# Chapter 3: Processes

# Chapter 3: Processes

- Process Concept
- Process Scheduling
- Operations on Processes
- Inter-Process Communication (IPC)
- IPC in Shared-Memory Systems
- IPC in Message-Passing Systems
- Examples of IPC Systems
- Communication in Client-Server Systems

# Objectives

- Identify the separate components of a process and illustrate how they are represented and scheduled in an operating system.
- Describe how processes are created and terminated in an operating system, including developing programs using the appropriate system calls that perform these operations.
- Describe and contrast *inter-process communication* using shared memory and message passing.
- Design *programs that uses pipes and POSIX shared memory* to perform inter-process communication.
- Describe *client-server communication* using sockets and remote procedure calls.
- Design *kernel modules* that interact with the Linux operating system.

# Process Concept

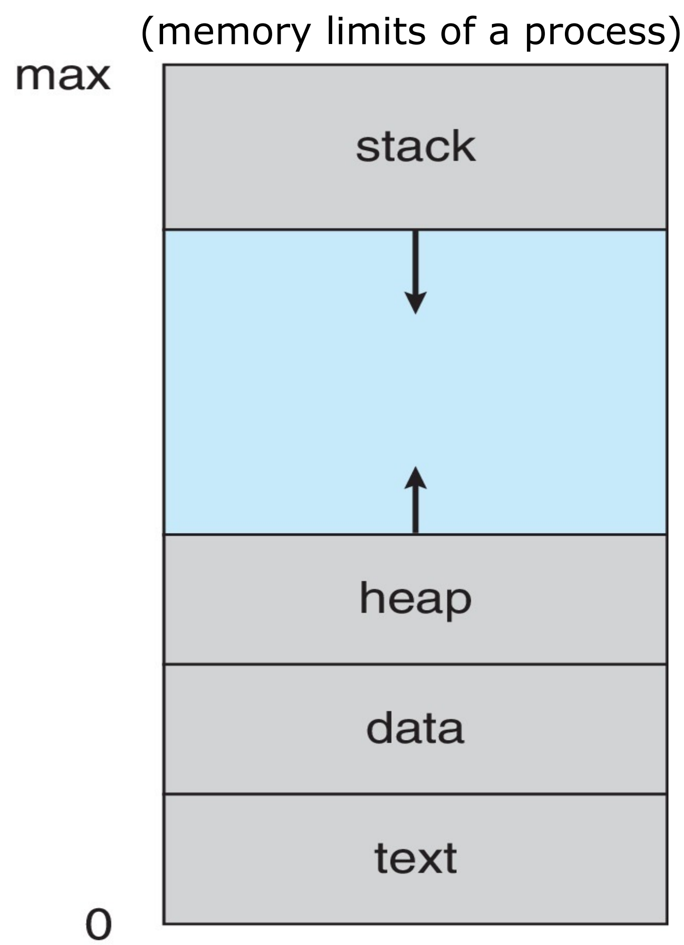
- An operating system executes a variety of programs that run as processes
- ***Process*** – a program in execution; process execution must progress in sequential fashion
- Multiple parts
  - The *program code*, also called ***text** section*
  - Current activity including *program counter*, and *processor registers*
  - ***Stack** section* containing temporary data
    - Function parameters, return addresses, local variables
  - ***Data** section* containing global variables
  - ***Heap** section* containing memory dynamically allocated during run time

