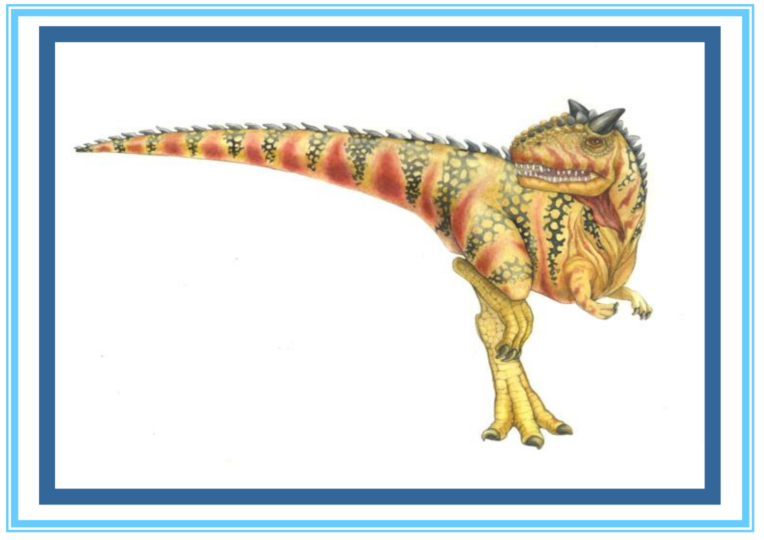
Chapter 3: Process Concept



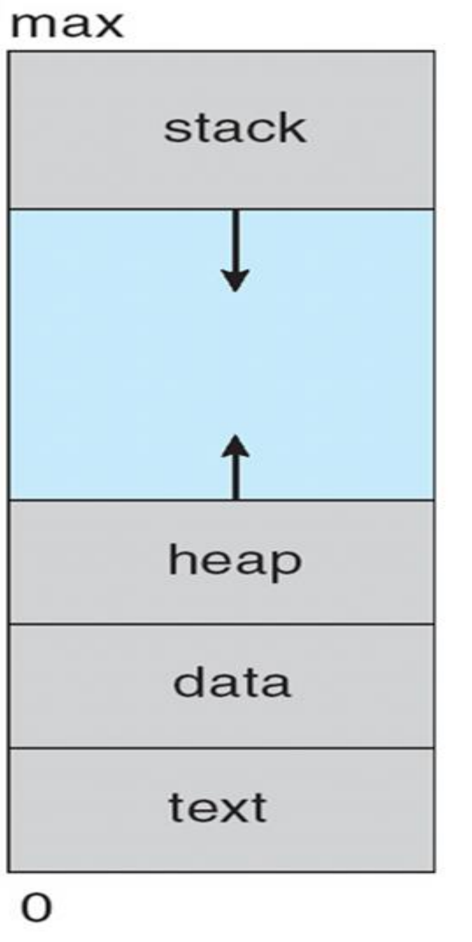
Chapter 3: Process Concept

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

Process Concept

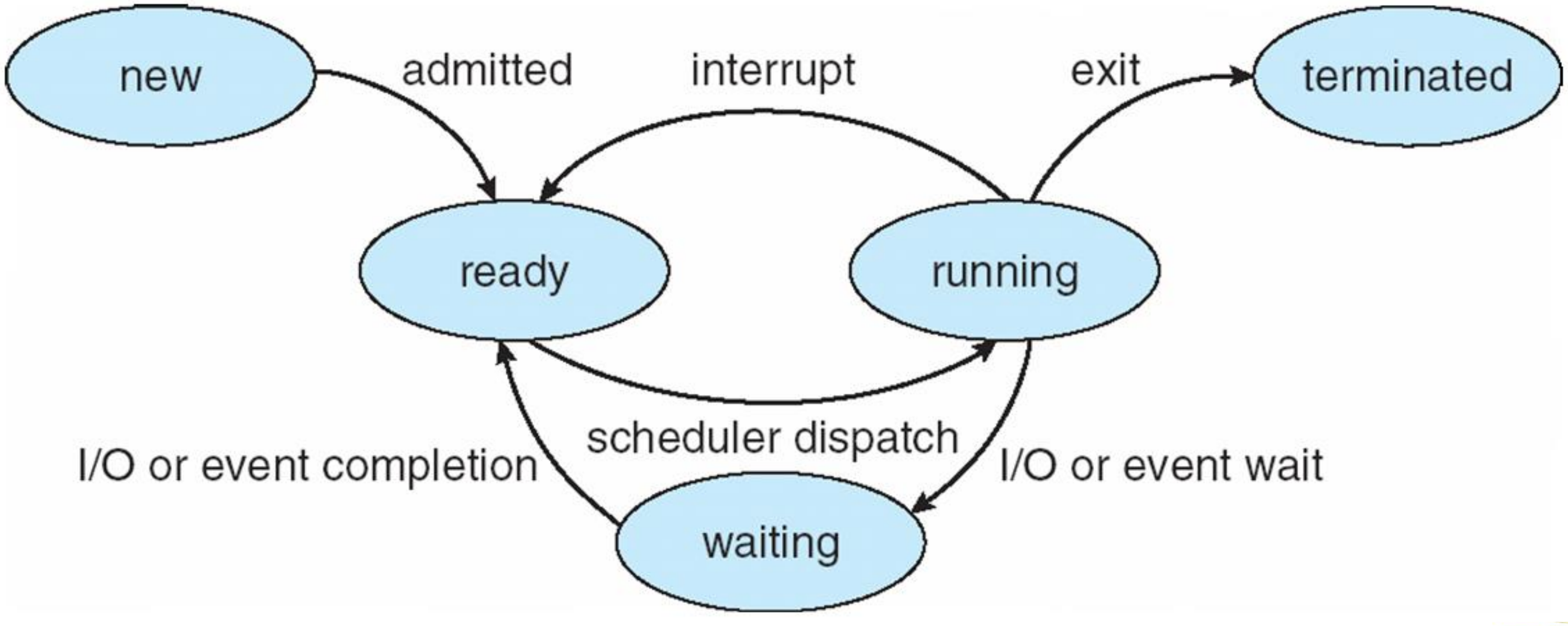
- An operating system executes a variety of programs:
  - Batch system – **jobs**
  - Time-shared systems – **user programs** or **tasks**
  - Textbook uses the terms ***job*** and ***process*** almost interchangeably
- **Process** – a program in execution
  - The program code, also called **text section**
  - **Data section** containing global variables
  - **Heap** containing memory dynamically allocated during run time
  - **Stack** containing temporary data
    - Function parameters, return addresses, local variables
  - Current activity including **program counter (PC)**, processor **registers**
- Program is ***passive*** entity stored on disk (**executable file**), process is ***active***
  - Program becomes process when the executable file is loaded into memory
- Execution of program started via GUI mouse clicks, command line entry of its name.
- 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
  - **ready**: The process is waiting to be assigned to a processor
  - **running**: Instructions are being executed
  - **waiting**: The process is waiting for some event to occur
  - **terminated**: The process has finished execution

