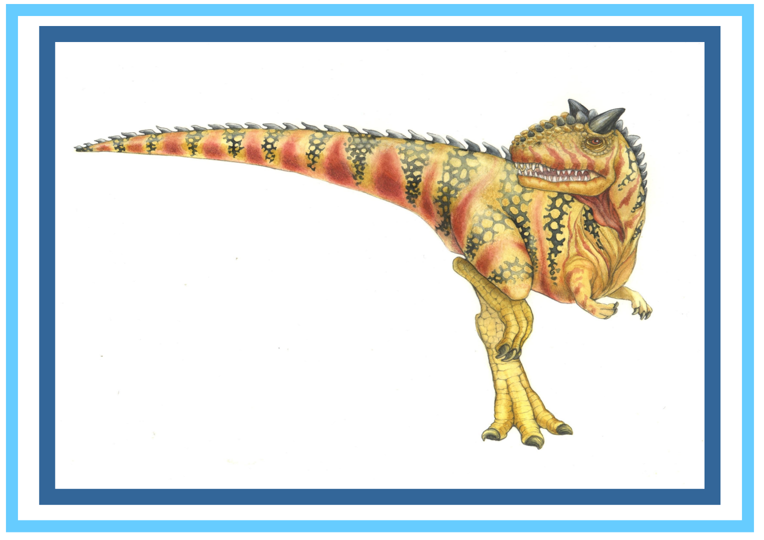
Chapter 3: Processes



Chapter 3: Processes

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

Objectives

- ***To introduce the notion of a process -- a program in execution, which forms the basis of all computation***
- ***To describe the various features of processes, including scheduling, creation and termination, and communication***
- ***To describe communication in client-server systems***

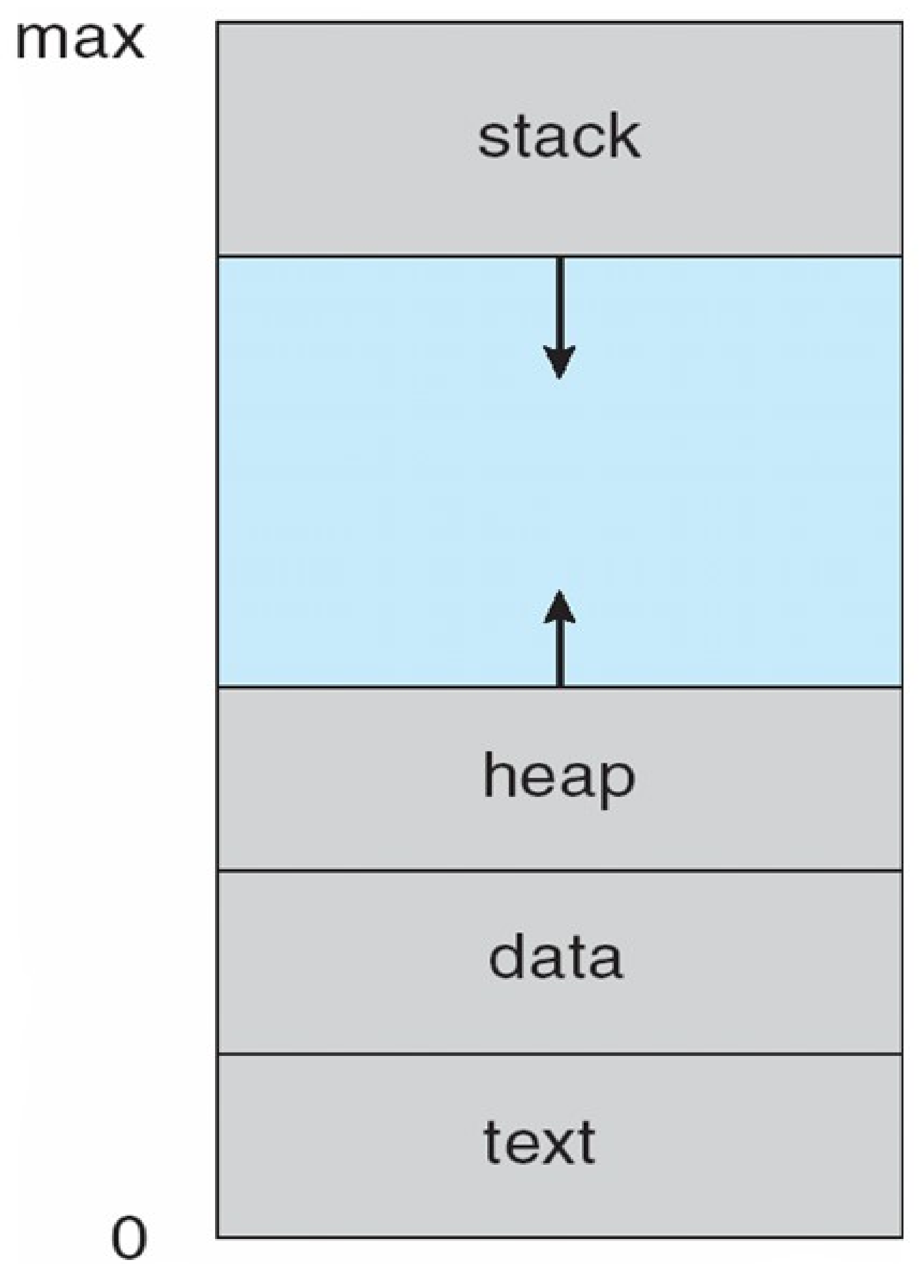
Process Concept

- ***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***
- ***A process includes:***
  - program counter
  - stack
  - data section

The Process

- ***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
- ***Program is passive entity, 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

