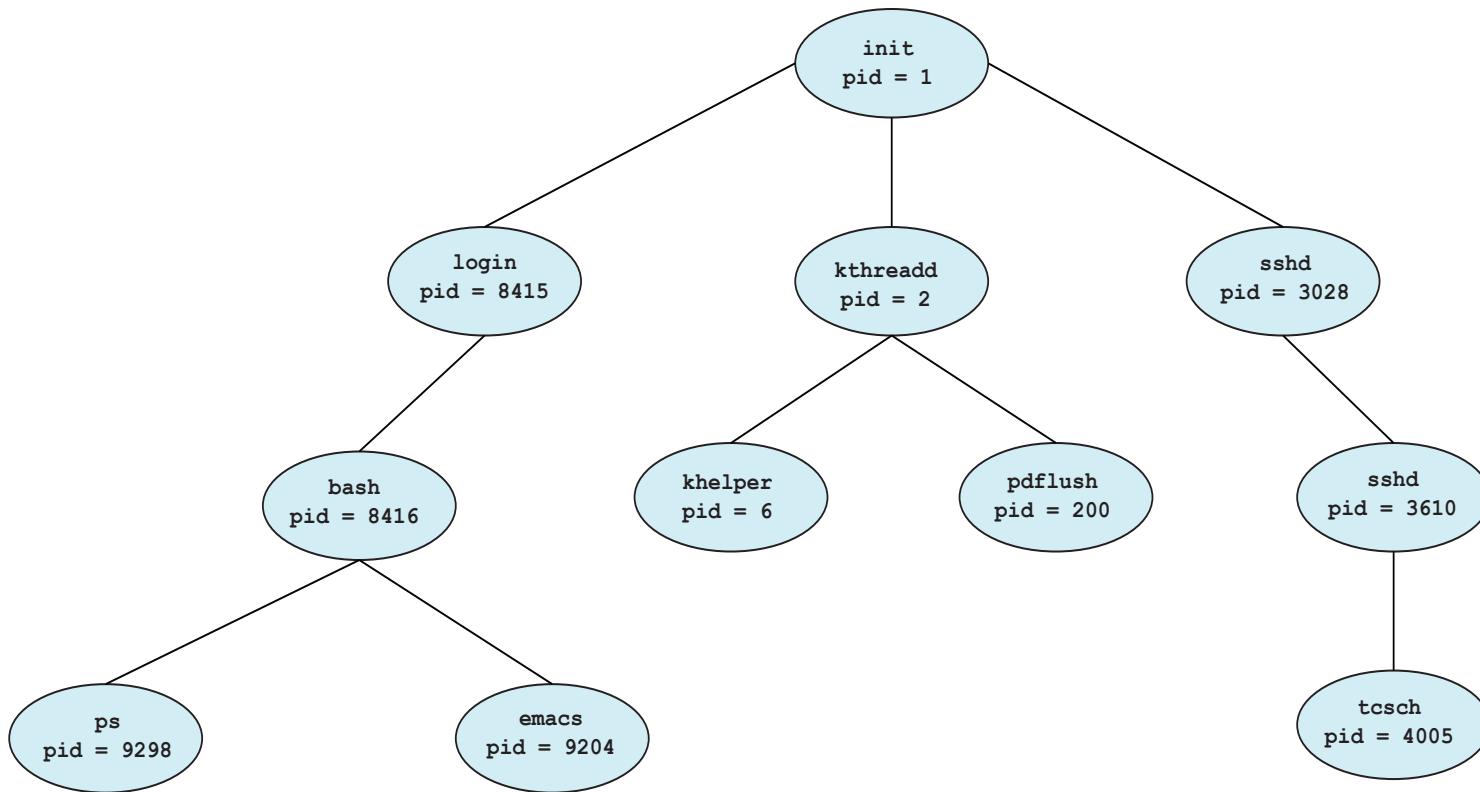
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- n Parent process create children processes, which, in turn create other processes, forming a tree of processes
- n Generally, process identified and managed via a process identifier (pid)
- n Resource sharing options
  - | Parent and children share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





