PART TWO :
PROCESS MANAGEMENT

Chapter 3: Processes
Chapter 4: Threads & Concurrency
Chapter 5: CPU Scheduling

Chapter 3

Processes

Chapter 3: Processes

- 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, including developing programs using the appropriate system calls that perform these operations
- Describe and contrast interprocess communication using shared memory and message passing
- Design programs that use 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

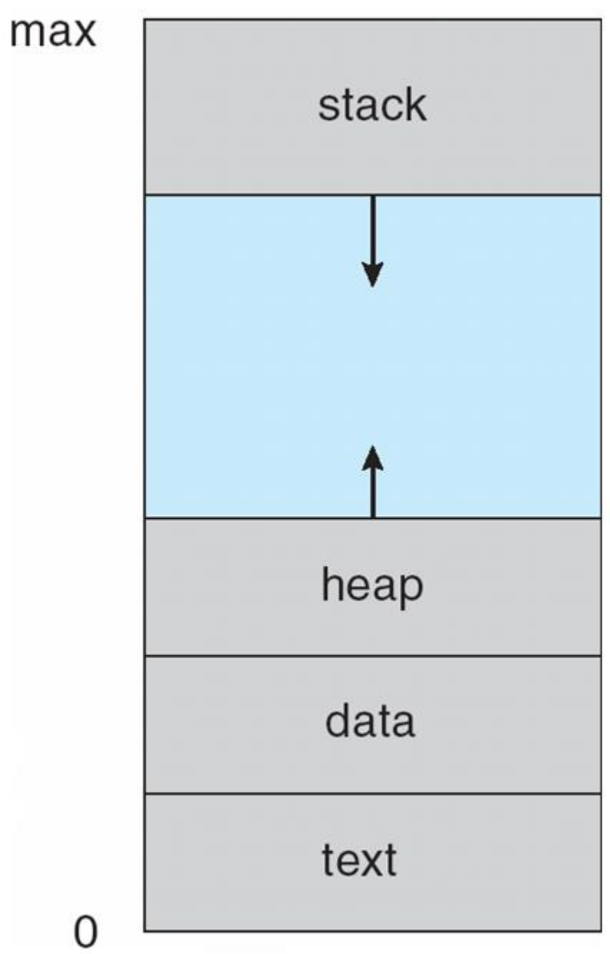
3.1 Process Concept

- An operating system executes a variety of programs:
  - Batch system – **jobs**
  - Time-shared systems – **user programs** or **tasks**
- Textbook uses the terms ***job*** and ***process*** almost interchangeably
- **Process** – a program in execution; process execution must progress in sequential fashion
- Multiple parts
  - The program code, also called **text section**
  - Current activity including **program counter**, **processor registers**
  - **Stack** containing temporary data
    - Function parameters, return addresses, local variables
  - **Data section** containing global variables
  - **Heap** containing memory dynamically allocated during run time

Process Concept (Cont.)

