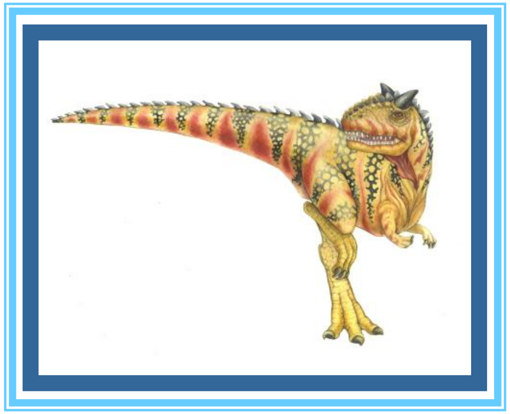
Chapter 3: Processes



Silberschatz, Galvin and Gagne ©2018

Outline

- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication
- 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 using system calls.
- Describe and contrast interprocess communication using shared memory and message passing.
- Design programs that uses pipes and POSIX shared memory to perform interprocess communication.
- Describe client-server communication using sockets and remote procedure calls.
- Design kernel modules that interact with the Linux operating system.

Process Concept

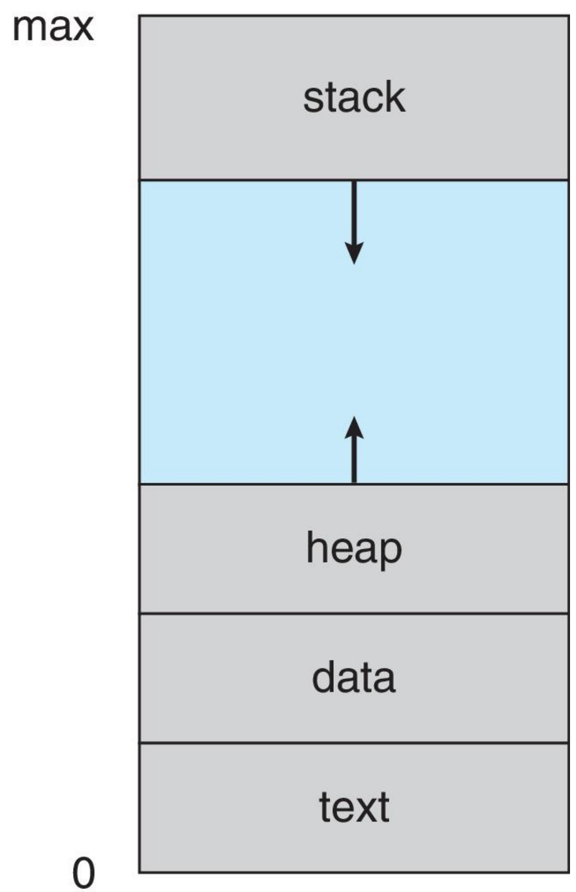
- An operating system executes a variety of programs that run as a process.
- Multiple processes can execute concurrently, with the CPU (or CPUs) multiplexed among them.
- **Process** – a program in execution; process execution must progress in sequential fashion. No parallel execution of instructions of a single process
- Multiple parts
  - The executable code, also called **text section**
  - Current activity including **program counter**, processor registers
  - **Stack** containing temporary data
    - Function parameters, return addresses, local variables
  - **Data section** containing global variables
  - **Heap** containing memory dynamically allocated during run time

Process Concept (Cont.)

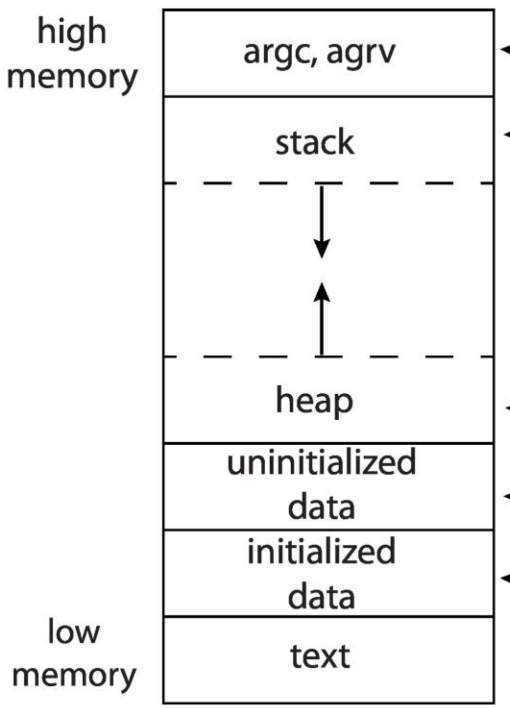
- Program is **passive** entity stored on disk (**executable file**); process is **active**
  - Program becomes process when an executable file is loaded into memory
- Execution of program started via GUI mouse clicks, command line entry of its name, etc.
- One program can be associated with several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

Process in Memory

- Sizes of the text and data sections are fixed (Why??)
- Operating system must ensure they do not ***overlap*** one another