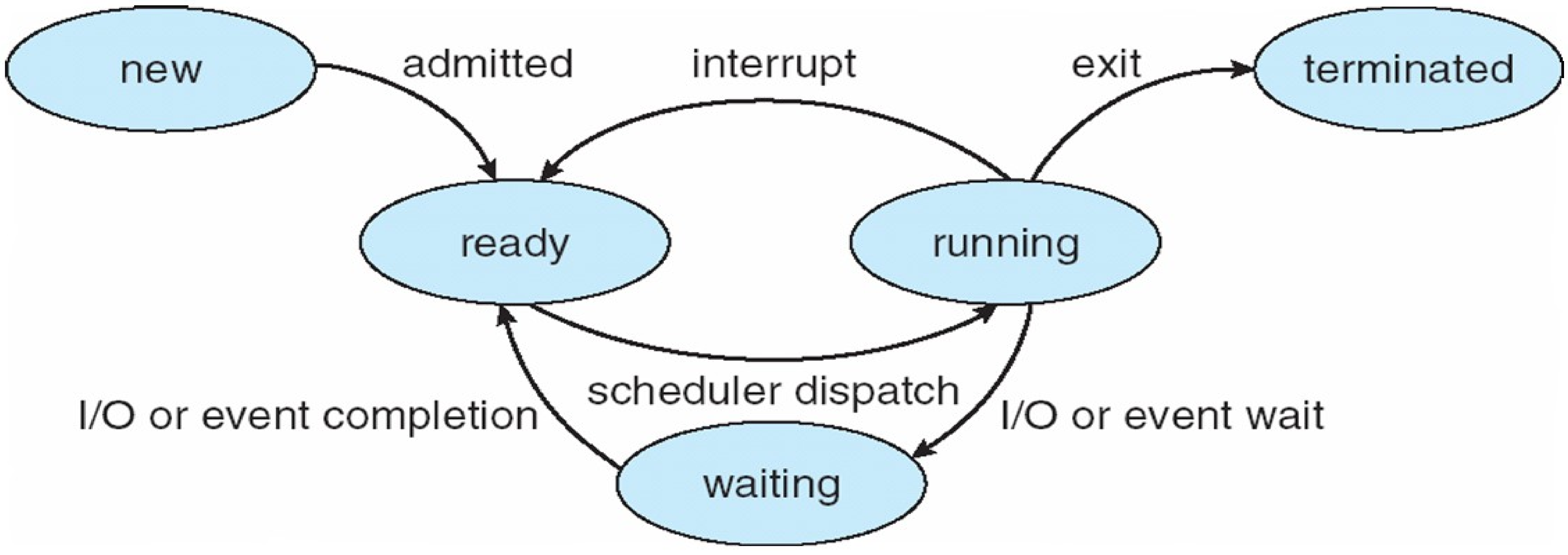
Process in Memory



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

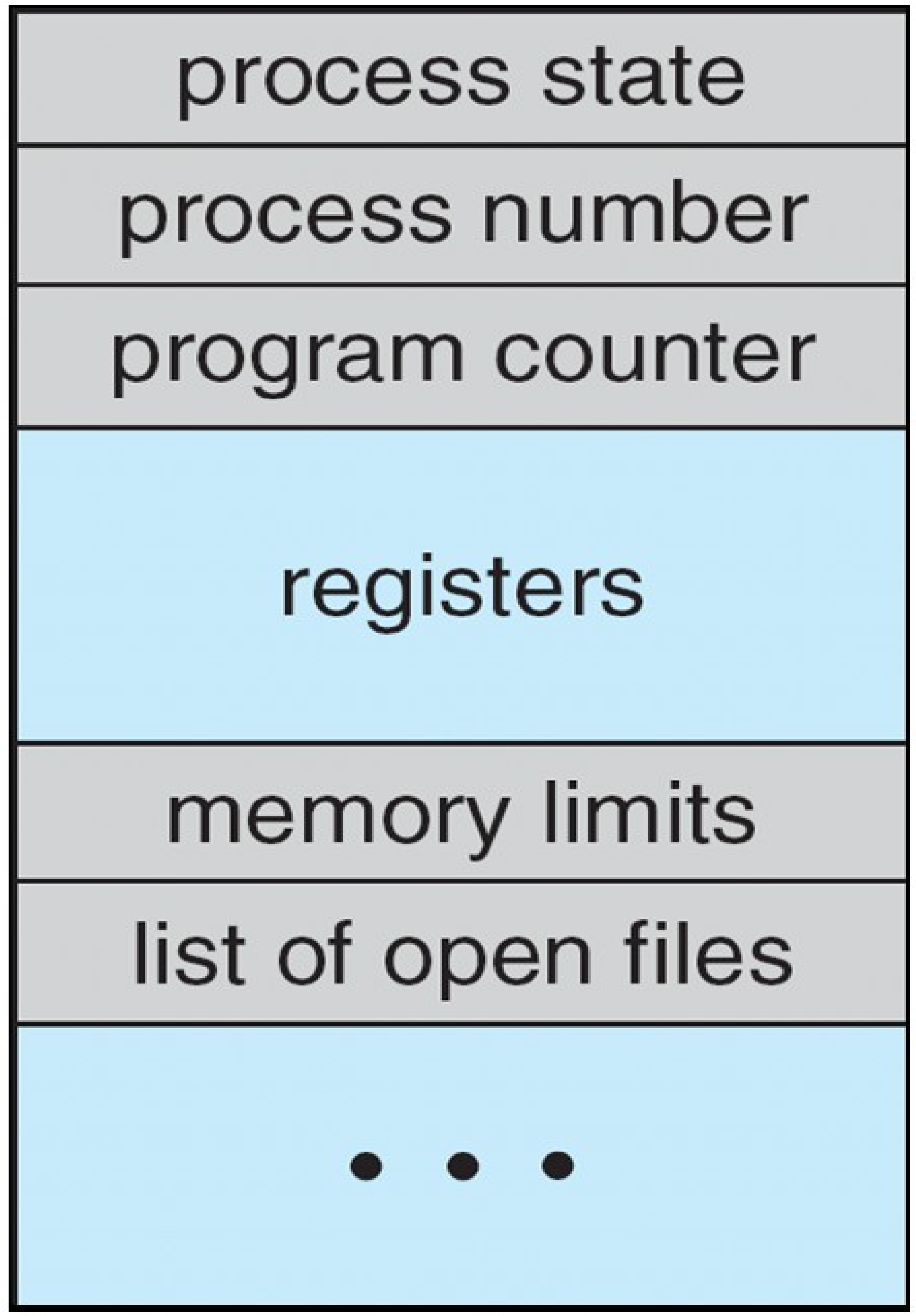


Process Control Block (PCB)