- 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

Process in Memory

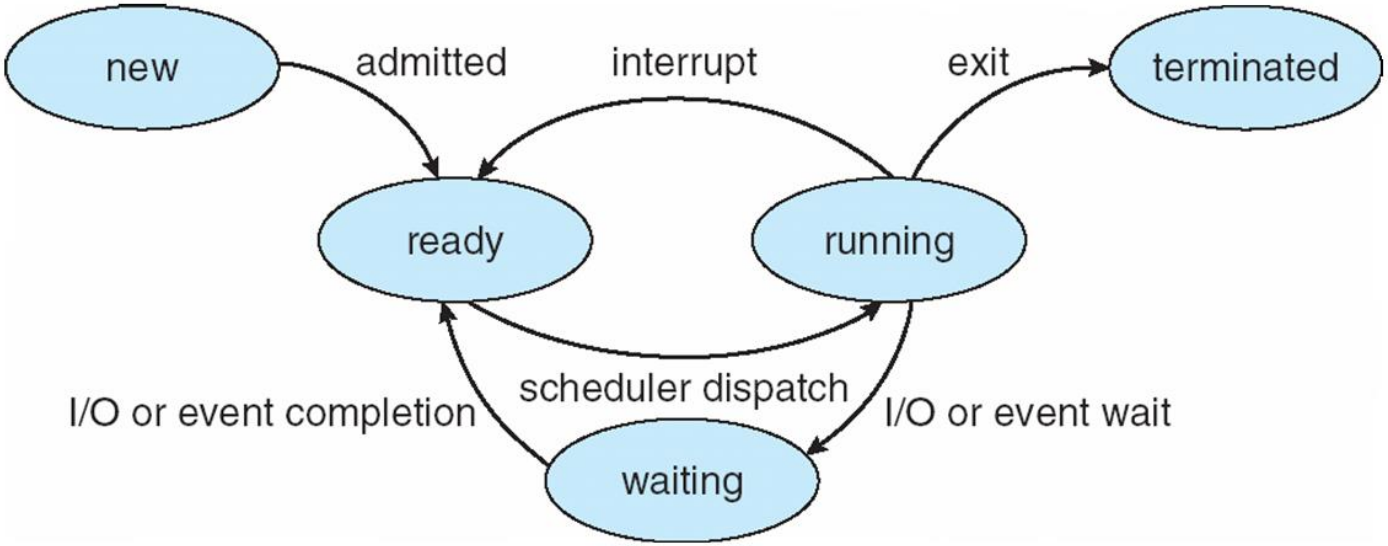


Process State

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

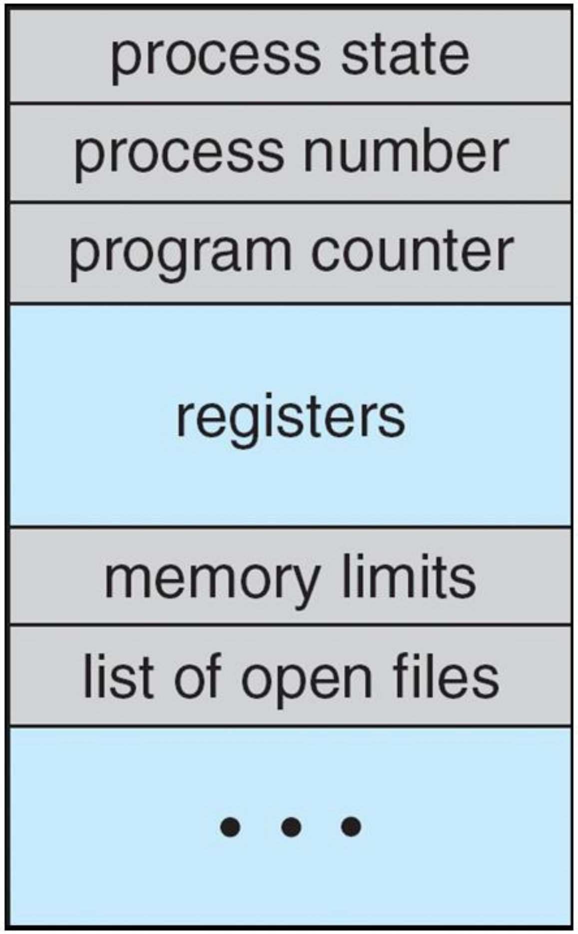


Process Control Block (PCB)

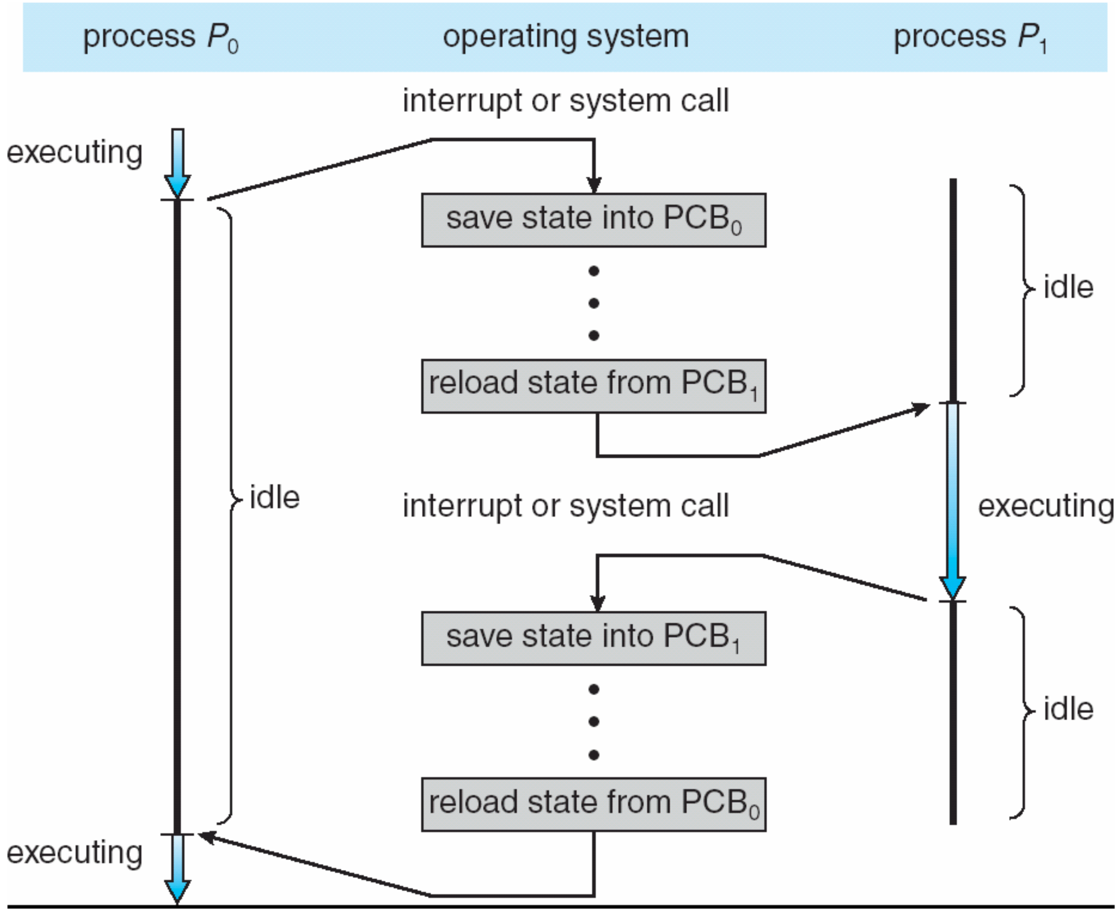
Information associated with each process

(also called **task control block**)

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



CPU Switch From Process to Process



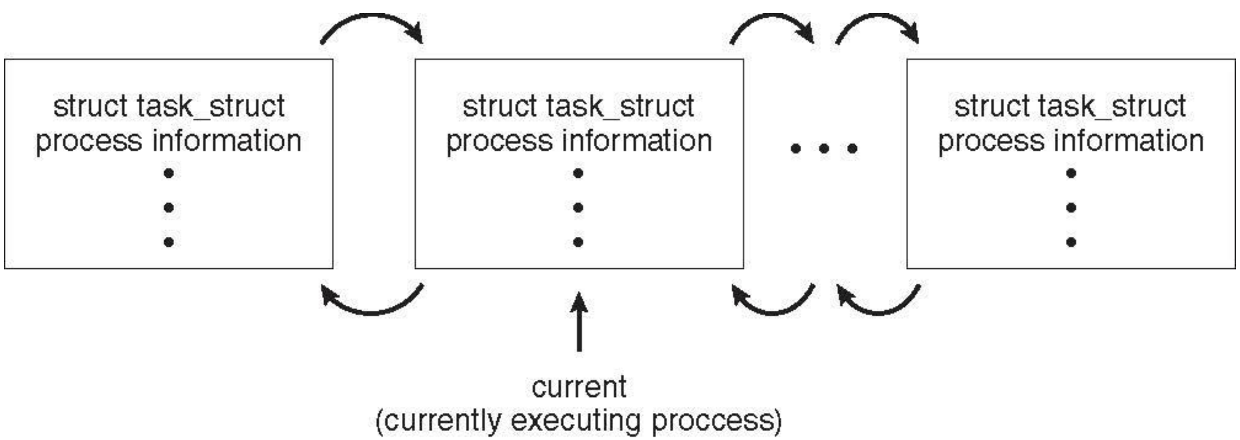
Threads

- 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
- See next chapter (CH 4)

