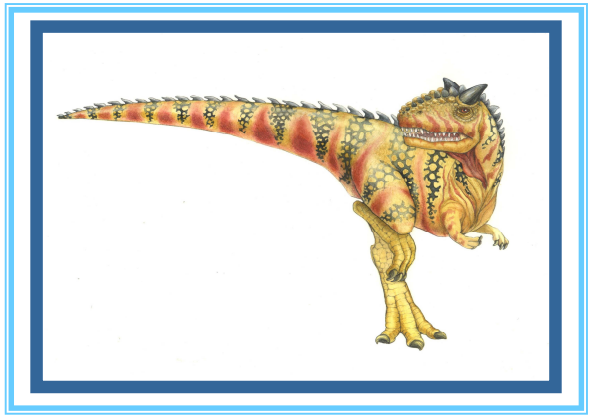
Chapter 3: Process Concept



Chapter 3: Process Concept

Process Concept

Process Scheduling

Operations on Processes

Interprocess Communication

Examples of IPC Systems

Communication in Client-Server Systems

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 explore interprocess communication using shared memory and message passing

To describe communication in client-server systems

Process Concept

An operating system executes a variety of programs:

- Batch system – **jobs***(OS proc executes _____ code, while user ones do ____ code)
- 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

Program is ***passive*** entity stored on disk (**executable file**), process is ***active***

- Program becomes process when executable file loaded into memory

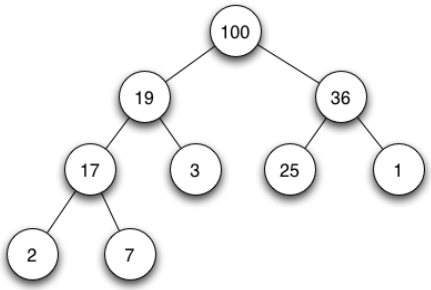
Execution of program started via GUI mouse clicks, command line entry of its name, etc

One program can be several processes

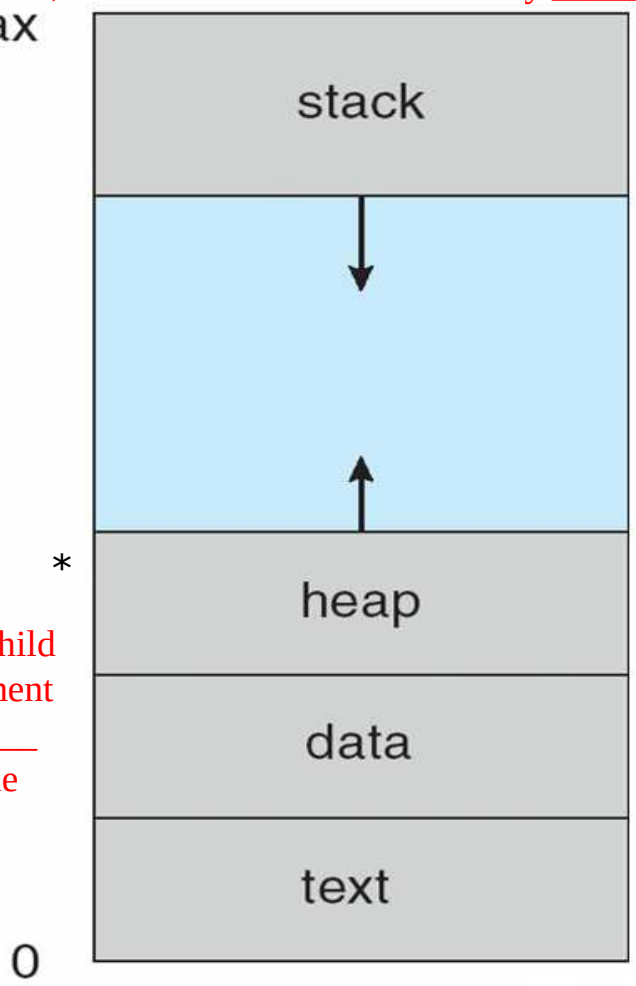
- Consider multiple users executing the same program

Process in Memory* (virtual addr space)

* (0x7ff…f; after this to 0xff…f is taken by _____)



(Heap: specialized ____ where if B is a child node of A, then key(A) ≥ key(B); an element with the greatest key is always in the _____ node (___-heap); crucial in priority queue and graph algorithm)