# Process Concept (Cont.)

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

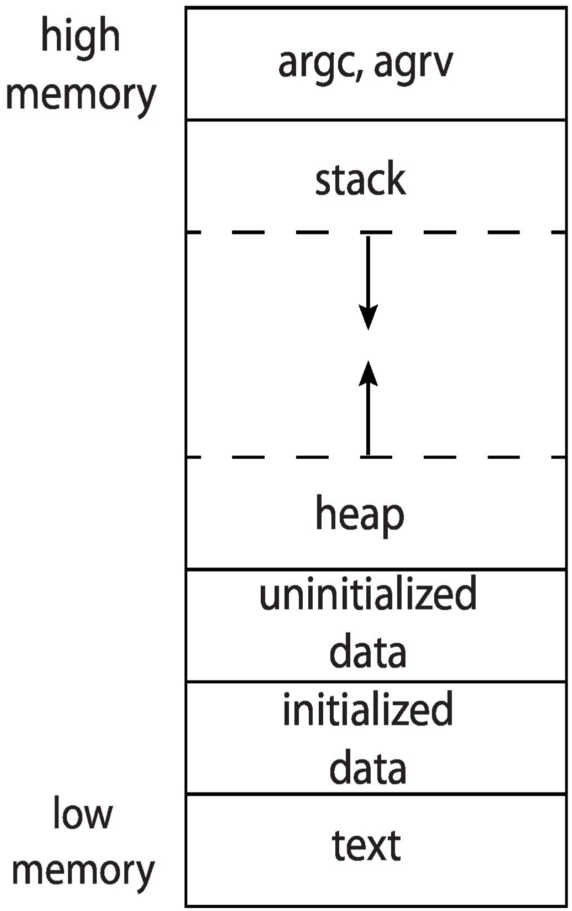
`#ps -aux`

# Process in Memory




***#size <pid>***

# Memory Layout of a C Program

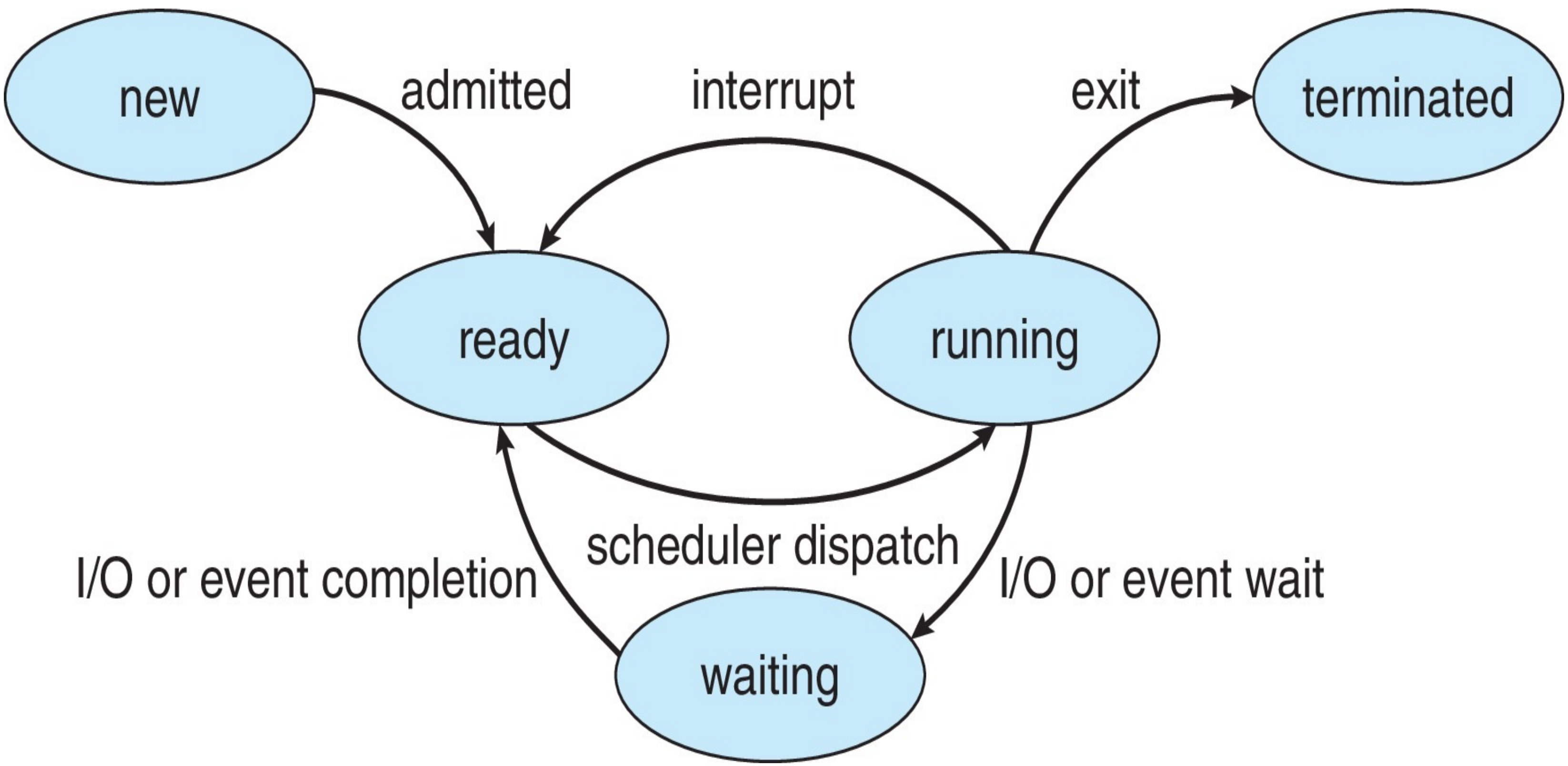



```
#include <stdio.h>
#include <stdlib.h>

int x;
int y = 15;

int main(int argc, char *argv[])
{
    int *values;
    int i;

    values = (int *)malloc(sizeof(int)*5);

    for(i = 0; i < 5; i++)
        values[i] = i;

    return 0;
}
```

# Process State

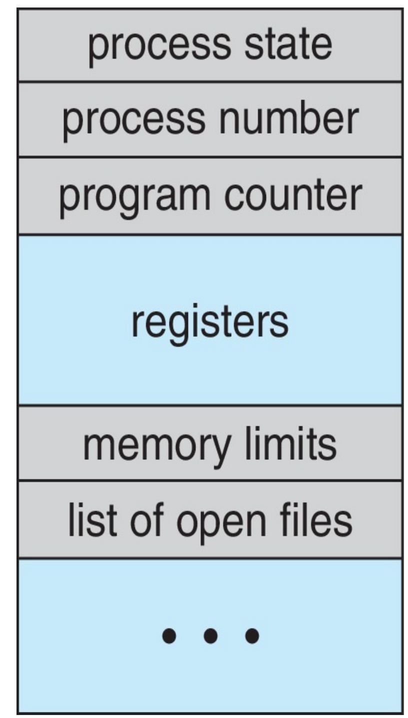
- As a process executes, it changes *state*
  - *New* – The process is being created
  - *Running* – Instructions are being executed
  - *Waiting* – The process is waiting for some event to occur
  - *Ready* – The process is waiting to be assigned to a processor
  - *Terminated* – The process has finished execution

# Diagram of Process State



# Process Control Block (PCB)

- **Process Control Block** (**PCB**) – Information associated with each process, also called **Task Control Block** (**TCB**), includes:
  - *Process state* – running, waiting, etc.
  - *Process number* – identity of the process
  - *Program counter* – location of instruction to next execute
  - *CPU registers* – contents of all process-centric registers
  - *CPU scheduling info* – 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