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 */
```



3.2 Process Scheduling

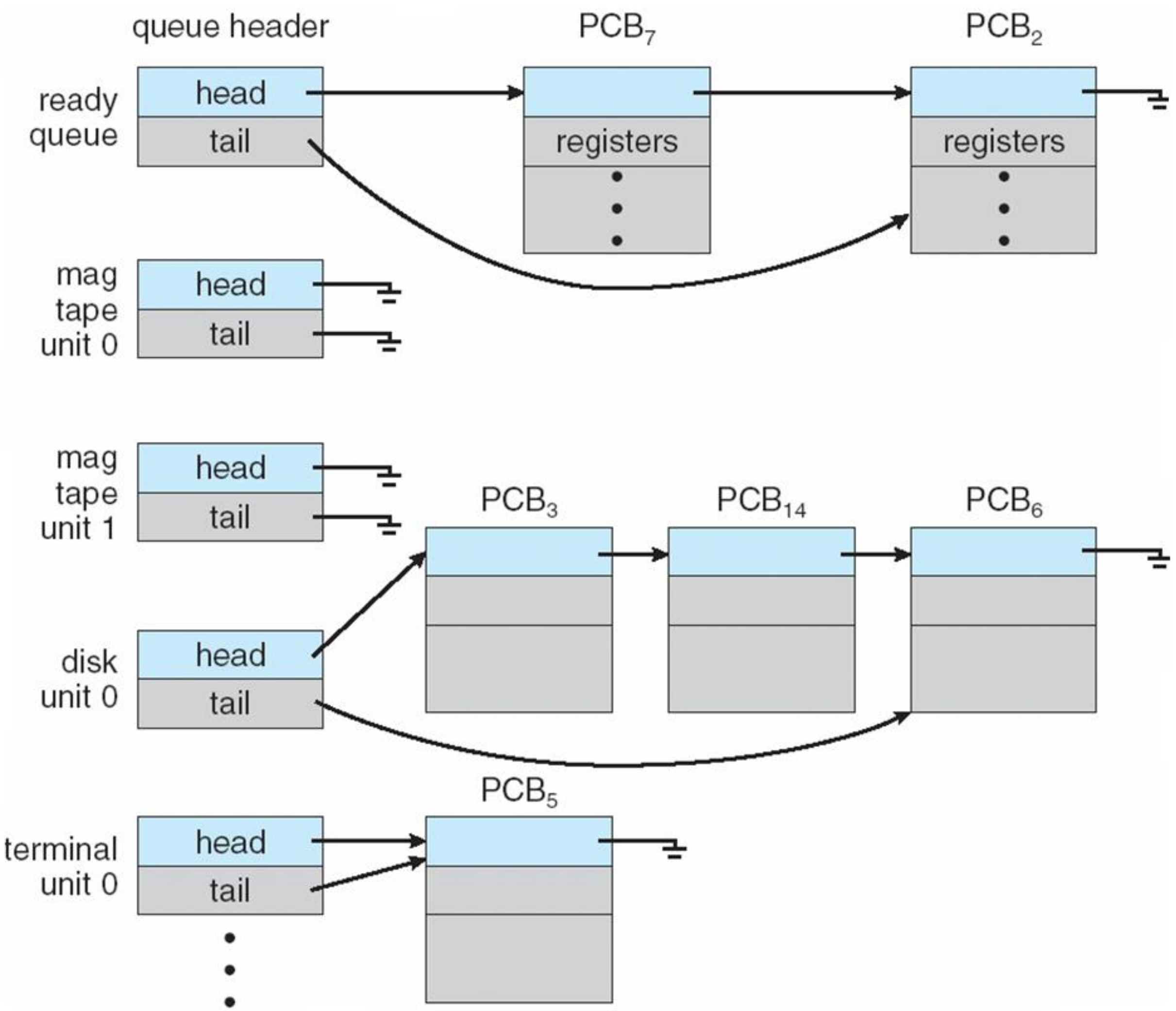
Maximize CPU use, quickly switch processes onto CPU for time sharing

Process scheduler selects among available processes for next execution on CPU

Maintains **scheduling queues** of processes

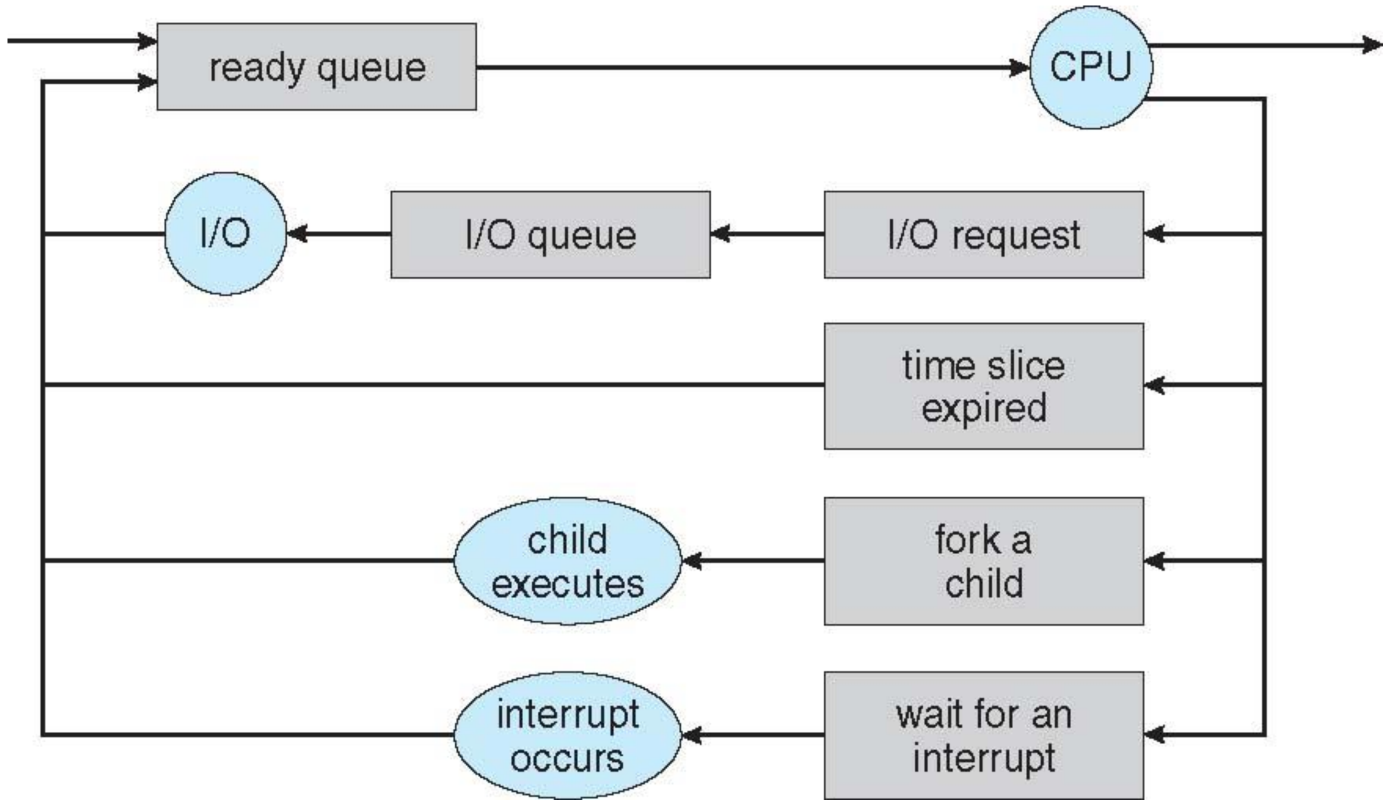
- **Job queue** – set of all processes in the system
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
- **Device queues** – set of processes waiting for an I/O device
- Processes migrate among the various queues

Ready Queue And Various I/O Device Queues



Representation of Process Scheduling

Queueing diagram represents queues, resources, flows



Schedulers

Short-term scheduler (or **CPU scheduler**) – selects which process should be executed next and allocates CPU

- Sometimes the only scheduler in a system
- Short-term scheduler is invoked frequently (milliseconds) $\Rightarrow$ (must be fast)

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**

Processes can be described as either:

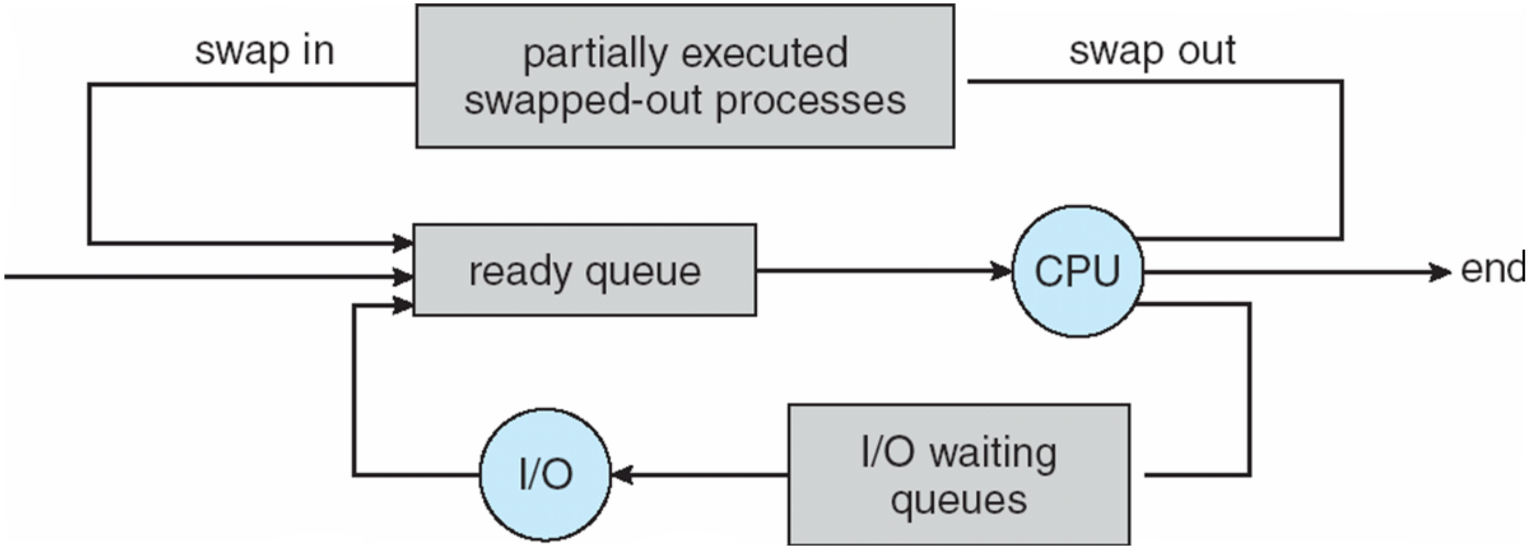
- **I/O-bound process** – spends more time doing I/O than computations, many short CPU bursts
- **CPU-bound process** – spends more time doing computations; few very long CPU bursts

Long-term scheduler strives for good ***process mix***

Addition of Medium Term Scheduling

Medium-term scheduler can be added if degree of multiple programming needs to decrease

- Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**



Multitasking in Mobile Systems

- Some mobile systems (e.g., early version of iOS before V4) allow only one process to run, others suspended
- Due to screen real estate, user interface limits iOS provides for a
  - Single **foreground** process- controlled via user interface
  - Multiple **background** processes– in memory, running, but not on the display, and with limits
  - Limits include single, short task, receiving notification of events, specific long-running tasks like audio playback
- Android runs foreground and background, with fewer limits
