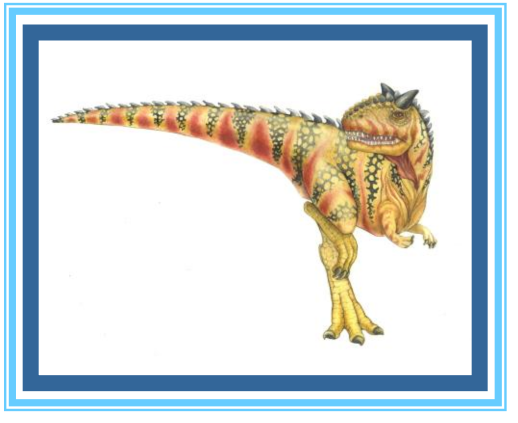
Chapter 3: Processes



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Chapter 3: Processes

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

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
- To describe communication in client-server systems

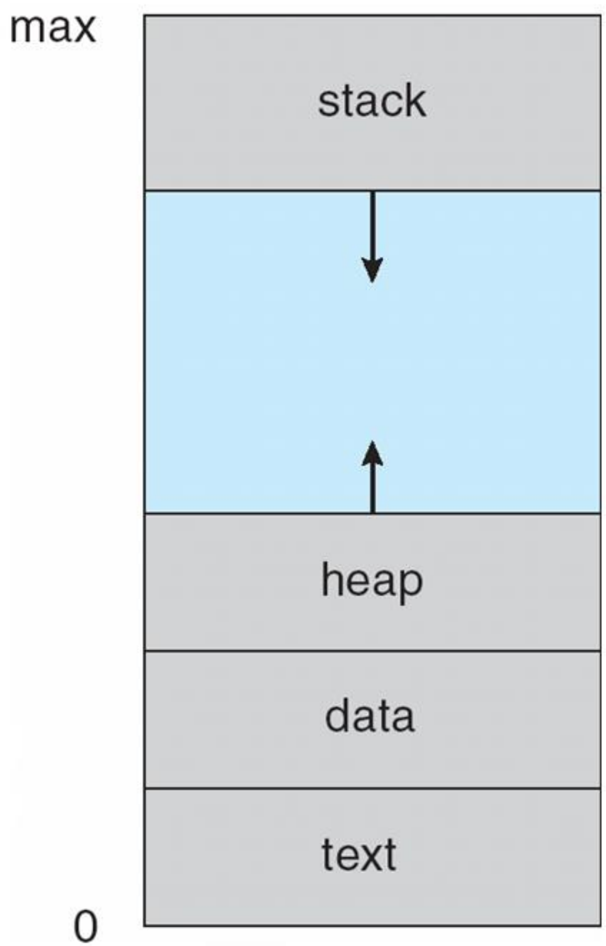
Process Concept

- An operating system executes a variety of programs:
  - Batch system – executes **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
    - System = collection of processes: OS processes and user processes
- Multiple parts (see 03-60-266)
  - The program code, also called **text section**
  - Current activity including **program counter** **(EIP reg)**, 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 in Memory



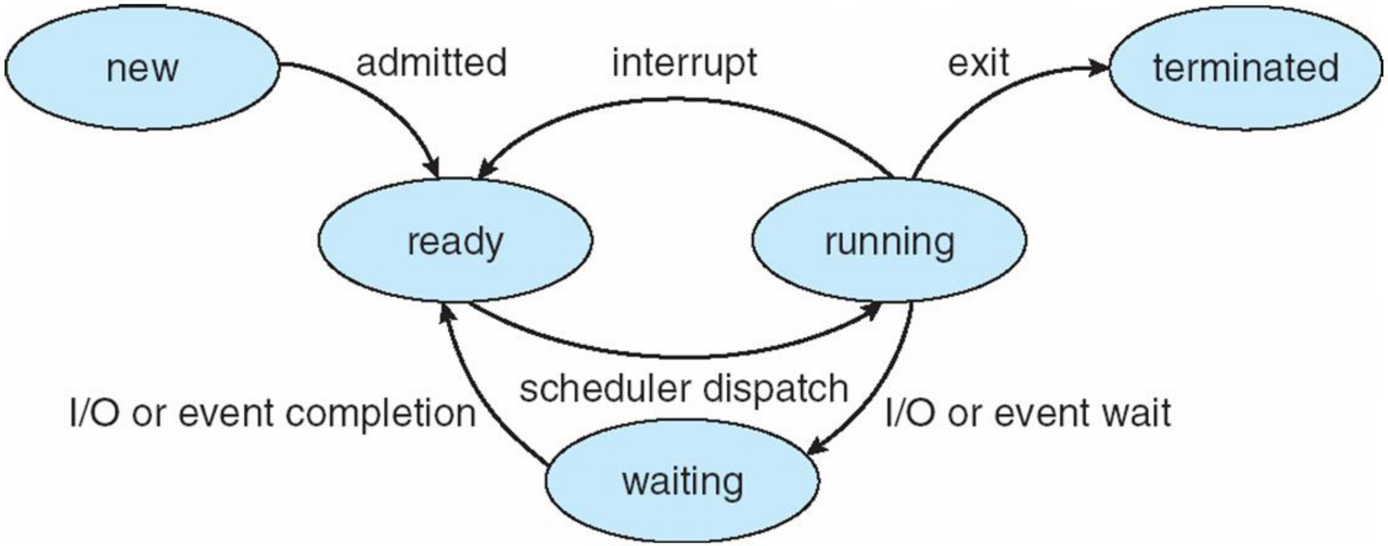
Process Concept

- 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
  - They are separate processes with equivalent code segment (i.e. ***same text section***)

Process State

- As a process executes, it changes **state**
  - Arbitrary state names, and vary across OS's
  - Number of states varies across OS's
- **new**: The process is being created
- **ready**: The process is waiting to be assigned to a processor
- **running**: Instructions are being executed
- **waiting**: The process is waiting for some event to occur
- **terminated**: The process has finished execution

