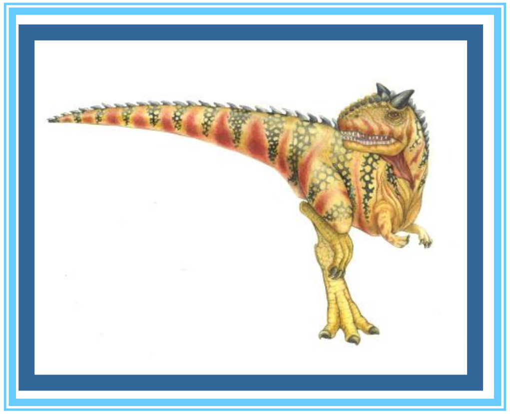
Chapter 3: Processes



Outline

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

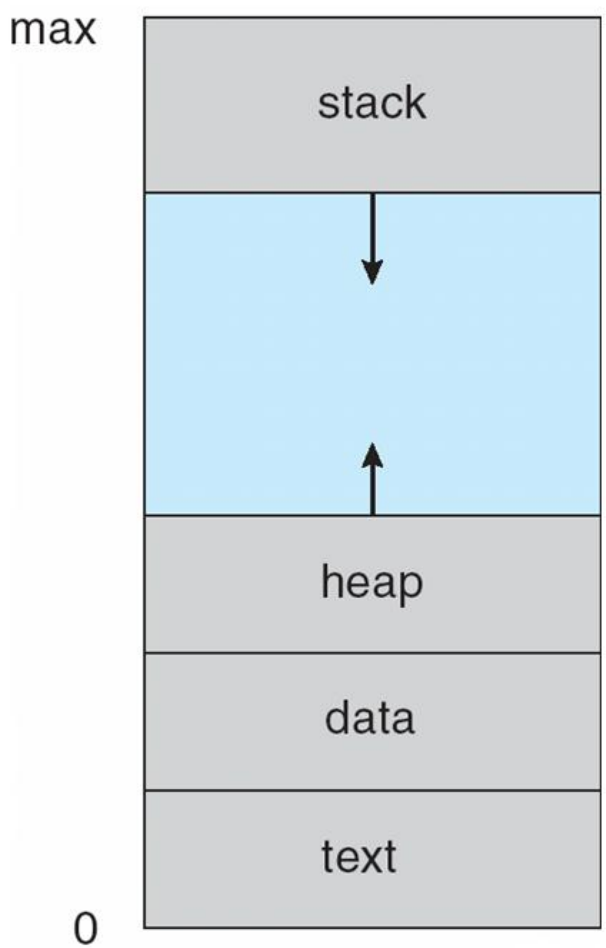
Objectives

- 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 describe communication in client-server systems

Process Concept

- An OS 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
  - A process includes:
    - program counter
    - stack
    - data section