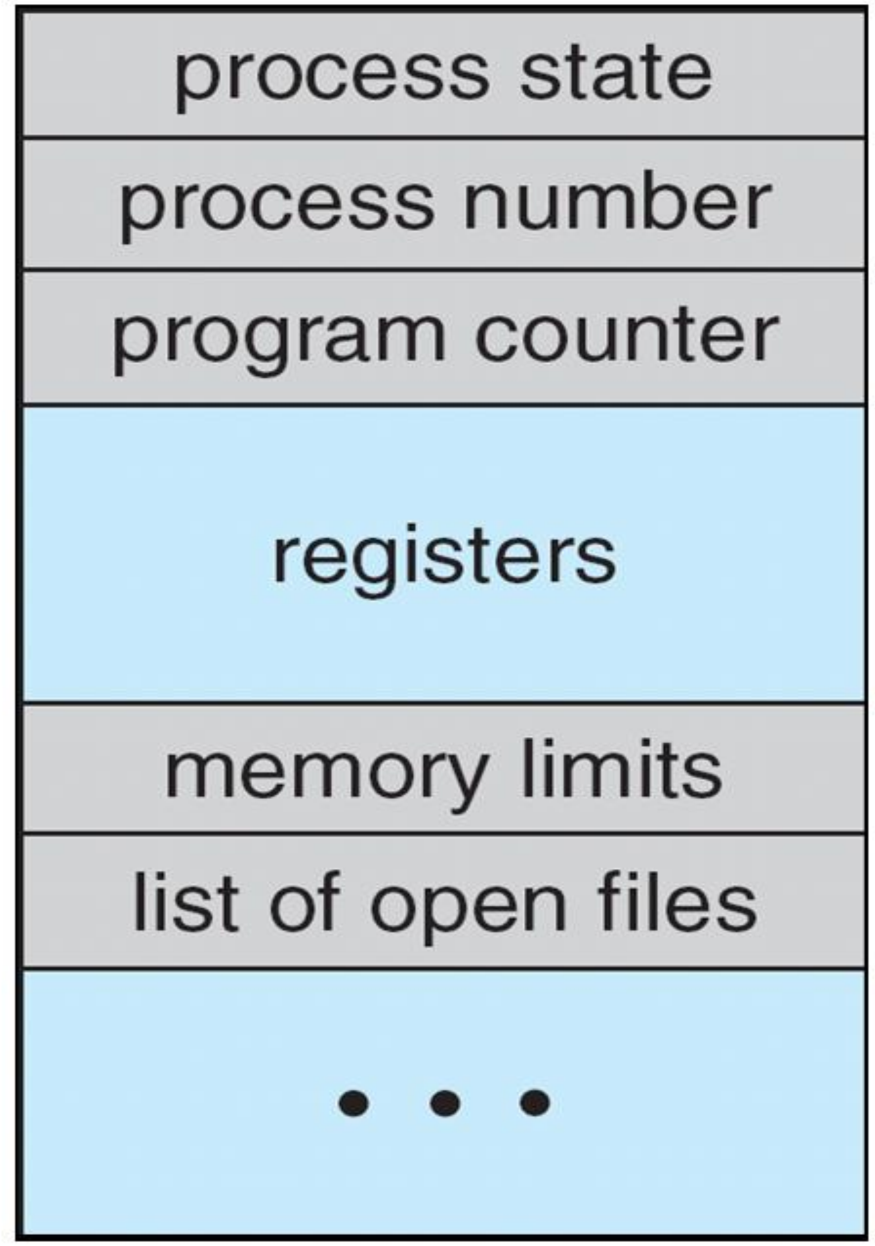


Process Control Block (PCB)

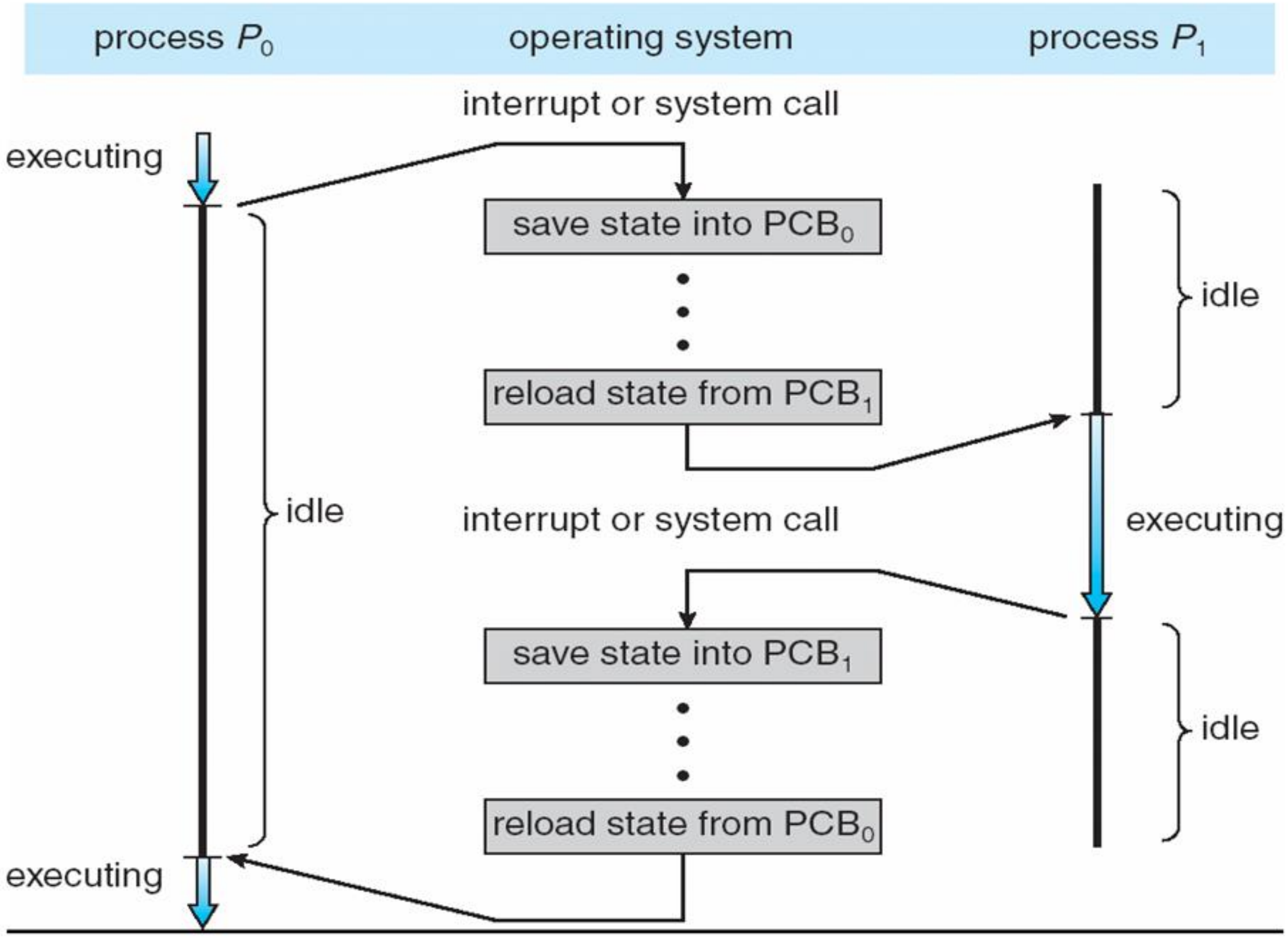
Information associated with each process

(also called **task control block (TCB)**)

- Process state – running, waiting, etc
- Program counter – location of instruction to be executed next
- 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