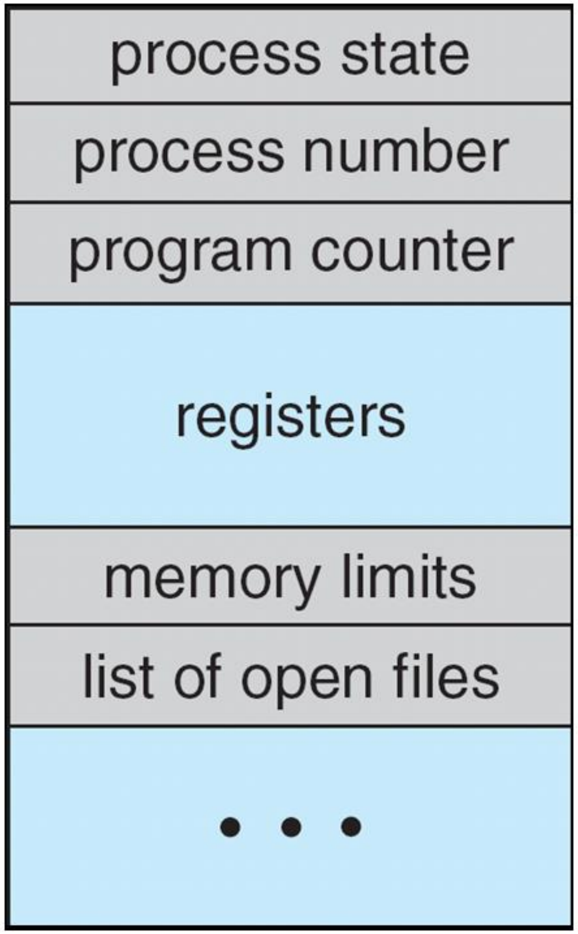
Diagram of Process State



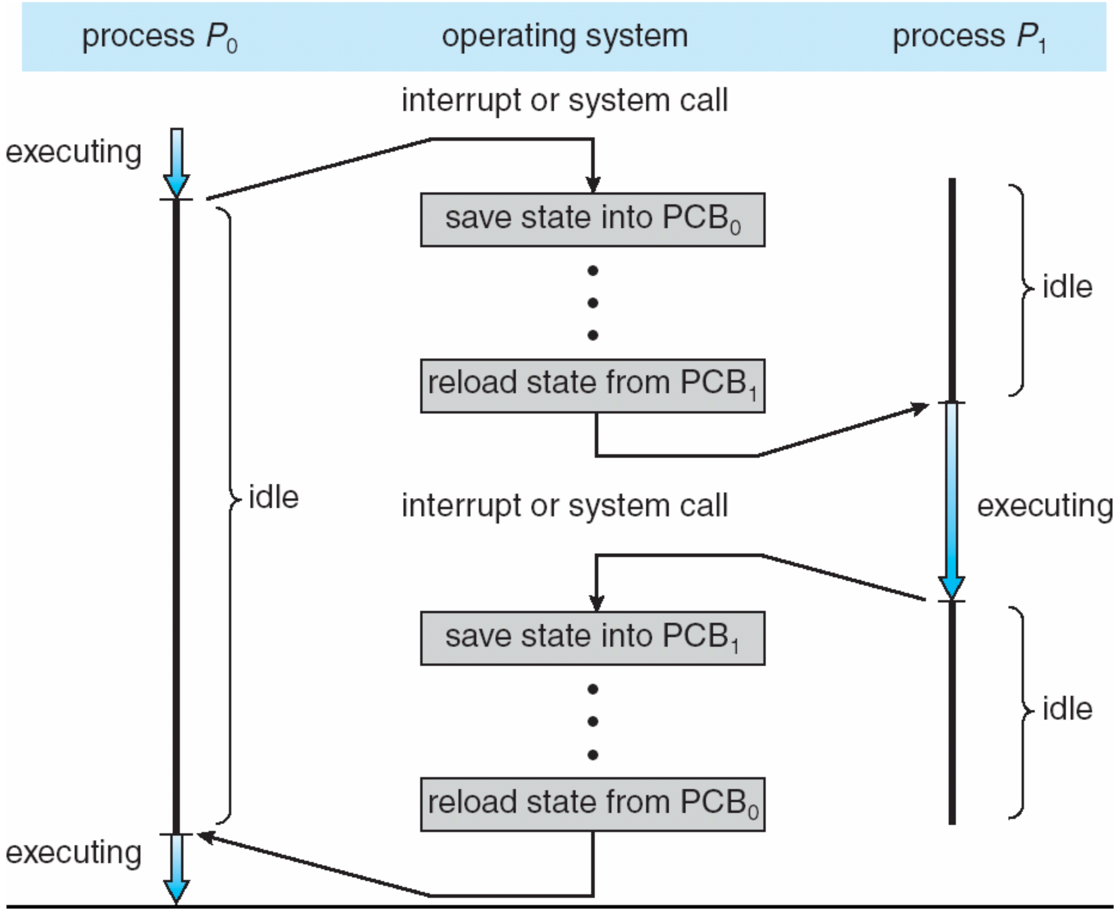
Process Control Block (PCB)

Process represented in OS by a **task control block** (i.e., a PCB = information associated with task)

- Process state – running, waiting, etc
- Program counter – address of next instruction to be executed for this process
- CPU registers – contents of all process-centric registers: EAX, ESI, ESP, EFLAGS, EIP, … etc
- CPU scheduling information – process priority, scheduling queue pointers, … etc
- Memory-management information – memory allocated to the process, EBP, segment registers, page and segment tables… etc
- Accounting information – CPU used, clock time elapsed since start, time limits, … etc
- I/O status information – I/O devices allocated to process, list of open files, … etc



CPU Switch From Process to Process



Threads

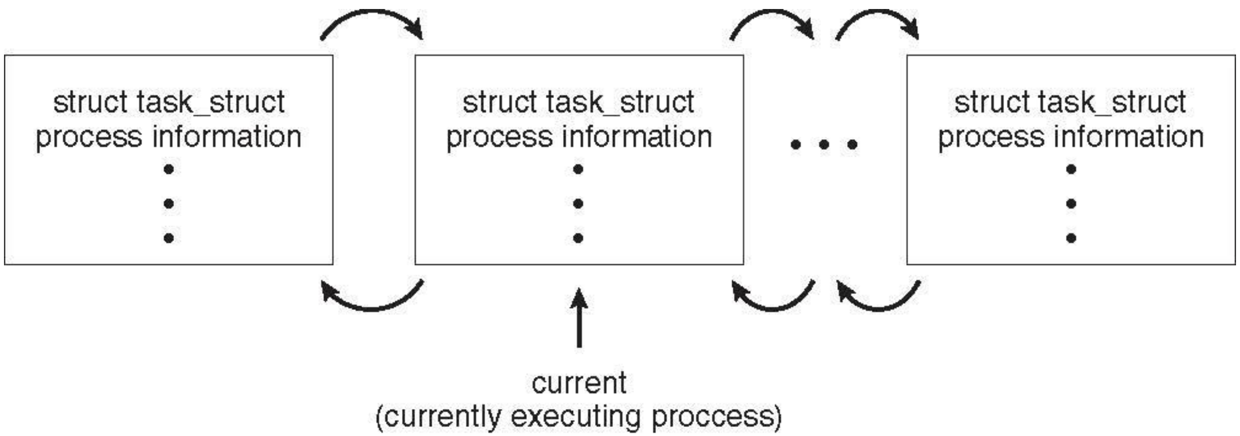
- So far, we have implied that a process has a single thread of execution
  - Performs only 1 task at a time
- Consider having multiple program counters per process
  - Multiple locations can execute at once
    - Multiple threads of control -> **threads**
- Must then have storage for thread details, multiple program counters in PCB
- See next chapter

Process Representation in Linux

Represented by the C structure `task_struct`

This PCB contains all necessary info for a process

```
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 */
```