Memory Layout of a C Program

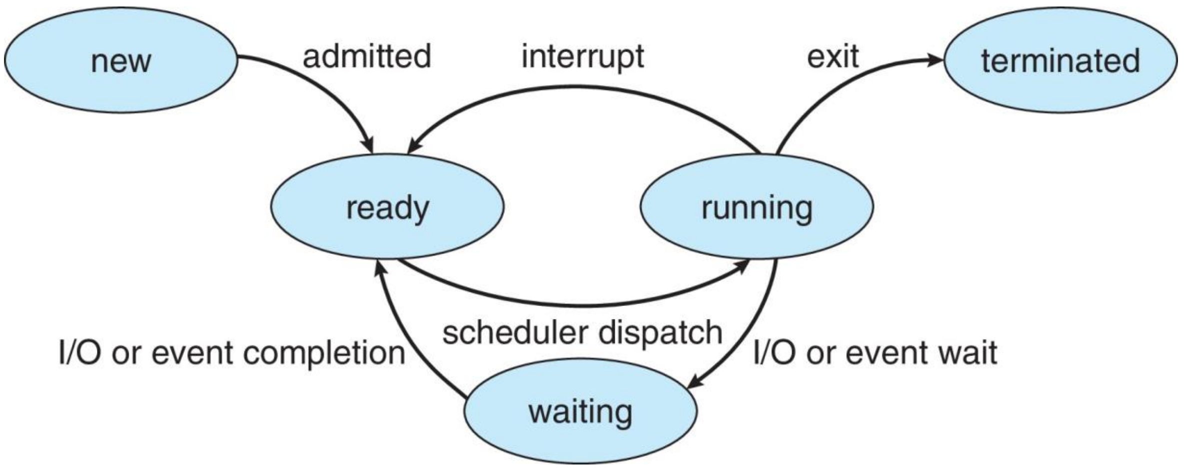



```c
#include <stdio.h>
#include <stdlib.h>

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
    - only one process can be running on any processor core at any instant
  - **Waiting**: The process is waiting for some event to occur
  - **Ready**: The process is waiting to be assigned to a processor
  - **Terminated**: The process has finished execution

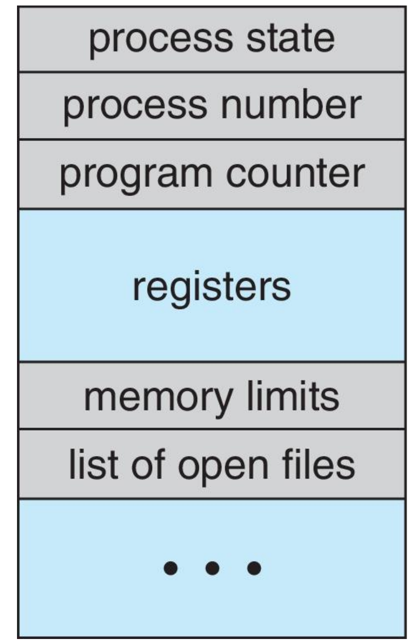
Diagram of Process State



Process Control Block (PCB)

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

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



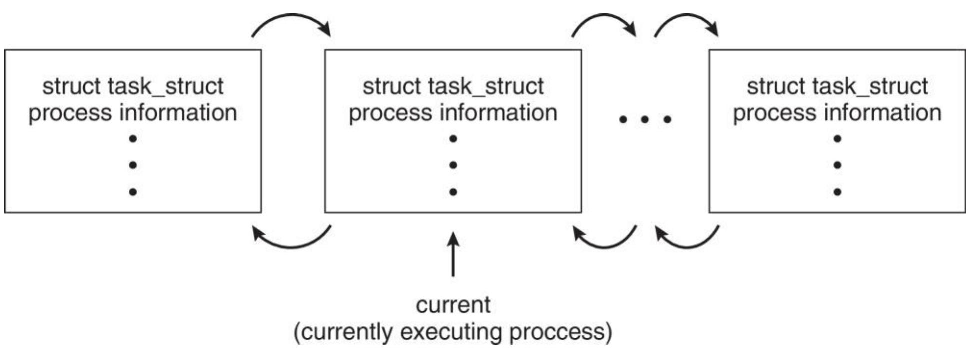
Threads

- 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**
- PCB must have storage for thread details, multiple program counters
- Example: A multithreaded word processor could, for example, assign one thread to manage user input while another thread runs the spell checker.

Process Representation in Linux

Represented by the C structure `task_struct` in <include/linux/sched.h>