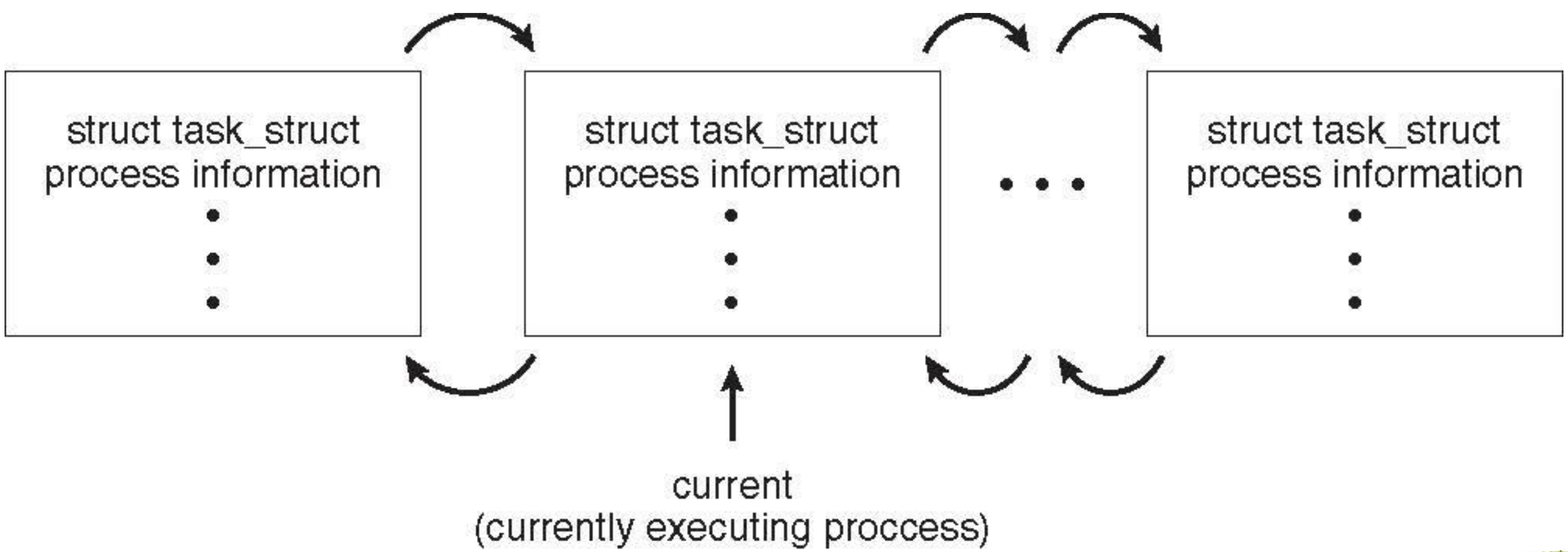
Threads

- 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

Process Representation in Linux

Represented by the C structure `task_struct`

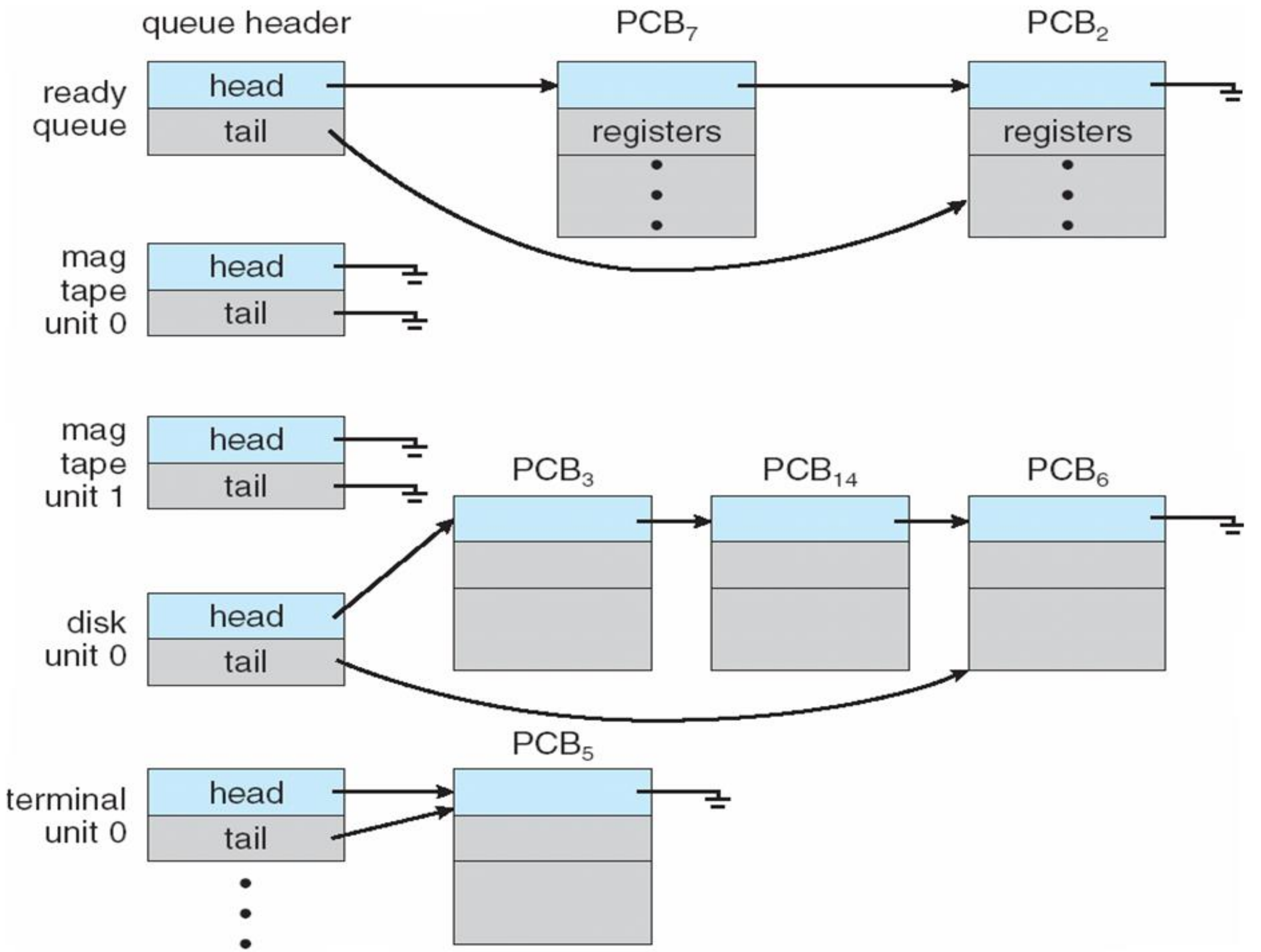
```
pid t_pid; /* process identifier */
long state; /* state of the process */
unsigned int time_slice /* scheduling information */
struct task_struct *parent; /* this process's parent */
struct list_head children; /* this process's children */
struct files_struct *files; /* list of open files */
struct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



Process Scheduling

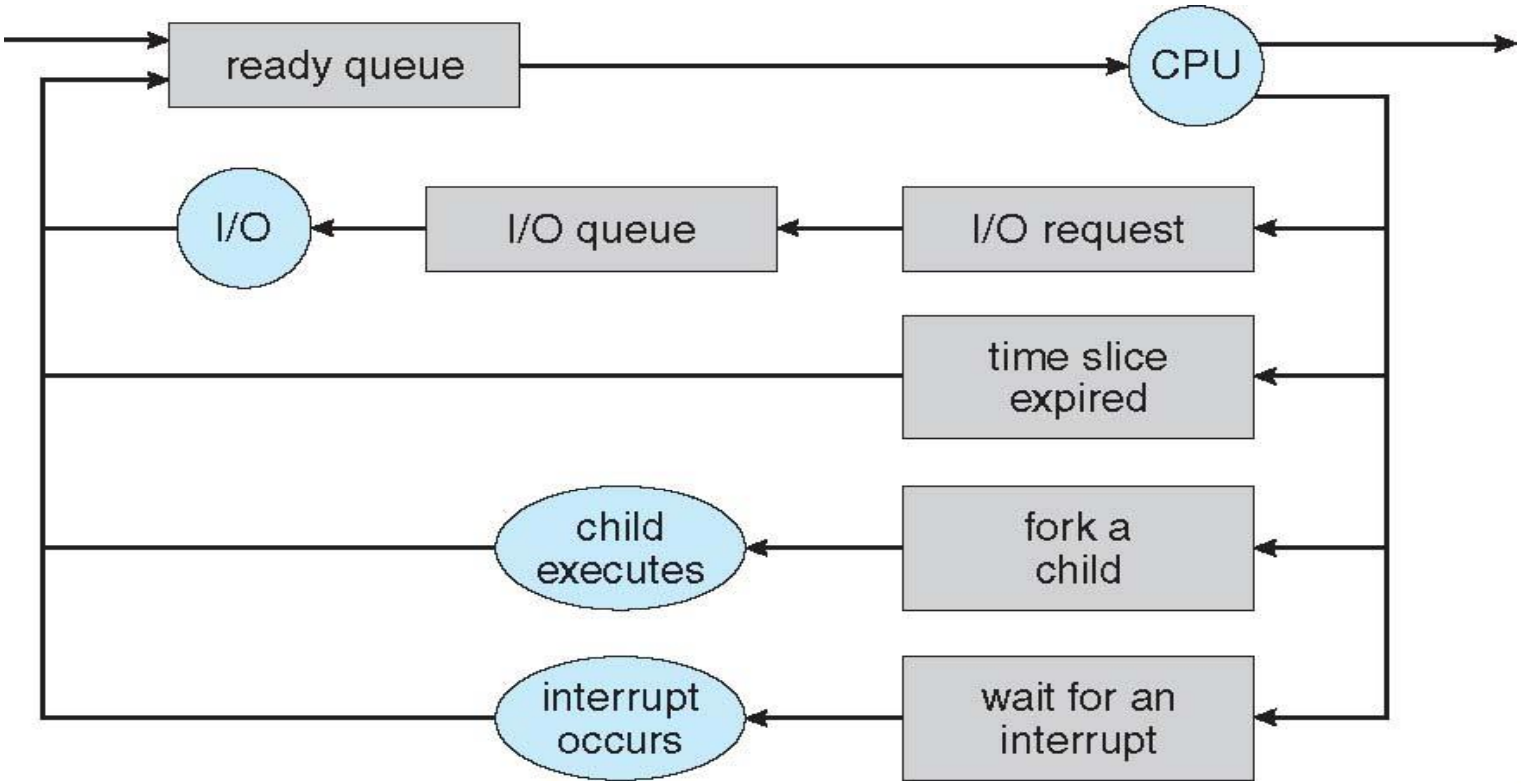
- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the system
  - **Ready queue** – set of all processes residing 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

- **Queuing diagram** represents queues, resources, flows

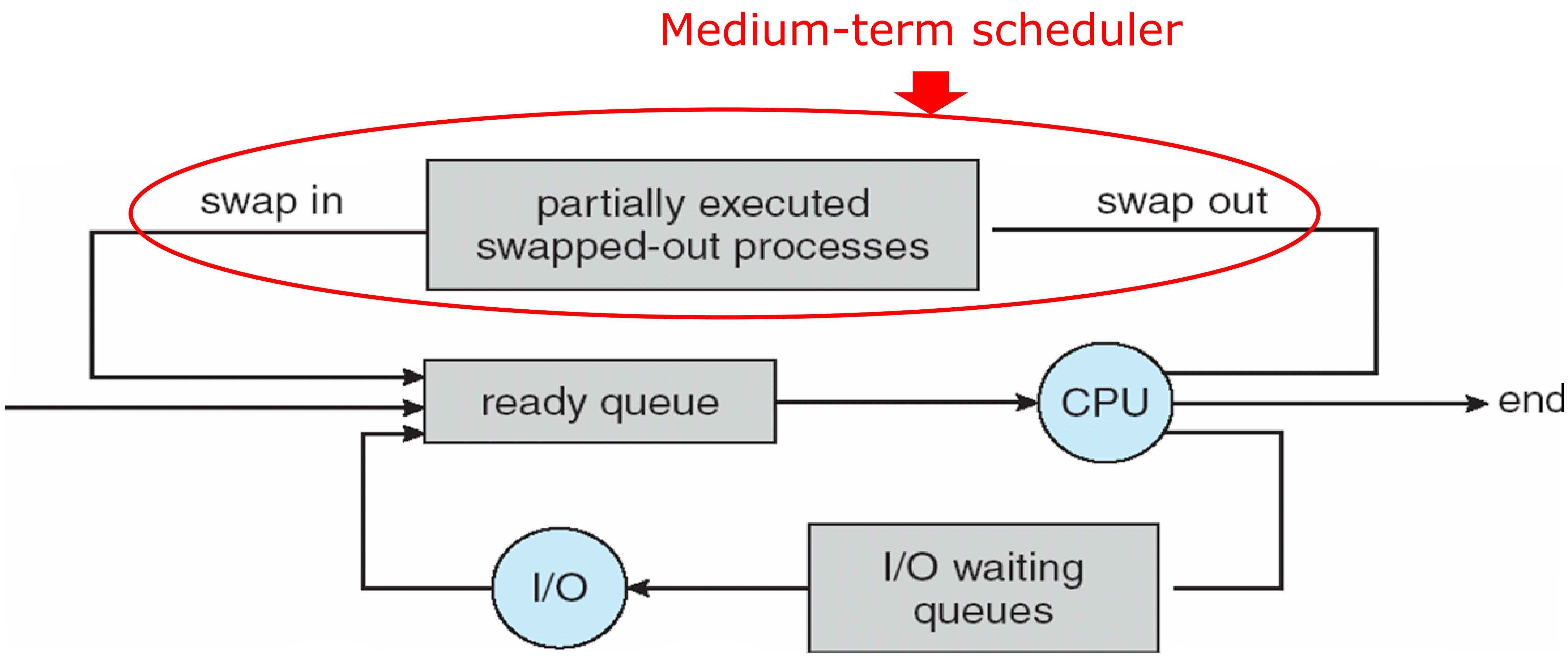


Schedulers

- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  - is invoked very infrequently (seconds, minutes) $\Rightarrow$ may be slow