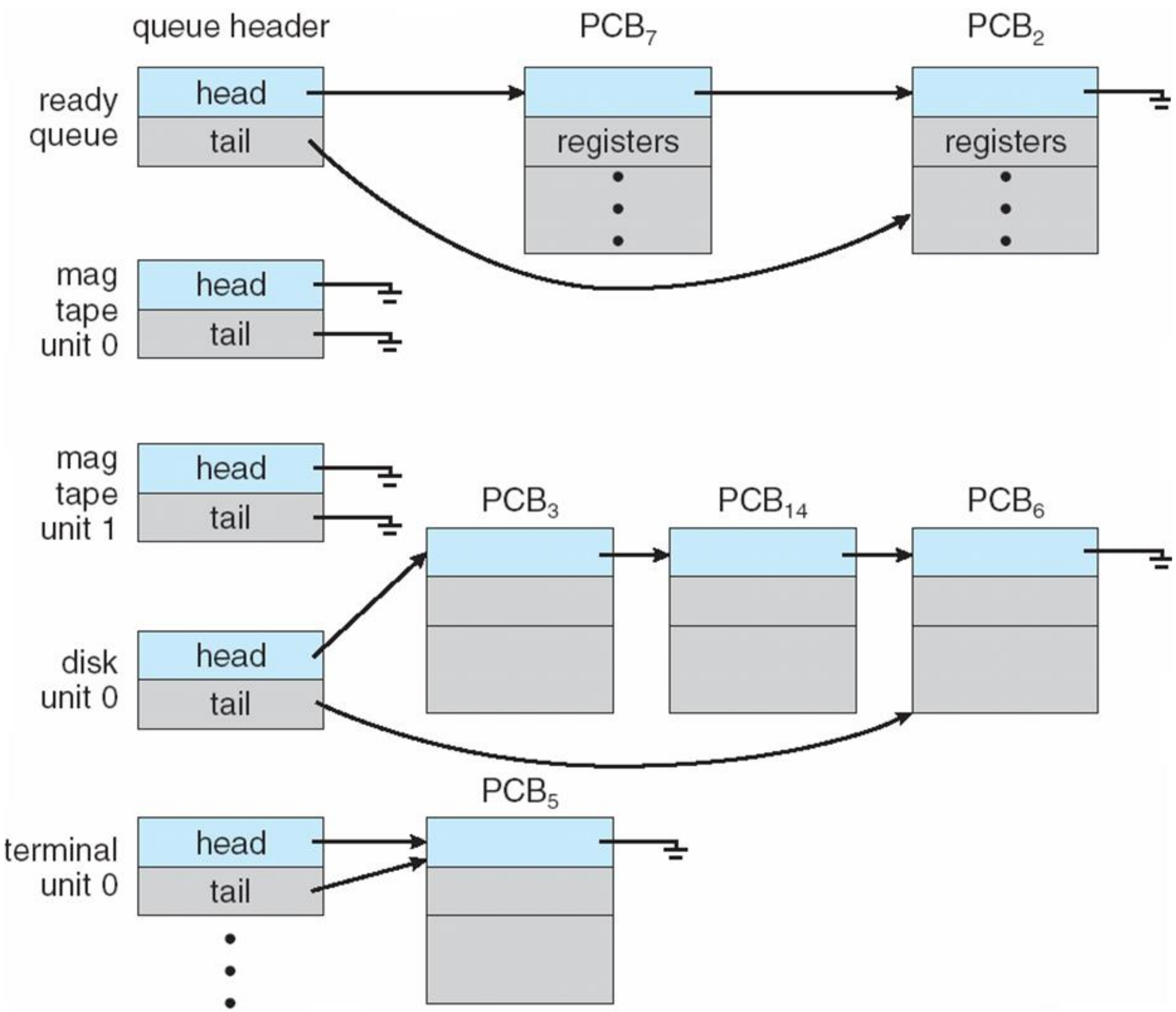
Process Scheduling

- OS Objectives: to maximize CPU utilization, and, to frequently switch among processes onto CPU for time sharing; so that users can interact with programs

- **Process scheduler** selects among available processes to be executed on CPU
  - Single-CPU system, multi-CPU system;
  - Process scheduler = ***CPU scheduler*** + ***Job scheduler*** + other schedulers

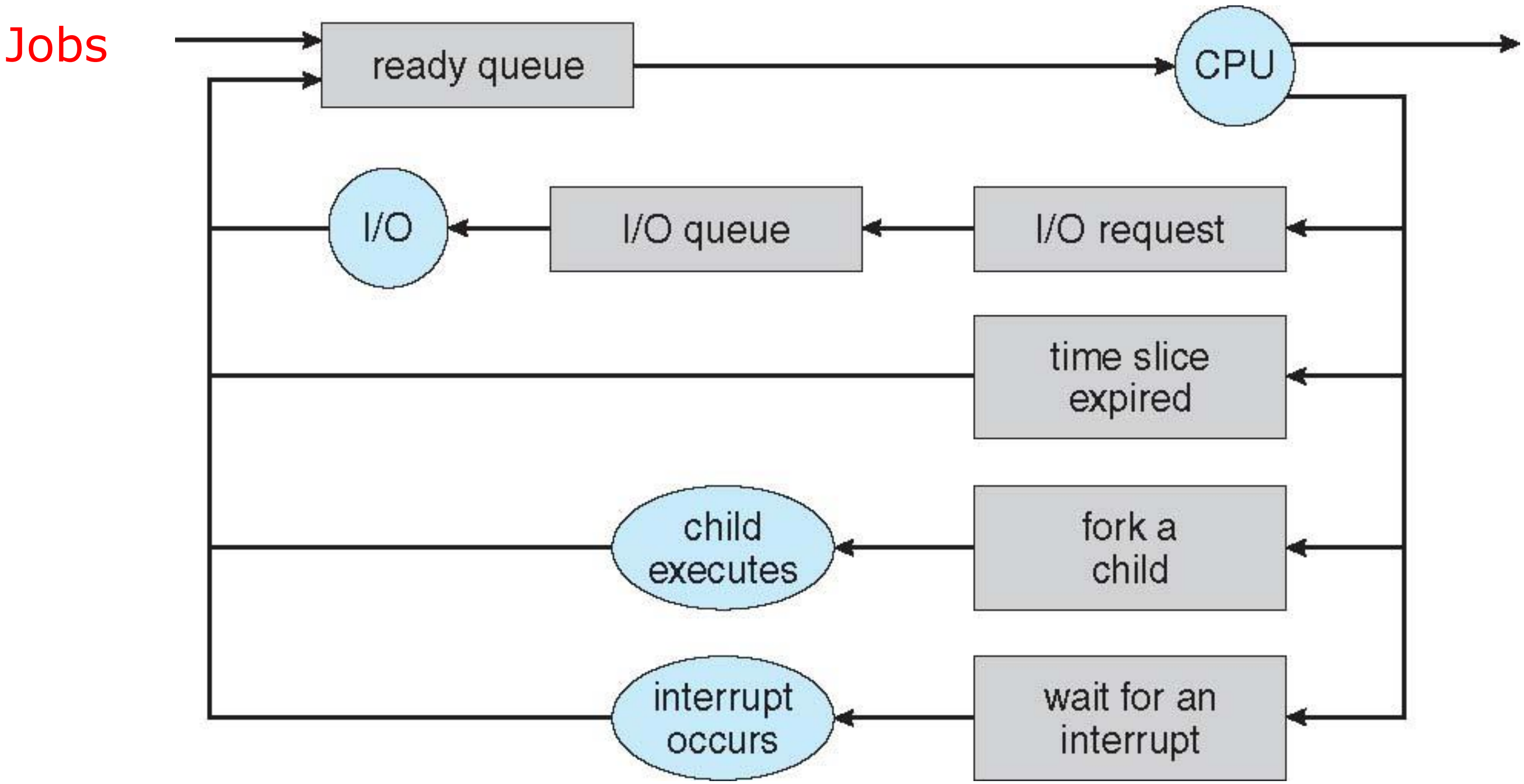
- Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the system
  - **Ready queue** – set of all processes ***residing in main memory***, ready and waiting to execute.
    - = Linked list of PCBs
  - **Device queues** – set of processes waiting for an I/O device
    - Each shared device has its associated device queue
  - Processes migrate among the various queues