```
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 */
```

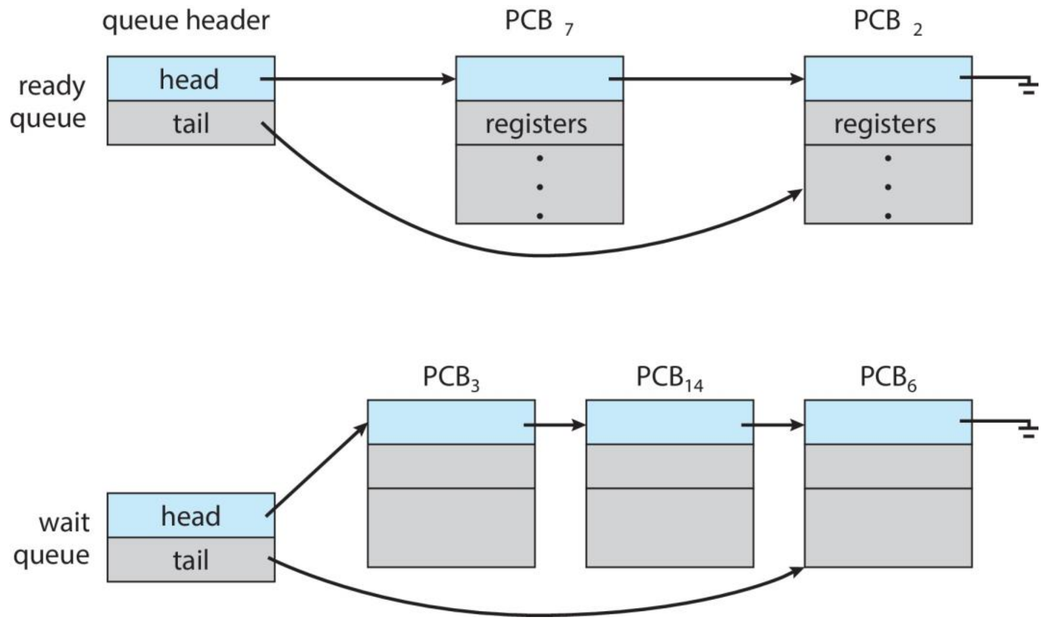


- Within the Linux kernel, all active processes are represented using a doubly linked list of `task_struct`

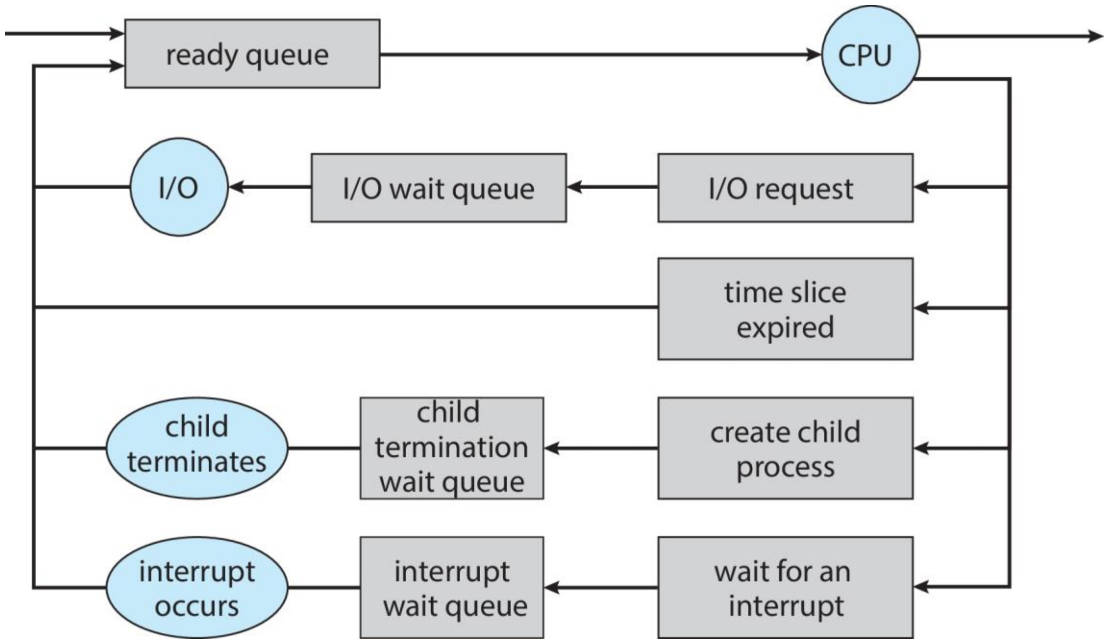
Process Scheduling

- For a system with a single CPU core, there will never be more than one process running at a time.
- In case more processes than cores, excess processes will have to wait until a core is free.
- The number of processes currently in memory is known as the **degree of multiprogramming**.
- **Process scheduler** selects among available processes for next execution on CPU core
- Goal -- Maximize CPU use, quickly switch processes onto 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 (i.e., I/O)
  - Processes migrate among the various queues (state diagram!!)

Ready and Wait Queues



Representation of Process Scheduling

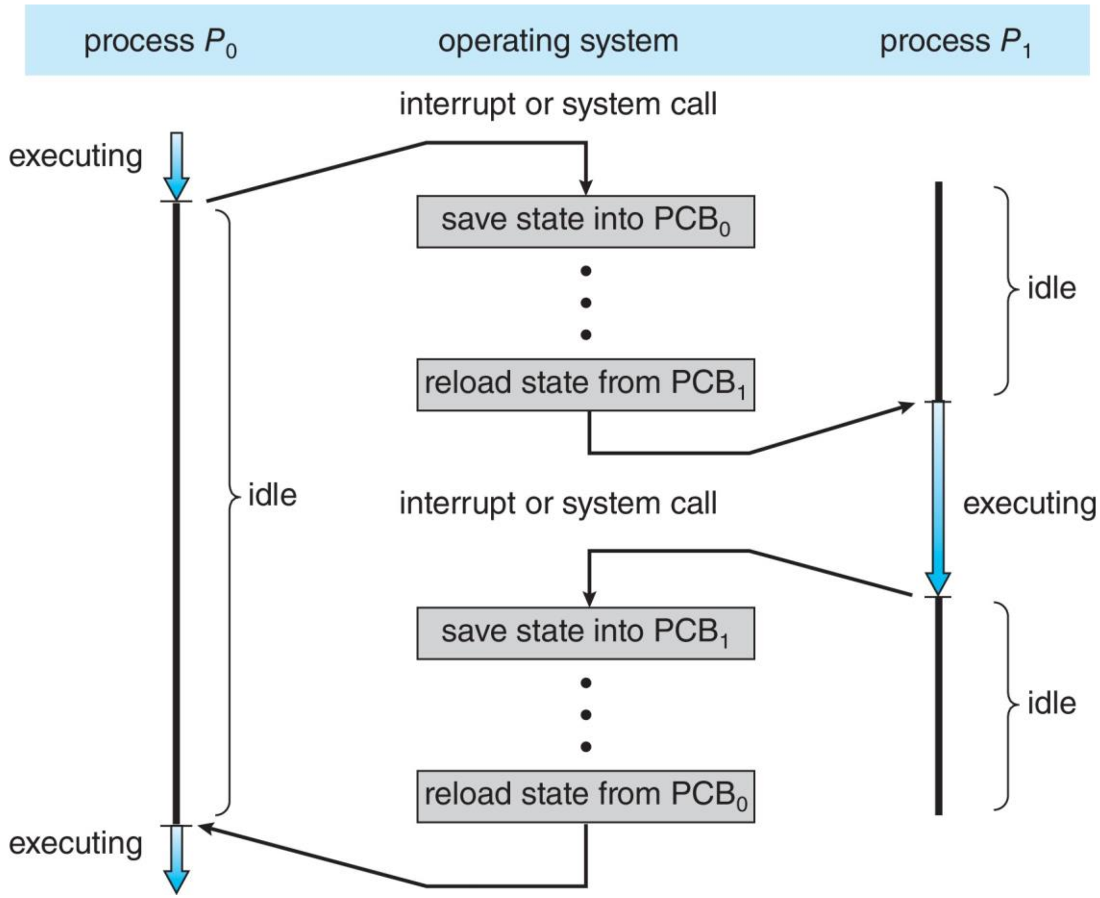