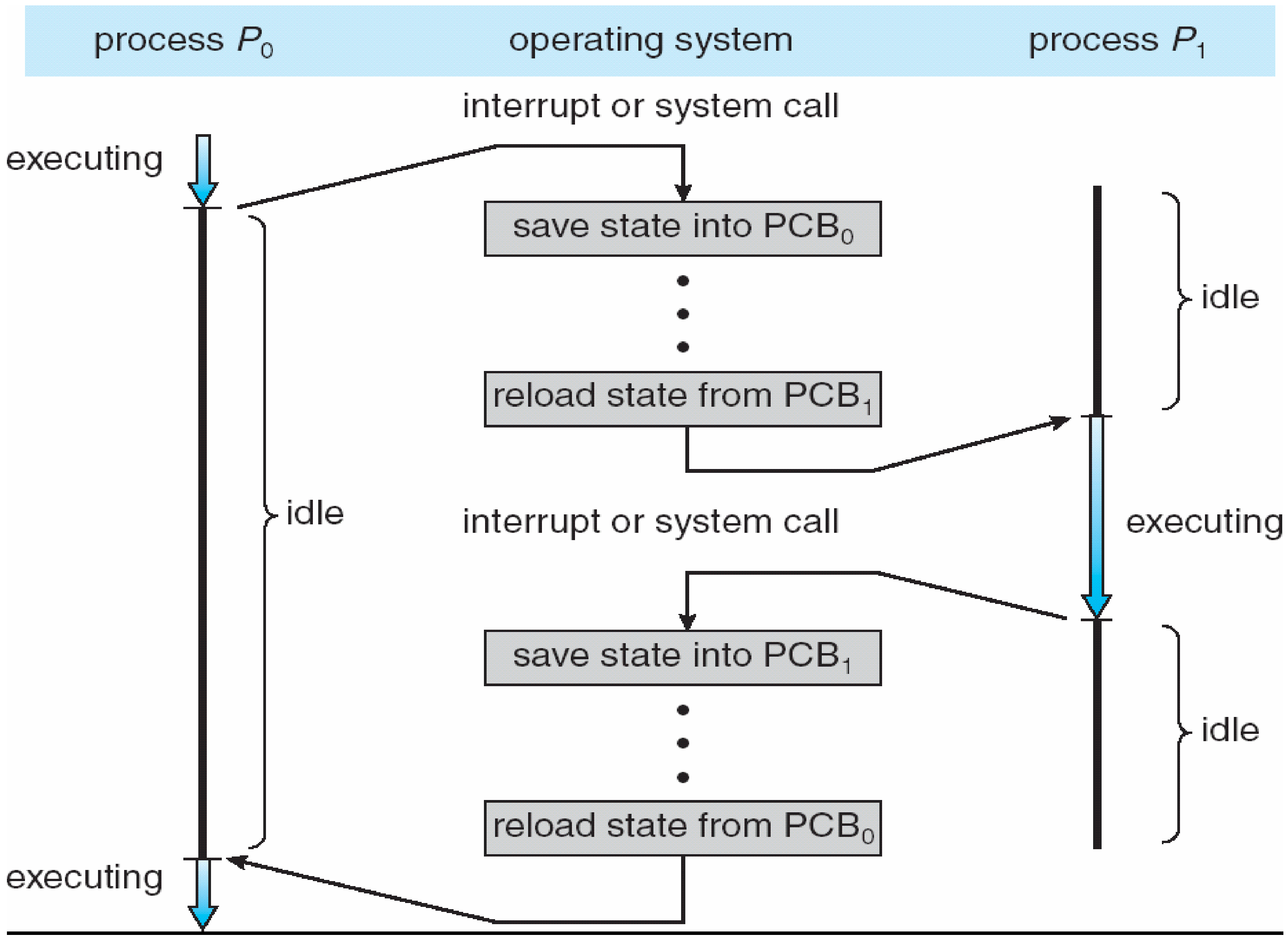
Information associated with each process