  - The long-term scheduler controls the **degree of multiprogramming**
- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - Sometimes the only scheduler in a system
  - is invoked very frequently (milliseconds) $\Rightarrow$ must be fast
- 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

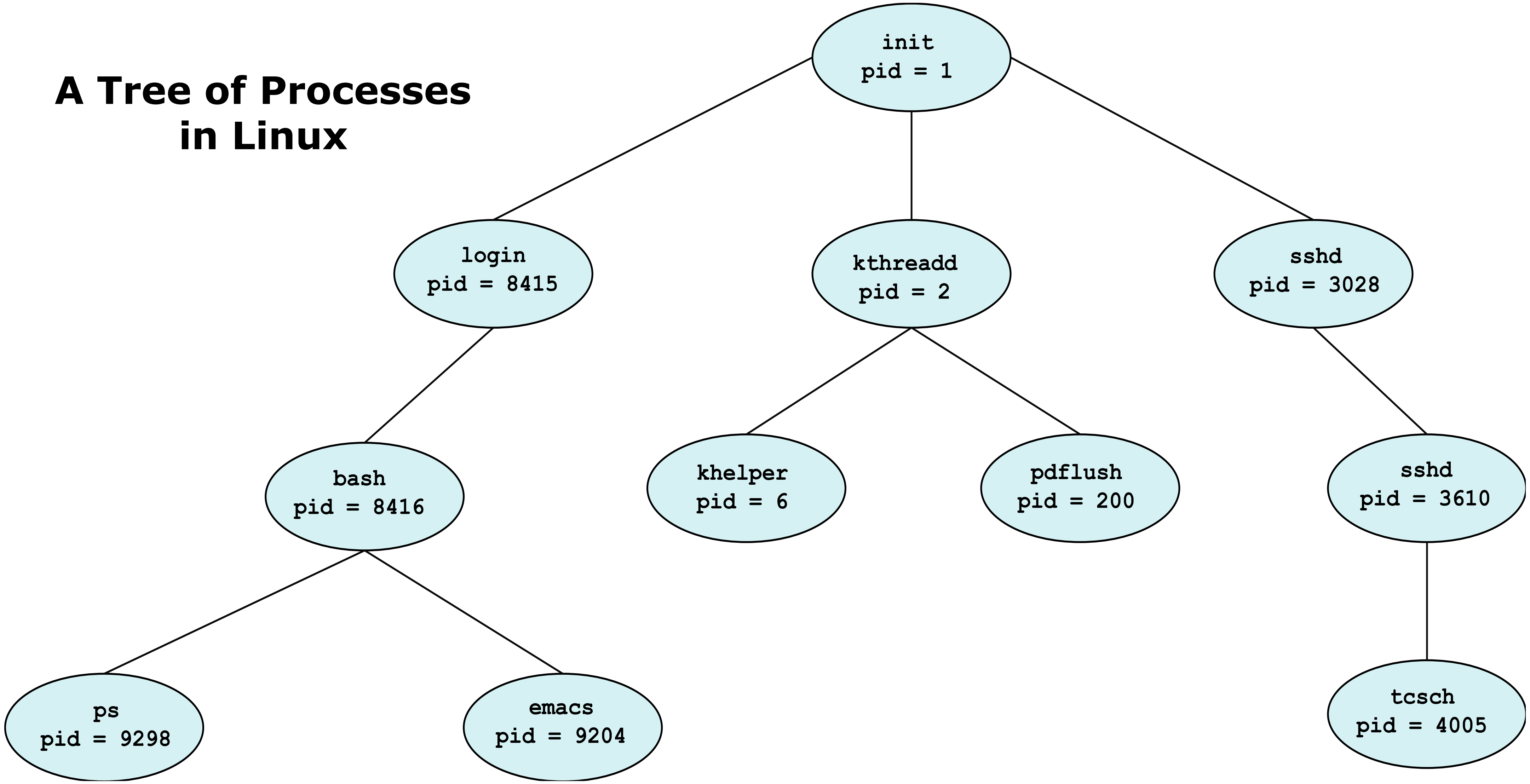
- Some systems / early systems allow only one process to run, others suspended
- iOS
  - Single **foreground** process- controlled via user interface
  - Multiple **background** processes– in memory, running, but not on the display, and with limits
  - Limits include short task, receiving notification 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 in background
  - 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 → longer the context switch
- Time dependent on hardware support
  - Some hardware provides multiple sets of registers per CPU → multiple contexts loaded at once

Operations on Processes - Process Creation

- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- Process identified and managed via a **process identifier** (**pid**)

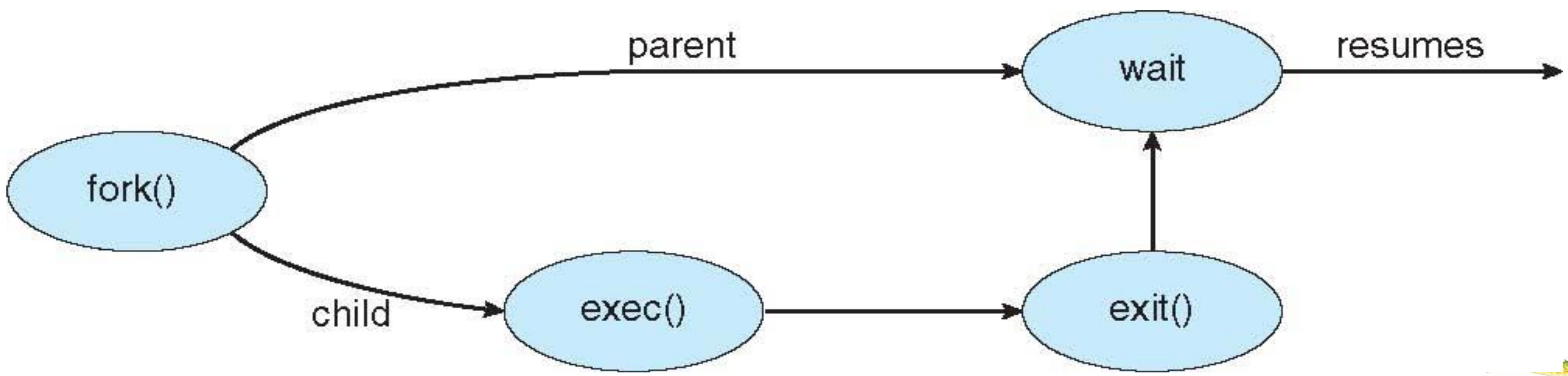


Operations on Processes - Process Creation

- 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
- **Address space**: two options
  - Child duplicate of parent (UNIX example: **fork**())
  - Child has a program loaded into it (UNIX example: **exec**())

Operations on Processes - Process Creation

- **fork()** : system call creates new process
  - The child process consists of a copy of the address space of parent process.
  - Both processes get return codes of fork() and continue executing the instruction after the fork()
    - Child gets the return code : 0
    - Parent gets the return code : child's PID
- **exec()** : system call used to replace the process' memory space with a new program
  - Typically, exec() is called after a **fork()**
  - After exec(), the child has the code and data that are total different from its parent



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;
}
```