Context Switch

- 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 pure 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 ➔ A context switch here simply requires changing the pointer to the current register set.

CPU Switch From Process to Process

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



Multitasking in Mobile Systems

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

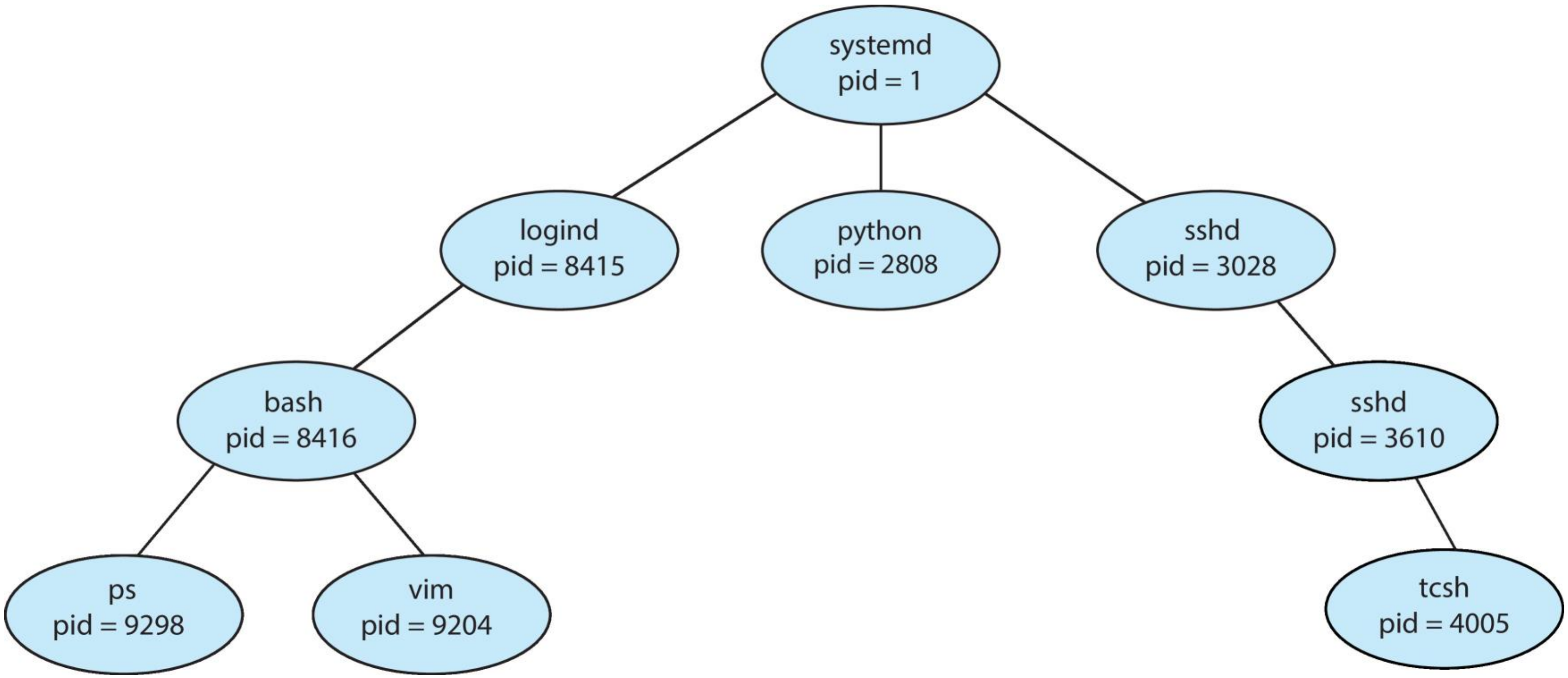
Process Creation

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

Process Creation (Cont.)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - **`fork()`** system call creates new process
  - **`exec()`** system call used after a **`fork()`** to replace the process' memory space with a new program
  - Parent process calls **`wait()`** waiting for the child to terminate

A Tree of Processes in Linux

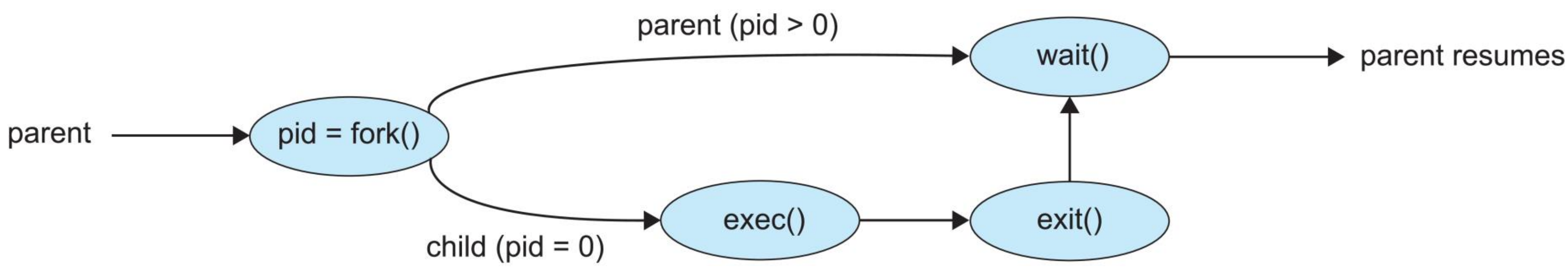


C Program Forking Separate Process