Ready Queue And Various I/O Device Queues



Representation of Process Scheduling

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

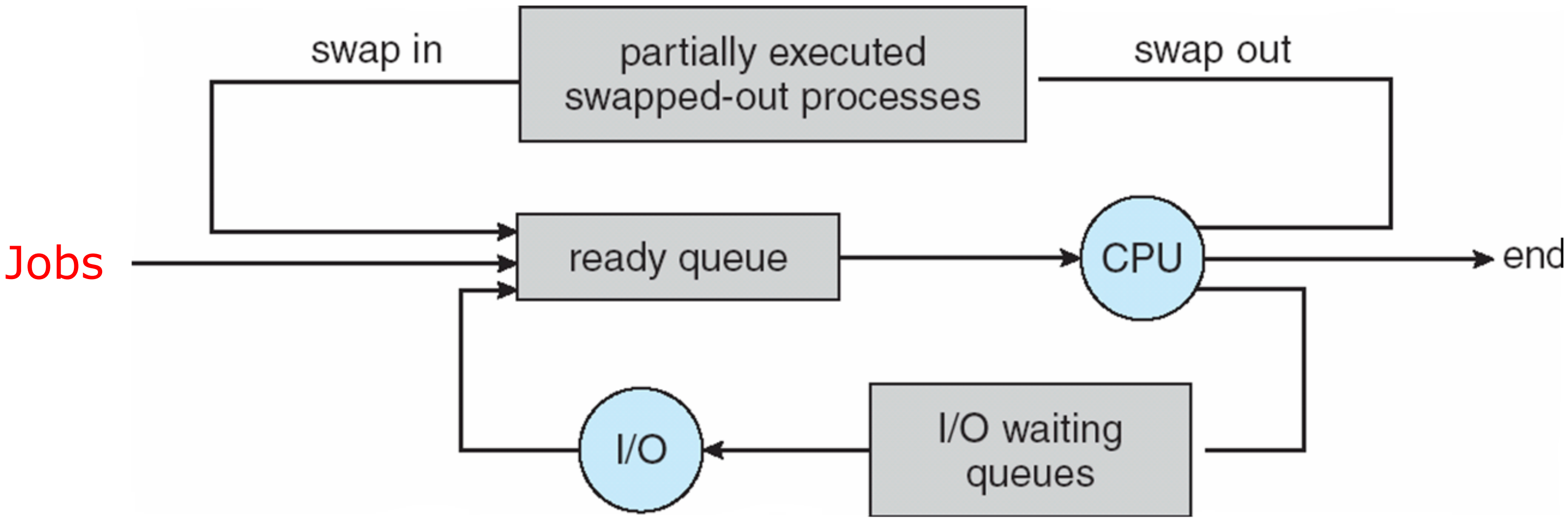


Schedulers

- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates the CPU to that process
  - Sometimes the only scheduler in a system. Time-sharing systems (UNIX, MS Windows)
  - 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**:
    - ***= Number of processes in memory*** (i.e., in the ready queue)
    - Stable degree: aver nb of process creation = aver nb of process departure
    - Thus, invoked only when a process leaves the system
- Processes can be described as either:
  - **I/O-bound process** – spends more time doing I/O than computations, many short CPU bursts. ***The ready queue is almost always empty if all processes are I/O-bound***
  - **CPU-bound process** – spends more time doing computations; few very long CPU bursts. ***The I/O queue is almost always empty if all processes are CPU-bound***
- Long-term scheduler strives for good ***process mix*** of I/O-bound and CPU-bound proc's

Addition of Medium Term Scheduling

- **Medium-term scheduler** added in some OS in order to reduce the degree of multi-programming (e.g. in some time-sharing systems)
  - Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**



  - Swapping helps improve process mix
  - Also necessary when memory needs to be freed up

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
  - = process state, all register values, memory information
  - **Save/restore** contextes to/from PCBs when switching among processes
    - Known as **context switch**
- 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. ***Typical speed is a few milliseconds***
  - Depends on machine: memory speed, nb of registers, load/save instrtuctions
- Time dependent on hardware support
  - Some hardware provides multiple sets of registers per CPU
    - ➔ multiple contexts loaded at once