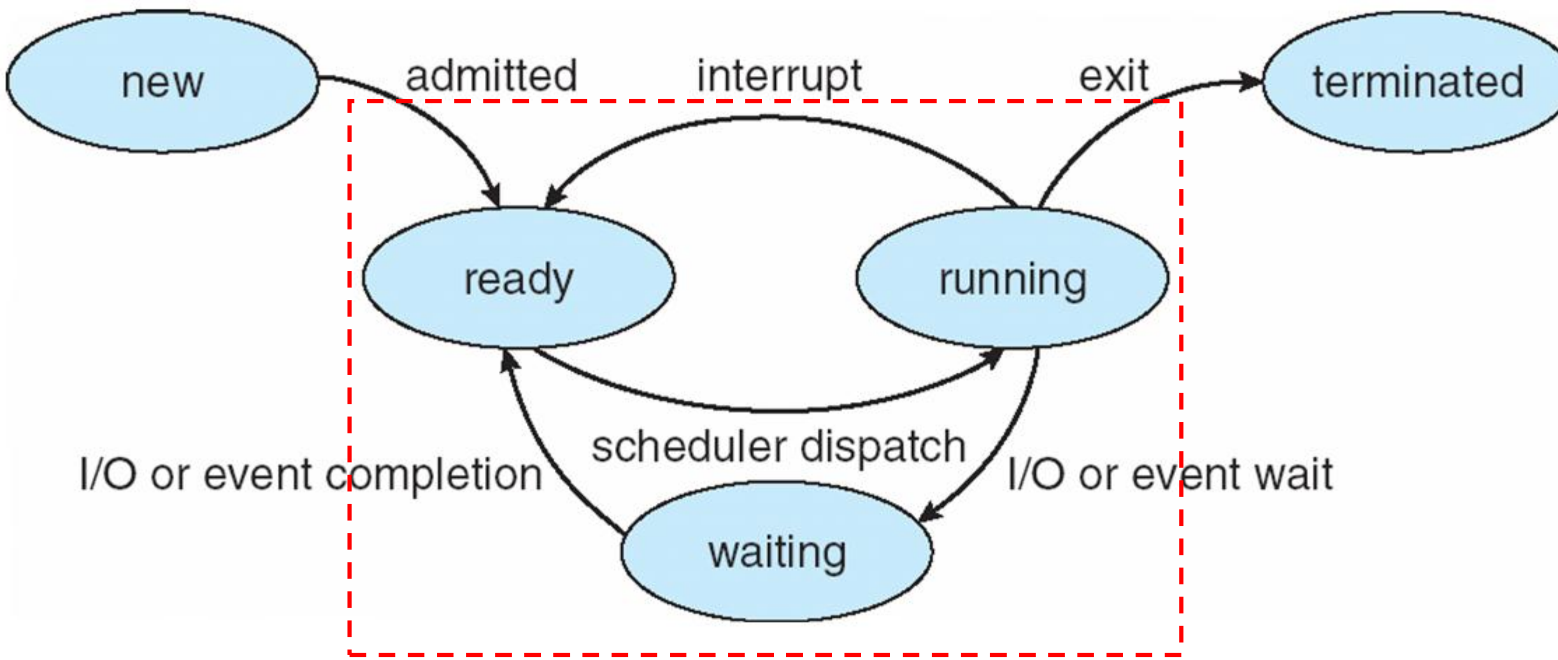
Process in Memory



Process State

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

Diagram of Process State

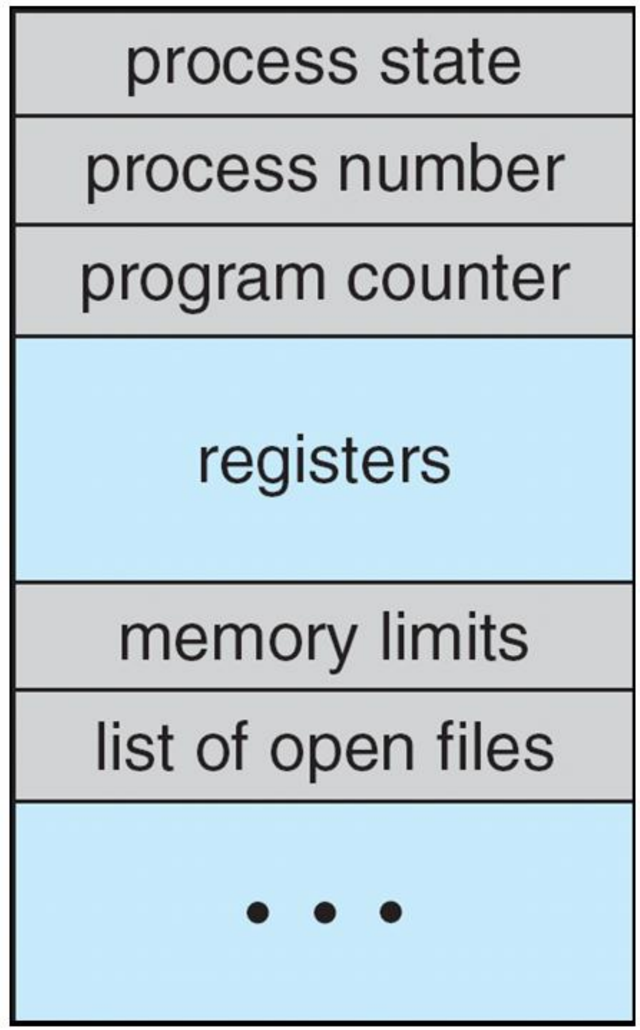


Process Control Block (PCB)

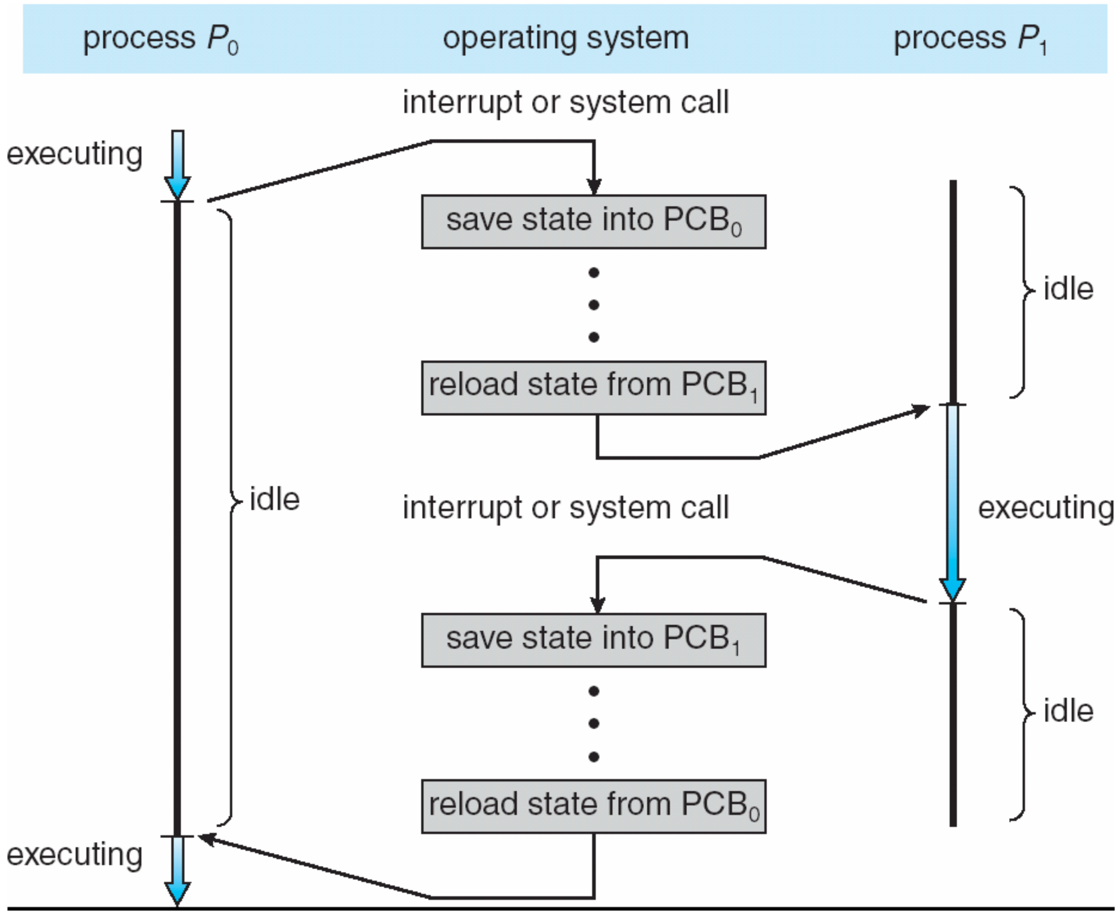
Information associated with each process

- Process state
- Program counter
- CPU registers
- CPU scheduling information
- Memory-management information
- Accounting information
- I/O status information

Process Control Block (PCB)