- *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



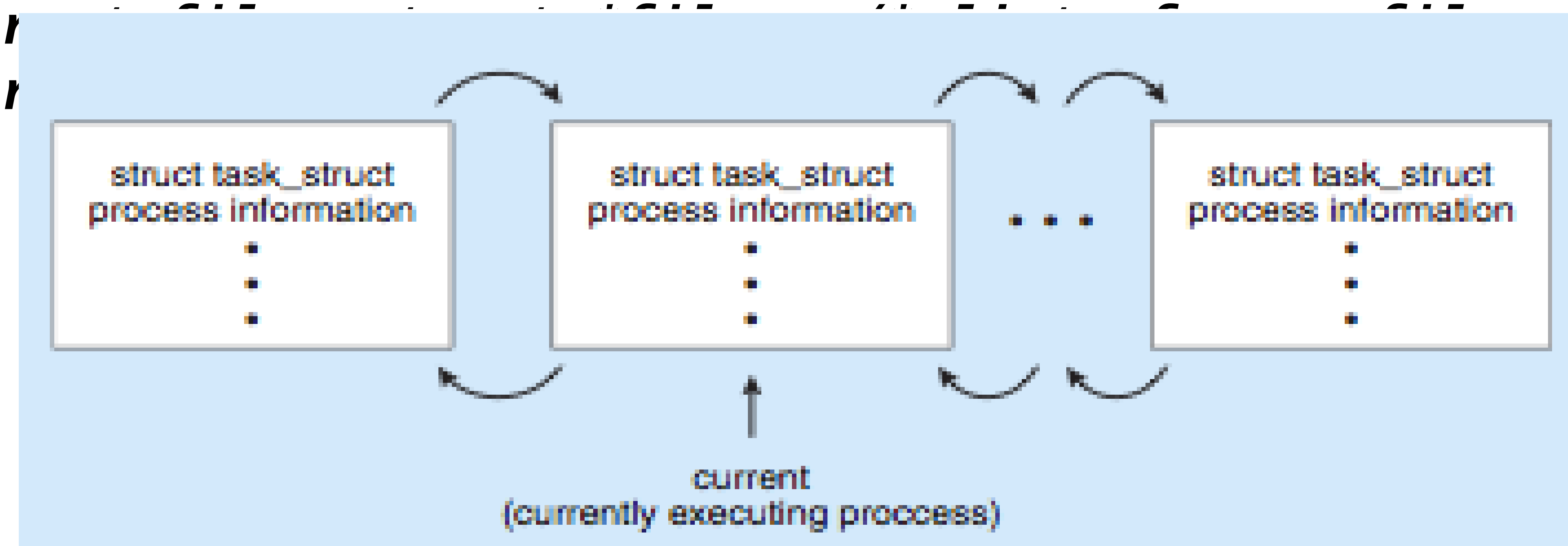
Process Scheduling

- ***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

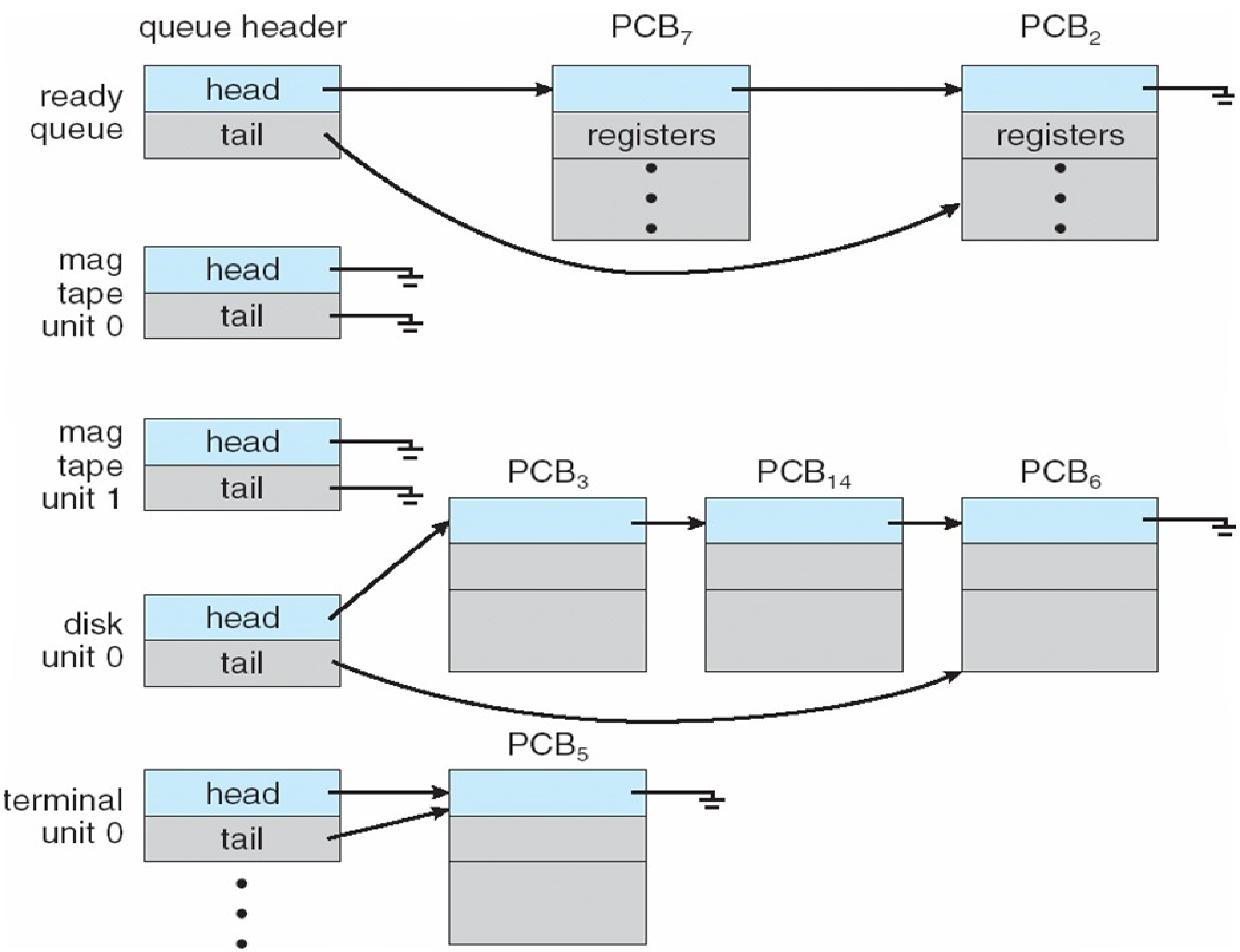
Process Representation in Linux

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

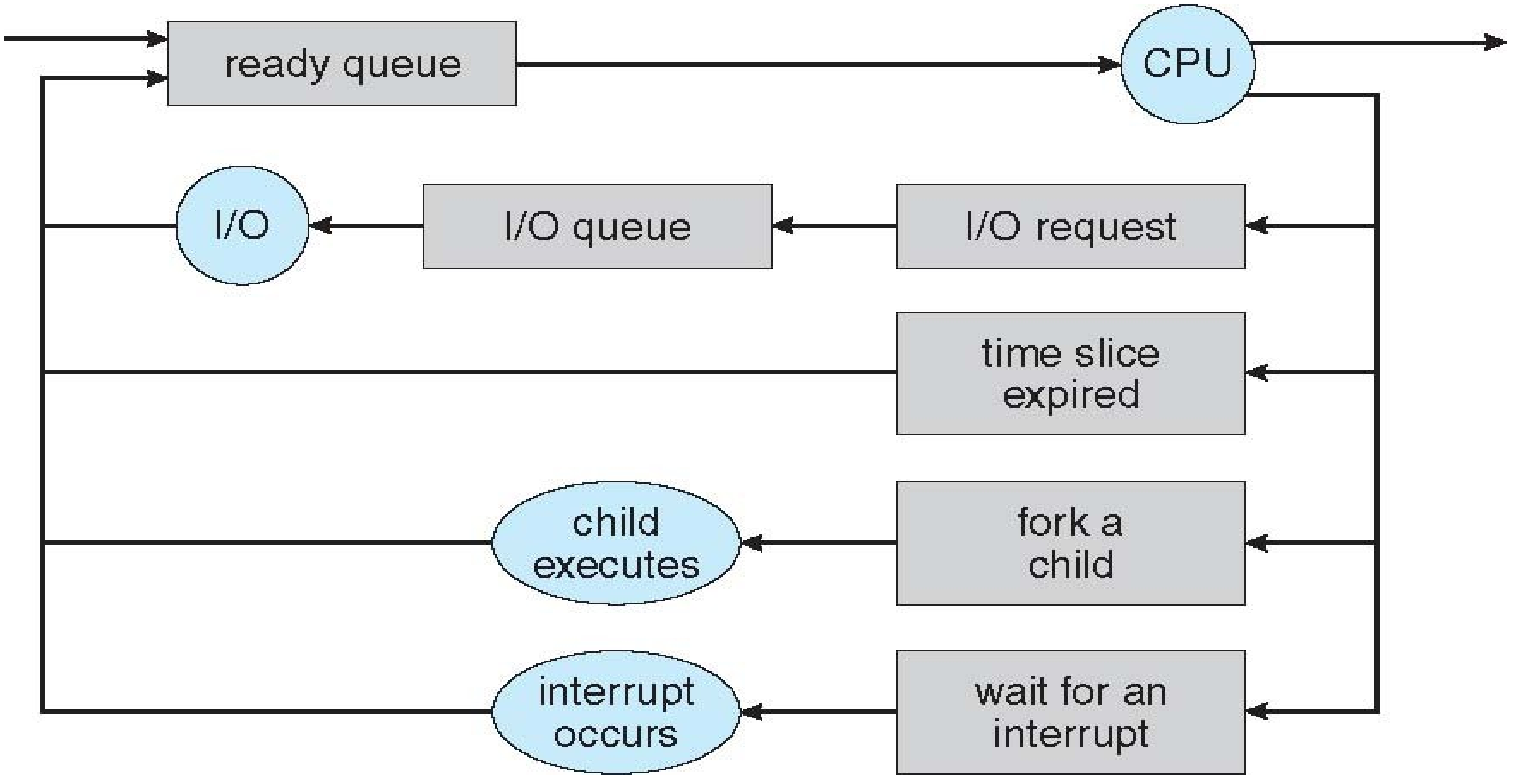
```
pid t pid; /* process identifier */
long state; /* state of the process */
unsigned int time slice /* scheduling information */
struct task struct *parent; /* this process's parent */
struct list head children; /* this process's children */
str */
str */
```