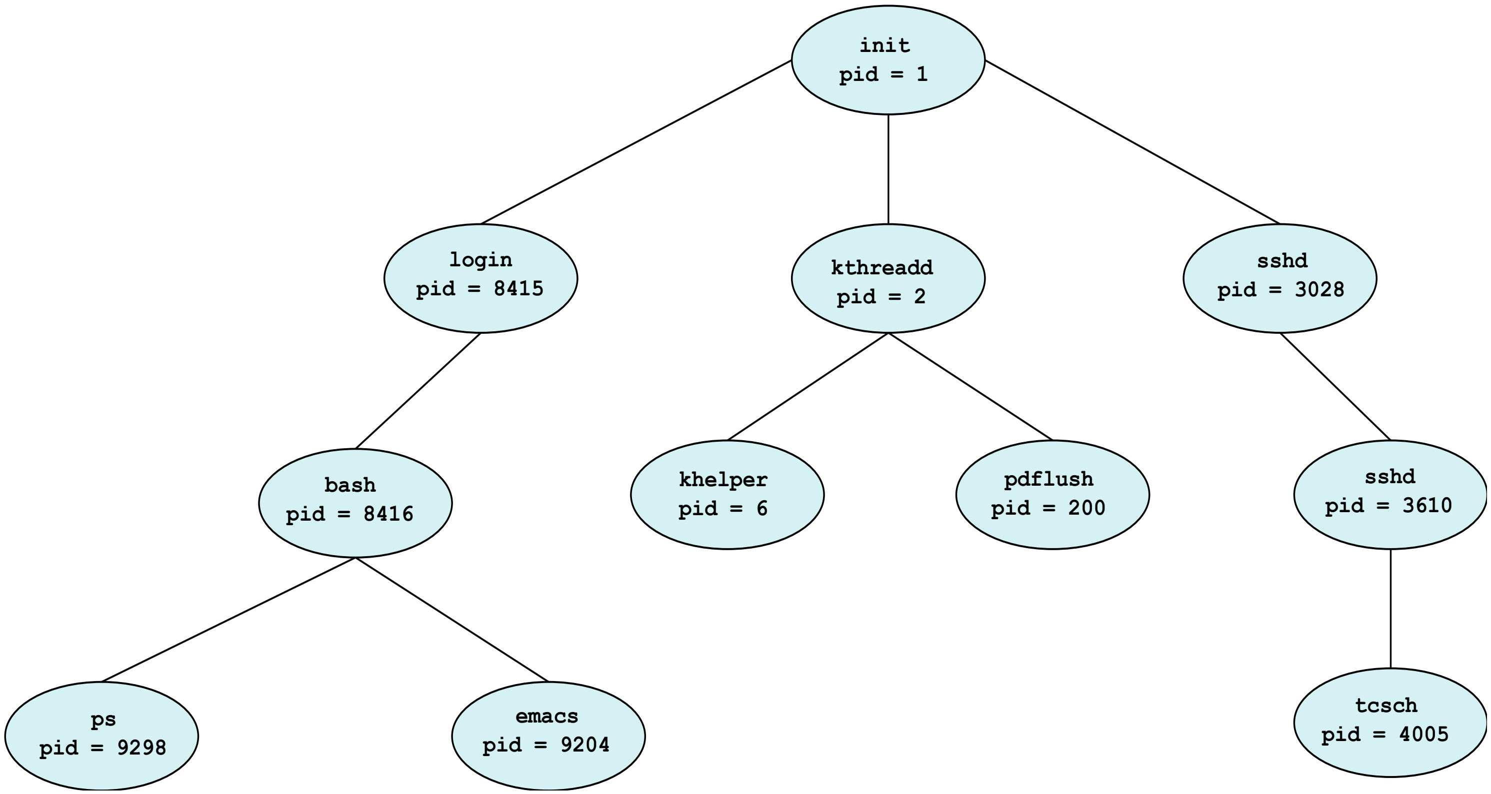
Operations on Processes

- Processes execute concurrently, are dynamically created/deleted
- Operating systems must provide mechanisms for:
  - process creation,
  - process termination,
  - and so on as detailed next

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**)
  - Unique handle to access various attributes of a process
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution options when a process creates a new process
  - Parent and children execute concurrently
  - Parent waits until children terminate

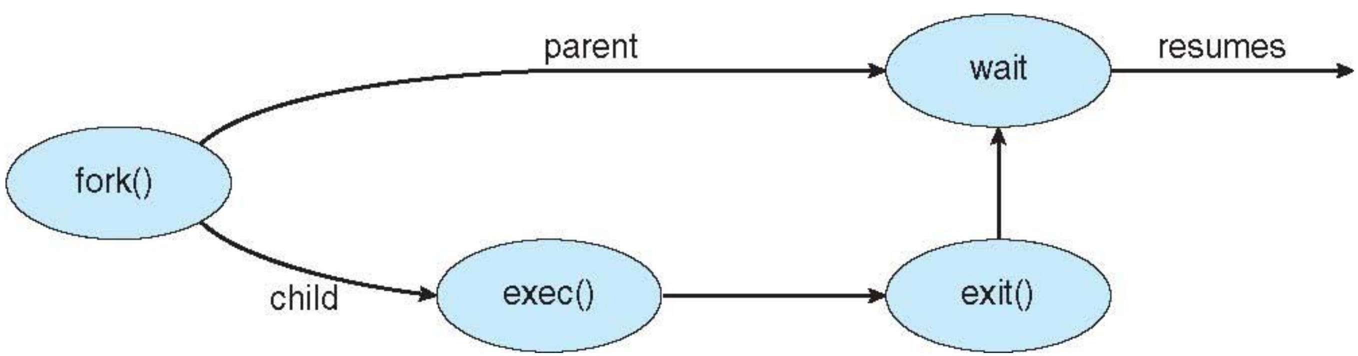
A Tree of Processes in Linux



Process Creation (Cont.)

- Address-space options when a process creates a new process
  - Child is a duplicate of parent
  - Child has a new 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

```c
#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()`** **`[or TerminateProcess]`** system-call. Some reasons for doing so:
  - [Parent needs to know the identities of its children]
  - Child has exceeded allocated resources
    - Parent must have a mechanism to inspect its children
  - 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 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.
  - This cascading 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);
```

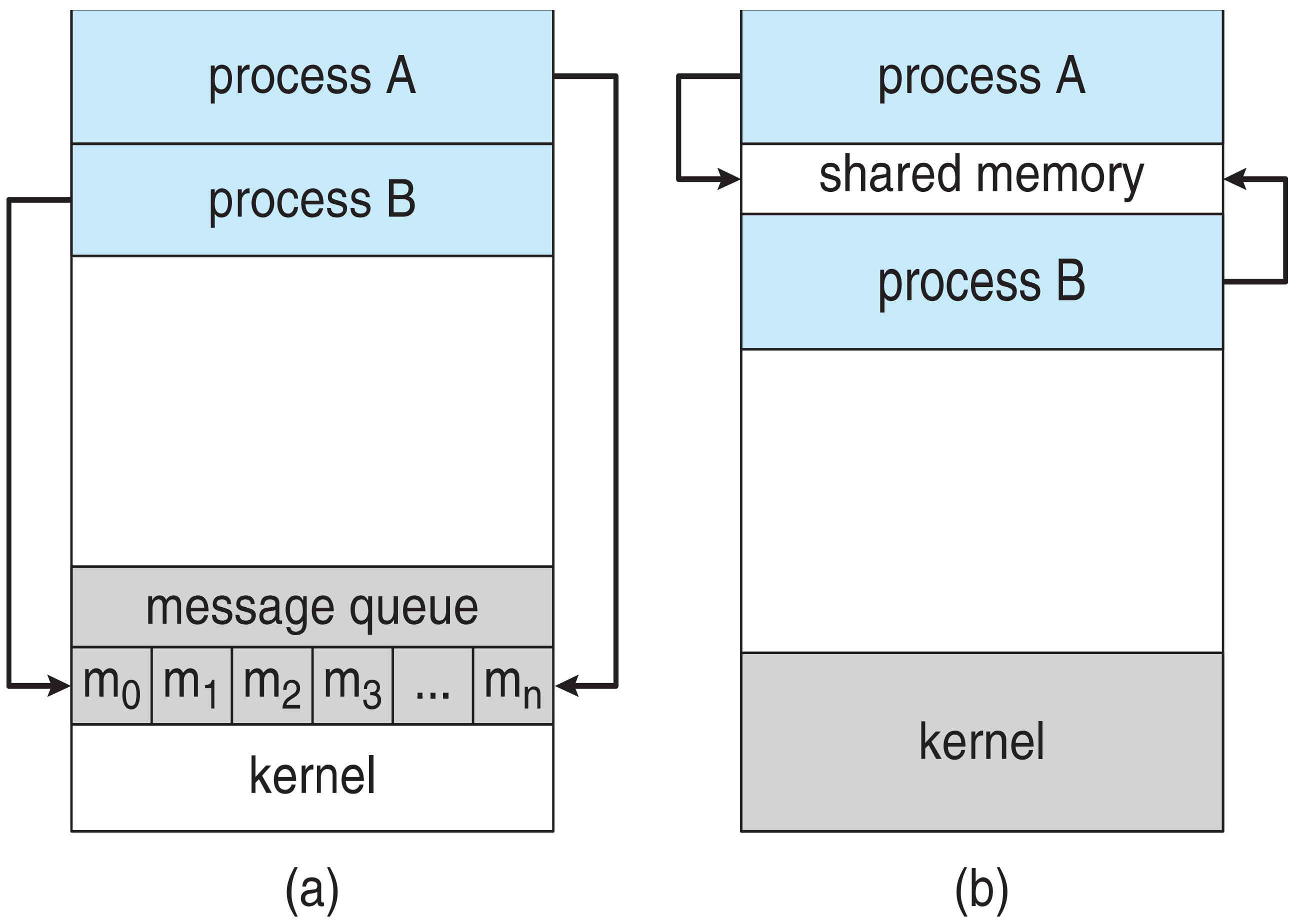
  - We can directly terminate a child using **`exit(1)`** with status parameter
  - **`wait()`** is passed a parameter allowing prt to obtain exit status of child
  - Parent knows which children has terminated
- **Zombie:** If parent has not yet invoked **`wait()`** but child process has terminated
- **Orphan:** If parent has terminated without invoking **`wait`** child process is alive

Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing; many users sharing the same file
  - Computation speedup; in multi-core systems
  - Modularity; recall Chap 2
  - Convenience; same user working on many tasks at the same time
- Cooperating processes need **interprocess communication** (**IPC**) mechanism to exchange data and information
- Two models of IPC
    - Many OS’s implement both IPC models
  - **Shared memory**; easier to implement and faster
  - **Message passing**; useful for exchanging small amounts of data

Communications Models

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



Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
  - Normally, OS prevent a process from accessing another process's memory.
    - Processes can agree to remove this restriction in shared-memory systems
- The communication is under the control of the users processes not the operating system.
  - Application programmer ***explicitly*** writes the code for sharing memory
  - Processes ensure that they not write to the same location simultaneously
- Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.
  - Solution to the ***producer-consumer problem***
    - Discussed in following slides
- Synchronization is discussed in great details in Chapter 5.

Shared-Memory Systems

- **Producer-Consumer Problem**
  - Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - Example:
    - Compiler outputs (***produces***) an assembly code
    - Assembler assembles (***consumes***) the assembly code
    - Provides a metaphor for the client-server paradigm
      - Server = producer. Ex: web server ***provides*** HTML files/images
      - Client = consumer. Ex: client web browser ***reads*** HTML files/images

- **Solution**: producer and consumer processes share a buffer (***shared-memory***)
  - Synchronization: consumer should not consume data not yet produced
  - Two types of buffers:
    - **unbounded-buffer** places no practical limit on the size of the buffer
    - **bounded-buffer** assumes that there is a fixed buffer size

SM: Bounded-Buffer – Shared-Memory Solution

- Shared data – buffer implemented as a circular array

```
#define BUFFER_SIZE 10
typedef struct {
   . . .
} item; item to be produced/consumed

item buffer[BUFFER_SIZE]; shared buffer
int in = 0; producer produces an item into in
int out = 0; consumer consumes an item from out
```

- Solution is correct, but can only use BUFFER_SIZE-1 elements
  - **Empty** if ***in = out*** and **Full** if ***((in + 1) % BUFFER_SIZE) = out***

SM: Bounded-Buffer – Producer

```
item next_produced;      stores new item to be produced
…
while (true)
{
      /* produce an item in next_produced */

      while (((in + 1) % BUFFER_SIZE) == out)
            ; /* do nothing   when the buffer is full */

      buffer[in] = next_produced;   item is produced

      in = (in + 1) % BUFFER_SIZE;  update in pointer
}
```

SM: Bounded Buffer – Consumer

```
item next_consumed;              stores item to be consumed
…
while (true)
{
      while (in == out)
            ; /* do nothing when the buffer is empty */

      next_consumed = buffer[out];  item is consumed

      out = (out + 1) % BUFFER_SIZE; update out pointer

      /* consume the item in next_consumed */
}
```

Message-Passing Systems

- Mechanism for processes to communicate and to synchronize their actions
  - Useful when communicating processes are in different computers
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - A ***communication link*** must exist between communicating processes, then
    - Communication operations:
      - **`send`**(*message*)
      - **`receive`**(*message*)
- The *message* size is either fixed-sized or variable-sized

Message-Passing Systems

- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a ***communication link*** between them
  - Exchange messages via send/receive
- Implementation issues: (we are concerned only with its logical implementation)
  - 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 Systems

- Implementation of communication link
  - (we are concerned only with its logical implementation)

- Physical:
  - Shared memory
  - Hardware bus
  - Network

- ***Logical:***
  - Direct or indirect communication
  - Synchronous or asynchronous communication
  - Automatic or explicit buffering

MP: 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
- Direct communication schemes
  - Symmetric: both sender and receiver must name the other to communicate
  - Asymmetric: only the sender names the recipient
    - **`send`** (*P, message*) – send a message to process *P*
    - **`receive`**(***id***, *message*) – receive a message from ***any*** process ***id***
- Problem with direct communication
  - Must explicitly state all process identifiers -- ***hard-coding***

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MP: Indirect Communication

- Messages are sent to 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

MP: Indirect Communication

- OS provides operations allowing a process to
  - create a new mailbox *M* (also called a port)
    - The ***owner*** is the process that creates the mailbox *M*
      - It can only receive messages through this mailbox *M*
    - A ***user*** is the process which can only send messages to this mailbox *M*
  - 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*

MP: Indirect Communication

- Mailbox sharing
  - Suppose processes P_1, P_2, and P_3 share mailbox *A*
  - P_1, sends a message to *A* by executing **`send`**(*A, message*)
  - P_2 and P_3 execute **`receive`**(*A, message*)
    - Who gets the message? … P_2 and P_3 ?
- 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.
    - **Round robin** algorithm where processes take turn in receiving messages
    - Sender is notified who the receiver was.

MP: Synchronization

- Message passing may be either blocking or non-blocking
- Blocking is considered **synchronous**
  - **Blocking send** -- the sender is blocked until the message is delivered
  - **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 retrieves:
    - A valid message, or
    - Null message
- Different combinations possible
  - If both send() and receive() are blocking, we have a **rendezvous**

MP: Synchronization

- Producer-consumer becomes trivial

```
message next_produced;
while (true)
{    producer invokes blocking send and waits until mess. delivered
    /* produce an item in next produced */
    send(M, next_produced);
}

message next_consumed;
while (true)
{   consumer invokes blocking receive and waits until mess. availabl
    receive(M, next_consumed);
    /* consume the item in next consumed */
}
```

MP: Buffering

- Queue of messages is attached to the communication link.