```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;
}
```

Process Creation (Cont.)

- After fork(), one of the two processes typically uses the exec() to replace the process's memory space with a new program.
- execlp() is a version of the exec() through which child process overlays its address space with the UNIX command /bin/ls
- The parent waits for the child process to complete with the wait()
  - When the child process completes, by either implicitly or explicitly, invoking exit() the parent process resumes from the call to wait()



Creating a Separate Process via Windows API

- Read by yourself

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 (**cascading termination**)
    - Normally initiated by the operating system

Process Termination

- 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);`

- When a process terminates, its resources are deallocated
  - However, its entry in the process table must remain there until the parent calls wait(), because it contains the process's exit status
  - All processes transition to this state when they terminate
- If no parent waiting (did not invoke **`wait()`**) process is a **zombie**
- If parent terminated without invoking **`wait()`**, process is an **orphan**

Interprocess Communication

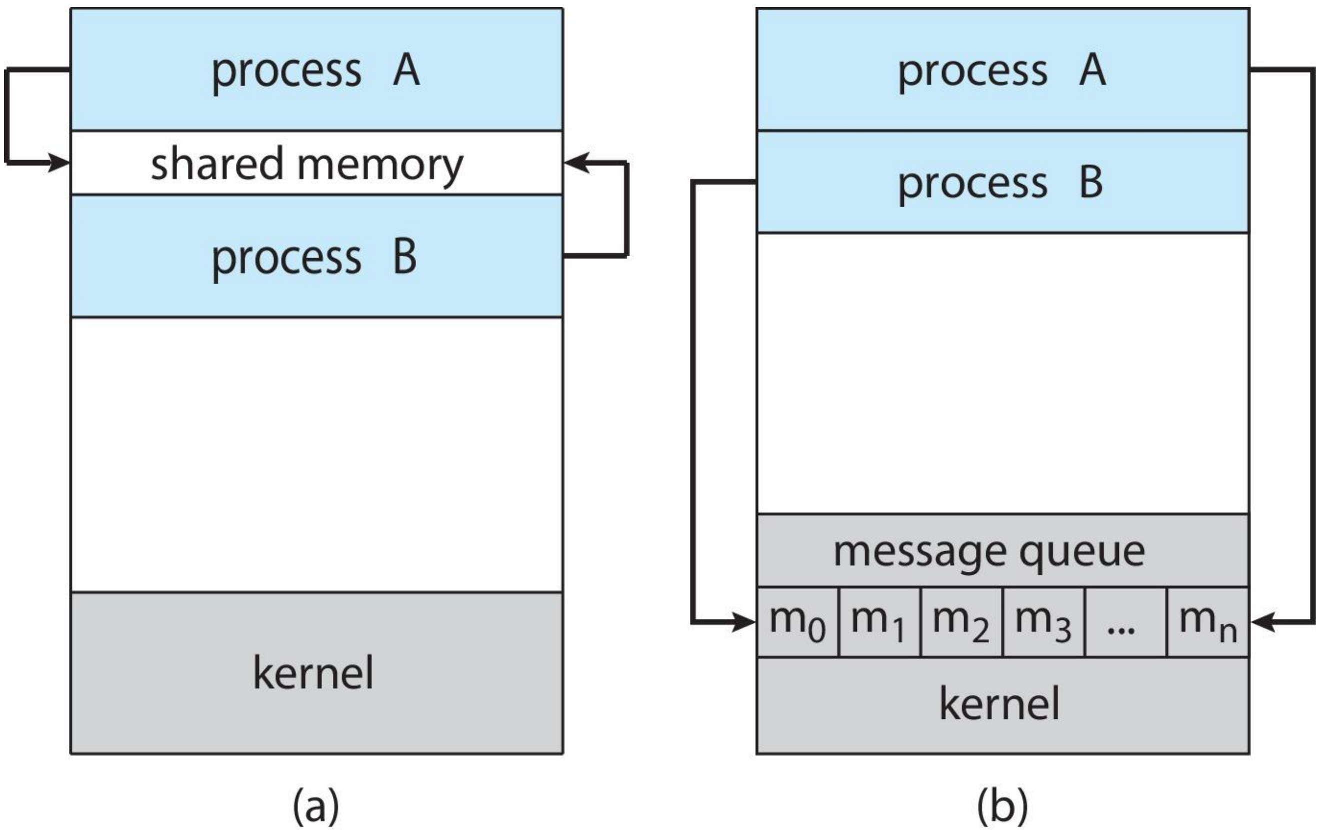
- Processes within a system may be ***independent*** or ***cooperating***
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing (allow concurrent access to such information)
  - Computation speedup (we must break it into subtasks)
  - Modularity
- Cooperating processes need **interprocess communication** (**IPC**)

Interprocess Communication

- Two models of IPC
  - **Shared memory**
    - Processes can then exchange information by reading and writing data to the shared region
    - Shared memory can be faster than message passing (Why??)
  - **Message passing**
    - communication takes place by means of messages exchanged between the cooperating processes
    - Useful for exchanging smaller amounts of data, because no conflicts need be avoided
    - easier to implement in a distributed system

Communications Models

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



IPC in Shared-Memory Systems

- Requires communicating processes to establish a region of shared memory
- Shared-memory region resides in the address space of the process creating the shared-memory segment.
  - OS tries to prevent one process from accessing another process's memory. Thus, processes agree to remove this restriction
- Exchange information by reading and writing data in the shared areas.
  - The form of the data and the location are determined by these processes and are not under the OS's control.

Producer-Consumer Problem

- Paradigm for cooperating processes:
  - *producer* process produces information that is consumed by a *consumer* process
    - e.g., a compiler may produce assembly code that is consumed by an assembler.
- Two variations:
  - **unbounded-buffer** places no practical limit on the size of the buffer:
    - Producer never waits
    - Consumer waits if there is no buffer to consume
  - **bounded-buffer** assumes that there is a fixed buffer size
    - Producer must wait if all buffers are full
    - Consumer waits if there is no buffer to consume

Bounded-Buffer – Shared-Memory Solution

- Shared data

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

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)
                ; /* empty buffer do nothing */
        next_consumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;

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

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

What about Filling all the Buffers?

- Suppose that we wanted to provide a solution to the consumer-producer problem that fills **all** the buffers.
- We can do so by having an integer **`counter`** that keeps track of the number of full buffers.
- Initially, **`counter`** is set to 0.
- The integer **`counter`** is incremented by the producer after it produces a new buffer.
- The integer **`counter`** is and is decremented by the consumer after it consumes a buffer.

Producer