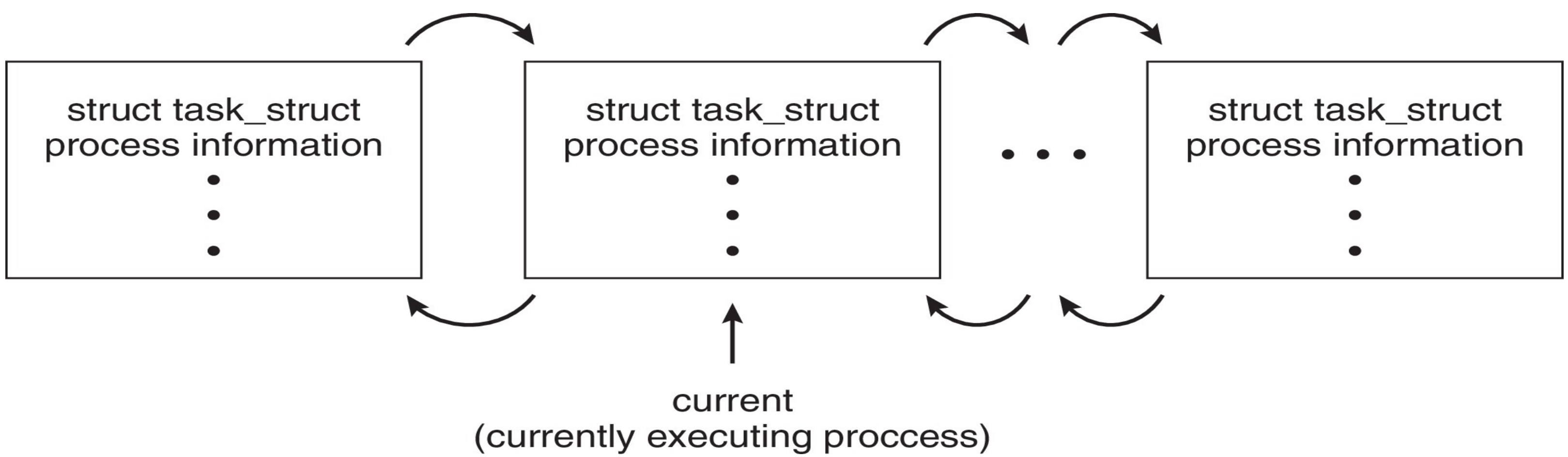
# Threads

- 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 Representation in Linux

- Represented by the C structure **`task_struct`**

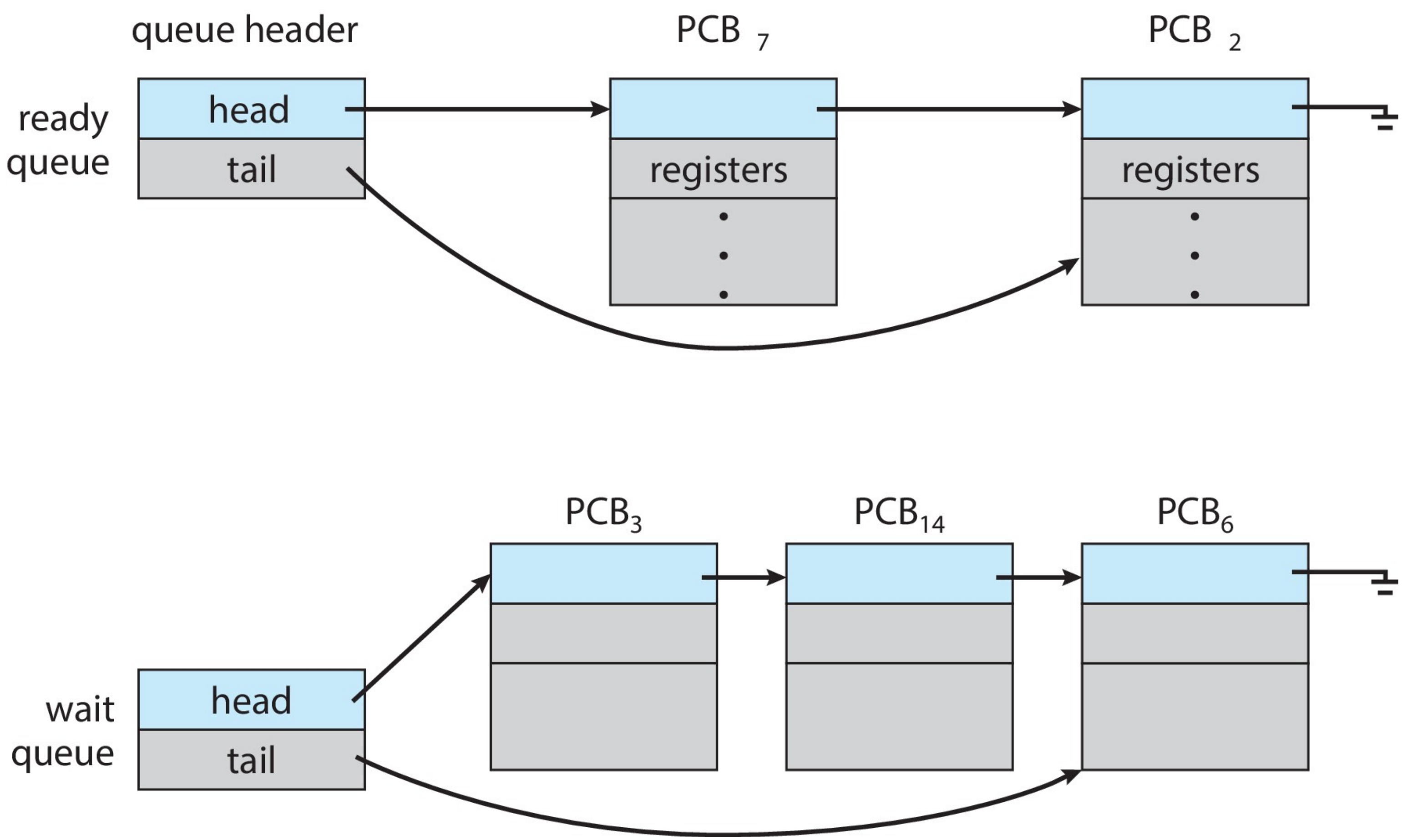
```
pid t_pid;                        /* process identifier */
long state;                       /* state of the process */
unsigned int time_slice           /* scheduling information */
struct task_struct *parent;       /* this process's parent */
struct list_head children;        /* this process's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



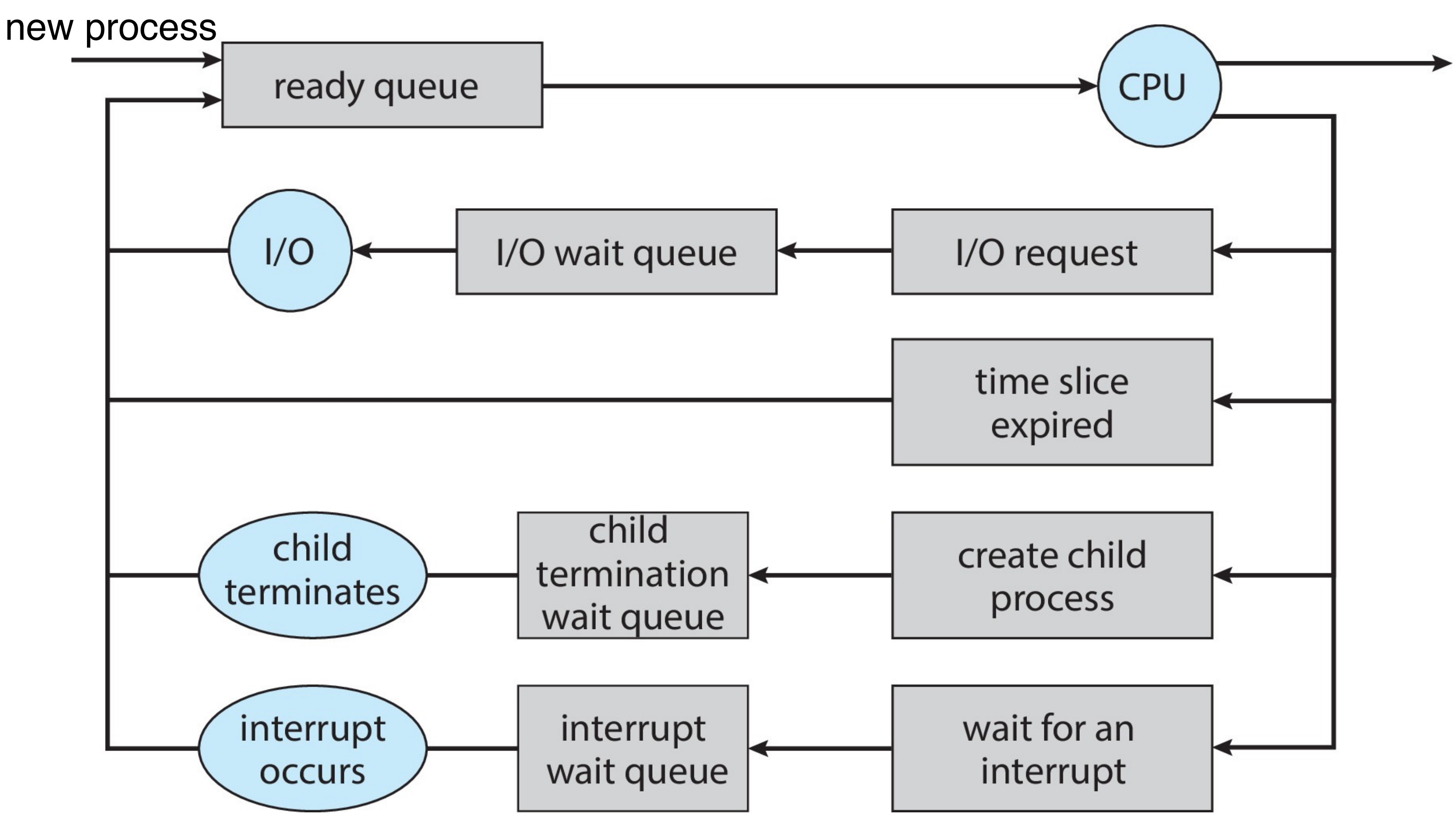
# Process Scheduling

- Maximize CPU use ⇢ quickly switch processes onto CPU core
- *Process scheduler* selects one process among available (ready) processes for next execution on CPU core