- Implemented in one of three ways

  1. Zero capacity – no messages are queued on a link.
     Sender must wait for receiver (rendezvous) to receive the message
     1. It means: there is no buffering: no message is waiting on the link

  2. Bounded capacity – queue has a finite length of *n* messages
     Sender must wait if link is full. If not, then
     2. Messages are placed on the buffer without waiting for receiver to receive

  3. Unbounded capacity – infinite length
     Sender never waits

MP: Examples of IPC Systems - POSIX

- POSIX Shared-Memory (message-passing is also available in POSIX)

  - Process first creates shared memory segment (*return int file desc for the sm*)
    `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);`

  - Map the shared memory to a file (*return pointer to the memory-mapped file*)

    `shm_ptr = (0, SIZE, PROT_WRITE, MAP_SHARED, shm_fd, 0);`

    - We use ***shm_ptr*** to access the shared-memory object ***shm_fd***

  - Now the process could write to the shared memory

    `sprintf(shm_ptr, "Writing to shared memory");`

  - Remove the shared memory object: `shm_unlink(name);`

MP: 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 obect */
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;
}
```

MP: 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;
}
```

MP: Examples of IPC Systems - Mach

- Mach communication is message based on message-passing
    - Especially designed for distributed systems or systems with few cores
  - Even system calls are messages
  - Each task gets two mailboxes at creation – Kernel-port and Notify-port
  - Only three system calls needed for message transfer

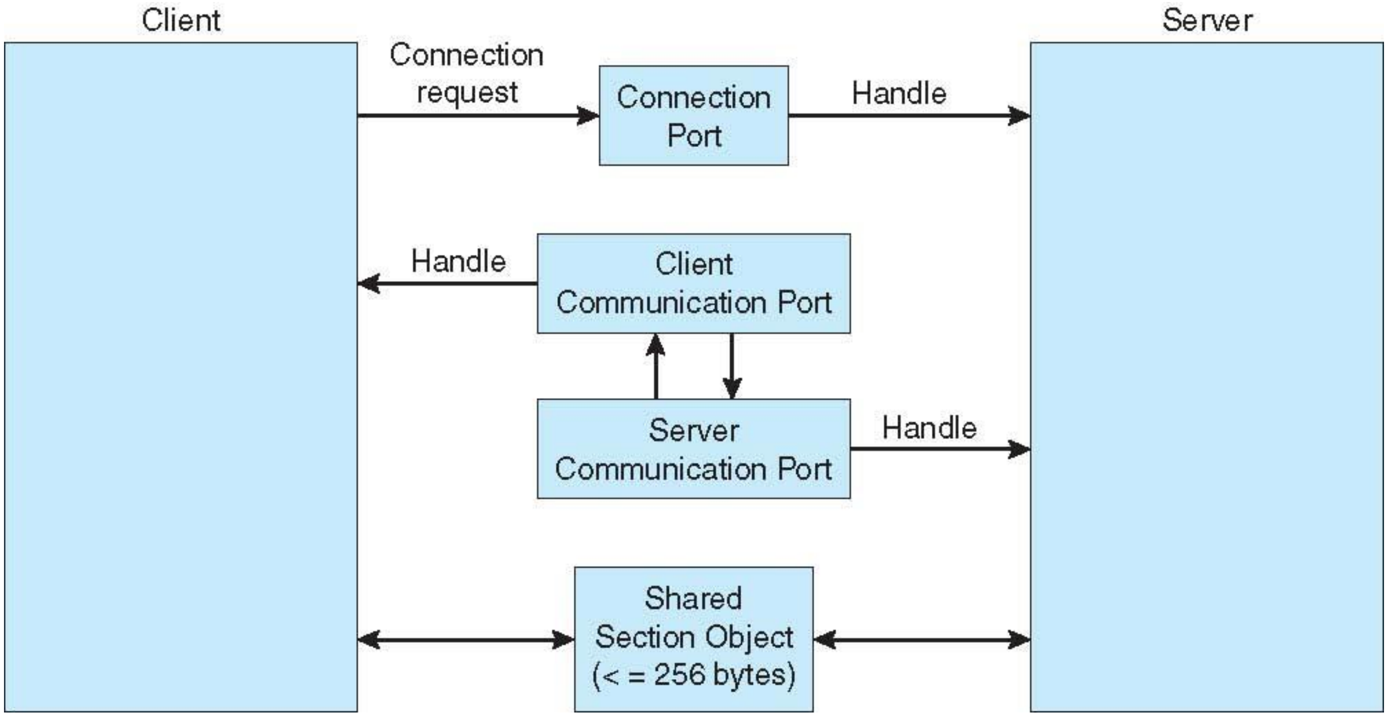
    `msg_send()`, **`msg_receive()`**, **`msg_rpc()`** [remote procedure call]

    `msg_rpc` sends message and wait for 1 return message from sender
  - Mailboxes needed for communication: created via **`port_allocate()`**
    - Empty queue of length 8 messages is also created for the link
  - 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

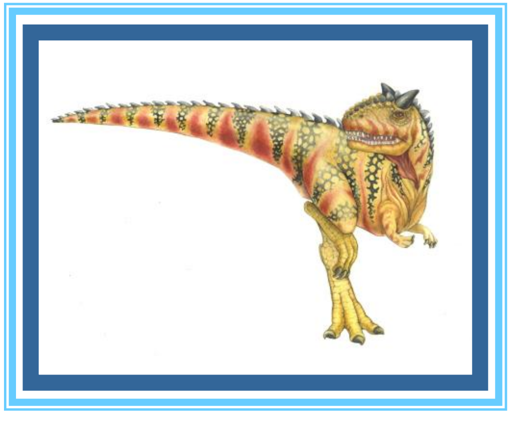
MP: Examples of IPC Systems – Windows

- 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. Two types of ports: connection port and communication port
  - 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.

MP: Local Procedure Calls in Windows



End of Chapter 3



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Multitasking in Mobile Systems