```
while (true) {
        /* produce an item in next produced */

        while (counter == BUFFER_SIZE)
                ; /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % BUFFER_SIZE;
        counter++;
}
```

Consumer

```
while (true) {
        while (counter == 0)
                ; /* do nothing */
        next_consumed = buffer[out];
        out = (out + 1) % BUFFER_SIZE;
        counter--;
        /* consume the item in next consumed */
}
```

Race Condition

- **`counter++`** could be implemented as

```
register1 = counter
register1 = register1 + 1
counter = register1
```

- **`counter--`** could be implemented as

```
register2 = counter
register2 = register2 - 1
counter = register2
```

- Consider this execution interleaving with "count = 5" initially:

S0: producer execute `register1 = counter` {register1 = 5}
S1: producer execute `register1 = register1 + 1` {register1 = 6}
S2: consumer execute `register2 = counter` {register2 = 5}
S3: consumer execute `register2 = register2 - 1` {register2 = 4}
S4: producer execute `counter = register1` {counter = 6 }
S5: consumer execute `counter = register2` {counter = 4}

Race Condition (Cont.)

- **Question – why was there no race condition in the first solution (where at most N – 1) buffers can be filled?**

IPC – Message Passing

- 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?

Implementation of Communication Link

- Physical Implementation:
  - Shared memory
  - Hardware bus
  - Network
- Logical Implementation:
  - Direct or indirect
  - Synchronous or asynchronous
  - Automatic or explicit buffering (bounded or unbounded buffer)

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, processes need to know only each other's identity to communicate
  - 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
- Two Variants
  - Both the sender process and the receiver process must name the other to communicate (***symmetry*** in addressing)
  - Sender names the recipient; the recipient is not required to name the sender (***asymmetry*** in addressing)

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
- Mailbox can be viewed abstractly as an object into which messages can be placed by processes and from which messages can be removed.
- 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 (port)
  - Send and receive messages through mailbox
  - Delete 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
  - P_1, P_2, and P_3 share mailbox A
  - P_1, sends; P_2 and P_3 receive
  - Who gets the message?
- Solutions depends on which of the following methods we choose
  - Allow a link to be associated with at most two processes
  - Allow only one process at a time to execute a receive operation (How??)
  - Allow the system to select arbitrarily the receiver (may be round robin). Sender is notified who the receiver was.

Synchronization

Message passing may be either blocking or non-blocking

- **Blocking** is considered **synchronous**
  - **Blocking send** -- the sender is blocked until the message is received
  - **Blocking receive** -- the receiver is blocked until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking send** -- the sender sends the message and continue
  - **Non-blocking receive** -- the receiver receives:
    - A valid message, or
    - Null message

Producer-Consumer: Message Passing

- Producer

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

 send(next_produced);
}
```