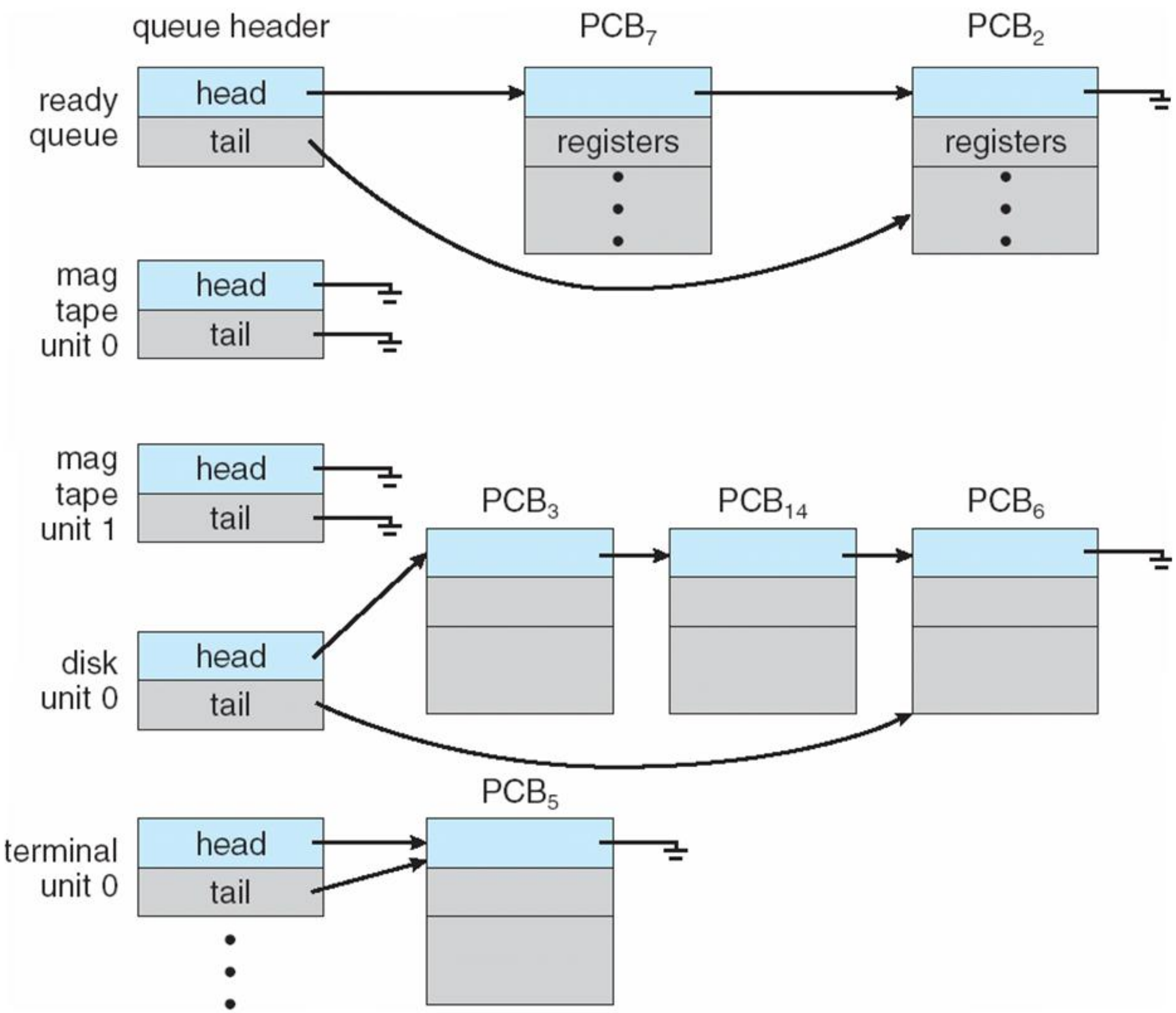
CPU Switch from Process to Process



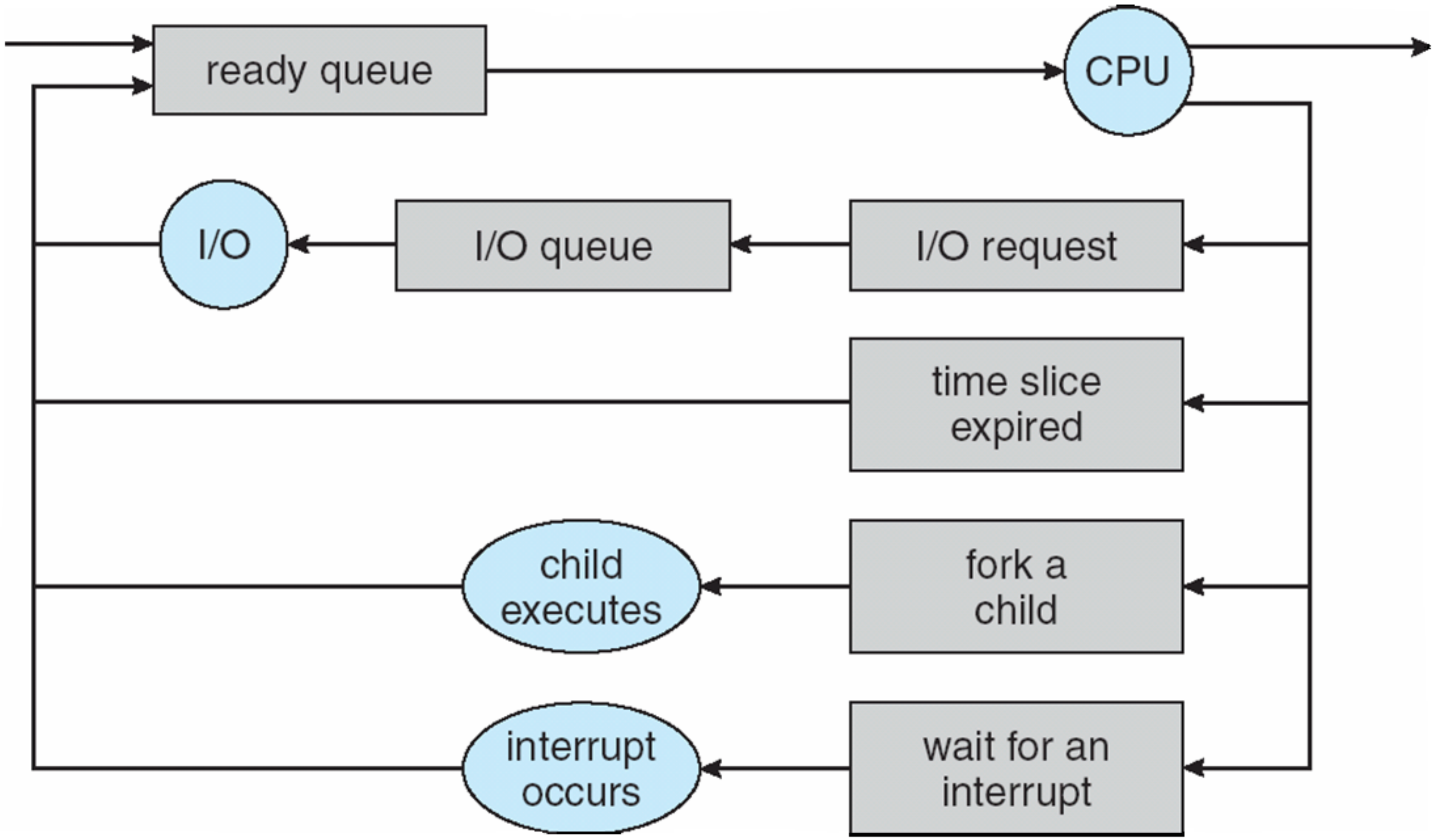
Process Scheduling Queues

- **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 various queues

Ready Queue and Various I/O Device Queues



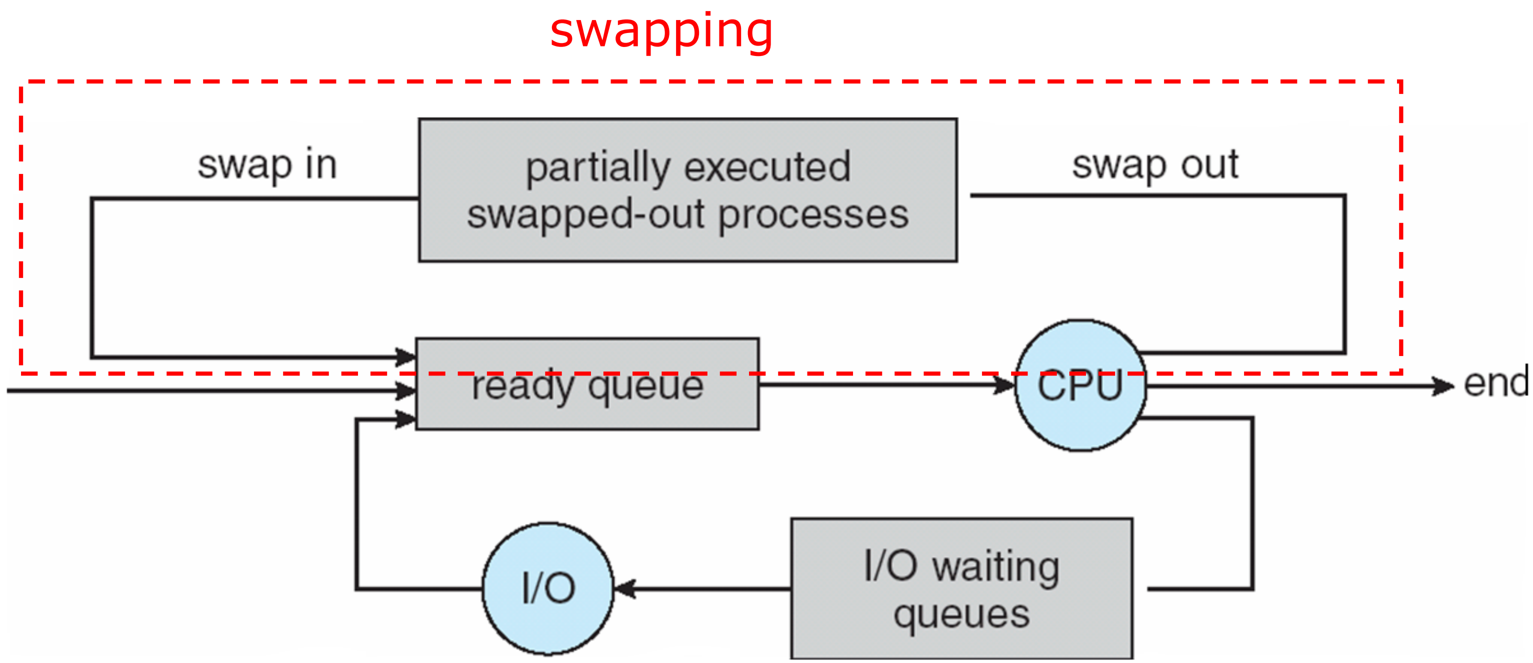
Representation of Process Scheduling



Schedulers

- **Long-term scheduler** (or job scheduler) – selects which processes should be brought into the ready queue
- **Short-term scheduler** (or CPU scheduler) – selects which process should be executed next and allocates CPU