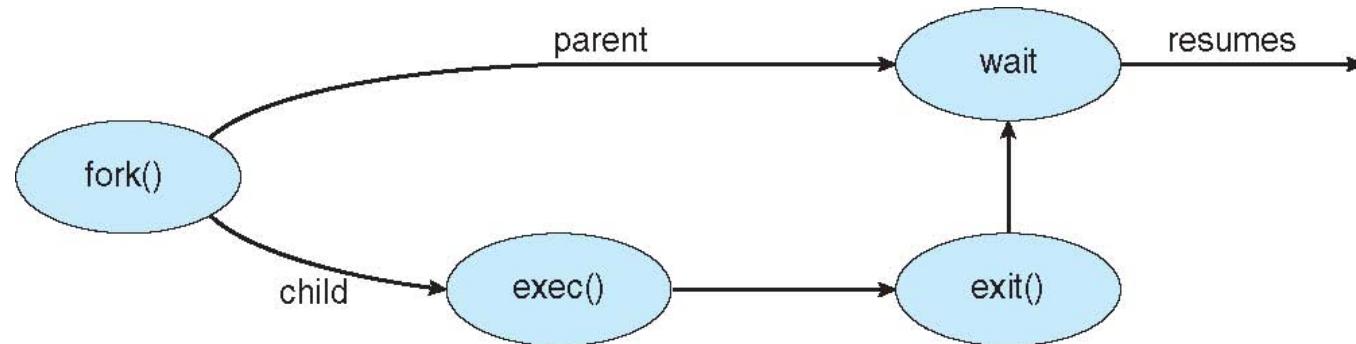
# A Tree of Processes in Linux





# Process Creation (Cont.)

- n Address space
  - | Child duplicate of parent
  - | Child has a program loaded into it
- n 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

- n 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
- n 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