Ready Queue And Various I/O Device Queues



Representation of Process Scheduling



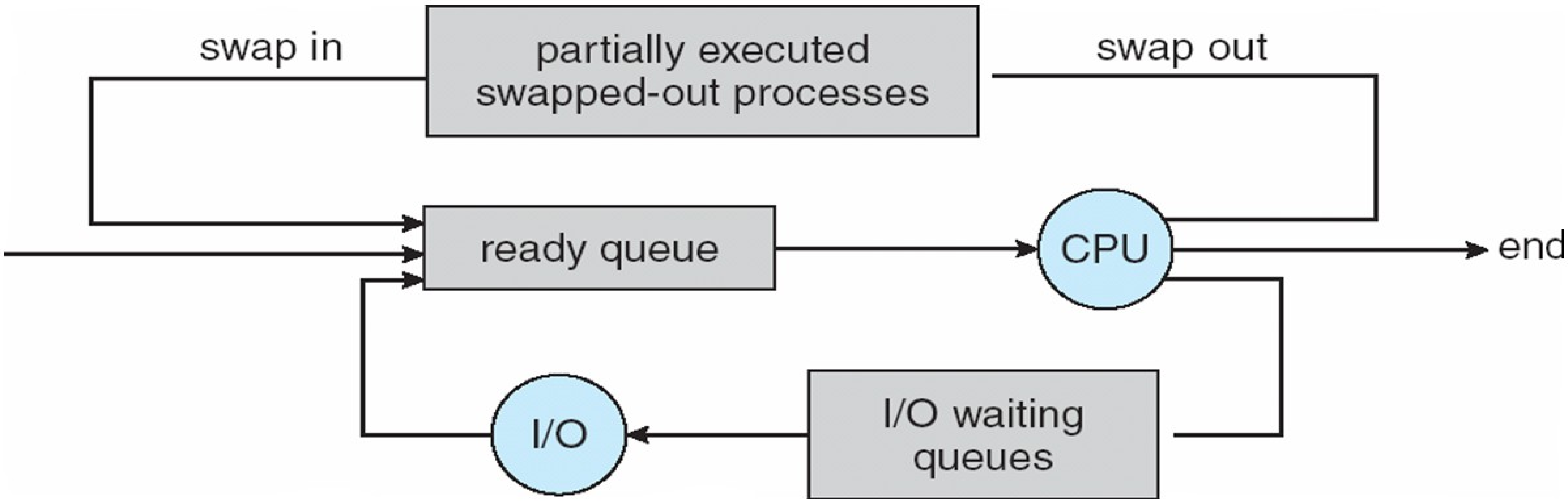
Schedulers

- ***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***
    - Sometimes the only scheduler in a system

Schedulers (Cont.)

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

Addition of Medium Term 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 overhead; the system does no useful work while switching***
  - The more complex the OS and the PCB -> longer the context switch
- ***Time dependent on hardware support***
  - Some hardware provides multiple sets of registers per CPU -> multiple contexts loaded at once