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

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

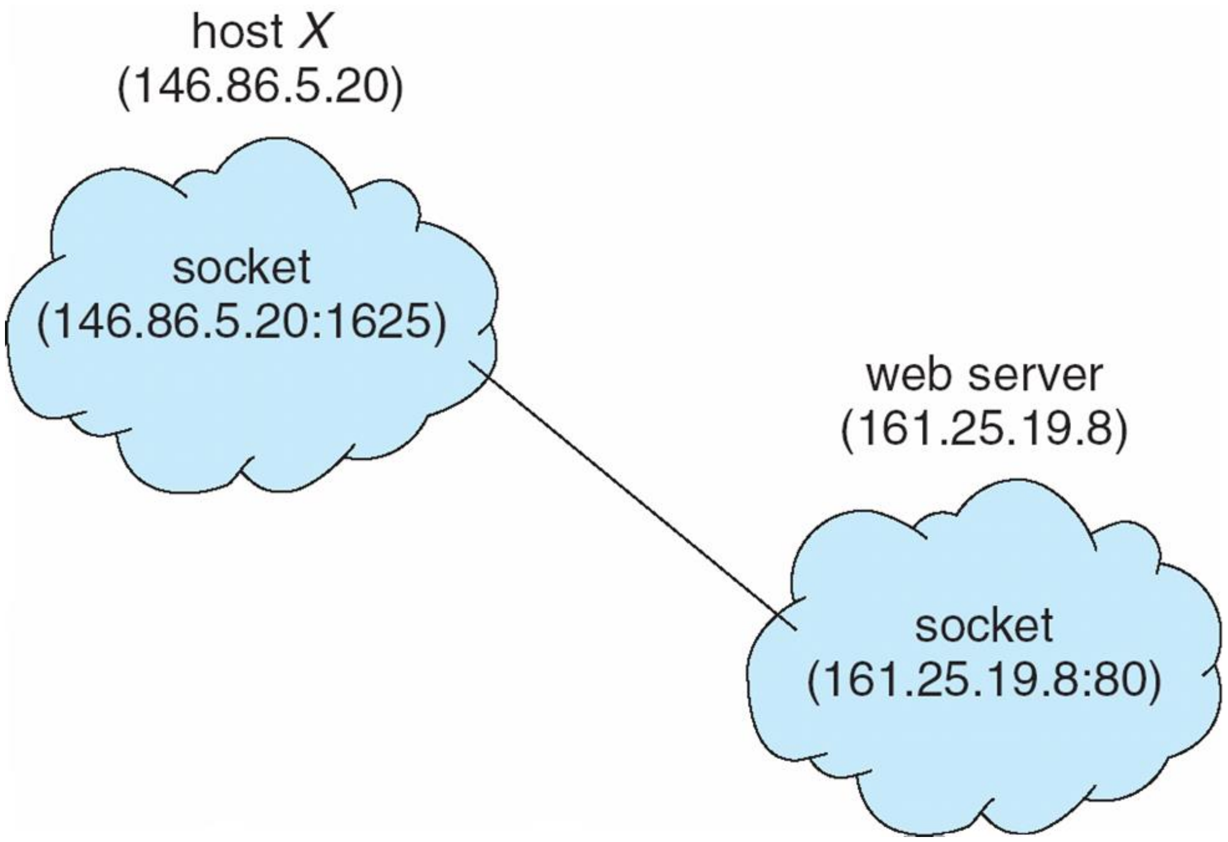
Communications in Client-Server Systems

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

Sockets

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

Socket Communication



Sockets in Java

- Three types of sockets
  - **Connection-oriented** (**TCP**)
  - **Connectionless** (**UDP**)
  - **`MulticastSocket`** class– data can be sent to multiple recipients
- 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);
      }
   }
}
```

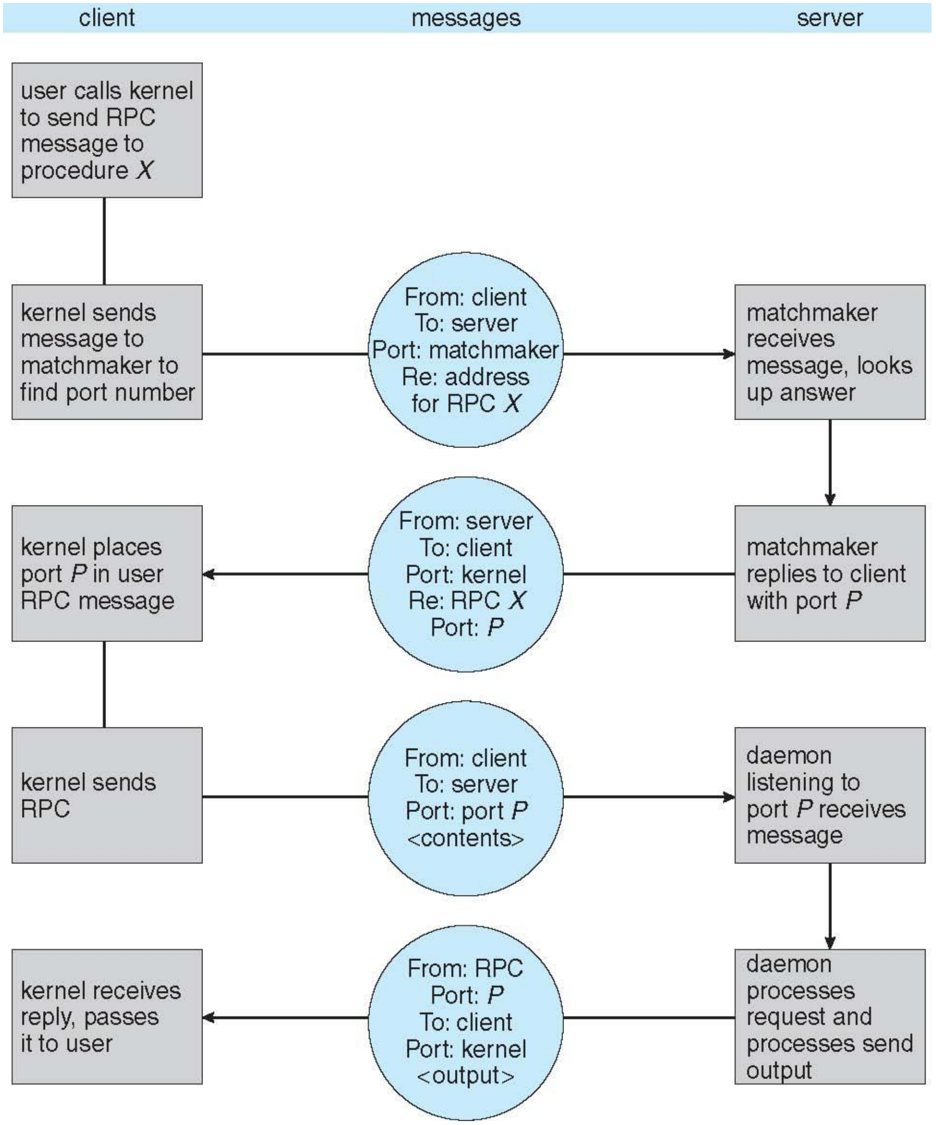
Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  - Again uses ports for service differentiation
- **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
- On Windows, stub code compile from specification written in **Microsoft Interface Definition Language** (**MIDL**)

Remote Procedure Calls (Cont.)

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

Execution of RPC

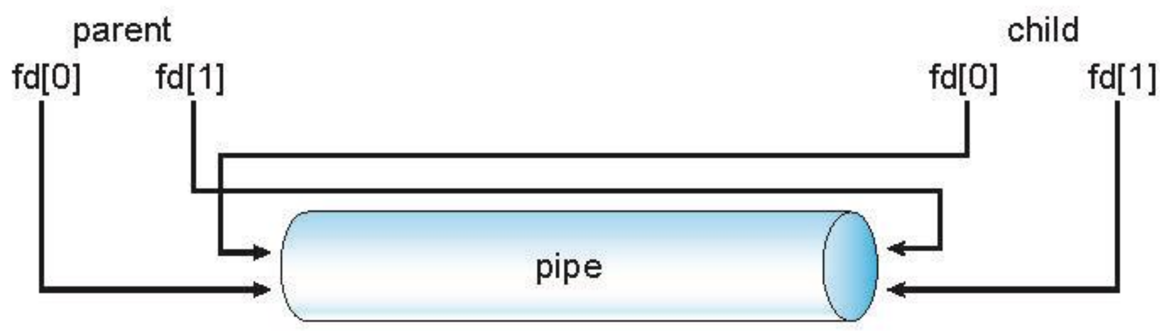


Pipes

- Acts as a conduit allowing two processes to communicate
- 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?
- 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.
- Named pipes – can be accessed without a parent-child relationship.

Ordinary Pipes

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



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

Named Pipes

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