- n Some operating systems do not allow child to exists 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.
- n 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);
```
- n If no parent waiting (did not invoke `wait()`) process is a **zombie**
- n If parent terminated without invoking `wait`, process is an **orphan**





# Multiprocess Architecture – Chrome Browser

- n Many web browsers ran as single process (some still do)
  - | If one web site causes trouble, entire browser can hang or crash
- n 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

---

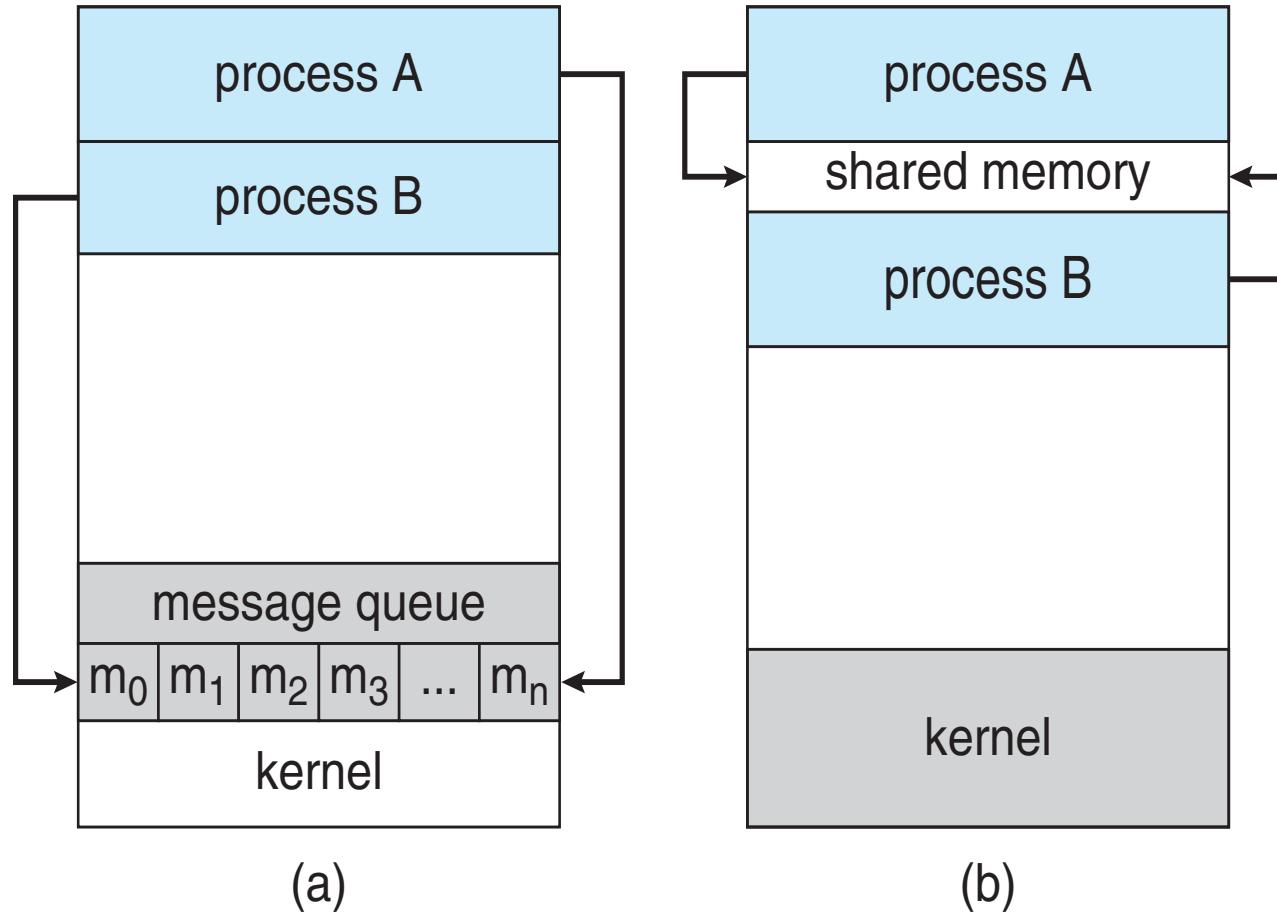
- n Processes within a system may be ***independent*** or ***cooperating***
- n Cooperating process can affect or be affected by other processes, including sharing data
- n Reasons for cooperating processes:
  - | Information sharing
  - | Computation speedup
  - | Modularity
  - | Convenience
- n Cooperating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

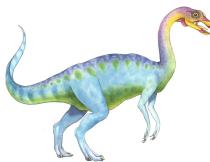




# Communications Models

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





# Cooperating Processes

---

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





# Producer-Consumer Problem

---

- n 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

- n Shared data

```
#define BUFFER_SIZE 10  
  
typedef struct {  
  
    . . .  
  
} item;  
  
  
item buffer[BUFFER_SIZE];  
int in = 0;  
int out = 0;
```

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



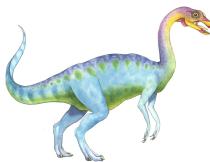


# Bounded-Buffer – Producer

---

```
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;  
}
```



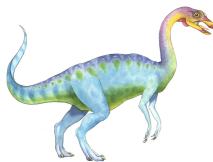


# Bounded Buffer – Consumer

---