- Maintains *scheduling queues* of processes
  - *Ready queue* – set of all processes residing in main memory, ready and waiting to execute
  - *Wait queues* – set of processes waiting for an event (e.g., I/O)
- Processes migrate among the various queues

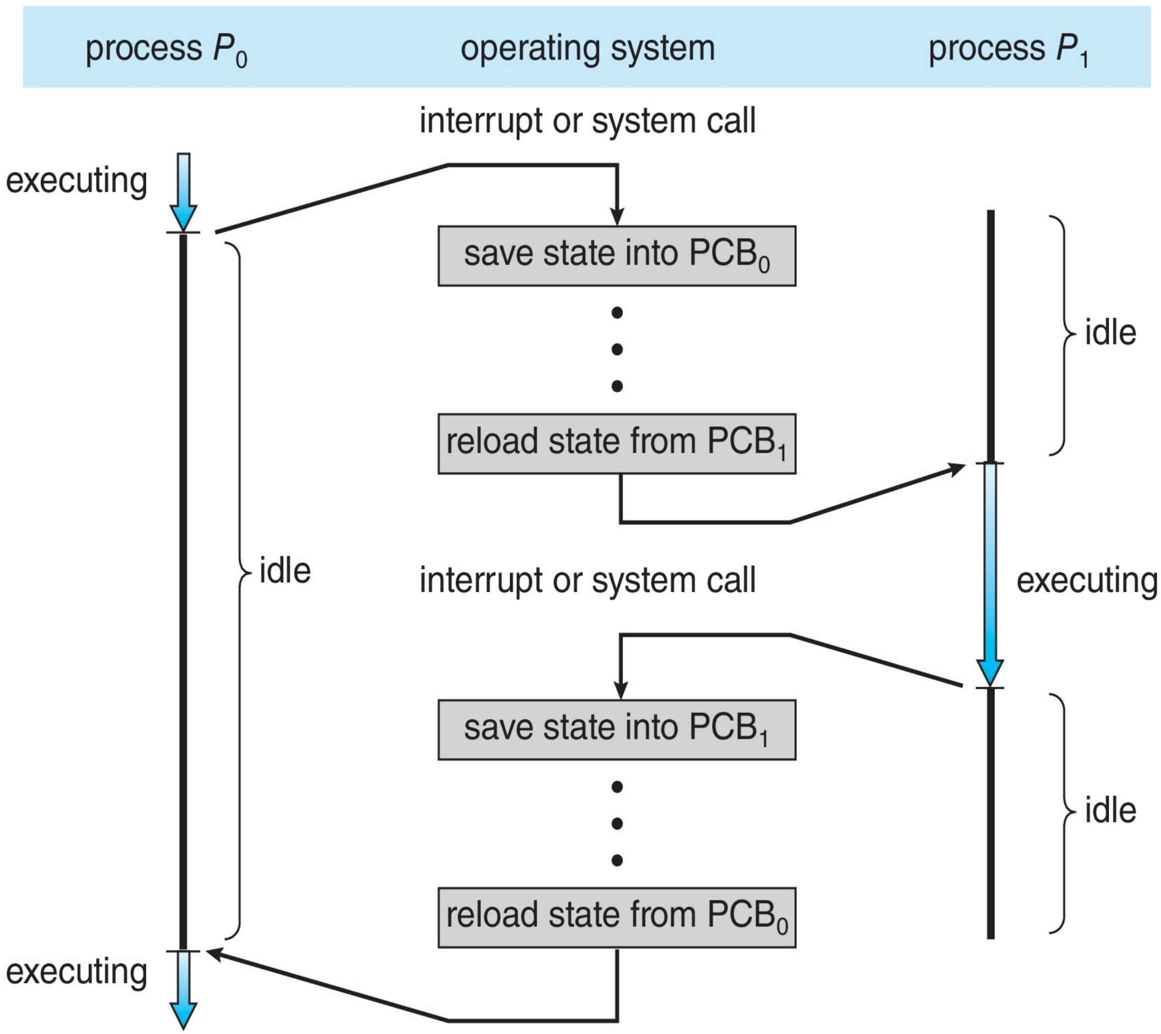
# Ready and Wait Queues



# Representation of Process Scheduling



# CPU Switch from Process to Process




- A *context switch* occurs when the CPU switches from one process to another.

# 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

# 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 state, 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

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

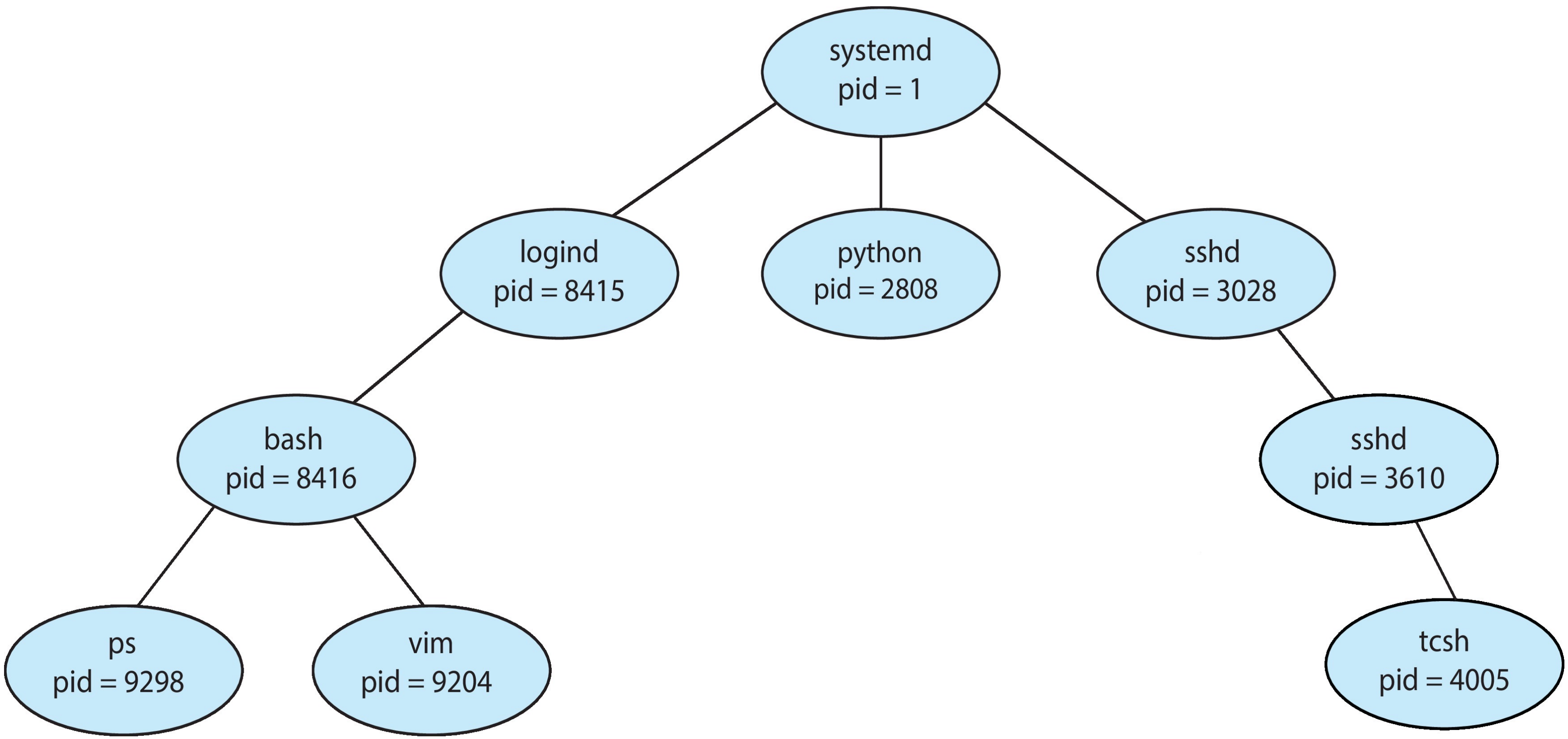