- Consumer

```
message next_consumed;
while (true) {
     receive(next_consumed);

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

- blocking send() and receive() statements

Buffering

- Whether communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue.
- 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

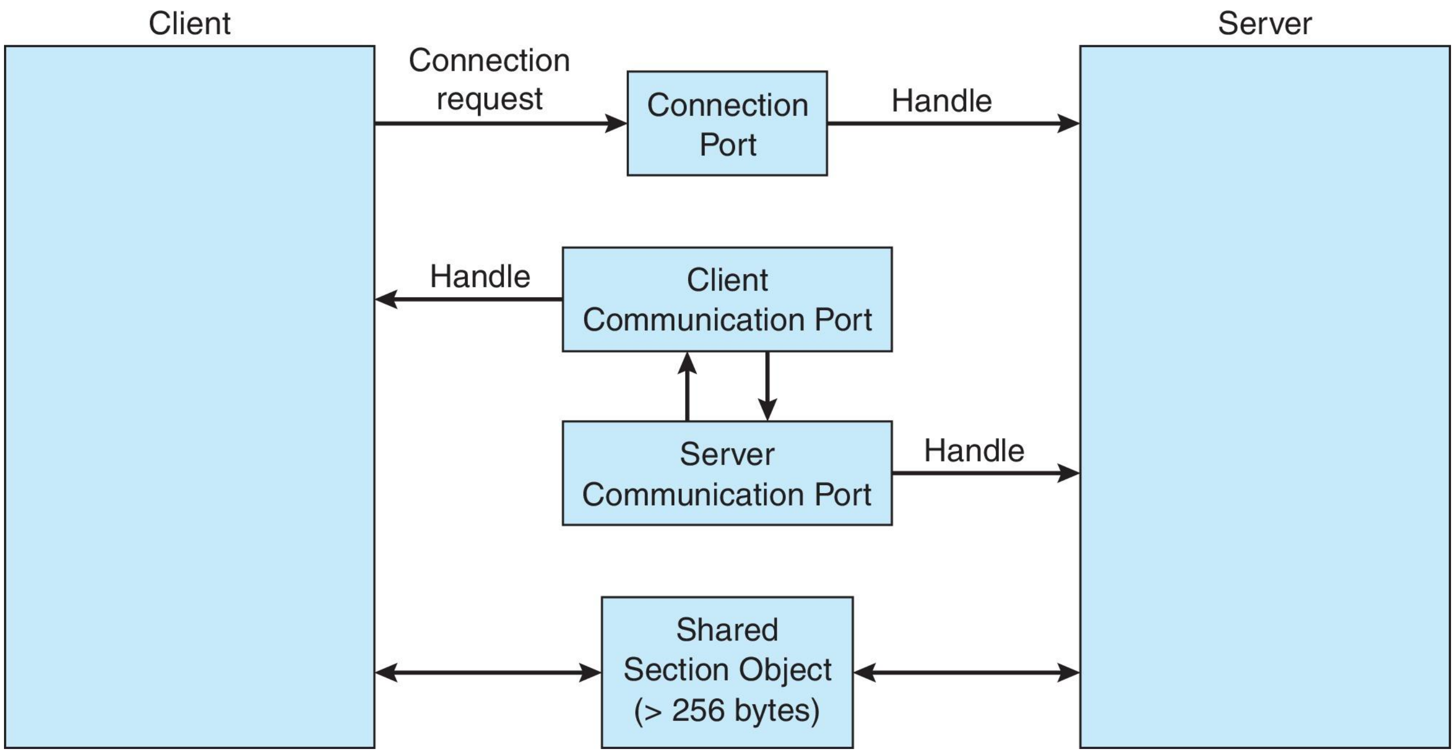
Examples of IPC Systems – Windows

- Windows provides support for multiple operating environments, or ***subsystems and* application programs** communicate with these subsystems via a message-passing mechanism.
  - application programs are clients of a subsystem server
- Message-passing centric via **advanced local procedure call (ALPC)** facility
  - Only works between processes on the same system
  - Uses ports (like mailboxes) to establish and maintain communication channels

Examples of IPC Systems – Windows

- 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.
    - one for client–server messages, the other for server–client messages
  - The client and server use the corresponding port handle to send messages or callbacks and to listen for replies.
- For small messages (up to 256 bytes), the port's message queue is used as intermediate storage