```
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 */  
}
```





# Interprocess Communication – Shared Memory

---

- n An area of memory shared among the processes that wish to communicate
- n The communication is under the control of the users processes not the operating system.
- n Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.
- n Synchronization is discussed in great details in Chapter 5.





# Interprocess Communication – Message Passing

---

- n Mechanism for processes to communicate and to synchronize their actions
- n Message system – processes communicate with each other without resorting to shared variables
- n IPC facility provides two operations:
  - | **send(message)**
  - | **receive(message)**
- n The *message size* is either fixed or variable





## Message Passing (Cont.)

- n If processes  $P$  and  $Q$  wish to communicate, they need to:
  - | Establish a **communication link** between them
  - | Exchange messages via send/receive
- n 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.)

---

- n Implementation of communication link

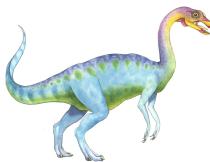
- | Physical:

- ▶ Shared memory
    - ▶ Hardware bus
    - ▶ Network

- | Logical:

- ▶ Direct or indirect
    - ▶ Synchronous or asynchronous
    - ▶ Automatic or explicit buffering

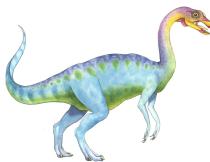




# Direct Communication

- n Processes must name each other explicitly:
  - | **send** ( $P$ , message) – send a message to process  $P$
  - | **receive**( $Q$ , message) – receive a message from process  $Q$
- n 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

---

- n 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
- n 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

---

- n Operations
  - | create a new mailbox (port)
  - | send and receive messages through mailbox
  - | destroy a mailbox

- n Primitives are defined as:

**send(A, message)** – send a message to mailbox A

**receive(A, message)** – receive a message from mailbox A





# Indirect Communication

---

- n 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?
- n 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.



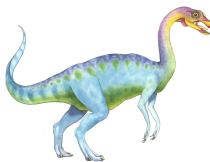


# Synchronization

---

- n Message passing may be either blocking or non-blocking
- n **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
- n **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
- n Different combinations possible
  - | If both send and receive are blocking, we have a **rendezvous**



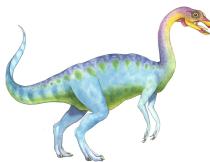


# Synchronization (Cont.)

- n 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 */  
}
```

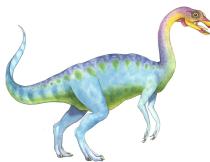




# Buffering

- n Queue of messages attached to the link.
- n implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.  
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





# Examples of IPC Systems - POSIX

## n POSIX Shared Memory

- | Process first creates shared memory segment  
`shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);`
- | Also used to open an existing segment to share it
- | Set the size of the object
- | `ftruncate(shm_fd, 4096);`

Now the process could write to the shared memory

- | `sprintf(shared_memory, "Writing to shared memory");`





# IPC POSIX Producer

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
    /* the size (in bytes) of shared memory object */
    const int SIZE = 4096;
    /* name of the shared memory object */
    const char *name = "OS";
    /* strings written to shared memory */
    const char *message_0 = "Hello";
    const char *message_1 = "World!";

    /* shared memory file descriptor */
    int shm_fd;
    /* pointer to shared memory object */
    void *ptr;

    /* create the shared memory object */
    shm_fd = shm_open(name, O_CREAT | O_RDWR, 0666);

    /* configure the size of the shared memory object */
    ftruncate(shm_fd, SIZE);

    /* memory map the shared memory object */
    ptr = mmap(0, SIZE, PROT_WRITE, MAP_SHARED, shm_fd, 0);

    /* write to the shared memory object */
    sprintf(ptr,"%s",message_0);
    ptr += strlen(message_0);
    sprintf(ptr,"%s",message_1);
    ptr += strlen(message_1);

    return 0;
}
```





# IPC POSIX Consumer

```
#include <stdio.h>
#include <stdlib.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
    /* the size (in bytes) of shared memory object */
    const int SIZE = 4096;
    /* name of the shared memory object */
    const char *name = "OS";
    /* shared memory file descriptor */
    int shm_fd;
    /* pointer to shared memory obect */
    void *ptr;

    /* open the shared memory object */
    shm_fd = shm_open(name, O_RDONLY, 0666);

    /* memory map the shared memory object */
    ptr = mmap(0, SIZE, PROT_READ, MAP_SHARED, shm_fd, 0);

    /* read from the shared memory object */
    printf("%s", (char *)ptr);