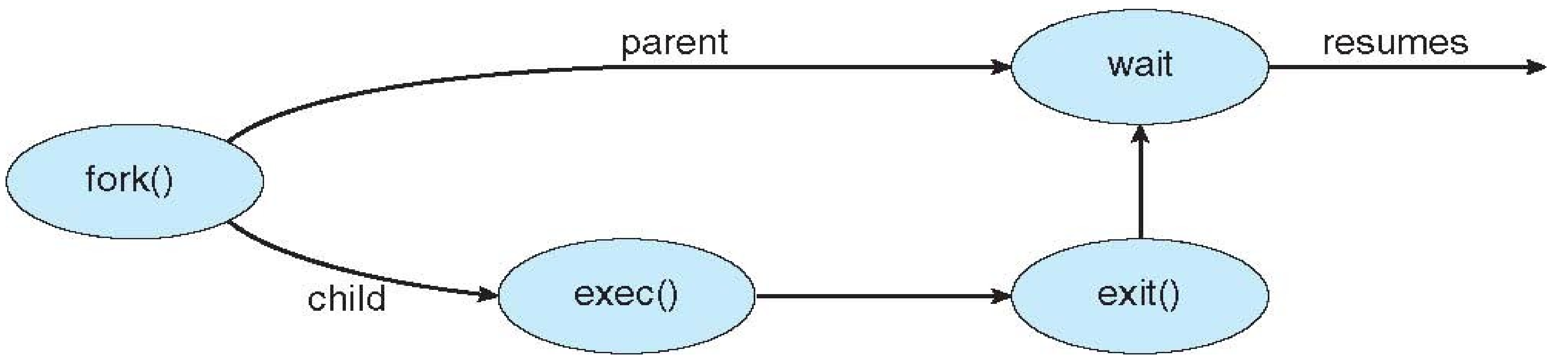
Process Creation

- ***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

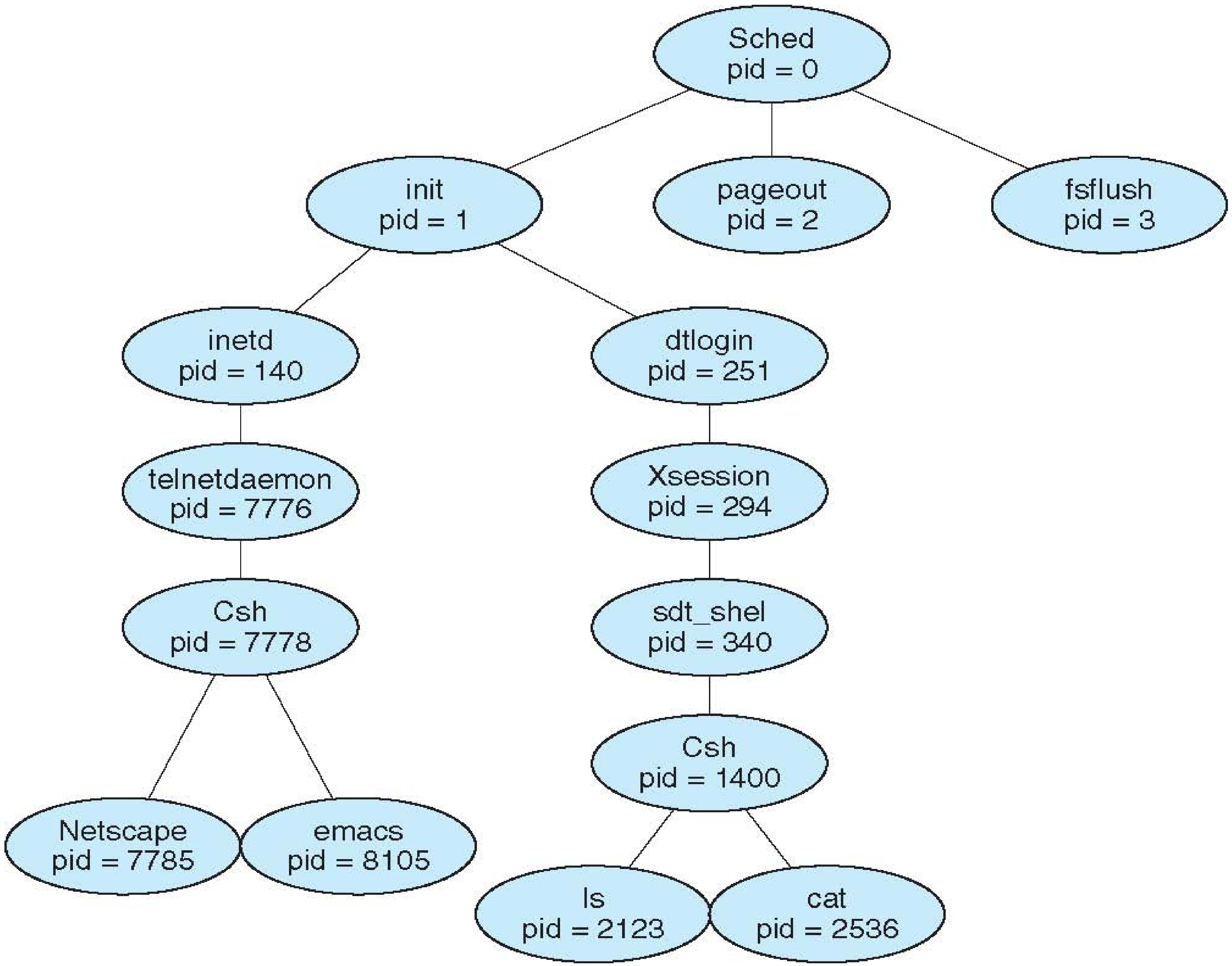
Process Creation



C Program Forking Separate Process

```
#include <sys/types.h>
#include <studio.h>
#include <unistd.h>
int main()
{
   pid_t  pid;
      /* fork another 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 */
           wait (NULL);
           printf ("Child Complete");
      }
      return 0;
}
```

A Tree of Processes on Solaris



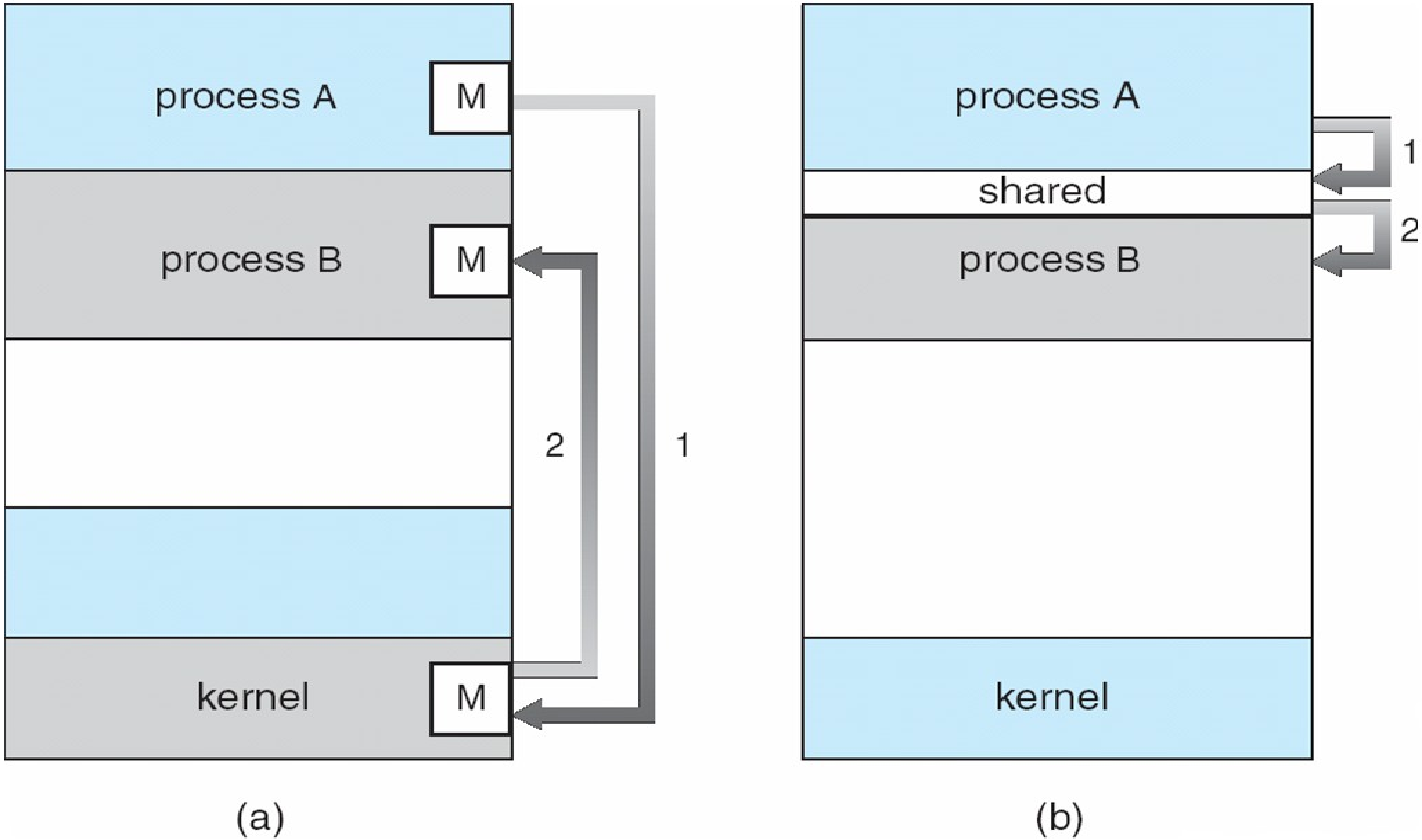
Process Termination

- ***Process executes last statement and asks the operating system to delete it (exit)***
  - Output data from child to parent (via **wait**)
  - Process' resources are deallocated by operating system
- ***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 operating system 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***
- ***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



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* 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***

Bounded-Buffer – Producer

```
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

```
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

- ***POSIX Shared Memory***
  - Process first creates shared memory segment

```
segment_id = shmget(IPC_PRIVATE, size, S IRUSR | S IWUSR);
```