# Process Creation

- *Parent processes* create *children processes*, which, in turn create other processes, forming a *tree of processes*
- 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

# Process Creation (Cont.)

- **Execution options**
  - Parent and children execute concurrently
  - Parent waits until children terminate
- **Address space**
  - Child duplicate of parent
  - Child has a program loaded into it

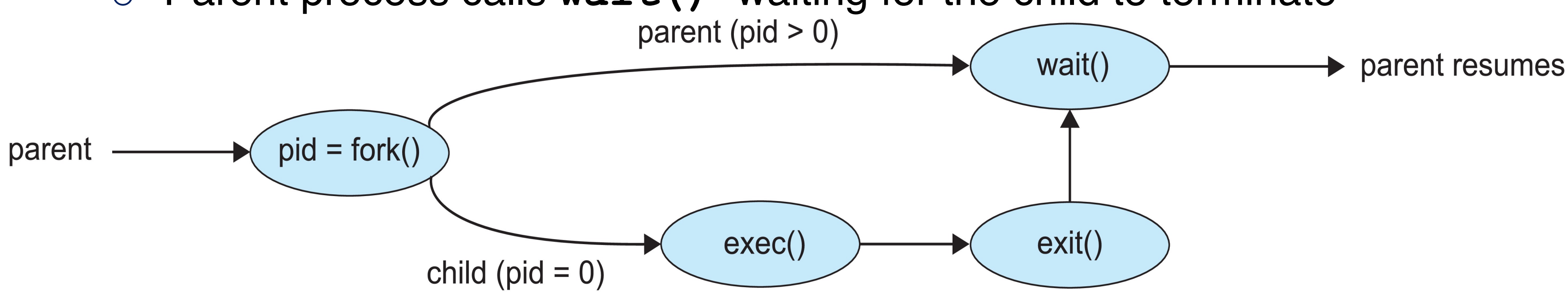
# A Tree of Processes in Linux




#pstree

# Process Creation (Cont.)

- UNIX examples
  - `system()` to execute a command from within a program
  - `fork()` system call creates new process
  - `exec()` system call used after a `fork()` to replace the process' memory space with a new program
  - Parent process calls `wait()` waiting for the child to terminate



# system() system call