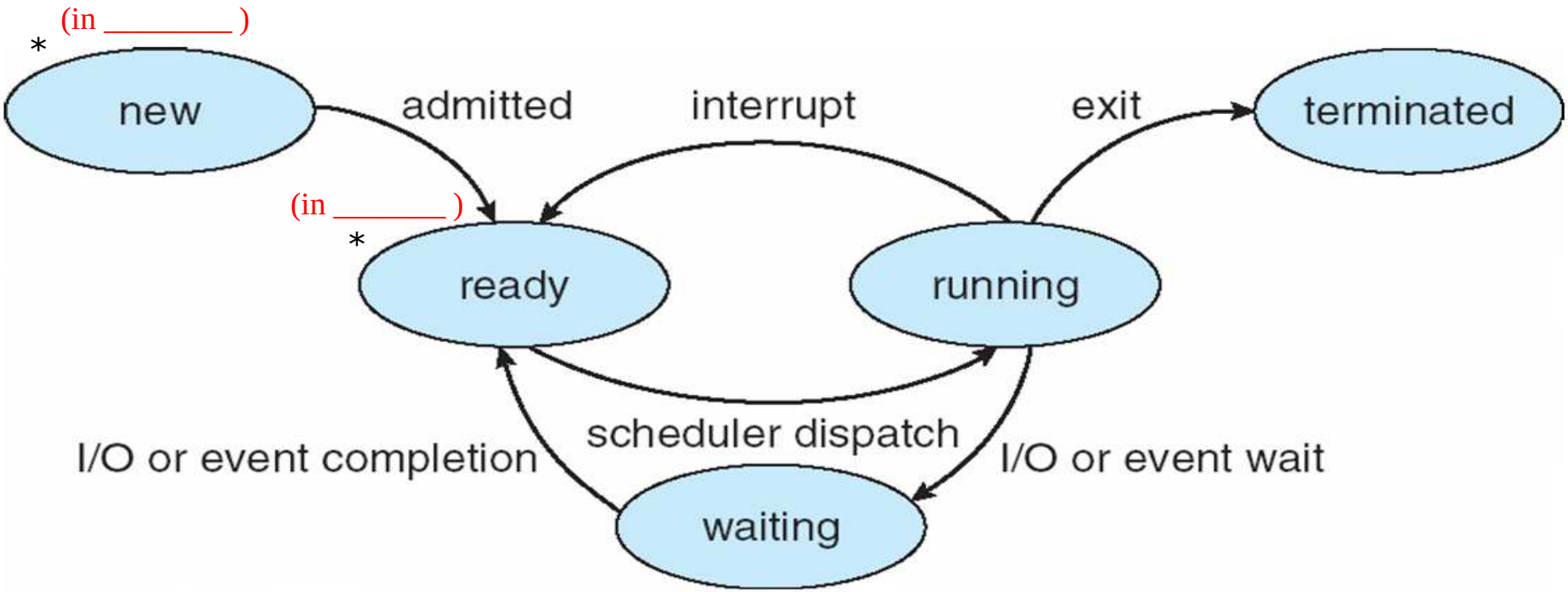


Process State

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

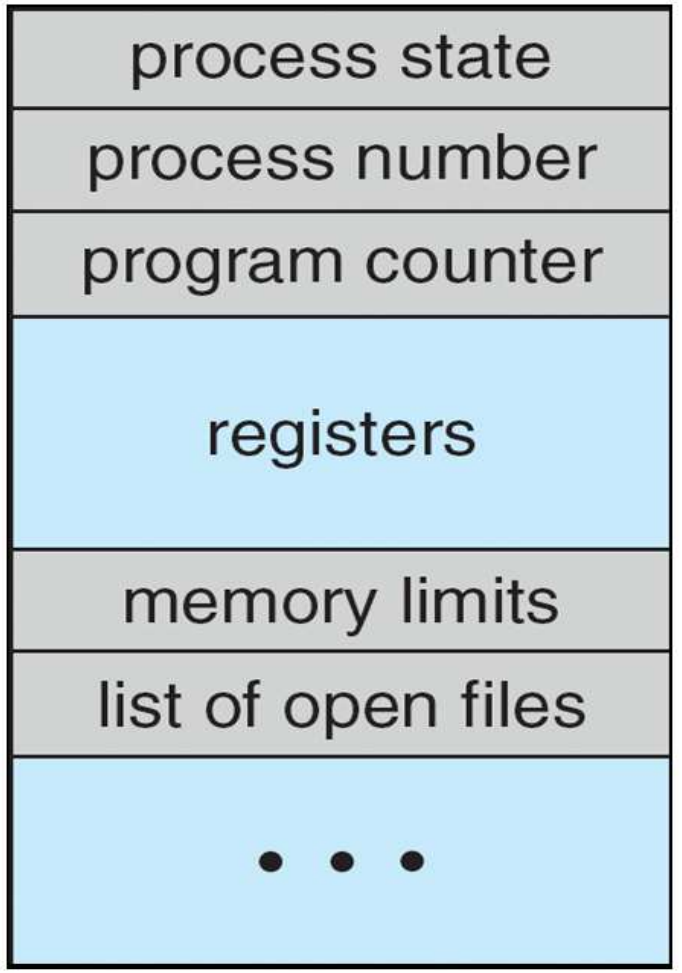


Process Control Block (PCB)