Return value of fork()

- 0 : in child process
- child's PID : in parent process

child

parent

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));

    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);
}
```

See if child process has terminated

Process Termination

- Process executes last statement and asks the OS to delete it (**`exit()`**)
  - Output data from child to parent
    - Parent wait for termination of a child by using **`wait()`**

```
pid t pid;
int status;
pid = wait(&status);     //return the PID of the child process
```

  - Process' resources are deallocated by operating system
- Parent may terminate execution of children processes (**`abort()`**) because
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - If parent is exiting
    - Some OSs do not allow child to continue if its parent terminates
      - All children terminated - **cascading termination**
- If no parent waiting, then terminated process is a **zombie (defunct)**
- If parent terminated, processes are **orphans**

Process Termination

- If no parent waiting, then terminated process is a **zombie (defunct)**
  - A zombie process is nothing but an entry in the process table, it doesn't have any code or memory.
  - This entry in PCB is still needed to allow the parent process to read its child's exit status. To clean up a zombie, it must be waited on by its parent.
- If parent terminated, processes are **orphans**
  - An orphan process is a computer process whose parent process has finished or terminated, though it remains running itself.
  - In a Unix-like operating system any orphaned process will be adopted by the **init** process.

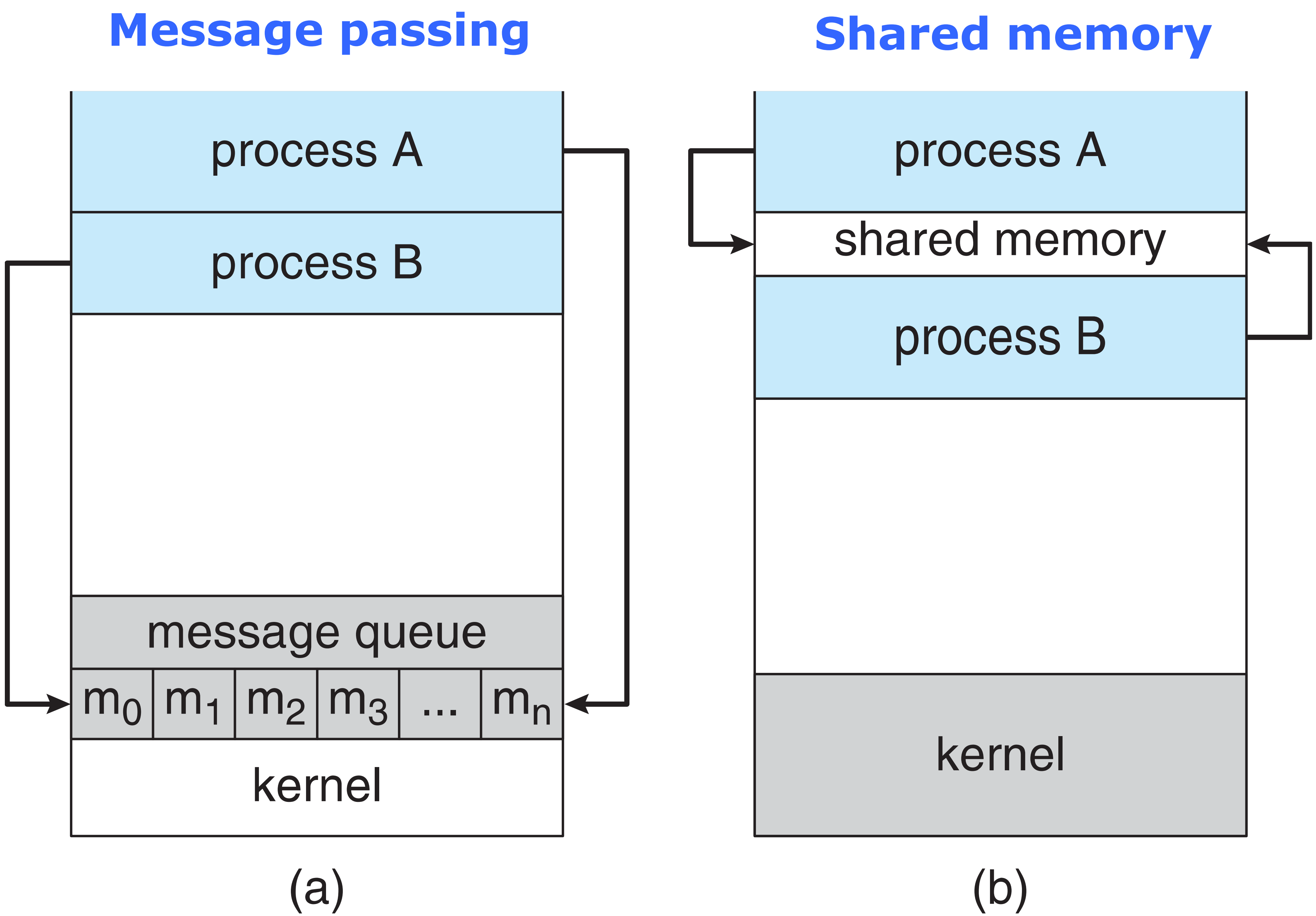
Multiprocess Architecture – Chrome Browser

- 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 categories
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript, new one for each website opened
    - Runs in **sandbox** restricting disk and network I/O (minimize effect of security exploits)
    - Several renderer processes may be active at the same time; one for each tab.
  - **Plug-in** process for each type of plug-in

Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
- **Independent** process cannot affect or be affected by another process
- **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



Producer-Consumer Problem

- Paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - **unbounded-buffer:** no practical limit on the size of the buffer
  - **bounded-buffer:** assumes that there is a fixed buffer size
    - Example: Shared-Memory Solution using Bounded-Buffer

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

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

Producer – Consumer using Bounded-Buffer

```
item next_produced;
while (true) {
     /* produce an item in next_produced */
     while (((in + 1)% BUF_SIZE) == out)
          ; /* do nothing */
     buffer[in] = next_produced;
     in =(in + 1)% BUF_SIZE;
}
```

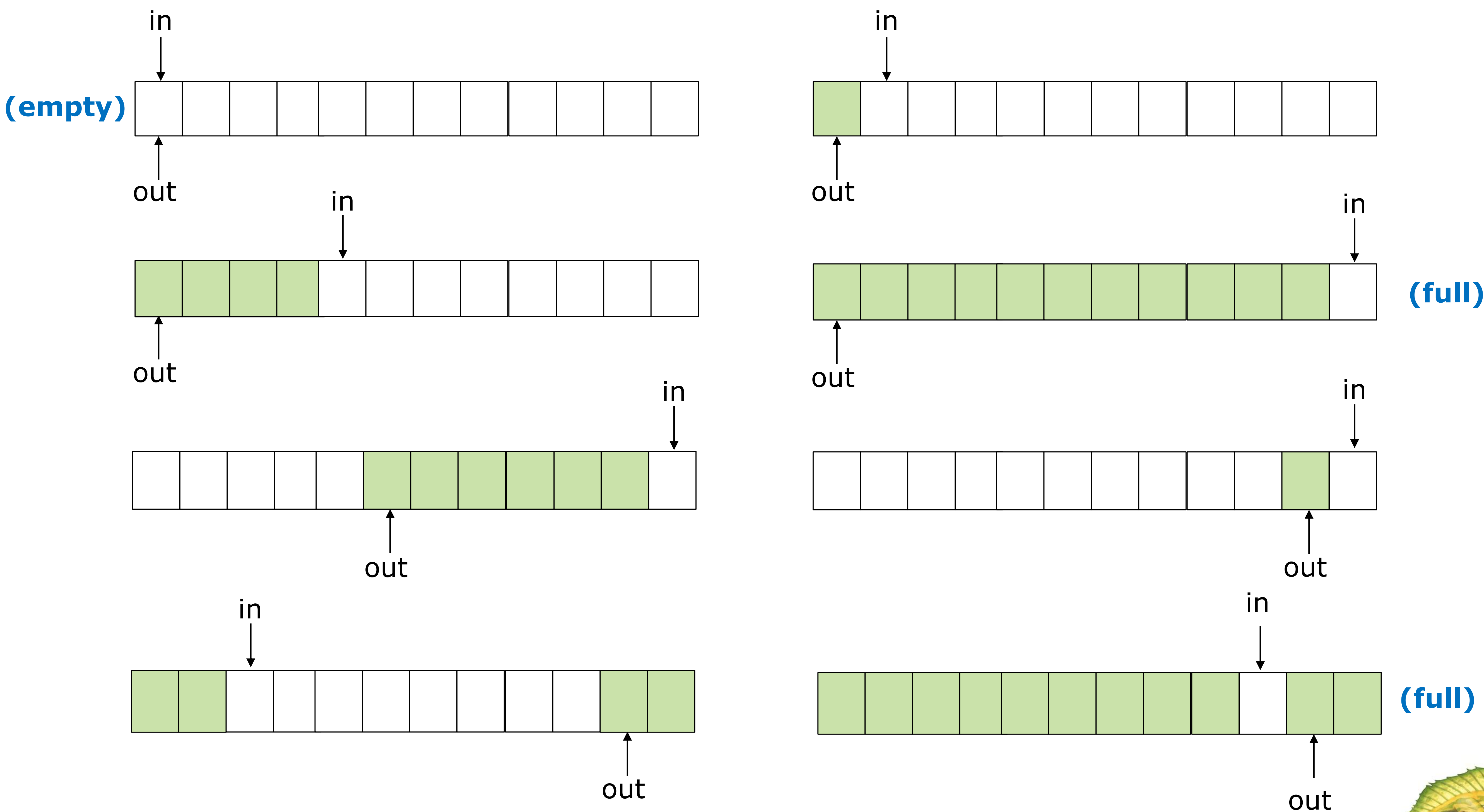
Producer

Consumer

```
item next_consumed;
while (true) {
          while (in == out)
                    ; /* do nothing */
          next_consumed = buffer[out];
          out =(out + 1)% BUF_SIZE;
          /* consume the item */
}
```

Note:
can only use BUF_SIZE-1 elements

Producer – Consumer using Bounded-Buffer



Interprocess Communication – Shared Memory

- An area of memory shared among the processes that wish to communicate
  - Fast communication compared to message passing because no need to copy data to kernel space
- The communication is under the control of the users processes not the operating system.
  - So, it is more complex for programmers to use
- 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 5.

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 is either 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, network)
  - **logical** (e.g., direct or indirect, synchronous or asynchronous, automatic or explicit buffering)

Message Passing – 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. The process need to know each other's identity.
  - 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 called 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
- Operations
  - create a new mailbox, destroy a mailbox
  - send and receive messages through 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 (e.g., 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:** sender blocks until the message is received by receiving process or mailbox
  - **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
- Different combinations possible
- If both send and receive are blocking, we have a **rendezvous**
  - Producer-consumer becomes trivial

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