    /* remove the shared memory object */
    shm_unlink(name);

    return 0;
}
```



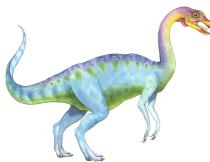


# Examples of IPC Systems - Mach

---

- n Mach communication is message based
  - | Even system calls are messages
  - | Each task gets two mailboxes at creation- Kernel and Notify
  - | Only three system calls needed for message transfer  
`msg_send()` , `msg_receive()` , `msg_rpc()`
  - | Mailboxes needed for communication, created via  
`port_allocate()`
  - | Send and receive are flexible, for example four options if mailbox full:
    - ▶ Wait indefinitely
    - ▶ Wait at most n milliseconds
    - ▶ Return immediately
    - ▶ Temporarily cache a message





# Examples of IPC Systems – Windows

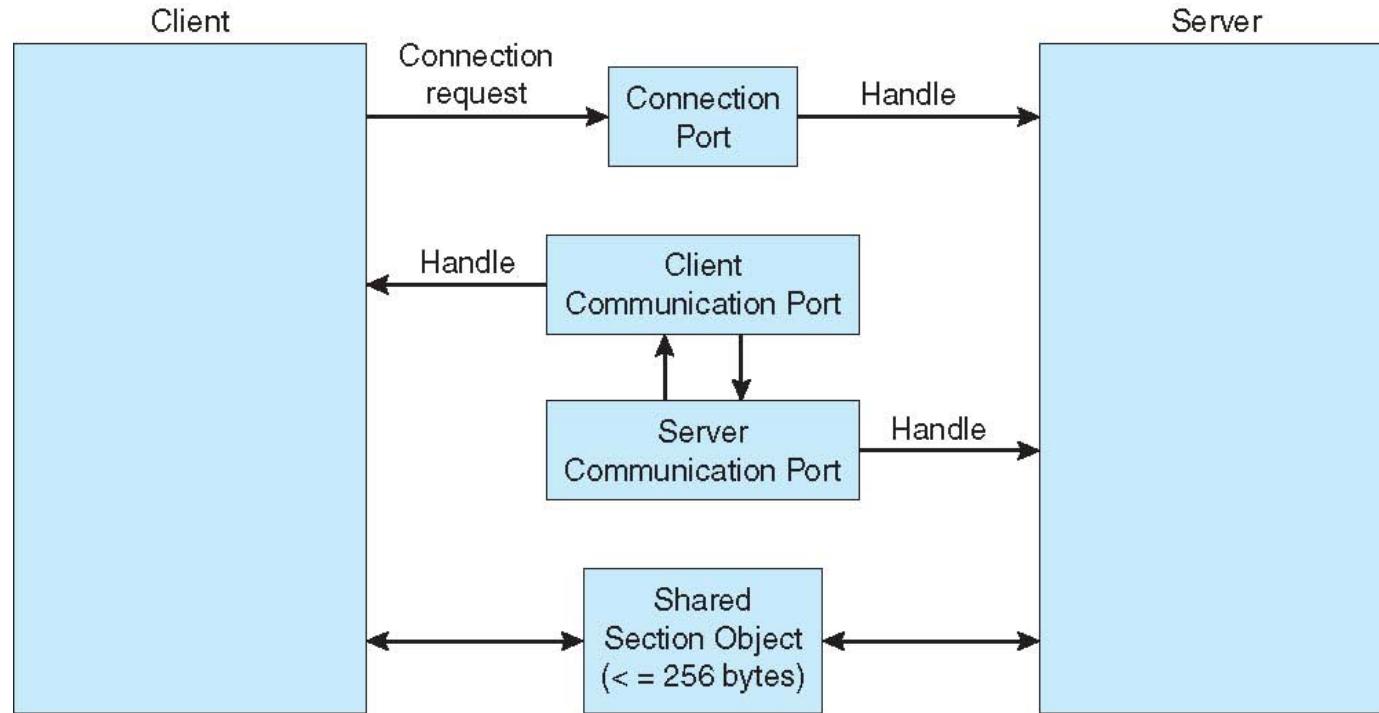
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- n Message-passing centric via **advanced local procedure call (LPC)** facility
  - | Only works between processes on the same system
  - | Uses ports (like mailboxes) to establish and maintain communication channels
  - | Communication works as follows:
    - ▶ The client opens a handle to the subsystem's **connection port** object.
    - ▶ The client sends a connection request.