Information associated with each process

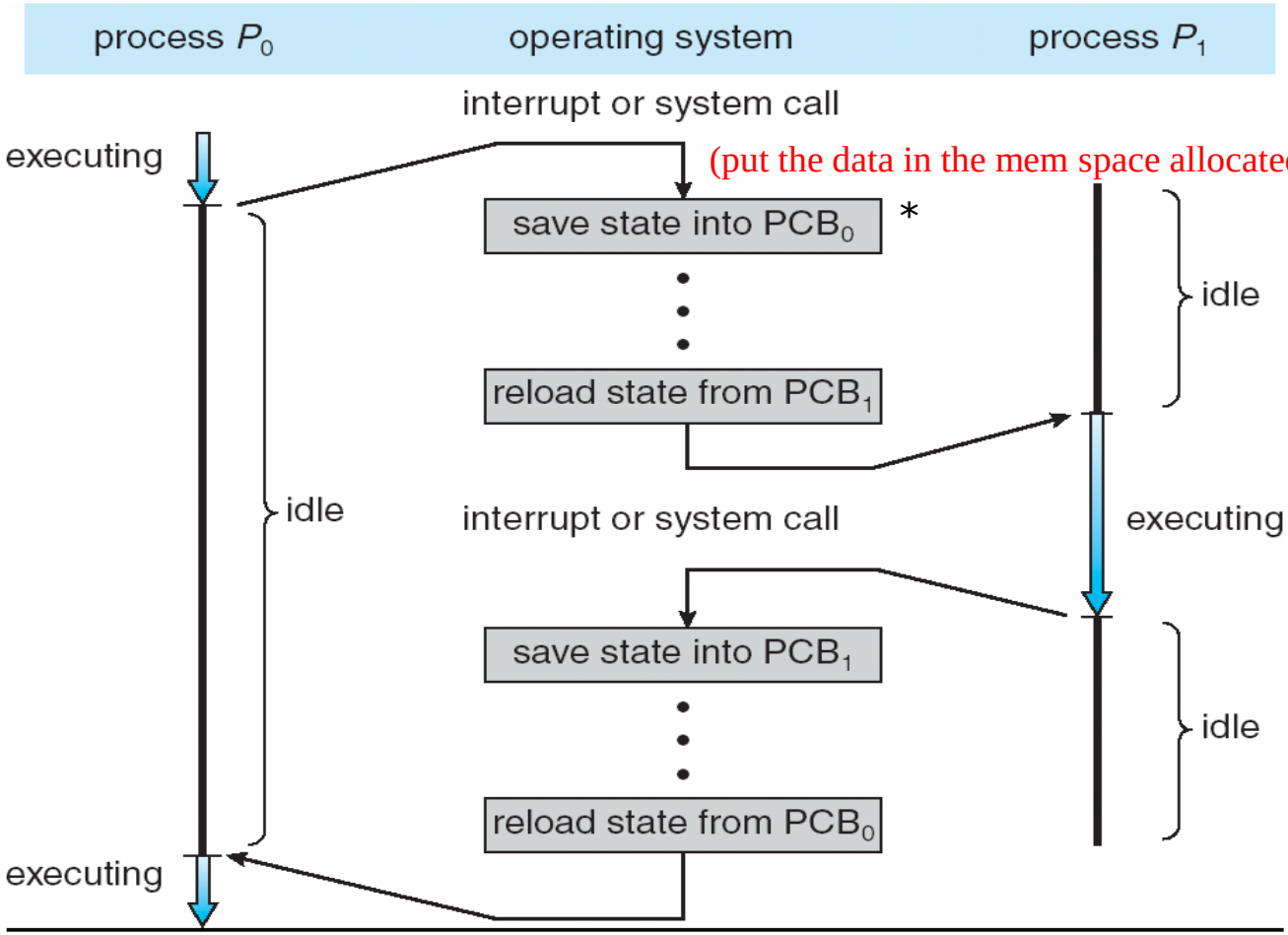
(also called **task control block**)

- 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*(scheduling parameter)
- Memory-management information – memory allocated to the process*(base & limit reg, page table, segment table)
- 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*

(_____ switch)



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**

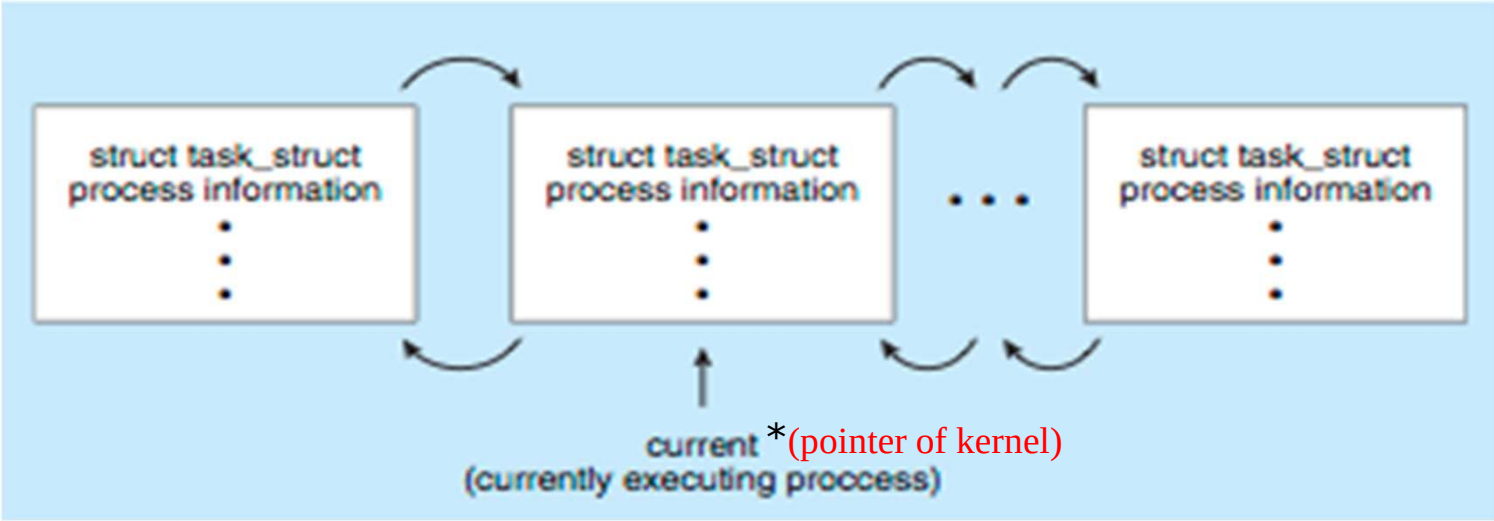
Must then have storage for thread details, multiple program counters in PCB

See next chapter

Process Representation in Linux

Represented by the C structure `task_struct` *(found in <linux/sched.h>)

```
pid t pid; /* process identifier */
long state; /* state of the process */
unsigned int time slice /* scheduling information */
struct task struct *parent; /* this process's parent */
struct list head children; /* this process's children */*(also sibling)
struct files struct *files; /* list of open files */
struct mm struct *mm; /* address space of this process */
```



*(ex) current -> state = new_state)