```
#include <stdlib.h>
int system(const char *command);
```

- hands the argument command to the command interpreter sh: $/bin/sh –c <command>
  - Ex: $/bin/sh –c ls
- If command is NULL, system() return a nonzero value if a shell is available, or 0 if no shell is available
- ould not be created or its status could not be

```
#include <stdlib.h>
int main ( )
{
int return_value ;
return_value = system ( "ls ." );
return return_value;
}
```

```
Vans-MacBook-Air:c-examp ltvan$ ./systemsimple
2.2.c.rtfd        ex             fork2.c        pid
addrspace         ex.c           forkp          pid.cpp
```

# C Program Forking A Separate Process: fork()

```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;
}
```

# Example

- ….
- int main(){
-  printf("Hello \n");
-  1. fork();
-  2. fork();
- printf("Hello \n");
- return 0;
- }

How many processes will be generated?

num of process = 2^n-1

# 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 (Cont.)

- 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
- 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);`**
  - ✓ **waitpid**() suspends execution of the calling process until a child specified by *pid* argument has changed state
- If no parent waiting (did not invoke **`wait()`**), process is a *zombie*
- If parent terminated without invoking **`wait()`**, process is an *orphan*

# waitpid() example

**#include <sys/types.h>**
**#include <sys/wait.h>**

**pid_t waitpid(pid_t *pid*, int *_status_, int *options*);**

- pid< -1: wait for any child process whose process group ID is equal to the absolute value of *pid*.
- pid =1: wait for any child process
- pid = 0: wait for any child process whose process group ID is equal to that of the calling process
- pid>0: wait for the child whose process ID is equal to the value of *pid*

```c
#include<stdio.h>
#include<sys/wait.h>
#include<unistd.h>

int main(){
  pid_t pid=fork();
  if(pid==0){
    printf("Child proc id = %d, groupid = %d \n",
getpid(),getpgrp());
  }
  else if(pid>0){
    waitpid(pid,NULL,0);
    printf("Parent proc id = %d \n",getpid());
  }
  return 0;
}
```

wait(&status) is equivalent to waitpid(-1, &status, 0);

```
Vans-MacBook-Air:c-examp ltvan$ ./forkwpidr
Child proc id = 9716, groupid = 9715
Parent proc id = 9715
```

# wait(&status) example

**#include <sys/types.h>**
**#include <sys/wait.h>**
**pid_t wait(int *status);**

```
#include <stdio.h>
#include <unistd.h>
#include <sys/wait.h>
int main (int argc, char *argv[]){
        int     return_code;
        int status;
        /* create a new process */
        return_code = fork();
        if (return_code > 0){


                int id = wait(&status);
                printf("Parent process: child's pid =%d  with returned value = %d \n",id,WEXITSTATUS(status));
                 printf("child's pid =%d  with raw returned value = %d \n",id,status);
                printf("Pid of child %d \n",return_code);
                return 0;
        }
        else if (return_code == 0){
                printf("This is child process \n");
                return 10;//exit(10);
        }
        else {
                printf("Fork error\n");
                return 1;
        }
}
```

# Exercise

- ✓ Given the following code:

```
int main(){
    int i;
    for(i=0; i<n;i++)
        fork();
    return 0;
}
```

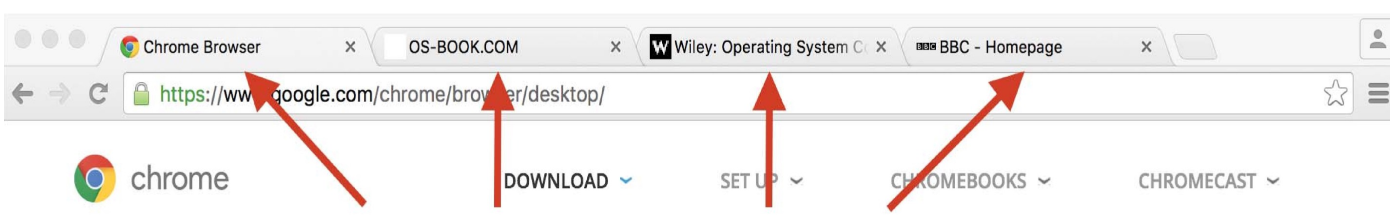
How many processes will be generated if n = 2?

# Importance Hierarchy of Android Process

- *Mobile operating systems* often have to terminate processes to reclaim system resources such as memory. From most to least important:
  - Foreground process
  - Visible process
  - Service process
  - Background process
  - Empty process
- Android will begin terminating processes that are least important.

# Multiprocess Architecture – Chrome Browser

- Many web browsers ran as a 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




Each tab represents a separate process.

# Inter-Process Communication (IPC)

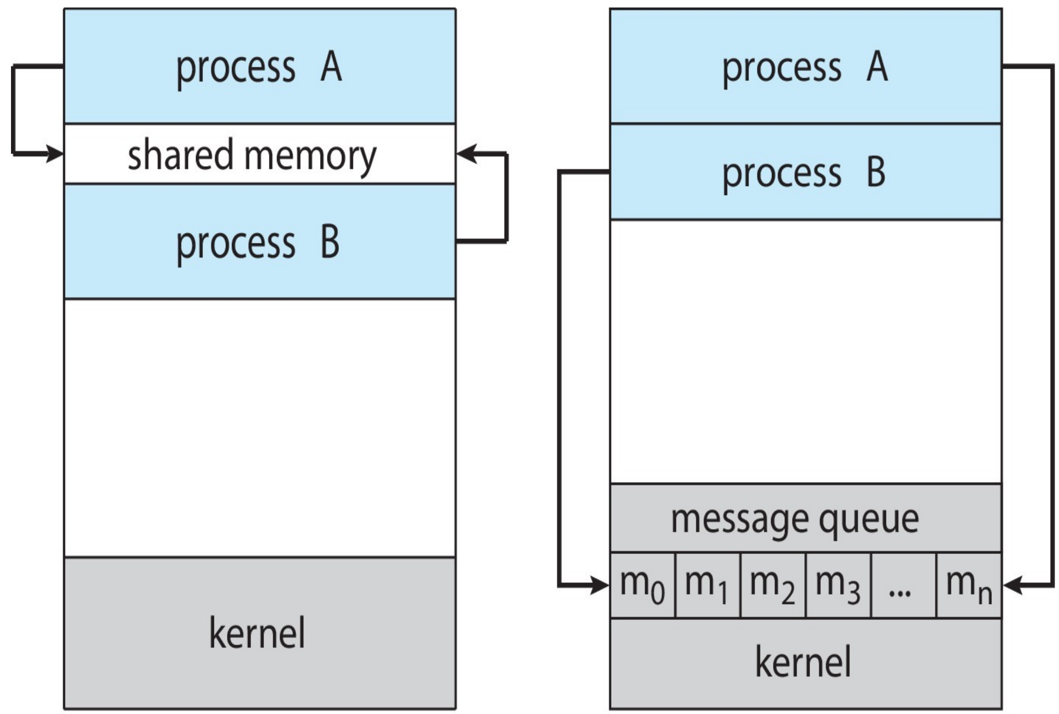
- Processes within a system may be *independent* or *cooperating*
  - *Independent process* does not share data with any other processes executing in the system
  - *Cooperating process* can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience
- Cooperating processes need **Inter-Process communication** (**IPC**)

# Communication Models

- Two models of IPC
  - *Shared memory*
  - *Message passing*

Shared memory

Message passing




(a) (b)

# Inter-Process 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.

# Producer-Consumer Problem

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

# Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
 . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```

- Solution is correct, but can only use BUFFER_SIZE-1 elements

# Producer Process – Shared Memory

```
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;
}
```

# Consumer Process – Shared Memory

```
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 */
}
```

# Inter-Process 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

# 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?

# 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 (Cont.)

- Operations
  - create a new mailbox (or 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 (Cont.)

- **Mailbox sharing**
  - <u>**Example**</u>
    - $P_1$, $P_2$, and $P_3$ share mailbox A,
    - $P_1$ sends; $P_2$ and $P_3$ receive.
    - Who gets the message?
  - <u>**Solutions**</u>
    - 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

# Message Passing – 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*

# Producer – Message Passing

```
message next_produced;

while (true) {
      /* produce an item in next_produced */

       send(next_produced);
}
```

# Consumer – Message Passing

```
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
  - *Zero capacity* – no messages are queued on a link
    - Sender must wait for receiver (rendezvous)
  - *Bounded capacity* – finite length of *n* messages
    - Sender must wait if link full
  - *Unbounded capacity* – infinite length
    - Sender never waits

# Examples of IPC Systems - POSIX

- **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
  - Set the size of the object

    ```
    ftruncate(shm_fd, 4096);
    ```

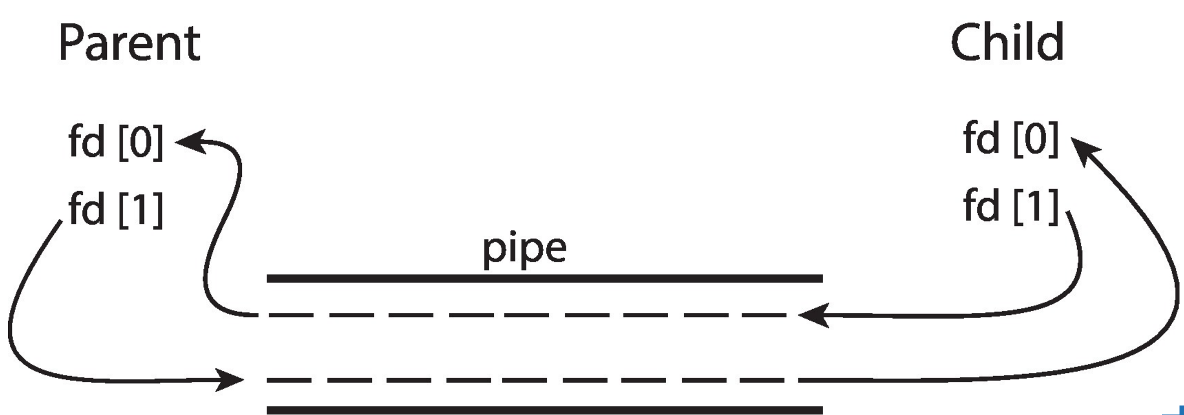
  - Use **`mmap()`** to memory-map a file pointer to the shared memory object
  - Reading and writing to shared memory is done by using the pointer returned by **`mmap()`**.