    - ▶ The server creates two private **communication ports** and returns the handle to one of them to the client.
    - ▶ The client and server use the corresponding port handle to send messages or callbacks and to listen for replies.





# Local Procedure Calls in Windows



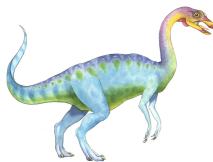


# Communications in Client-Server Systems

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





# Sockets

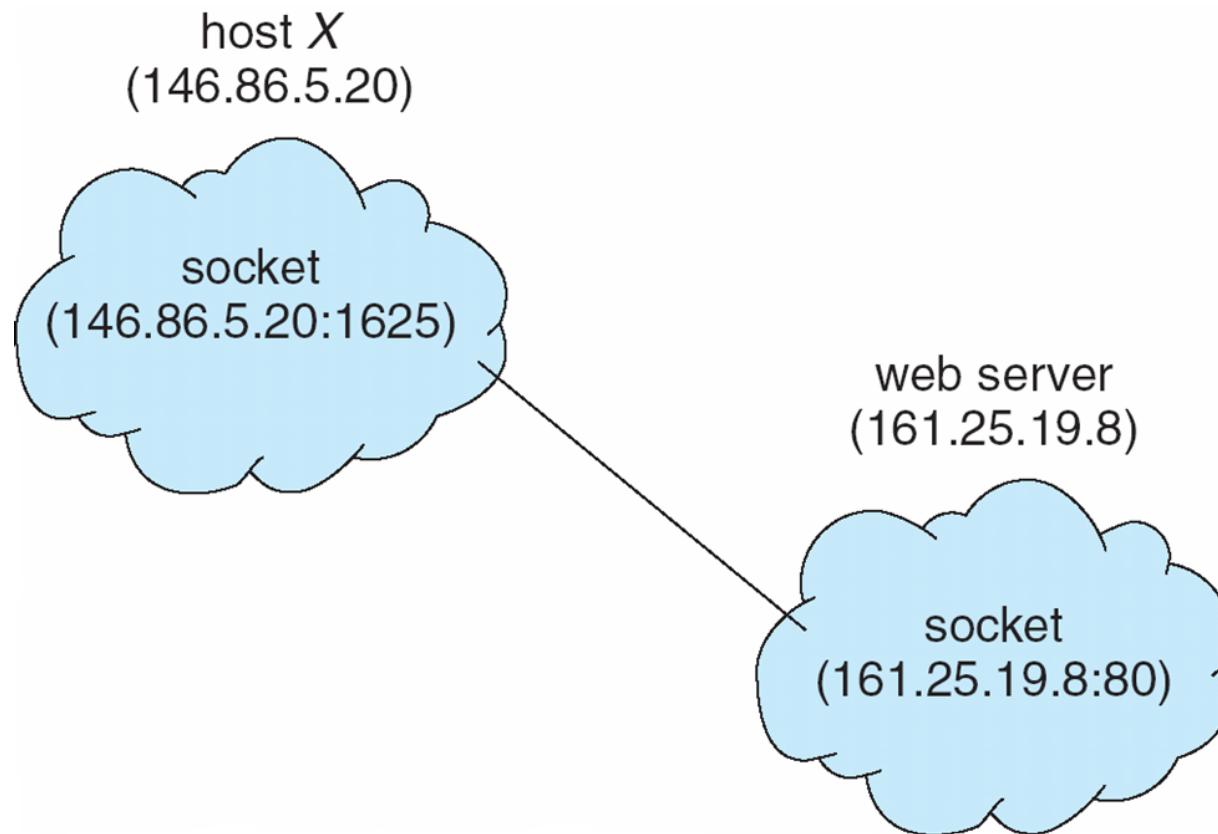
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- n A **socket** is defined as an endpoint for communication
- n Concatenation of IP address and **port** – a number included at start of message packet to differentiate network services on a host
- n The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- n Communication consists between a pair of sockets
- n All ports below 1024 are **well known**, used for standard services
- n Special IP address 127.0.0.1 (**loopback**) to refer to system on which process is running





# Socket Communication





# Sockets in Java

- n Three types of sockets
  - | Connection-oriented (TCP)
  - | Connectionless (UDP)
  - | MulticastSocket class— data can be sent to multiple recipients
- n Consider this “Date” server:

```
import java.net.*;
import java.io.*;

public class DateServer
{
    public static void main(String[] args) {
        try {
            ServerSocket sock = new ServerSocket(6013);

            /* now listen for connections */
            while (true) {
                Socket client = sock.accept();

                PrintWriter pout = new
                    PrintWriter(client.getOutputStream(), true);

                /* write the Date to the socket */
                pout.println(new java.util.Date().toString());

                /* close the socket and resume */
                /* listening for connections */
                client.close();
            }
        } catch (IOException ioe) {
            System.err.println(ioe);
        }
    }
}
```





# Remote Procedure Calls

---

- n Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  - | Again uses ports for service differentiation
- n **Stubs** – client-side proxy for the actual procedure on the server
- n The client-side stub locates the server and **marshalls** the parameters
- n The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server
- n On Windows, stub code compile from specification written in **Microsoft Interface Definition Language (MIDL)**





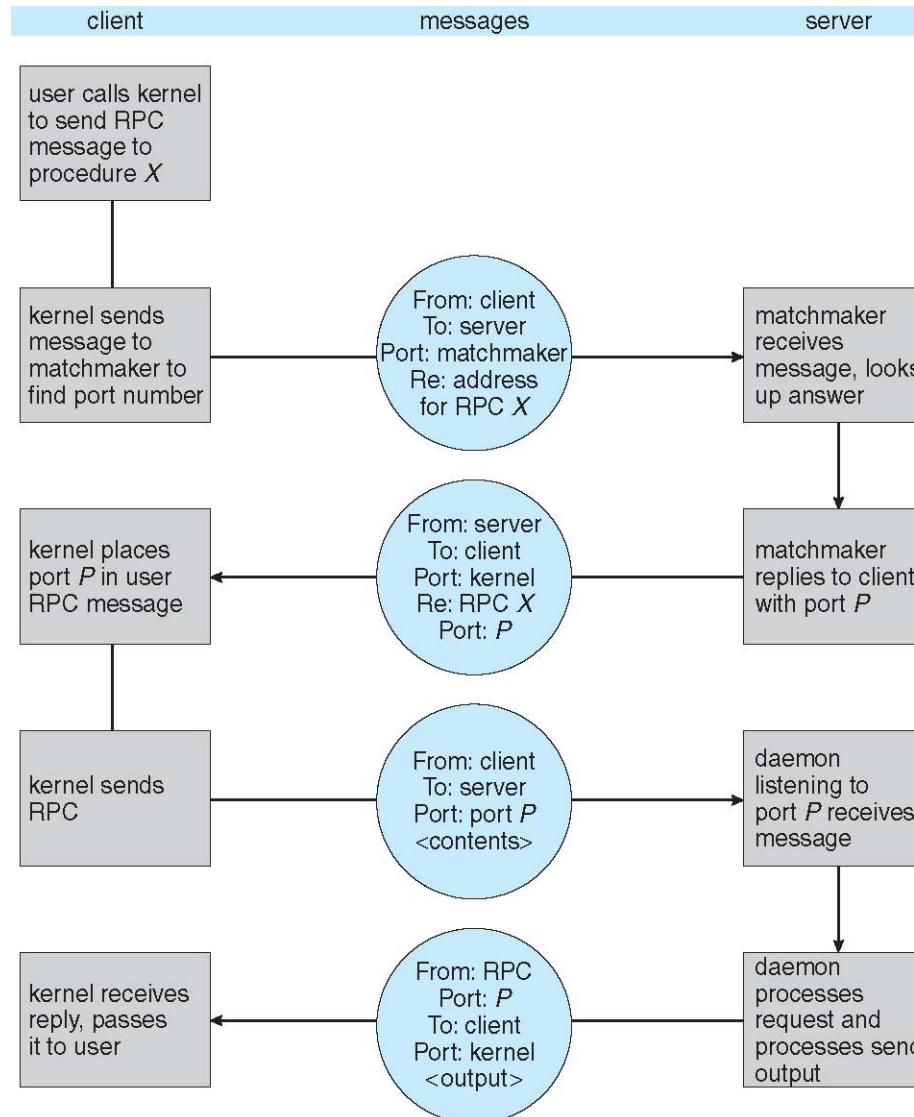
# Remote Procedure Calls (Cont.)

- n Data representation handled via **External Data Representation (XDL)** format to account for different architectures
  - | **Big-endian** and **little-endian**
- n Remote communication has more failure scenarios than local
  - | Messages can be delivered **exactly once** rather than **at most once**