Process Scheduling

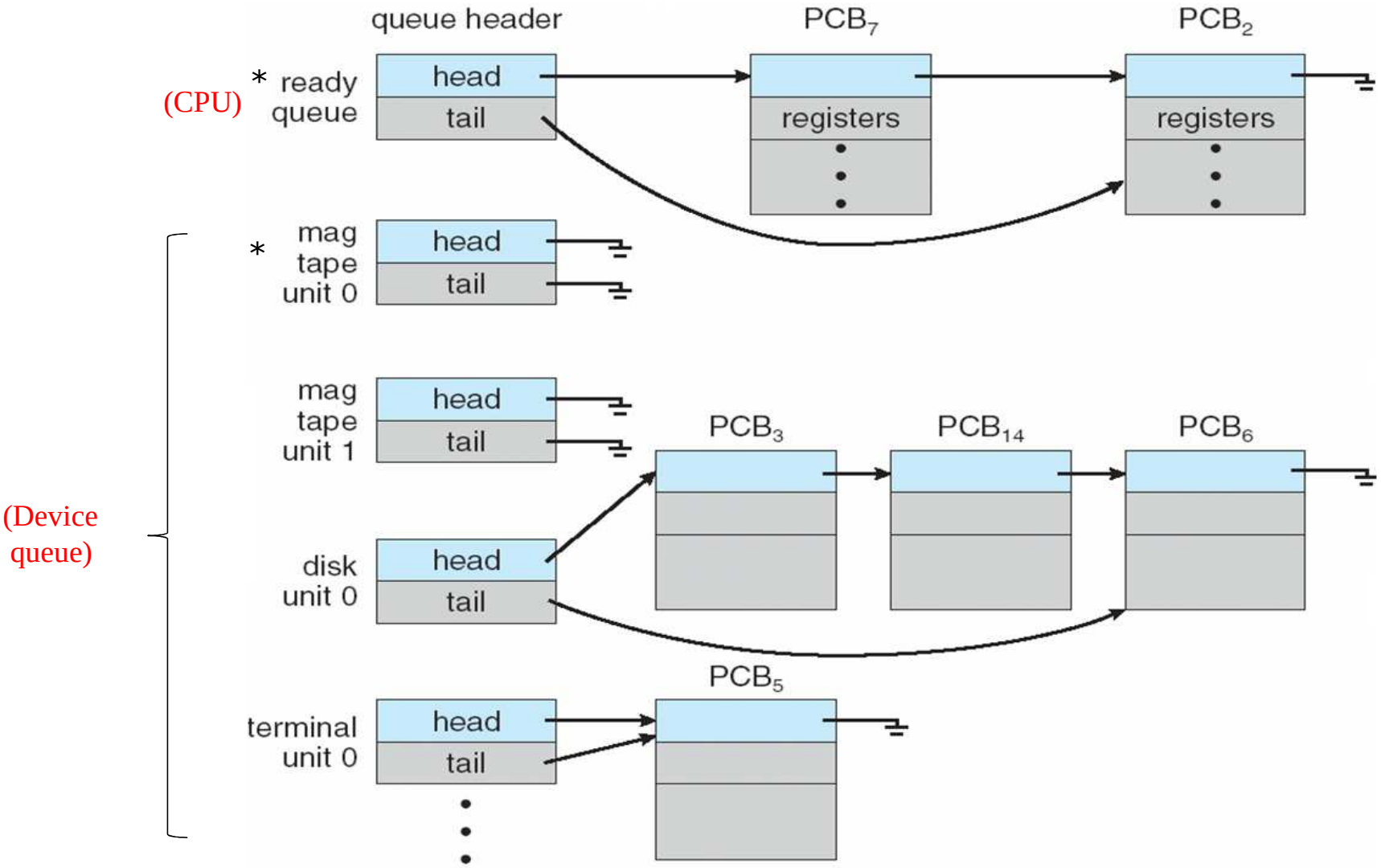
Maximize CPU use, quickly switch processes onto CPU for time sharing

Process scheduler selects among available processes for next execution on CPU

Maintains **scheduling queues** of processes

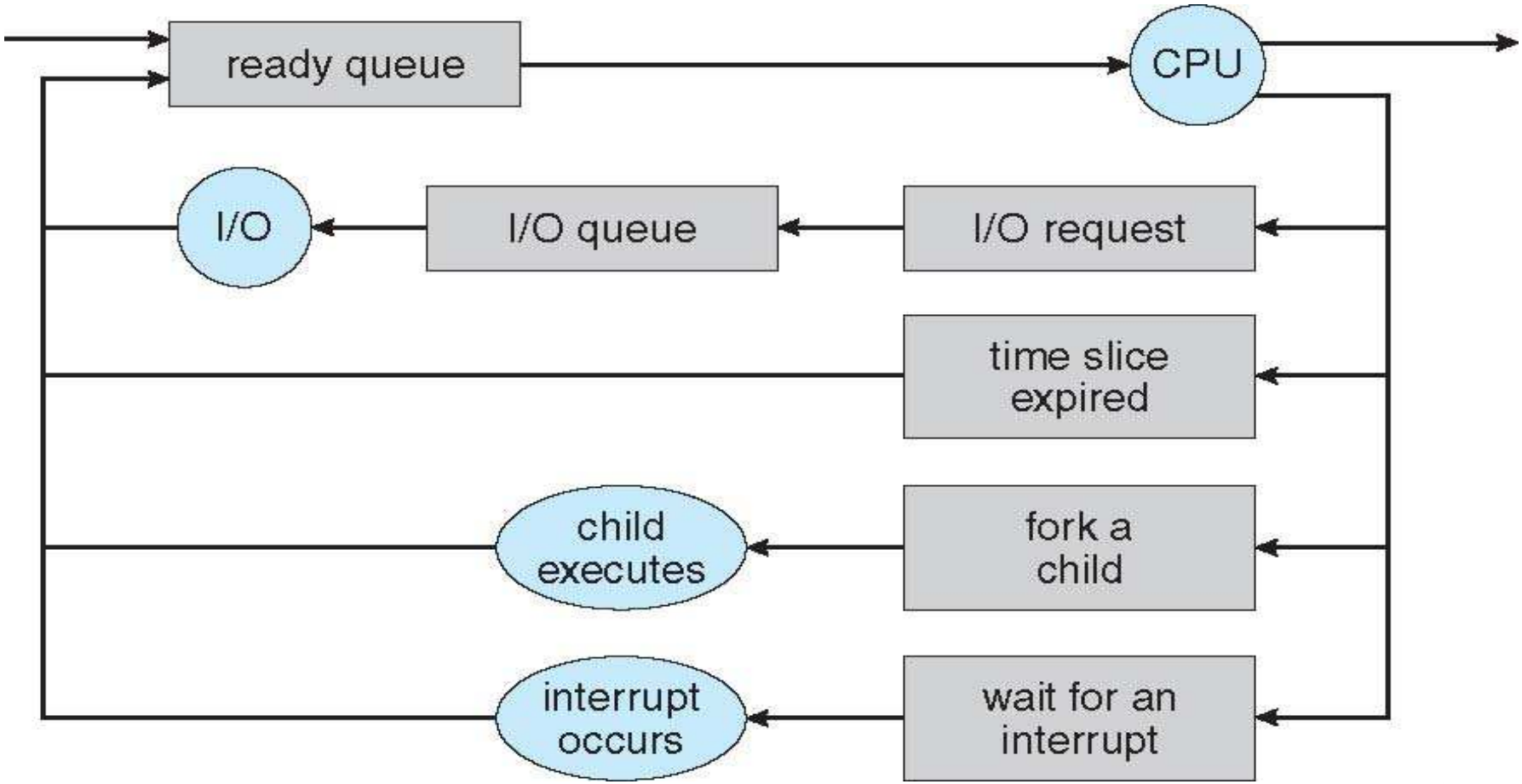
- **Job queue** – set of all processes in the system
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute* (linked list)
- **Device queues** – set of processes waiting for an I/O device
- Processes migrate among the various queues