Addition of Medium Term Scheduling



Schedulers (Cont)

- Short-term scheduler: invoked very frequently (milliseconds) $\Rightarrow$ (must be fast)
- Long-term scheduler: invoked very 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

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
- Time dependent on hardware support

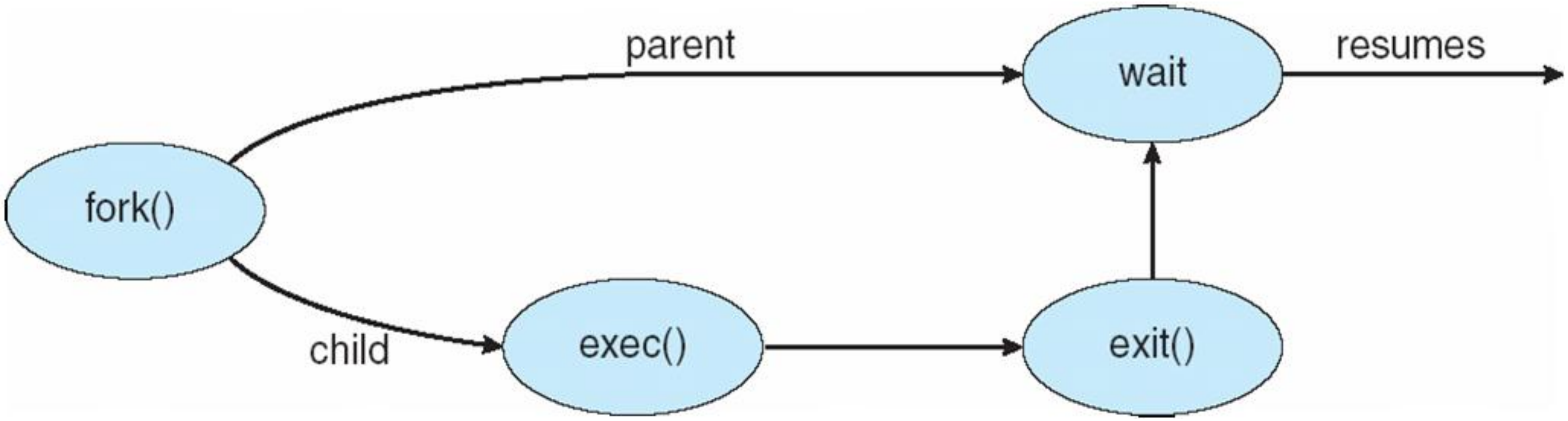
Process Creation

- **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
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - 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