# 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 (e.g., *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



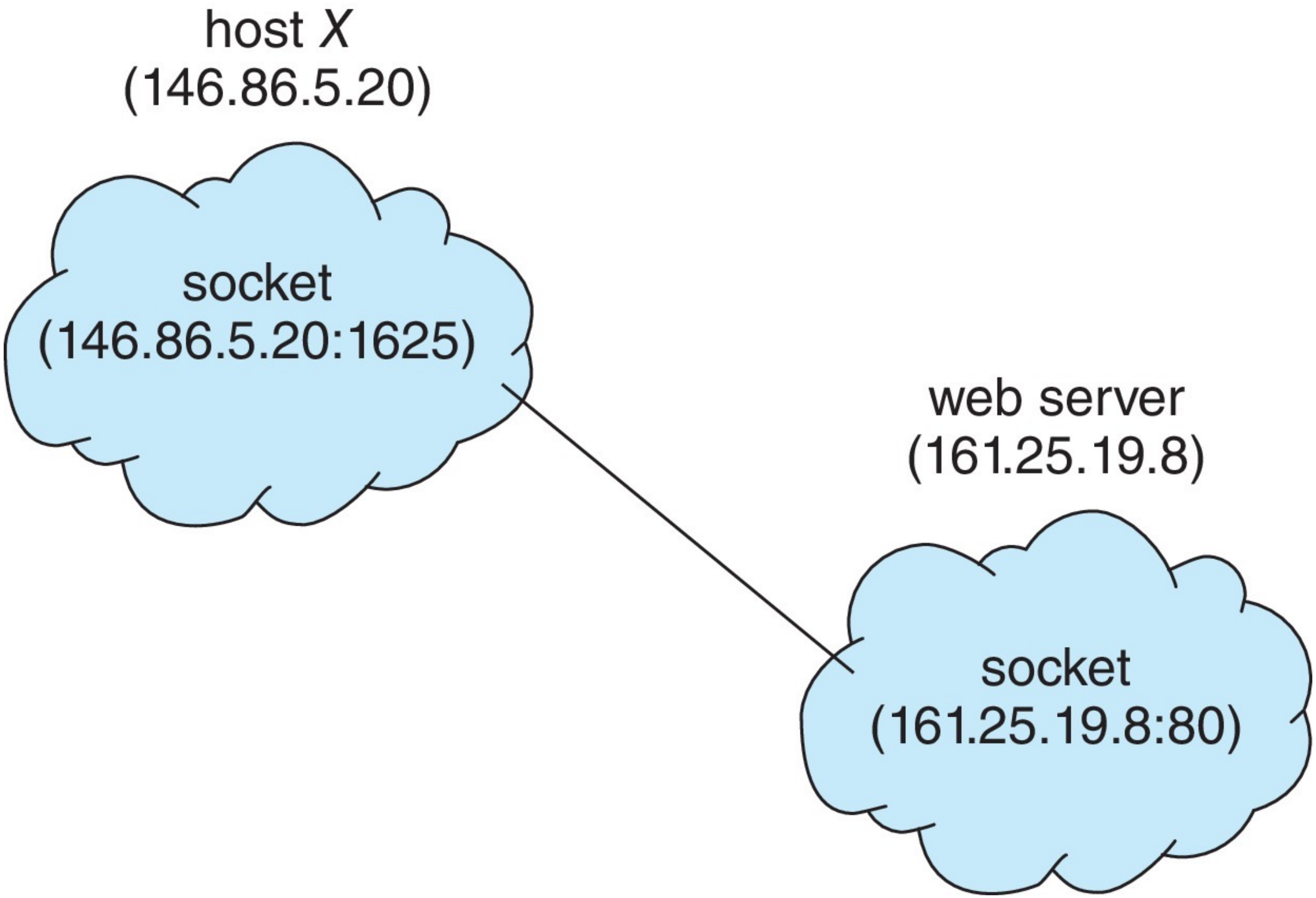
# Named Pipes

- *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

# Communications in Client-Server Systems

- **Sockets**
  - A *socket* is defined as an endpoint for communication
  - It is a concatenation of *IP address* and *port* – a number included at start of message packet to differentiate network services on a host
    - E.g., 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
- **Remote Procedure Calls (RPC)**

# Socket Communication



# Sockets in Java – 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);
    }
  }
}
```

- Three types of sockets
  - *Connection-oriented (TCP)*
  - *Connectionless (UDP)*
  - **`MulticastSocket`** class– data can be sent to multiple recipients
- Consider this "Date" *server* in Java:

# Sockets in Java – Client

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

public class DateClient
{
   public static void main(String[] args) {
      try {
         /* make connection to server socket */
         Socket sock = new Socket("127.0.0.1",6013);

         InputStream in = sock.getInputStream();
         BufferedReader bin = new
            BufferedReader(new InputStreamReader(in));

         /* read the date from the socket */
         String line;
         while ( (line = bin.readLine()) != null)
            System.out.println(line);

         /* close the socket connection*/
         sock.close();
      }
      catch (IOException ioe) {
         System.err.println(ioe);
      }
   }
}
```

- The equivalent "Date" *client*

# Remote Procedure Calls

- **Remote Procedure Call** (**RPC**) abstracts procedure calls between processes on *networked systems*
  - Again uses *ports* for service differentiation
- *Stubs* – proxies for the actual procedure on the server and client sides
  - The *client-side stub* locates the server and *marshals* 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** (**XDR**) format to account for different architectures
  - E.g., *Big-endian* (Motorola) and *little-endian* (Intel x86)
- 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

# End of Chapter 3