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

```
shared_memory = (char *) shmat(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()`

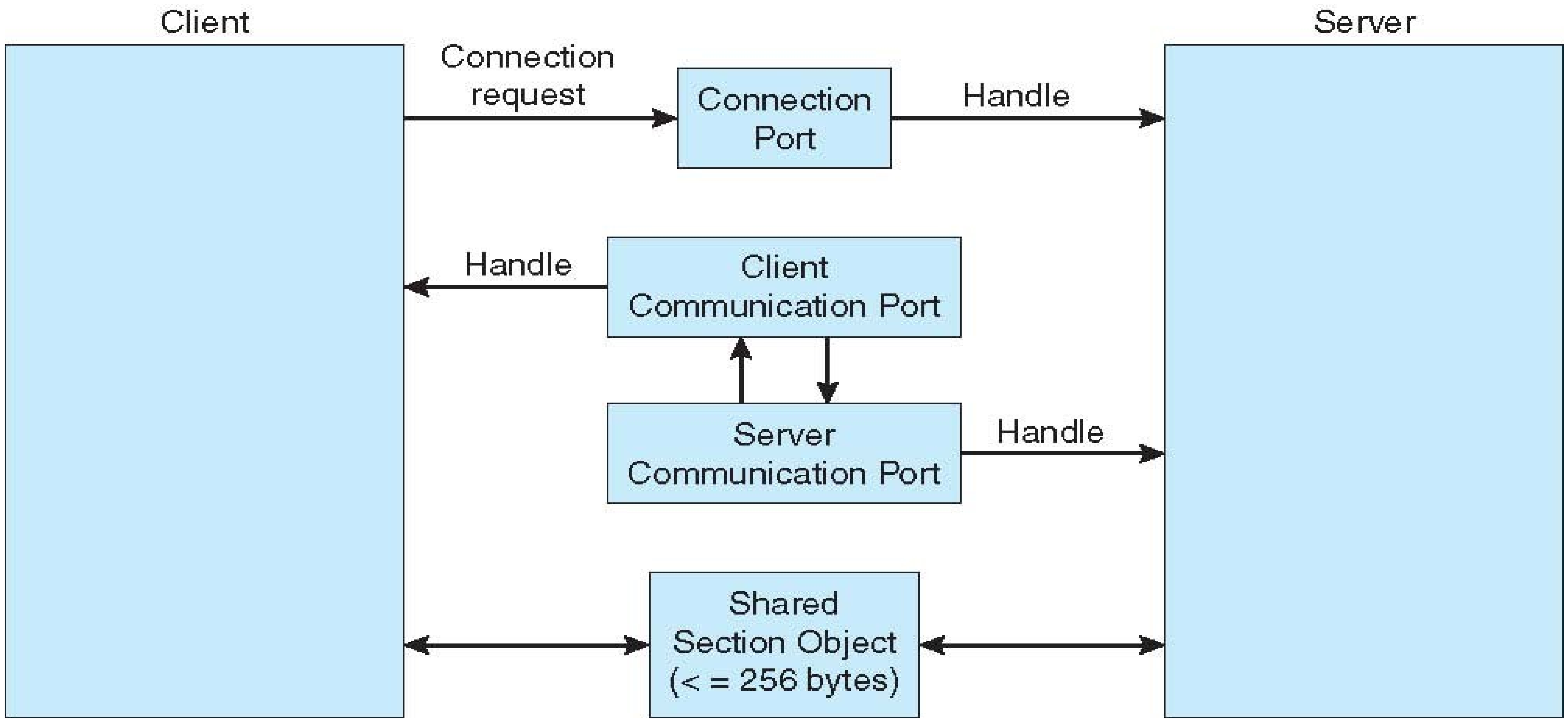
  - Mailboxes needed for commuication, created via

`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



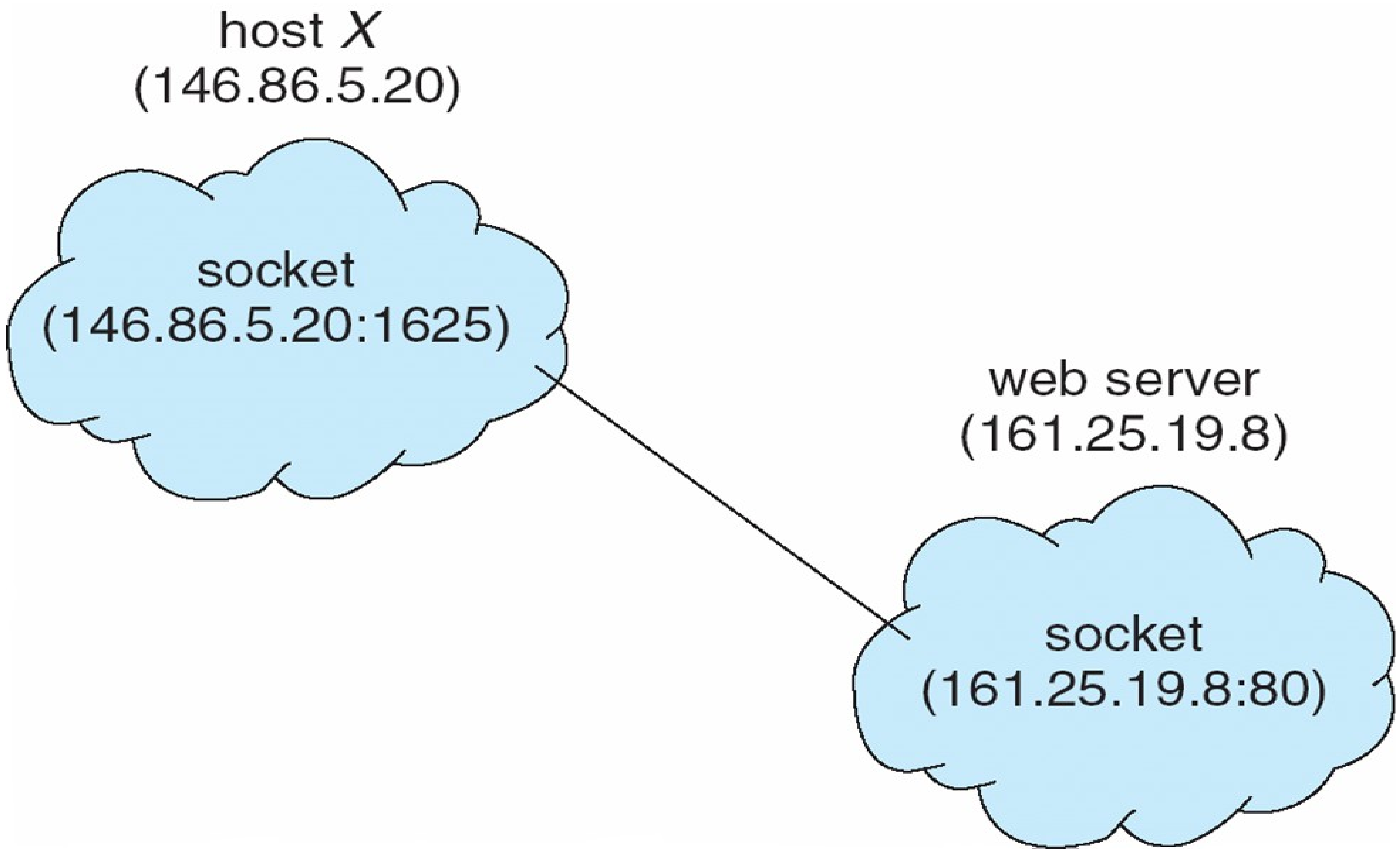
Communications in Client-Server Systems

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