Process Creation



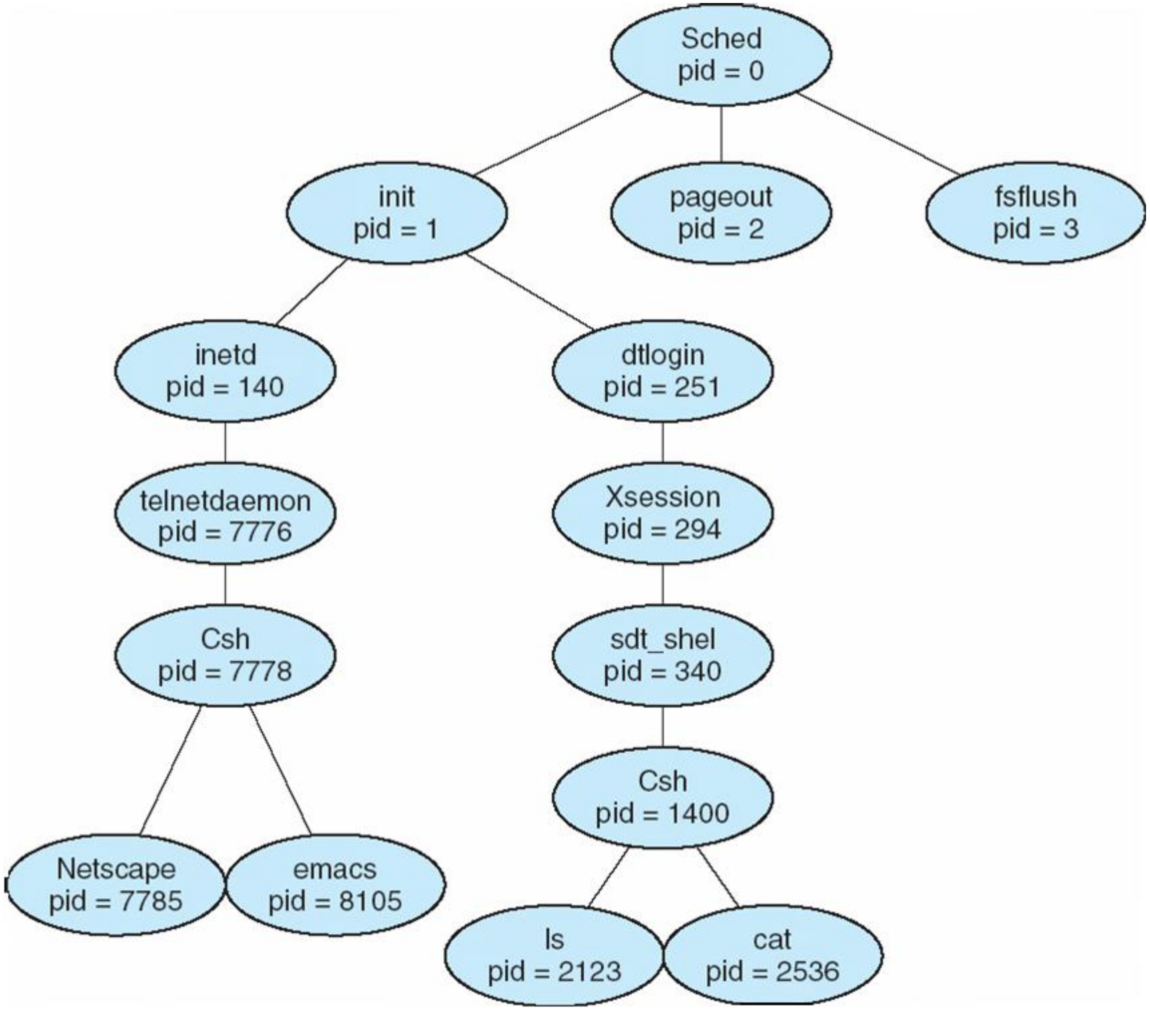
C Program Forking Separate Process (Fig. 3.10)

```
int main()
{
pid_t  pid;
    /* fork another process */
    pid = fork();
    if (pid < 0) { /* error occurred */
           fprintf(stderr, "Fork Failed");
           exit(-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");
           exit(0);
    }
}
```

Process Creation in Win32 API (Fig. 3.12)

- CreateProcess()
  - Similar to fork() in UNIX
- WaitForSingleObject()
  - Similar to wait() in UNIX
- CloseHandle()
  - Similar to exit() in UNIX