- Larger messages must be passed through a **section object**

Local Procedure Calls in Windows

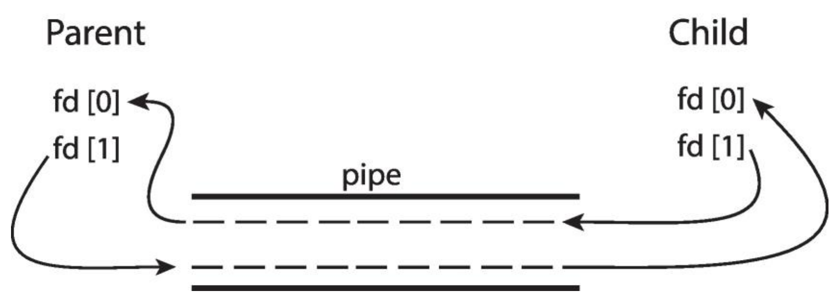


Pipes

- Acts as a channel allowing two processes to communicate
- First IPC mechanisms in early UNIX systems
- 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
  - If two-way communication is required, two pipes must be used
- Require parent-child relationship between communicating processes



- Windows calls these **anonymous pipes**
- UNIX treats a pipe as a special type of file. Thus, pipes can be accessed using ordinary read() and write() system calls

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

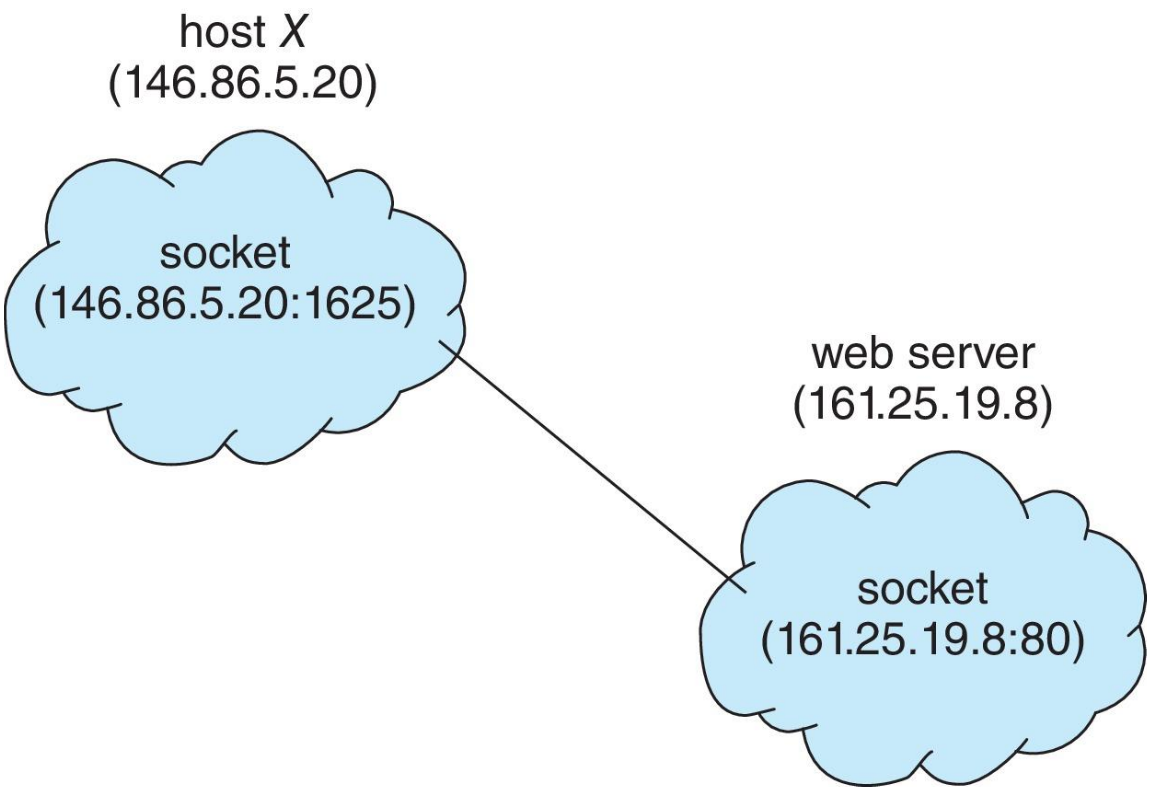
Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls

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
  - FTP server listens to port 21; and a web, or HTTP, server listens to port 80
- 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 in Java:

```
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);
      }
   }
}
```

Sockets in Java

The equivalent Date 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);
      }
   }
}
```

Remote Procedure Calls

- Read by yourself

End of Chapter 3