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

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 very frequently (milliseconds) ⇒ (must be fast) *(100)

Long-term scheduler is invoked very infrequently (seconds, minutes) ⇒ (may be slow)

*(Nonexistent in Unix and Windows since they are _____ system; new proc is put in ____ for short-term scheduler)

The long-term scheduler controls the **degree of multiprogramming*** (_____ of proc)

Processes can be described as either:

I/O-bound process – spends more time doing I/O than computations, many short CPU bursts

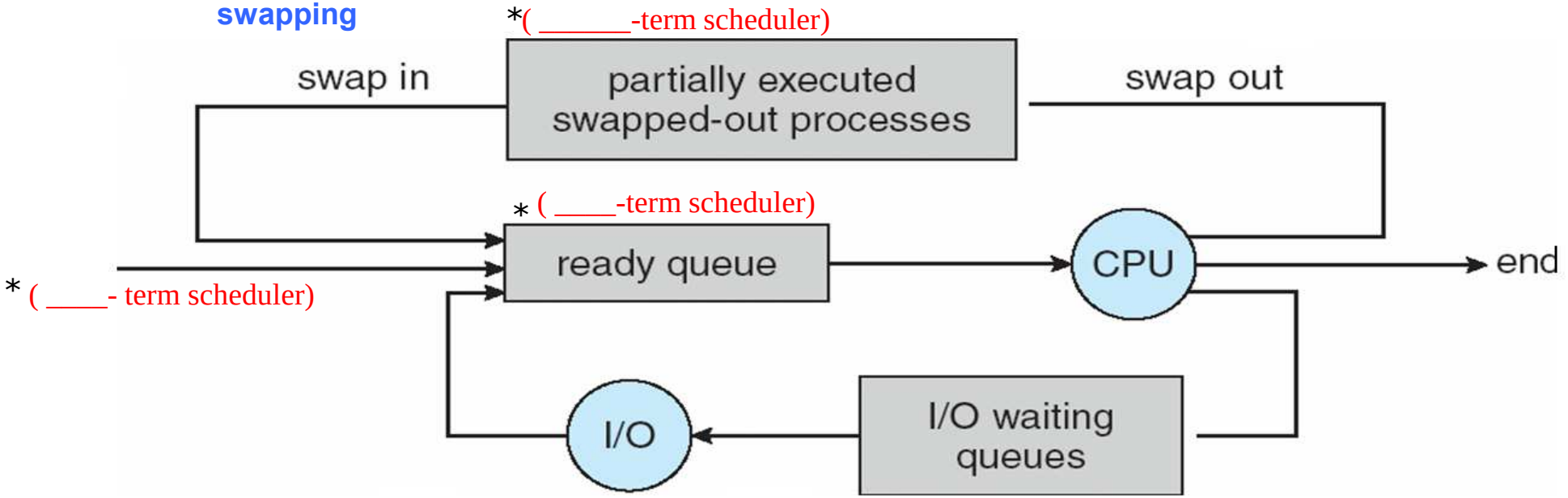
CPU-bound process – spends more time doing computations; few very long CPU bursts

Long-term scheduler strives for good ***process mix*** *(for maximizing both I/O and CPU _____)

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 *(before iOS __)

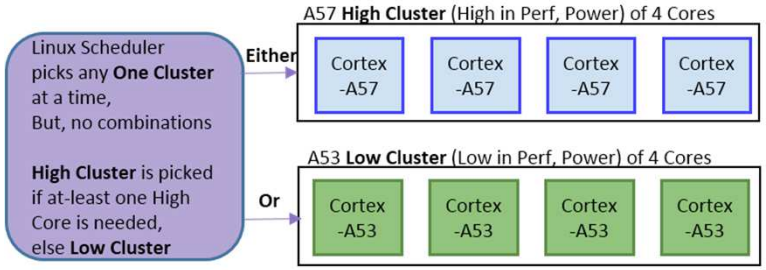
Due to screen real estate, user interface limits iOS provides for a