A Tree of Processes on a Typical Solaris



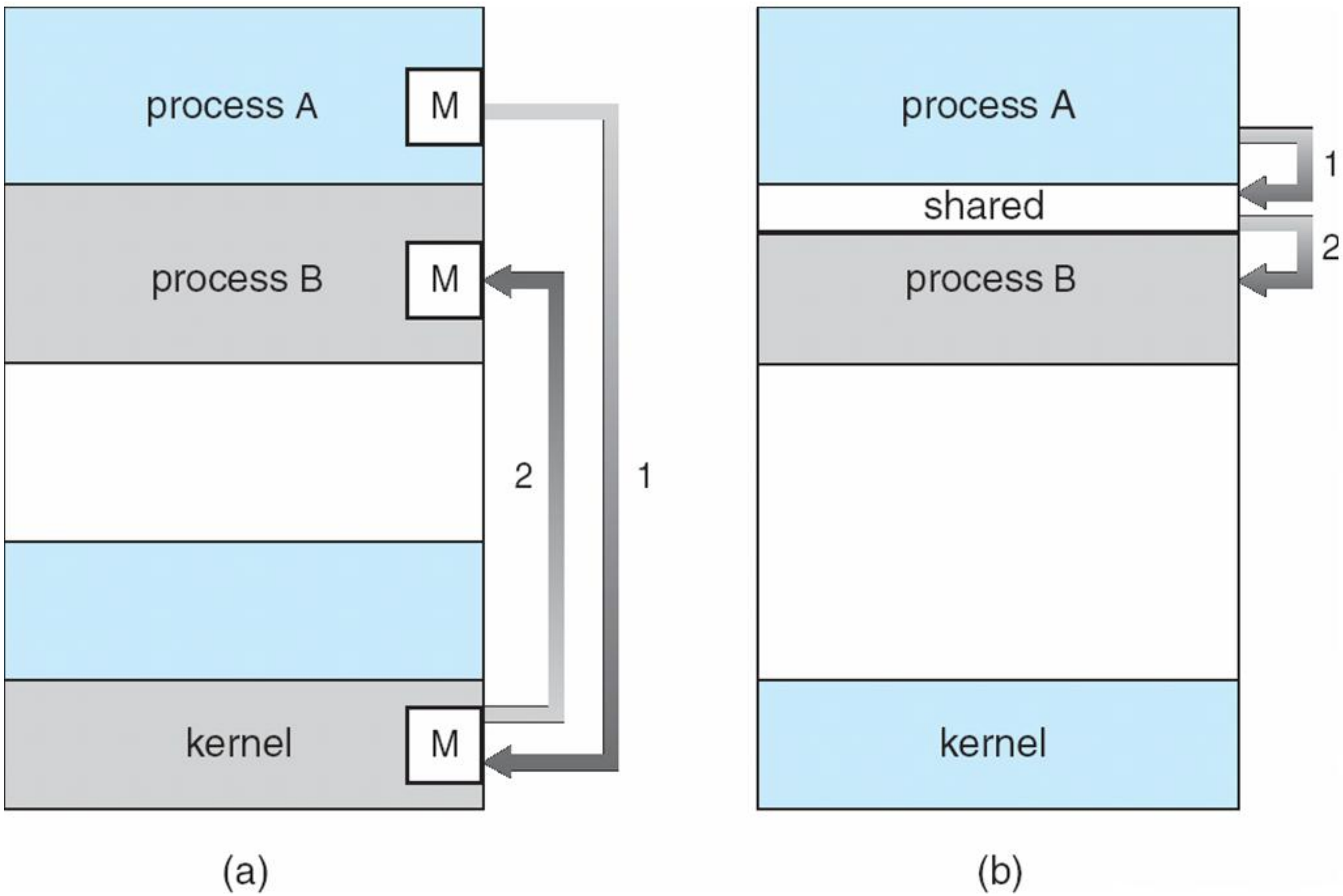
Process Termination

- Process executes last statement and asks the OS to delete it (**exit**)
  - Output data from child to parent (via **wait**)
  - Process' resources are deallocated by OS
- Parent may terminate execution of children processes (**abort**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - If parent is exiting
    - Some OS do not allow child to continue if its parent terminates
      - All children terminated - **cascading termination**

Interprocess Communication

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

Communications Models



Cooperating Processes

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

Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - *unbounded-buffer*: no practical limit on buffer size
  - *bounded-buffer*: 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

Bounded-Buffer – Producer (Fig. 3.14)

```
while (true) {
  /* Produce an item */
  while (((in + 1) % BUFFER_SIZE) ==
  out)
    ; // do nothing - no free buffers
  buffer[in] = item;
  in = (in + 1) % BUFFER_SIZE;
}
```

Bounded Buffer – Consumer (Fig. 3.15)

```
while (true) {
   while (in == out)
      ; // do nothing -- nothing to
   consume

   // remove an item from the buffer
   item = buffer[out];
   out = (out + 1) % BUFFER_SIZE;
   return item;
}
```

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*) – message size fixed or variable
  - **receive**(*message*)
- If *P* and *Q* wish to communicate, they need to:
  - establish a *communication link* between them
  - exchange messages via send/receive
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus)
  - logical (e.g., logical properties)

Implementation Questions

- 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

- Operations
  - create a new mailbox
  - 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** has the sender block until the message is received
  - **Blocking receive** has the receiver block until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking** send has the sender send the message and continue
  - **Non-blocking** receive has the receiver receive a valid message or null

Buffering

- Queue of messages attached to the link; implemented in one of three ways
  1. Zero capacity – 0 messages
     Sender must wait for receiver (rendezvous)
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits

Examples of IPC Systems – POSIX (Fig. 3.16)

- POSIX Shared Memory
  - Process first creates shared memory segment

```
seg_id = shmget(IPC_PRIVATE, size, S_IRUSR |
  S_IWUSR);
```

  - Process wanting access to that shared memory must attach to it

```
shared_memory = (char *) shmat(seg_id, NULL, 0);
```

  - Now the process could write to the shared memory

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

  - When done a process can detach the shared memory from its address space

```
shmdt(shared_memory);
```

Examples of IPC Systems - Mach

- Mach: communication is message based
  - Even system calls are messages
  - Each task gets two mailboxes at creation - Kernel and Notify
  - Only three system calls needed for message transfer

  `msg_send(), msg_receive(), msg_rpc()`

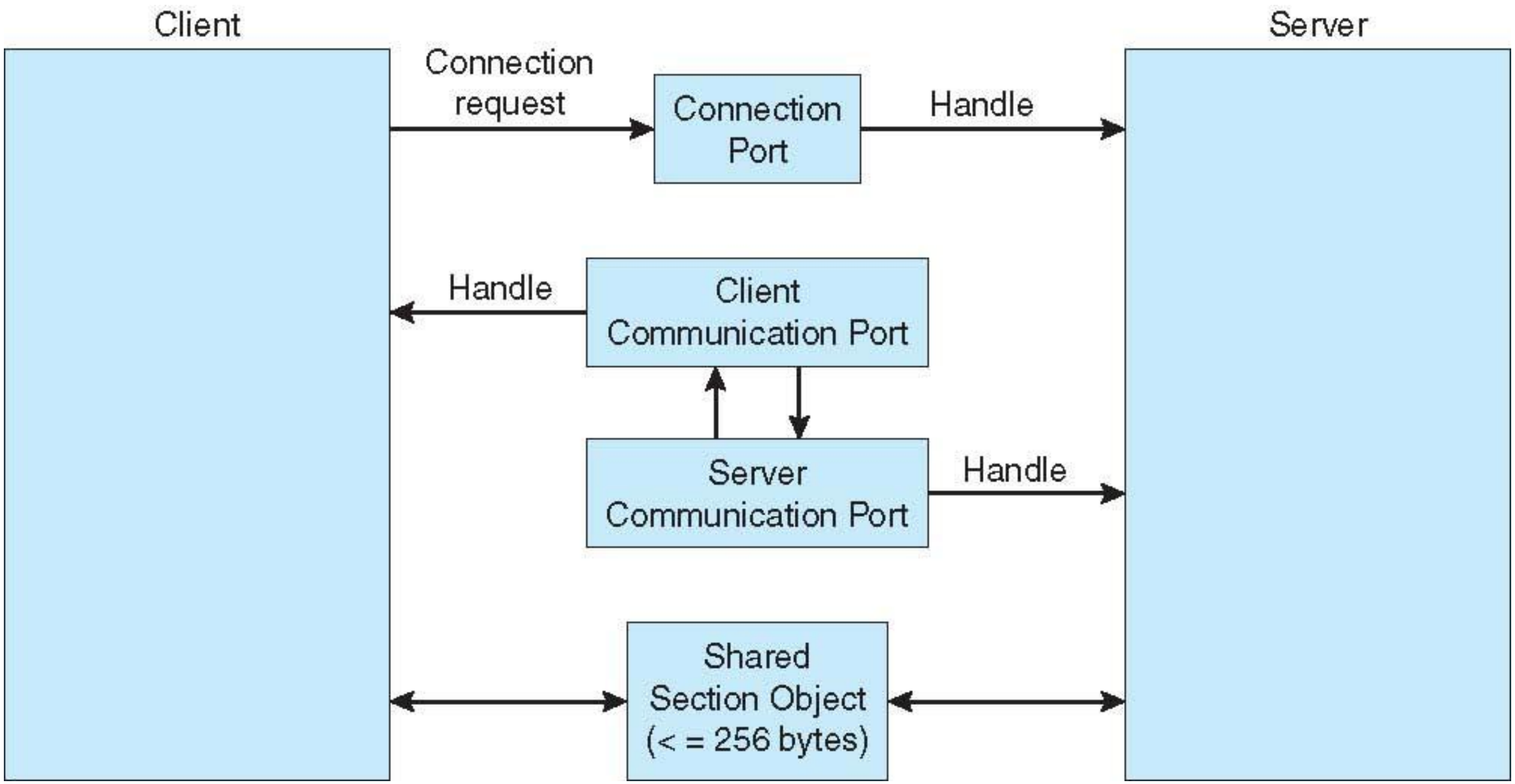
  - Mailboxes needed for communication, created via