  - Background process uses a **service** to perform tasks
  - Service can keep running even if background process is suspended
  - Service has no user interface, small memory use

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

3.3 Operations on Processes

System must provide mechanisms for:

process creation,

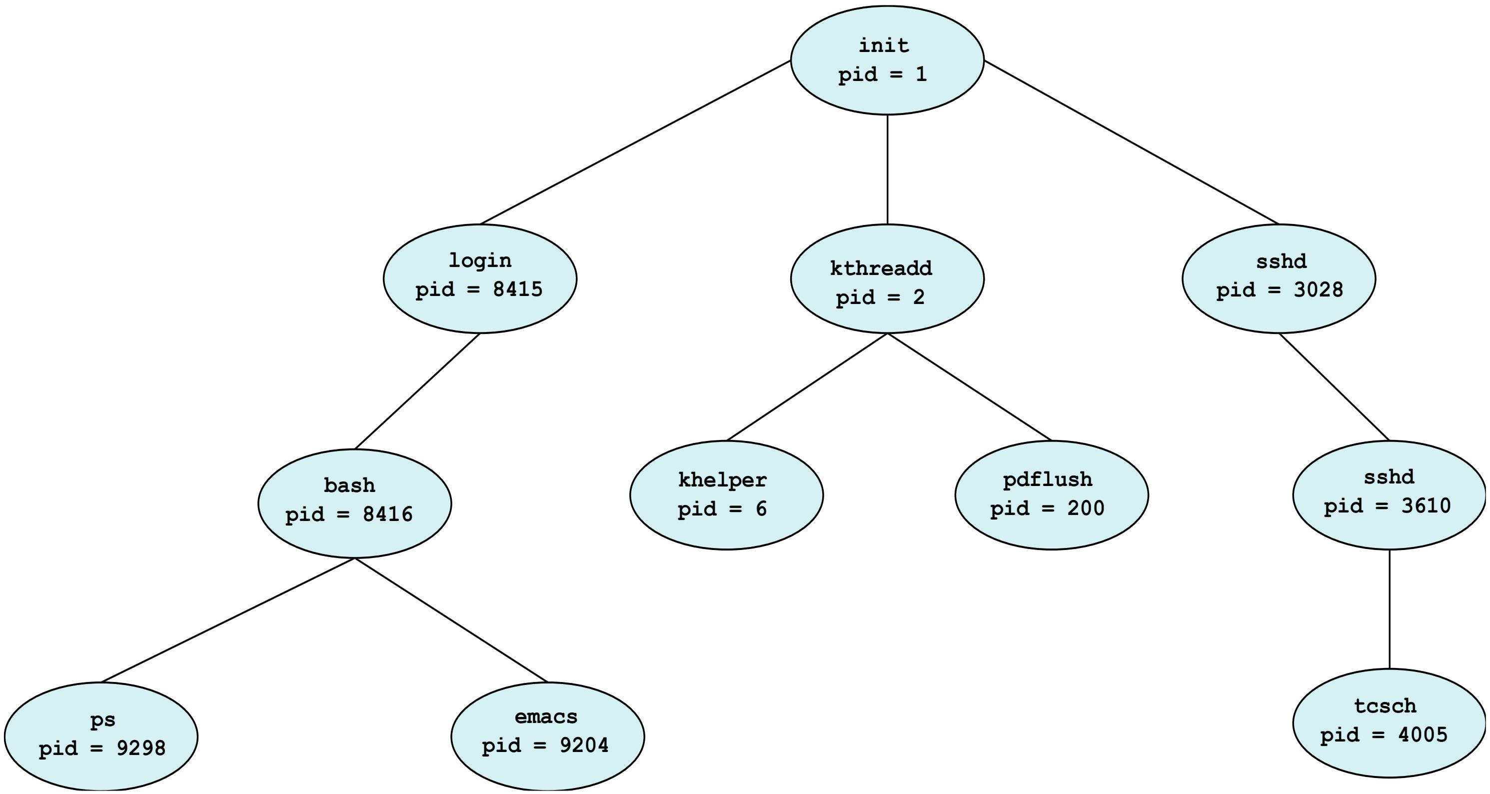
process termination,

and so on as detailed next

Process Creation

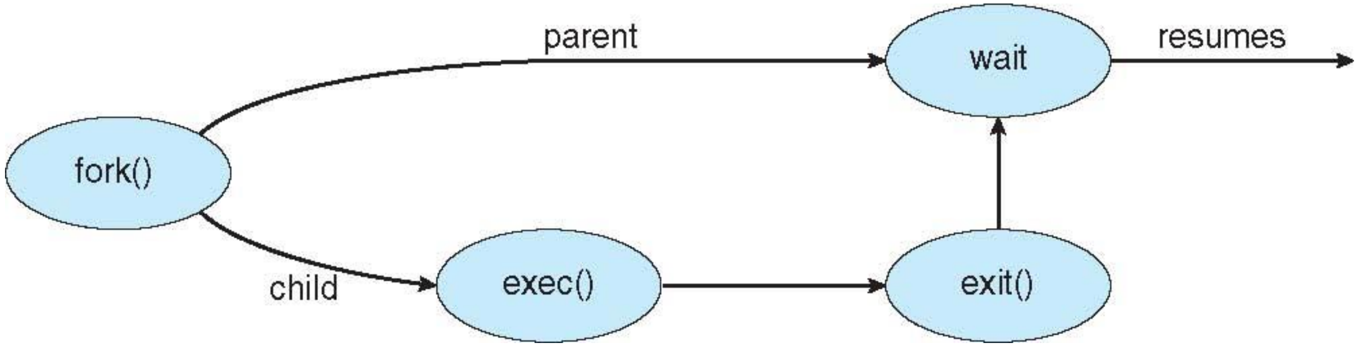
- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- Generally, process identified and managed via a **process identifier (pid)**
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of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

A Tree of Processes in Linux



Process Creation (Cont.)

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



C Program Forking Separate Process

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

int main()
{
pid_t pid;

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

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

    return 0;
}
```