- Single **foreground** process- controlled via user interface *(appearing on the _____)
- Multiple **background** processes– in memory, running, but not on the display, and with limits *(due to _____ life &mem use)
- Limits include single, short task, receiving notification of events, specific long-running tasks like audio playback
  - *((ex) completing download from a net)
  - * ((ex) new email msg)

Android runs foreground and background, with fewer limits

- Background process uses a **service** to perform tasks
  - *((ex) separate app component)
  - * ((ex) streaming audio)
- Service can keep running even if background process is suspended
- Service has no user interface, small memory use

* (_____ big.LITTLE heterogeneous computing arch; Oct. 2011, Cortex-A7)



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

(mem speed, no of ___ to be copied, existence of special _____ such as load/store all reg)

Time dependent on hardware support *

Some hardware provides multiple sets of registers per CPU -> multiple contexts loaded at once

* ((ex) UltraSPARC)

Operations on Processes

System must provide mechanisms for process creation, 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**)

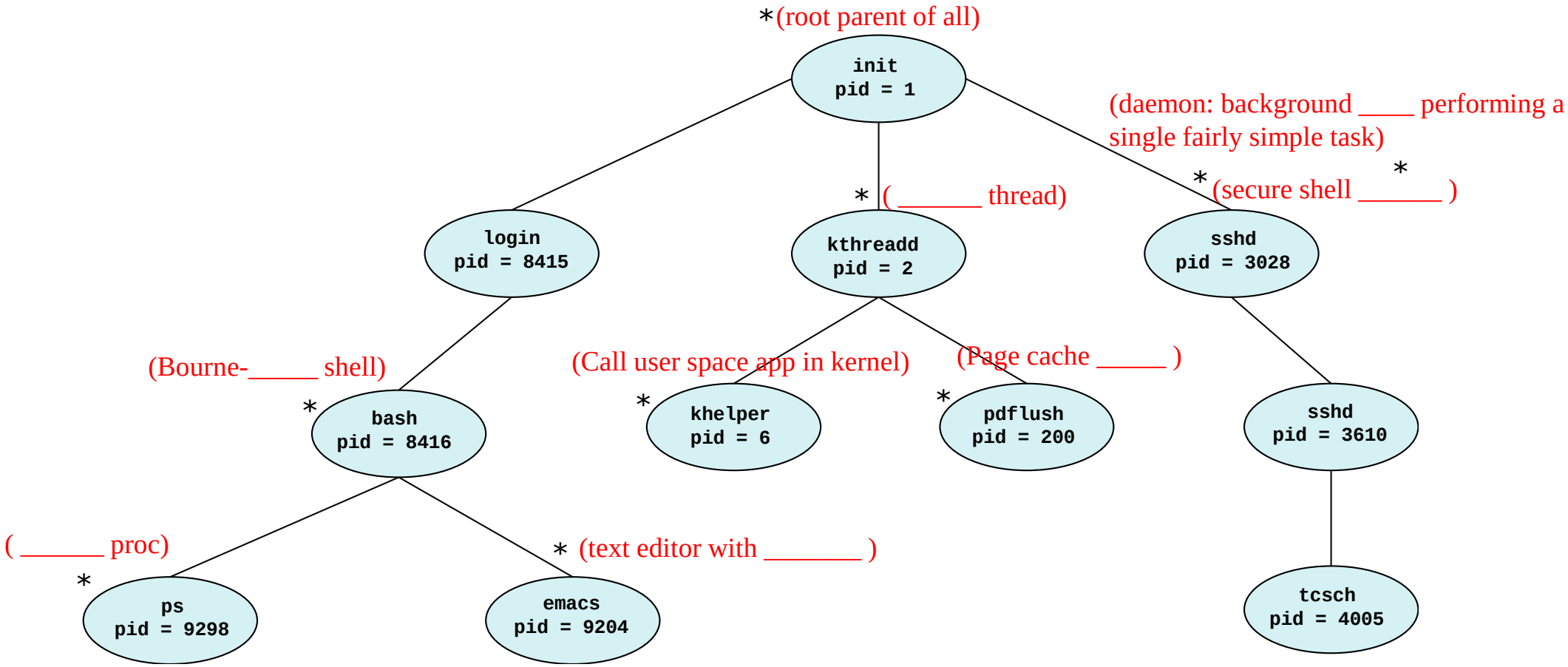
Resource sharing options

- Parent and children share all resources
- Children share subset of parent's resources* (to prevent system _____)
- Parent and child share no resources

Execution options

- Parent and children execute concurrently* (Unix)
- Parent waits until children terminate

A Tree of Processes in Linux



Process Creation (Cont.)