  `port_allocate()`

Examples of IPC Systems – Windows XP

- Message-passing centric via 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 XP



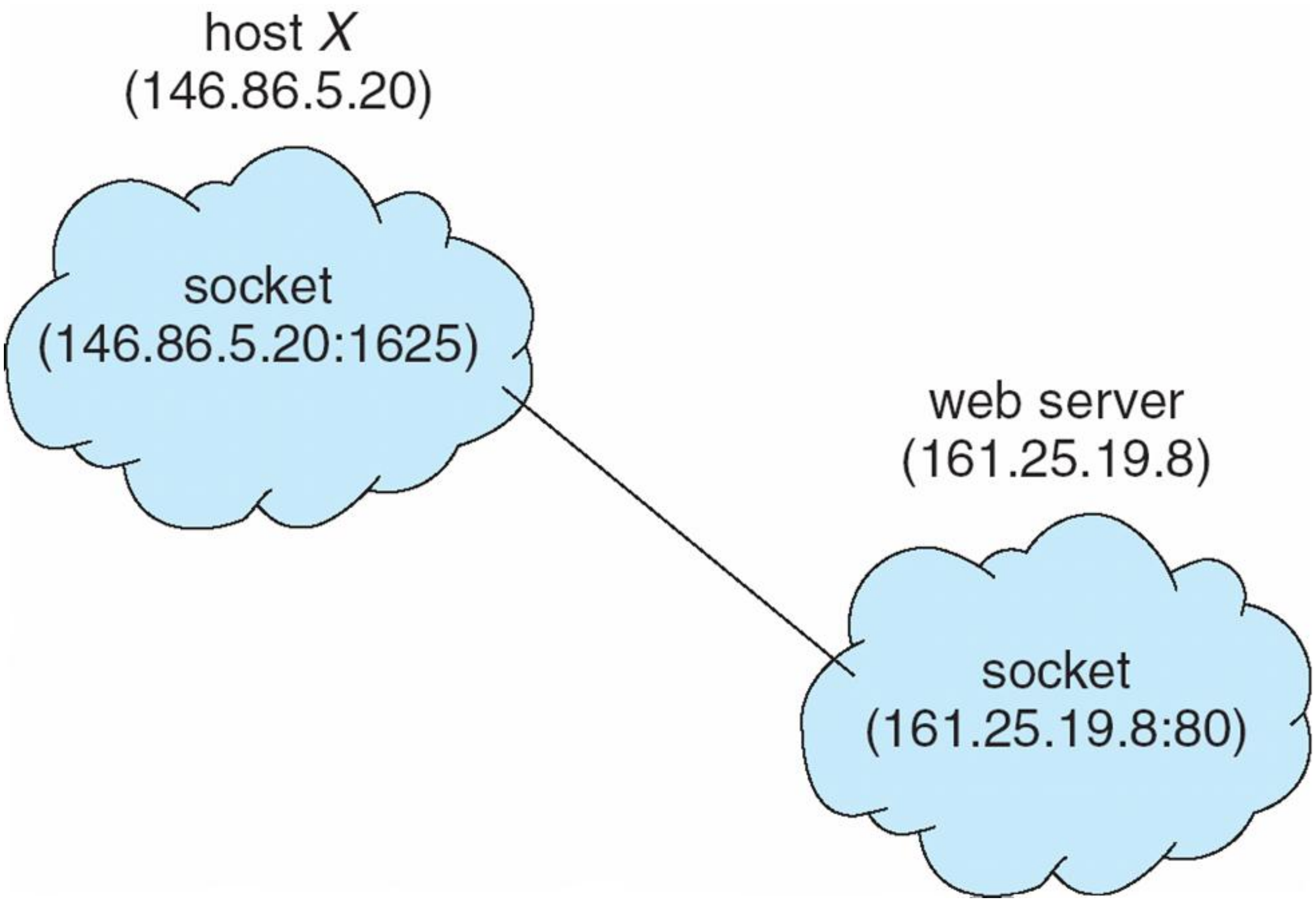
Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls
- Pipes

Sockets

- A socket: an *endpoint for communication*
  - Concatenation of IP address and port
  - The socket **161.25.19.8:1625**: port **1625** on host **161.25.19.8**
- Communication consists of a pair of sockets

Socket Communication



BSD Socket

- BSD Socket
  - socket()
  - close()
- Server
  - bind()
  - listen()
  - accept()
- Client
  - connect()
- Data transfer
  - send()/read()
  - recv()/write()