Creating a Separate Process via Windows API

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

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

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

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

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

Process Termination

- Process executes last statement and then asks the operating system to delete it using the **`exit()`** system call.
  - Returns status data from child to parent (via **`wait()`**)
  - Process' resources are deallocated by operating system
- Parent may terminate the execution of children processes using the **`abort()`** system call. Some reasons for doing so:
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - The parent is exiting and the operating systems does not allow a child to continue if its parent terminates

Process Termination

Some operating systems do not allow child to 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);
```

If no parent waiting (did not invoke **`wait()`**) process is a **zombie**

If parent terminated without invoking **`wait`**, process is an **orphan**

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:

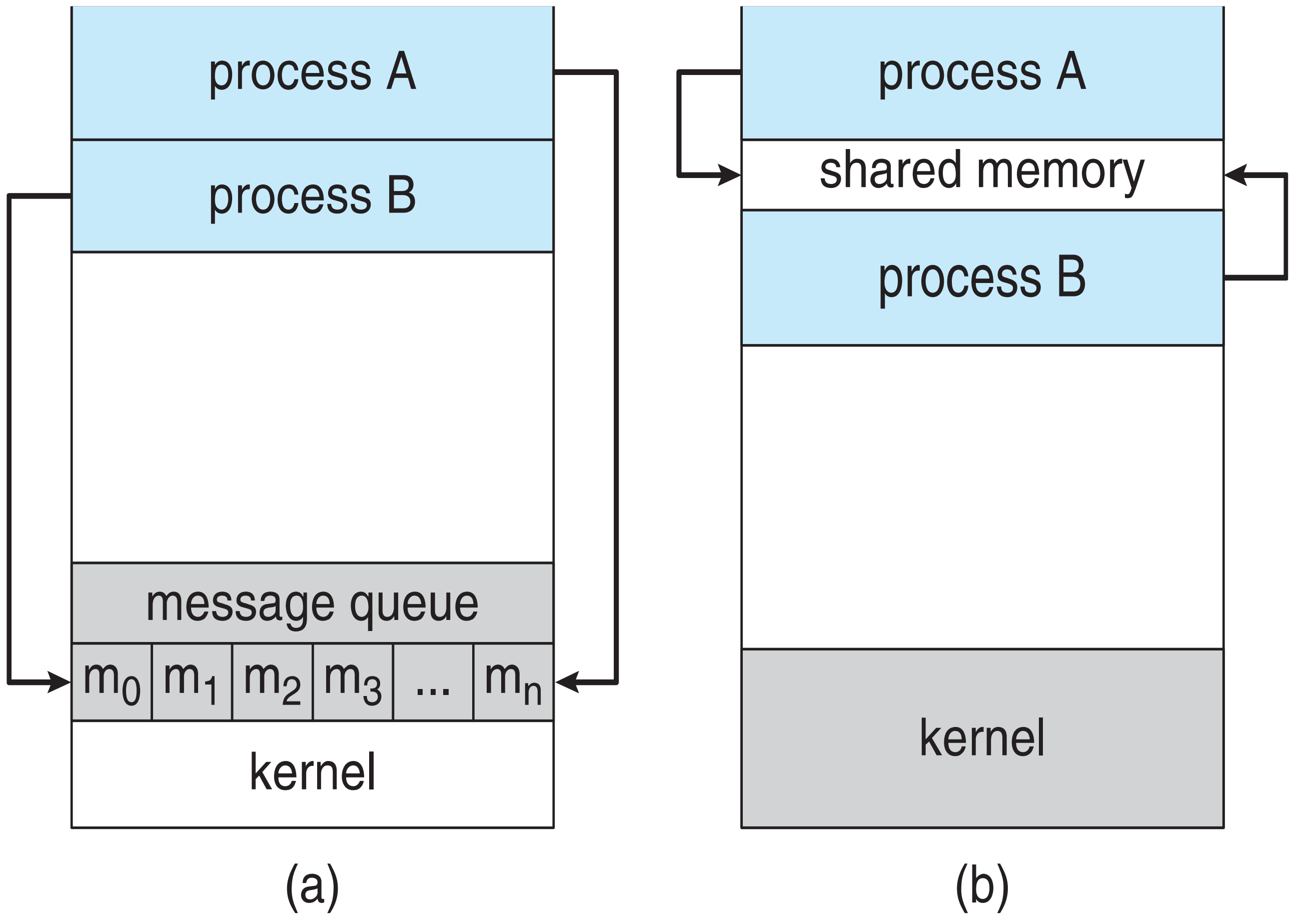
- **Browser** process manages user interface, disk and network I/O
- **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
  - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
- **Plug-in** process for each type of plug-in

3.4 Interprocess Communication

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

Communications Models

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



Producer-Consumer Problem

Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process

- **unbounded-buffer** places no practical limit on the size of the buffer
- **bounded-buffer** assumes that there is a fixed buffer size

Bounded-Buffer – Shared-Memory Solution

Shared data

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

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

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 */
}
```

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

Interprocess 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.

Synchronization is discussed in great details in Chapter 6.

Interprocess 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?

Message Passing (Cont.)

Implementation of communication link

- Physical:
  - Shared memory
  - Hardware bus
  - Network
- Logical:
  - Direct or indirect
  - Synchronous or asynchronous
  - Automatic or explicit buffering

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

Operations

- create a new mailbox (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

- 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
  - 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

- 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**

Synchronization (Cont.)

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

Queue of messages attached to the link.