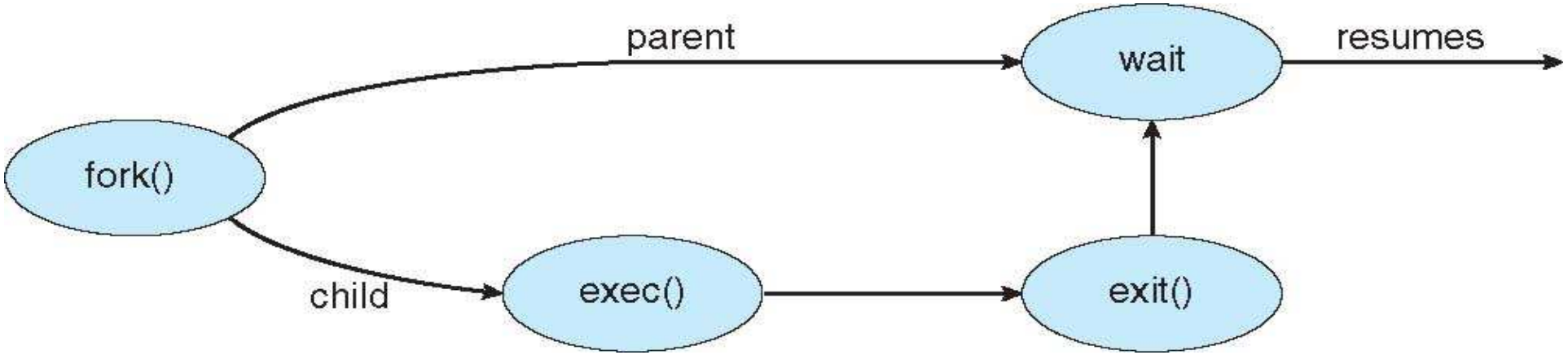
Address space

- Child duplicate of parent* (Unix)
- Child has a program loaded into it* (DEC VMS, NT)

UNIX examples

- **`fork()`** system call creates new process* (pid of child is returned to _____ after fork)
- **`exec()`** system call used after a **`fork()`** to replace the process' memory space with a new program

*(copy on _____)



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);
    } * (execve|l|le|v|vp)
    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

```
#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 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 systems do not allow child to continue if its parent terminates
    - All children terminated - **cascading termination**

Wait for termination, returning the pid:* (in _____ proc)

```
pid t pid; int status;
pid = wait(&status);
```

If no parent waiting, then terminated process is a **zombie**

If parent terminated, processes are **orphans** *(in Unix, ____ proc becomes new parent)

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

*(2008; freeware; component of Chrome OS; ___ % & ___ % share of desktop & all platforms, respectively)

Google Chrome Browser is multiprocess with 3 categories

- **Browser** process manages user interface, disk and network I/O* (only ___ browser proc)
- **Renderer** process renders web pages, deals with HTML, Javascript, new one for each website opened
  - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits

*(a virtual container in which _____ prog can be safely run; virtualization) *

- **Plug-in** process for each type of plug-in (_____mechanism for separating running programs)

* (such as Flash or QuickTime)

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:

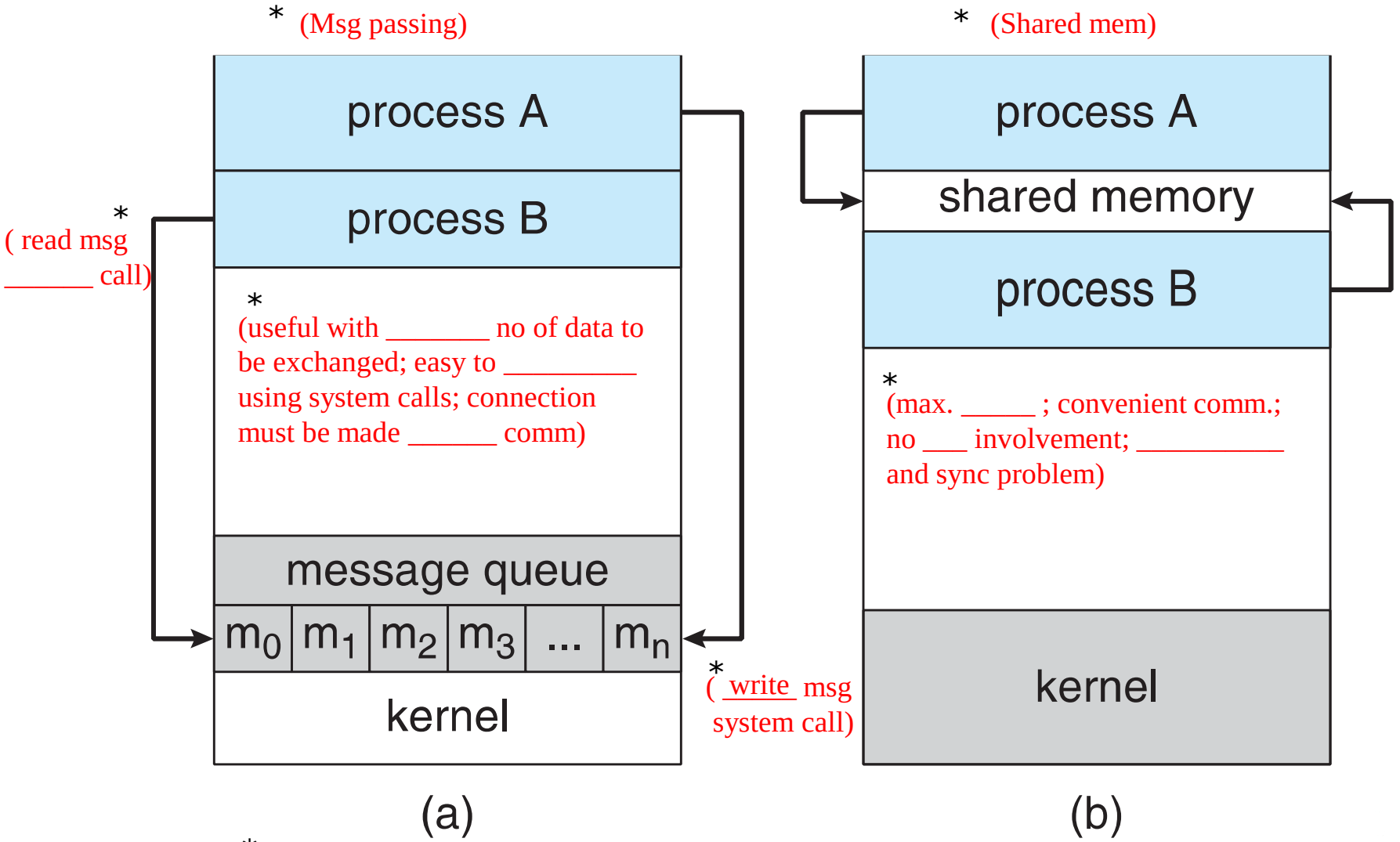
- Information sharing
- Computation speedup
- Modularity
- Convenience

Cooperating processes need **interprocess communication** (**IPC**)

Two models of IPC

- **Shared memory**
- **Message passing**

Communications Models



* (read msg _____ call)

* (useful with _____ no of data to be exchanged; easy to _____ using system calls; connection must be made _____ comm)

* (write msg system call)

* (max. _____ ; convenient comm.; no ___ involvement; _____ and sync problem)

* ((ex) IBM WebSphere MQ, Java Msg Service)

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* (producer does not ____)

bounded-buffer assumes that there is a fixed buffer size * (producer waits if buffer ____)

* (Two approaches for buffer implementation:
i) OS using ____
ii) coded by programmer using _____)

Bounded-Buffer – Shared-Memory Solution

Shared data

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

item buffer[BUFFER_SIZE];
int in = 0;*(in: position to put ____ data)
int out = 0;*(out: position of _____ data to get out)
```