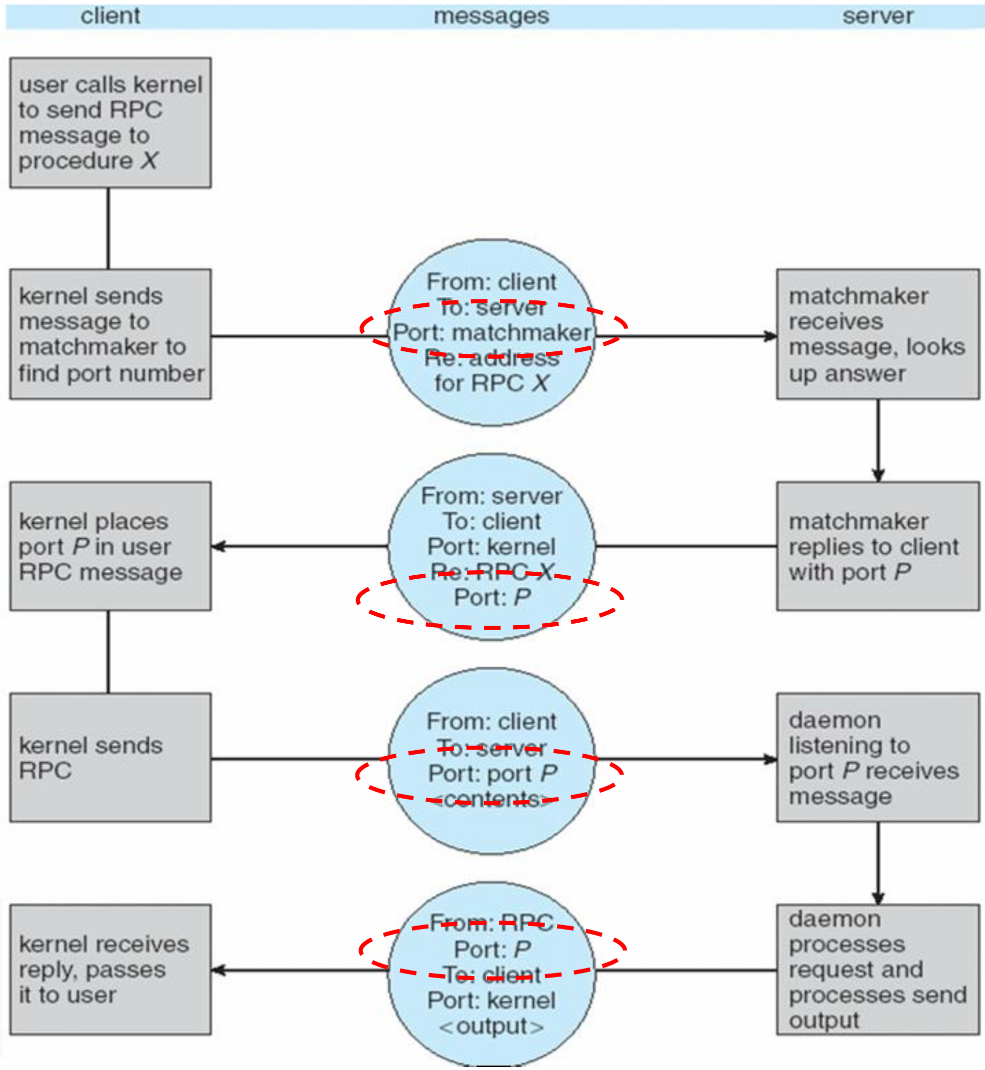
Example Java Socket Programs

- An example Date server (Fig. 3.19)
  - ServerSocket
  - Socket
    - accept()
    - getOutputStream()
    - close()
- An example Date client (Fig. 3.20)
  - Socket
    - getInputStream()

Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
- **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

Execution of RPC



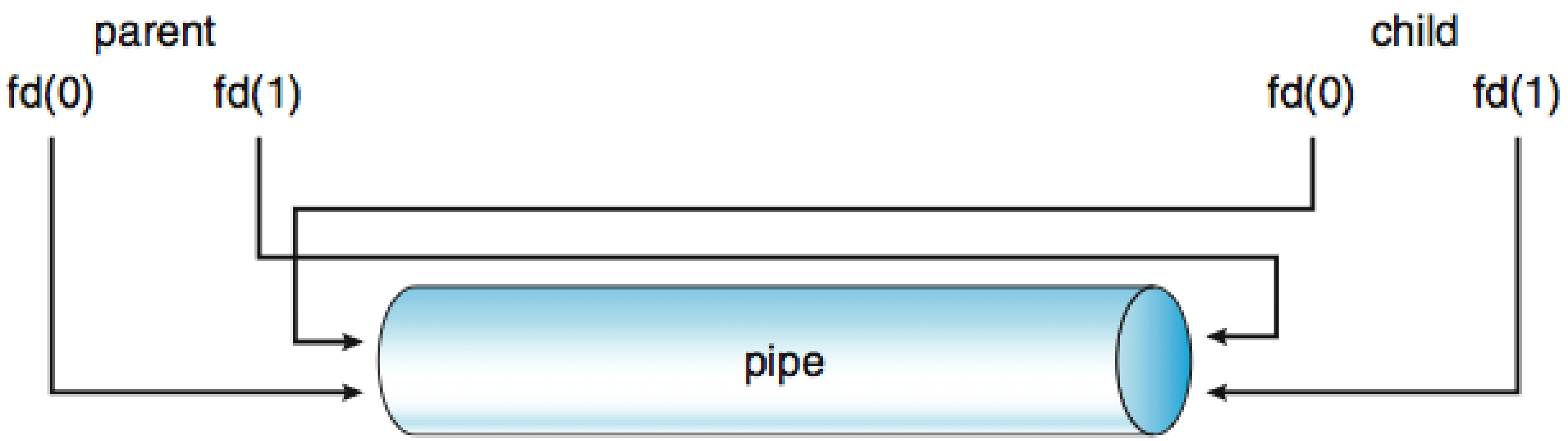
Pipes

- 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

- **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

Ordinary Pipes



Ordinary Pipes in UNIX

- (Fig. 3.23 & Fig. 3.24)
- Functions
  - pipe()
  - read()
  - write()
  - close()

Anonymous Pipes in Windows

- (Fig. 3.25-3.27)
- Functions
  - CreatePipe()
  - WriteFile()
  - ReadFile()
  - CloseHandle()

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

Named Pipes in UNIX and Windows

- FIFO in UNIX
  - mkfifo()
  - open()
  - read()
  - write()
  - close()
- Named pipes in Windows
  - CreateNamedPipe()
  - ConnectNamedPipe()
  - ReadFile()
  - WriteFile()

End of Chapter 3