```
message next_consumed;
while (true) {
   receive(next_consumed);
   /* consume the item */
}
```

Buffering

- Queue of messages attached to the link; implemented in one of three ways
    1. Zero capacity (no buffering) – 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
    `shm_fd = shm_open(name, O_CREAT | O_RDRW, 0666);`
  - Also used to open an existing memory segment to share it
  - Set the size of the object

    `ftruncate(shm_fd, 4096);`
  - Memory map the shared memory object

    ptr = mmap(0, SIZE, PROT_WRITE, MAP_SHARED, shm_fd, 0) ;
  - Now the process could write to the shared memory using the pointer **ptr**

IPC POSIX Producer

```c
#include <stdio.h>
#include <stlib.h>
#include <string.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size 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_RDRW, 0666);

   /* 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

```c
#include <stdio.h>
#include <stlib.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main()
{
/* the size 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

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

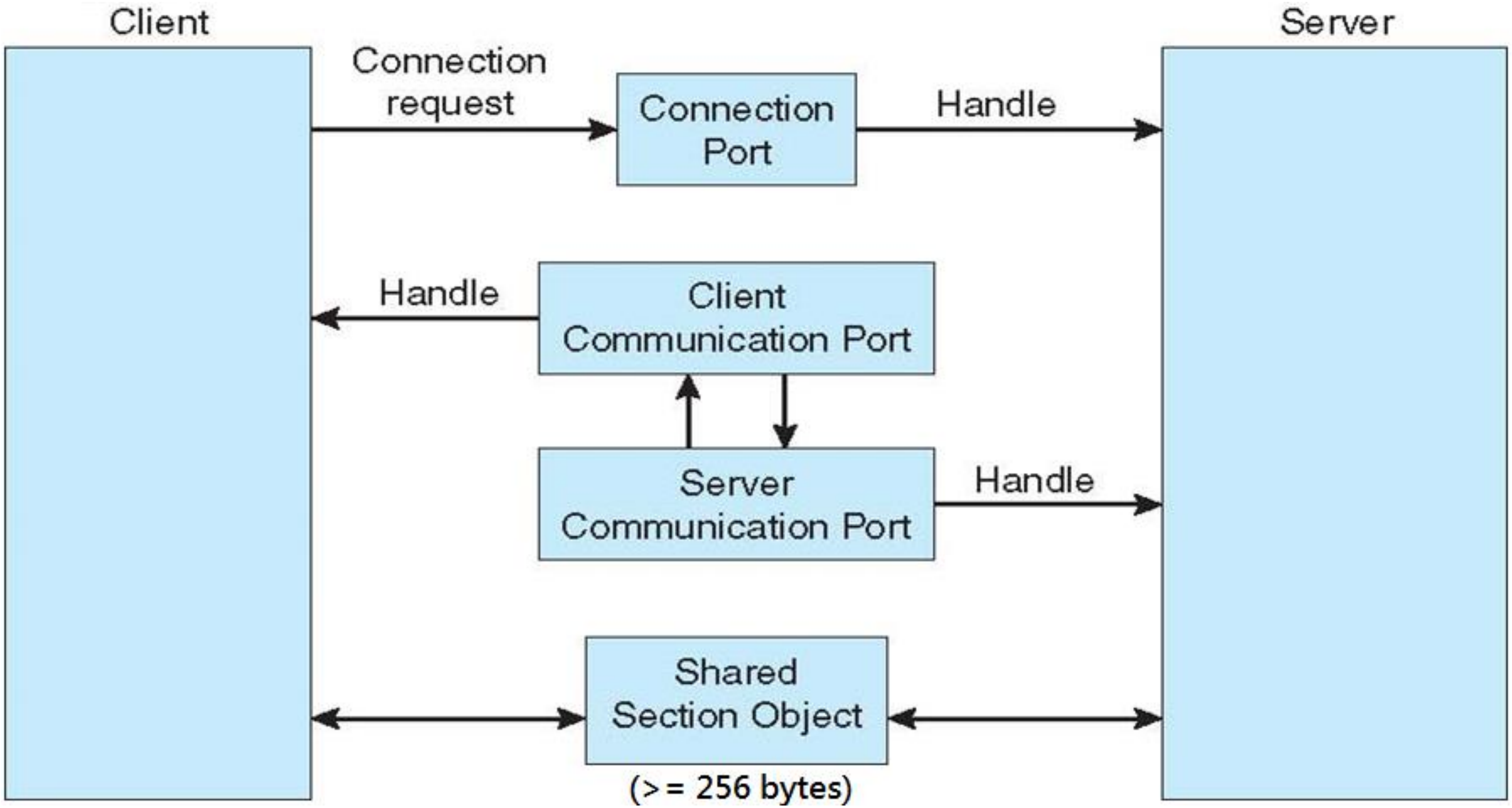
    `msg_send(), msg_receive(), msg_rpc()`
  - Mailboxes needed for commuication, created via (in Mach, mailbox is called port).

    `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 (kept by OS, only one can be kept)

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 XP



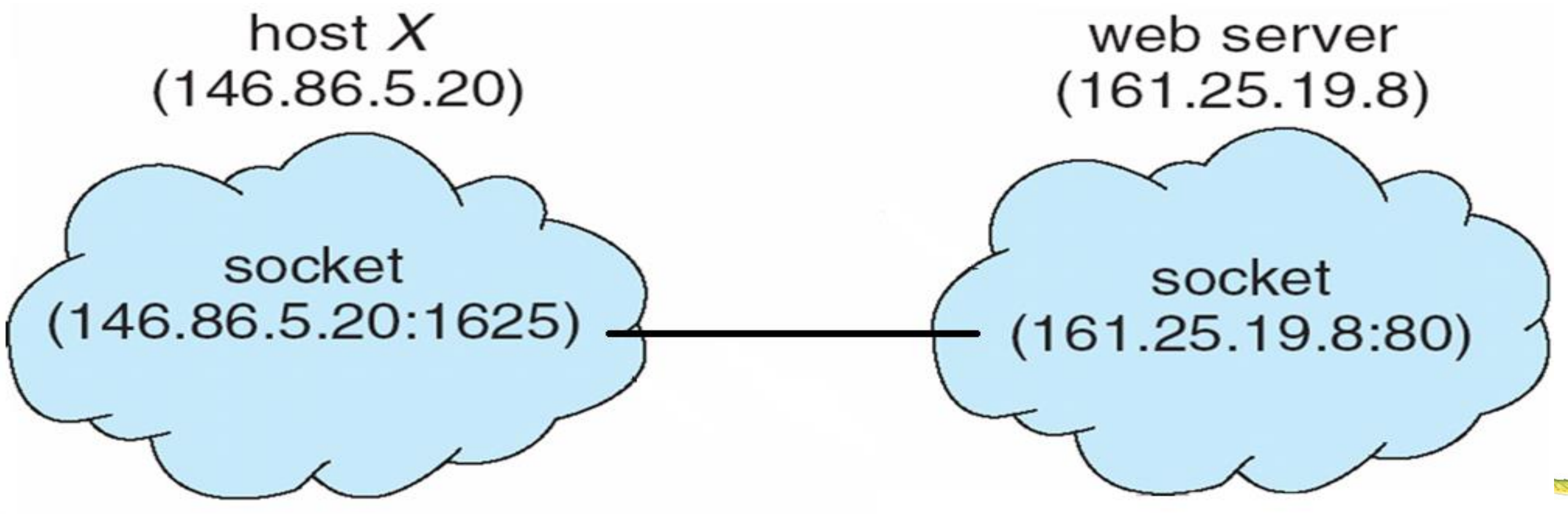
Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls
- Pipes

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 (e.g., the figure below)
- All ports below 1024 are ***well known***, used for standard services
  - e.g., telnet: 23, ftp: 21, http: 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

TCP Example: "Date" server

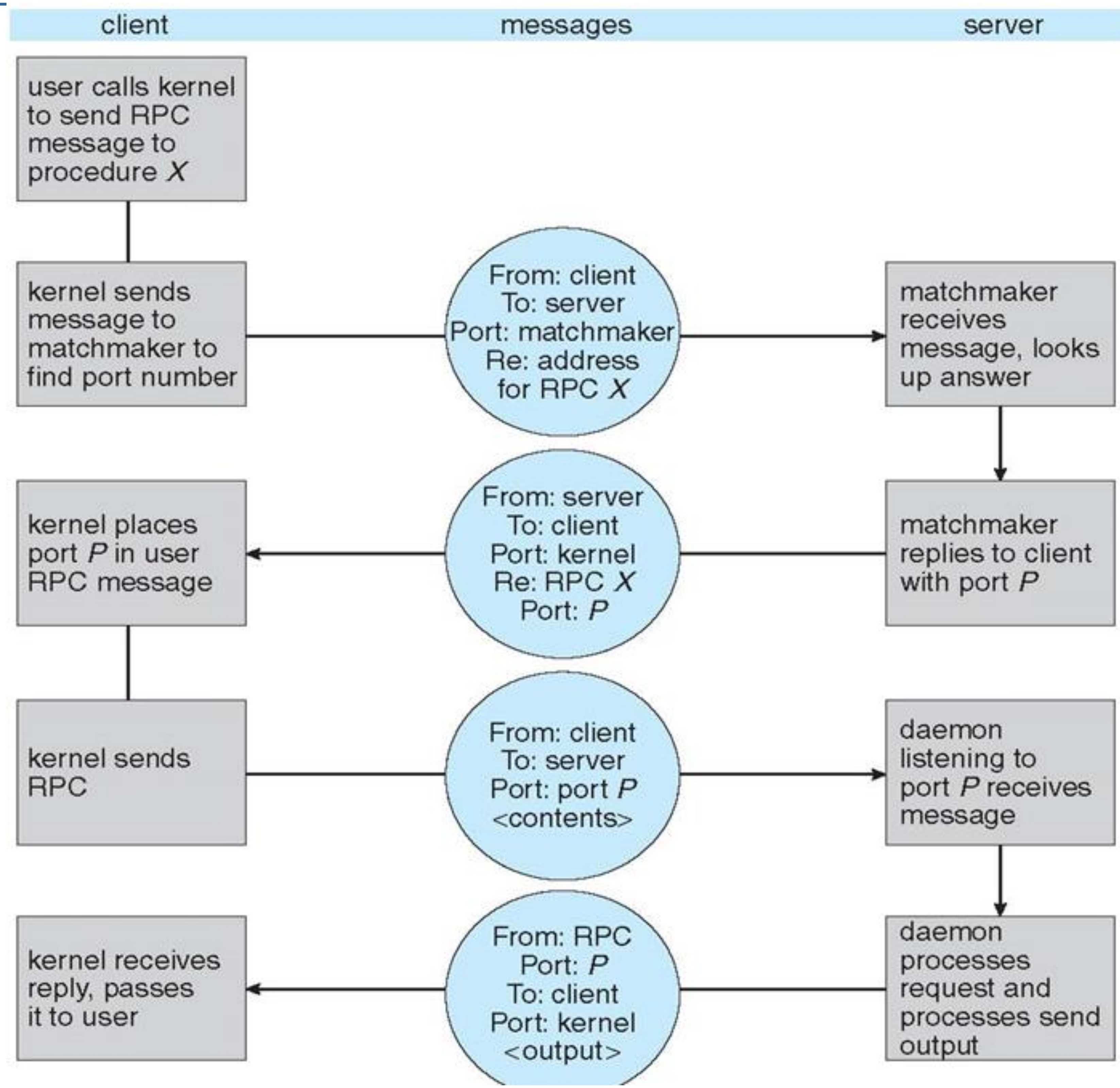
Port number