Sockets

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

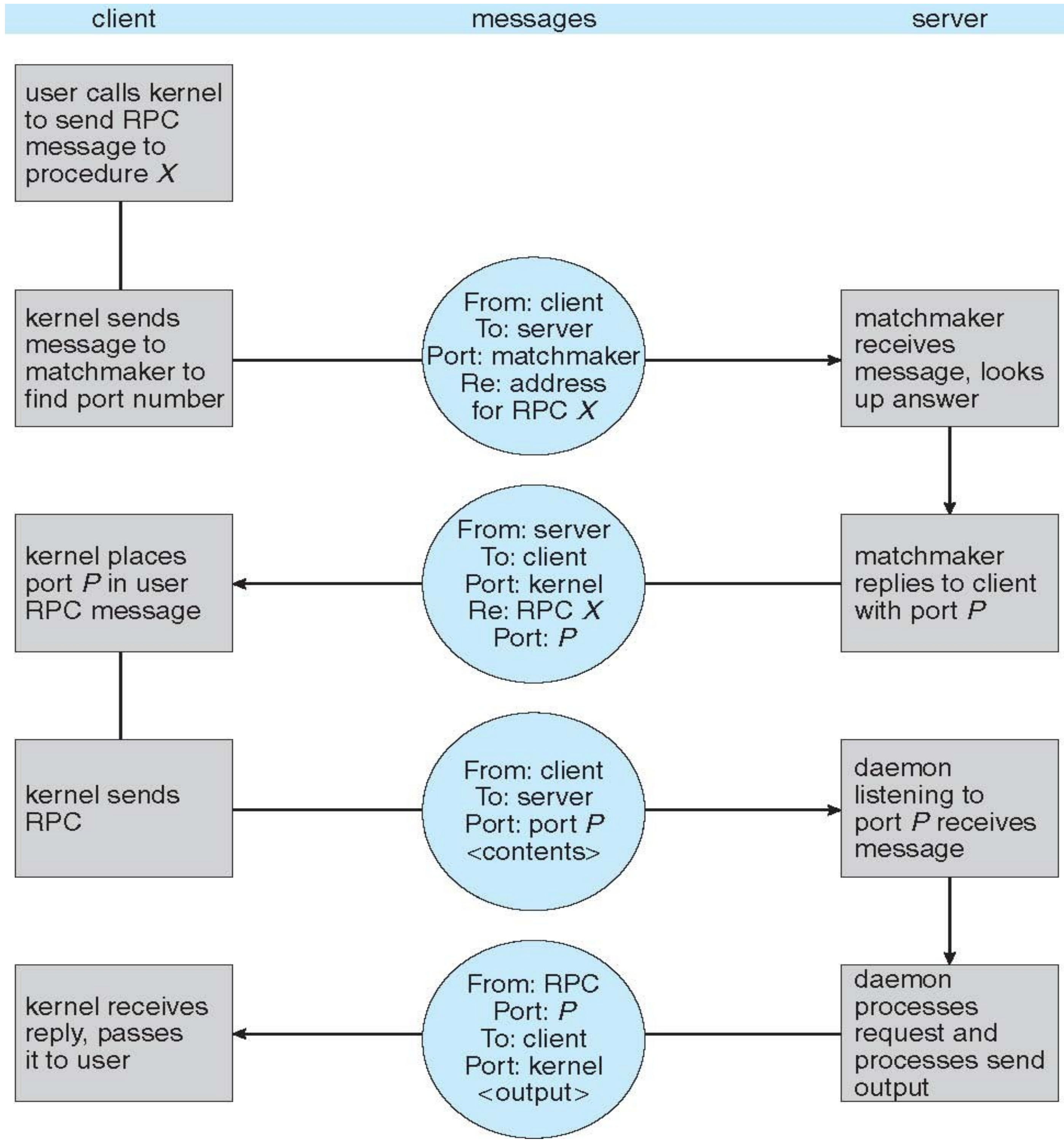
Socket Communication



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

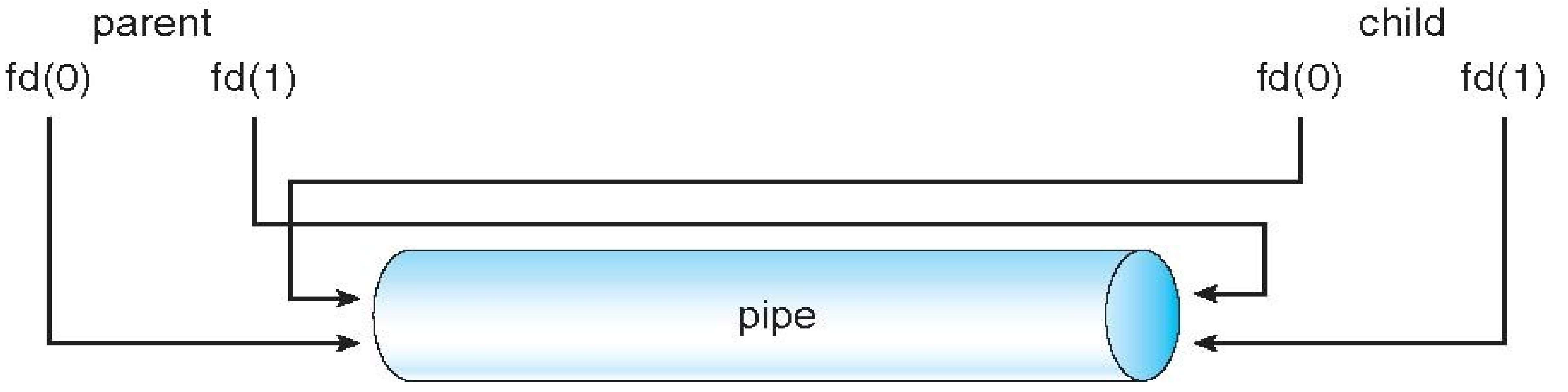
- ***Acts as a conduit allowing two processes to communicate***

- ***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



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