- n OS typically provides a rendezvous (or **matchmaker**) service to connect client and server





# Execution of RPC



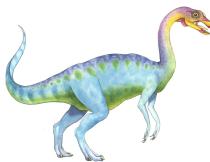


# Pipes

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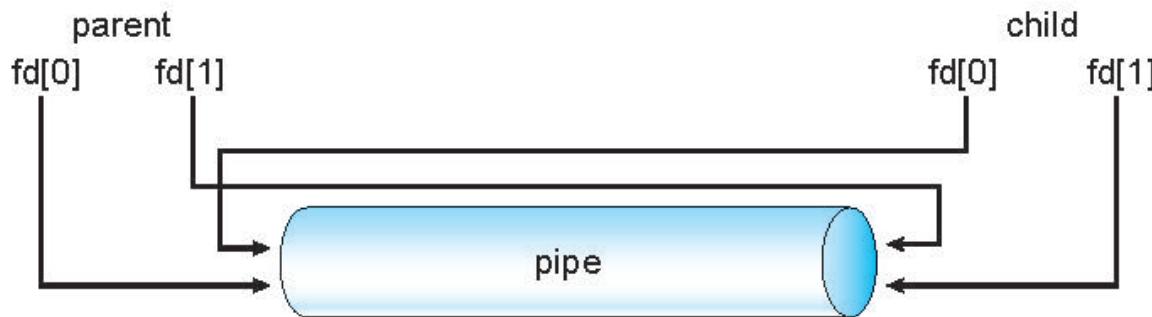
- n Acts as a conduit allowing two processes to communicate
- n Issues:
  - | Is communication unidirectional or bidirectional?
  - | In the case of two-way communication, is it half or full-duplex?
  - | Must there exist a relationship (i.e., **parent-child**) between the communicating processes?
  - | Can the pipes be used over a network?
- n Ordinary pipes – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
- n Named pipes – can be accessed without a parent-child relationship.





# Ordinary Pipes

- n Ordinary Pipes allow communication in standard producer-consumer style
- n Producer writes to one end (the **write-end** of the pipe)
- n Consumer reads from the other end (the **read-end** of the pipe)
- n Ordinary pipes are therefore unidirectional
- n Require parent-child relationship between communicating processes



- n Windows calls these **anonymous pipes**
- n See Unix and Windows code samples in textbook





# Named Pipes

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- n Named Pipes are more powerful than ordinary pipes
- n Communication is bidirectional
- n No parent-child relationship is necessary between the communicating processes
- n Several processes can use the named pipe for communication
- n Provided on both UNIX and Windows systems



# End of Chapter 3