```
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 */
            client.close();
         }
      }
      catch (IOException ioe) {
         System.err.println(ioe);
      }
   }
}
```

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
- Data representation handled via **External Data Representation** (**XDR**) format to account for different architectures
  - **Big-endian** and **little-endian**
- Remote communication has more failure scenarios than local
- OS typically provides a rendezvous (also called a **matchmaker**) service to connect client and server

Execution of RPC

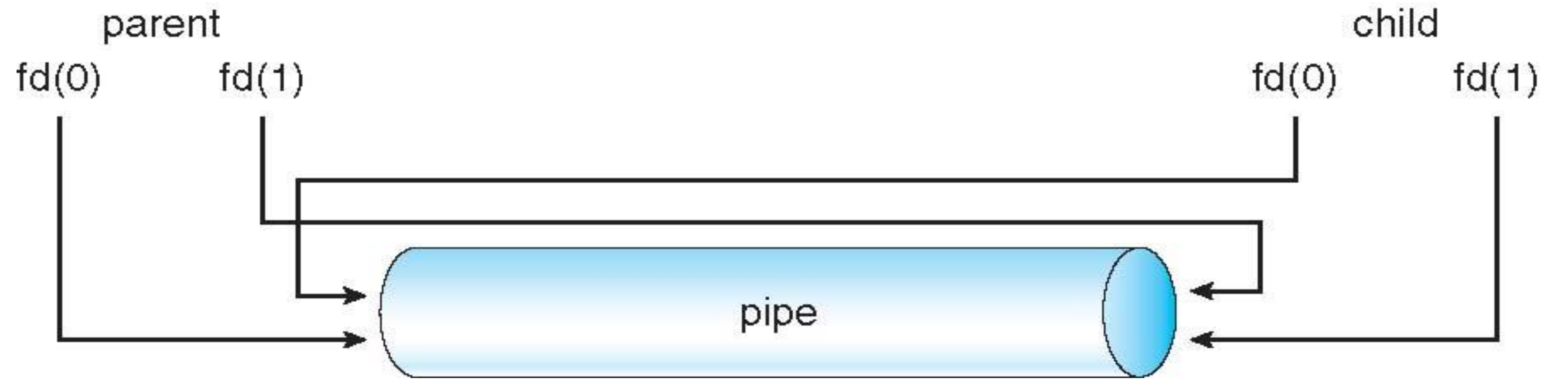


Pipes

- 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



- Windows calls these **anonymous pipes**
  - They are limited to parent-child relationships
  - Read from and written to as files.

Ordinary Pipes

```
#define READ_END  0
#define WRITE_END 1

int fd[2];

pipe( fd );
pid = fork( );
```

```
         if (pid > 0) { /* parent process */
            /* close the unused end of the pipe */
            close(fd[READ_END]);                          ← fd[0]

            /* write to the pipe */
fd[1] →     write(fd[WRITE_END], write_msg, strlen(write_msg)+1);

            /* close the write end of the pipe */
            close(fd[WRITE_END]);
         }
         else { /* child process */
            /* close the unused end of the pipe */
            close(fd[WRITE_END]);                         ← fd[1]

            /* read from the pipe */
fd[0] →     read(fd[READ_END], read_msg, BUFFER_SIZE);
            printf("read %s",read_msg);

            /* close the write end of the pipe */
            close(fd[READ_END]);
         }
```

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
  - UNIX (named pipe are termed fifos)
    - Created with mkfifo() and manipulated with read(), write(), open(), close()
    - Requires all processes running on the same machine.
  - Windows
    - CreateNamePipe(), ConnectNamePipe(), ReadFile(), WriteFile().
    - Processes may reside on the same or different machines.

Named Pipes

- Example of mkfifo in Linux

Process 1

```
mkfifo( "tp",  0644);
outfd = open( "tp", O_WRONLY);

write(outfd, buf, n);

close(outfd);
```

Process 2

```
infd = open( "tp", O_RDONLY);

read(infd, buf,  1024)

close(infd);
```