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

3.7 Examples of IPC Systems

- 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 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;
}
```

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 Message Passing

- Mach communication is message based
  - Even system calls are messages
  - Each task gets two mailboxes at creation- Task Self and Notify
  - Only three system calls needed for message transfer
  - `msg_send()`, `msg_receive()`, `msg_rpc()`
  - Mailboxes needed for commuication, 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 - Mach

```
#include<mach/mach.h>

struct message {
   mach_msg_header_t header;
   int data;
};

mach_port_t client;
mach_port_t server;

      /* Client Code */

struct message message;

// construct the header
message.header.msgh_size = sizeof(message);
message.header.msgh_remote_port = server;
message.header.msgh_local_port = client;

// send the message
mach_msg(&message.header, // message header
   MACH_SEND_MSG, // sending a message
   sizeof(message), // size of message sent
   0, // maximum size of received message - unnecessary
   MACH_PORT_NULL, // name of receive port - unnecessary
   MACH_MSG_TIMEOUT_NONE, // no time outs
   MACH_PORT_NULL // no notify port
);
```

Examples of IPC Systems - Mach

```
/* Server Code */

struct message message;

// receive the message
mach_msg(&message.header, // message header
   MACH_RCV_MSG, // Receiving a message
   0, // size of message sent
   sizeof(message), // maximum size of received message
   server, // name of receive port
   MACH_MSG_TIMEOUT_NONE, // no time outs
   MACH_PORT_NULL // no notify port
);
```

Figure 3.18 Example program illustrating message passing in Mach.

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
  - 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

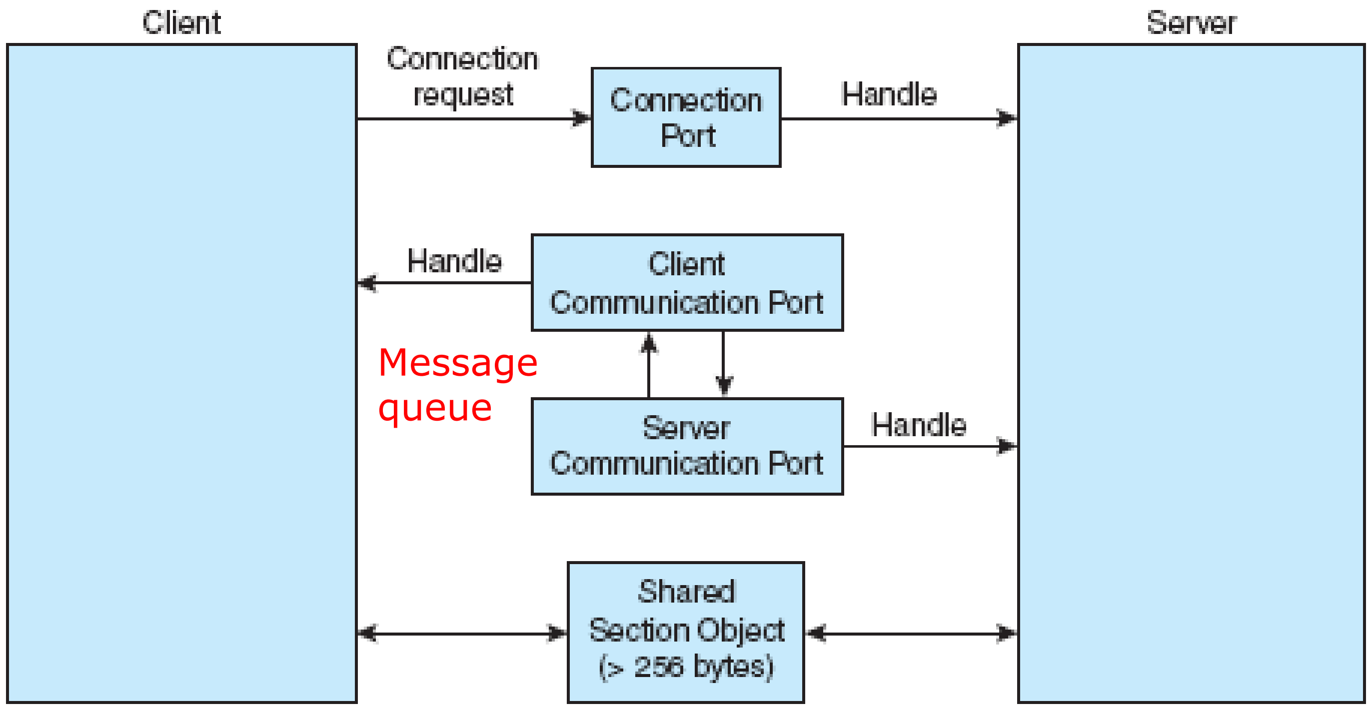


Figure 3.19 Advanced local procedure calls in Windows.

3.8 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

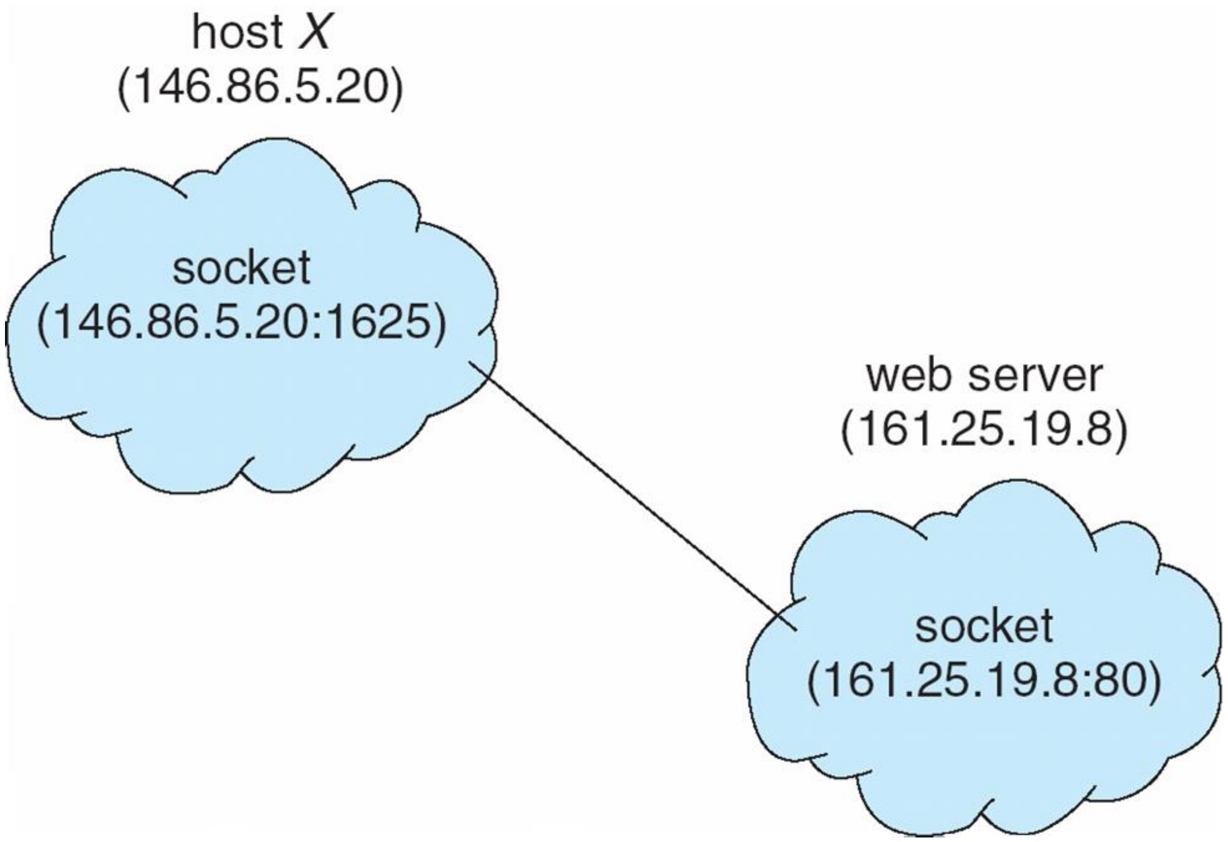
The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**

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)** : Socket class
- **Connectionless (UDP)** : DatagramSocket class
- **`MulticastSocket`** class (subclass of DatagramSocket class) – data can be sent to multiple recipients

Consider this “Date” server:

Date client

```
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();    /* block */

            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

```
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);
      }
   }
}
```

Figure 3.28 Date client.

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

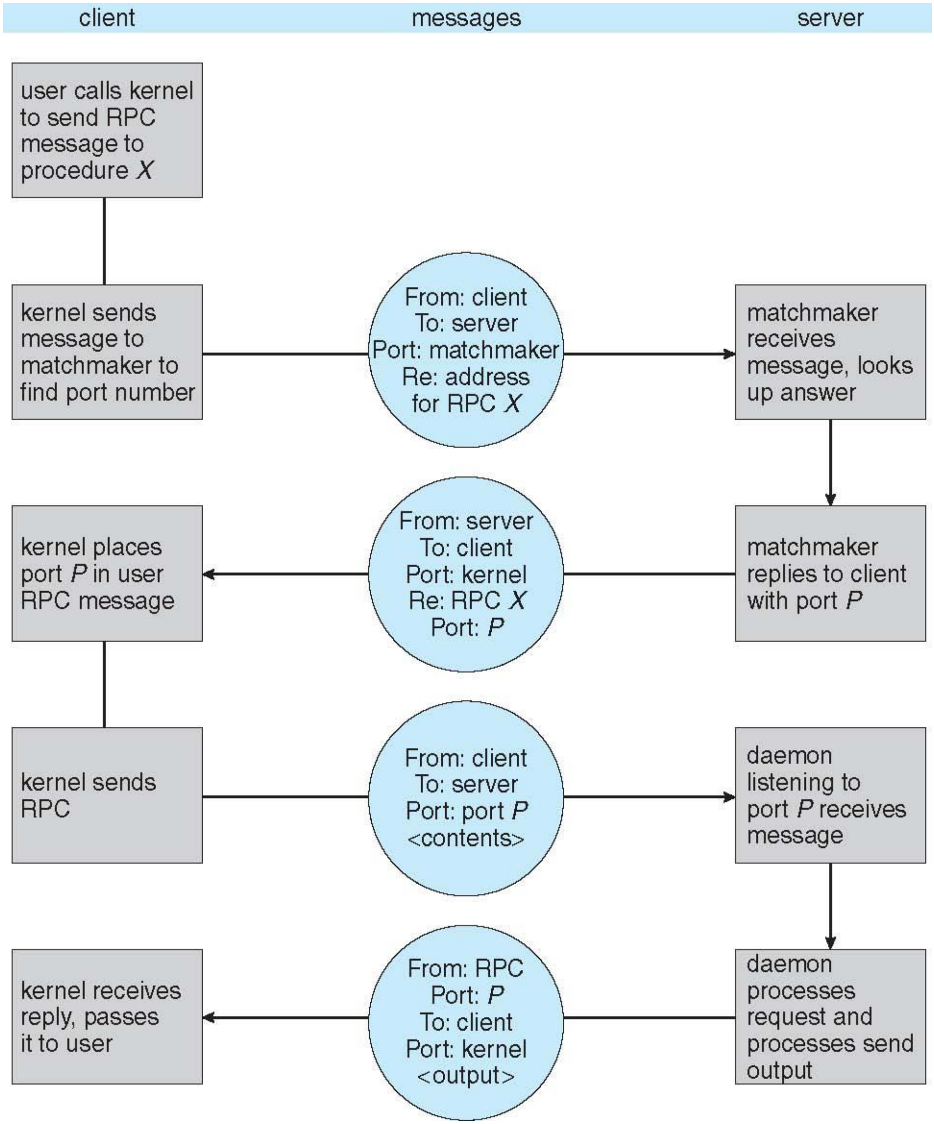
The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server

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

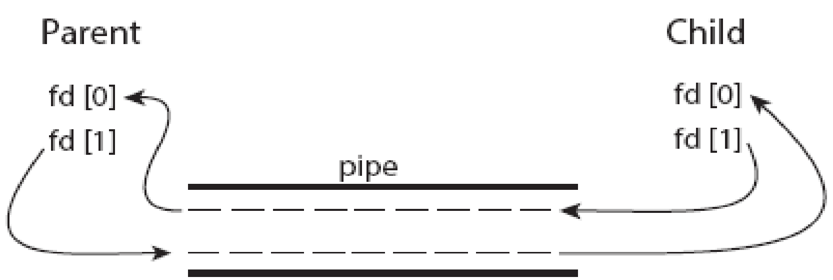


Figure 3.20 File descriptors for an ordinary pipe.

- Windows calls these **anonymous pipes**
- See Unix (P141-142 Figure3.21&3.22) and Windows (P143-145 Figure 3.23-3.25) 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

End of Chapter 3