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

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;
}
```

* (Assume in=9, out=0 (means 9 items have been put to buffer[0],…,[8]). Then, while loop becomes _____ . So, only 9 entries out of 10 entries are usable.)

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 */
}
```

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*)*

(Fixed msg size: easy implementation but difficult _____)

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., direct or indirect, synchronous or asynchronous, automatic or explicit buffering)

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?* (buffer space?)

Is the size of a message that the link can accommodate fixed or variable?

Is a link unidirectional or bi-directional? * (proc can only send or receive?)

* (Other issues: direct/indirect comm; symm/asymm in naming(sender names receiver, but not receiver in asymm); automatic/explicit buffering; send by copy/reference; fixed/variable size msg)

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

*(Disadv: limited _____ since change of a proc name needs examining all other proc definitions)

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 *(mailbox)

- Link established only if processes share a common mailbox*(owned by a ____ by declaring it or OS)
- A link may be associated with many processes* (when they share a common _____)
- Each pair of processes may share several communication links
- Link may be unidirectional or bi-directional

*(G_____ _____ is required when the owner of mailbox is _____)

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*** (needs _____ between the sender & receiver)

- **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

}

Synchronization (Cont.)

- 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 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 – 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

* (For Async comm: P → Q
  P: send (Q, msg) Q: receive (P, msg)
  receive(Q, msg) send(P, msg) or reply(P, Ack);

  Here send( ) is _____ while reply( ) is nonblocked comm)

* (RPC is similar to _____ comm:
  Msg = subroutine call
  Return msg = result of subroutine call)

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 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 <stlib.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_RDRW, 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 <stlib.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

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)

`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

*

(_____ sends notification of event occurrences to the _____ port)

Examples of IPC Systems – Windows

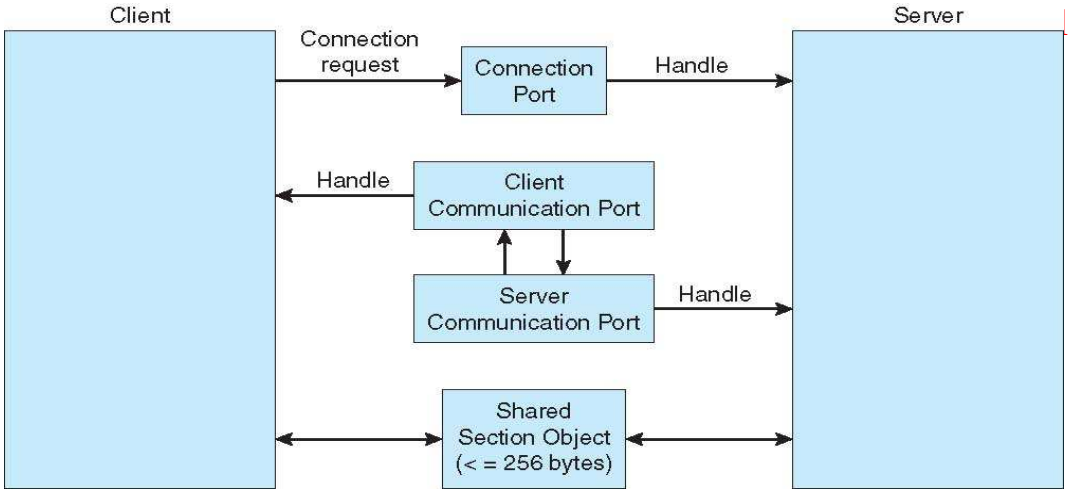
Message-passing centric via **advanced local procedure call (LPC)** facility

Only works between processes on the same system

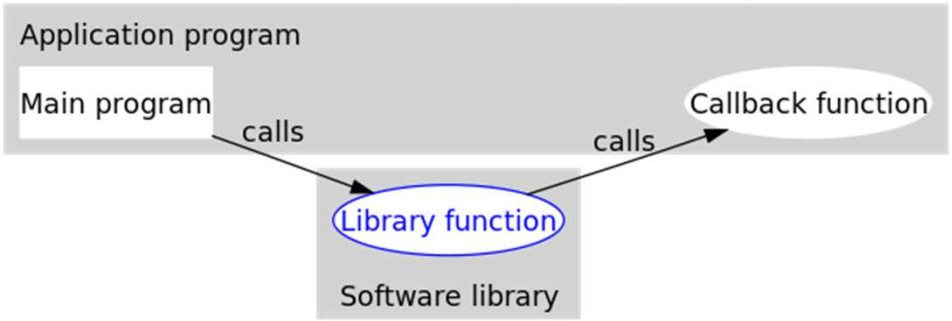
Uses ports (like mailboxes) to establish and maintain communication channels

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.

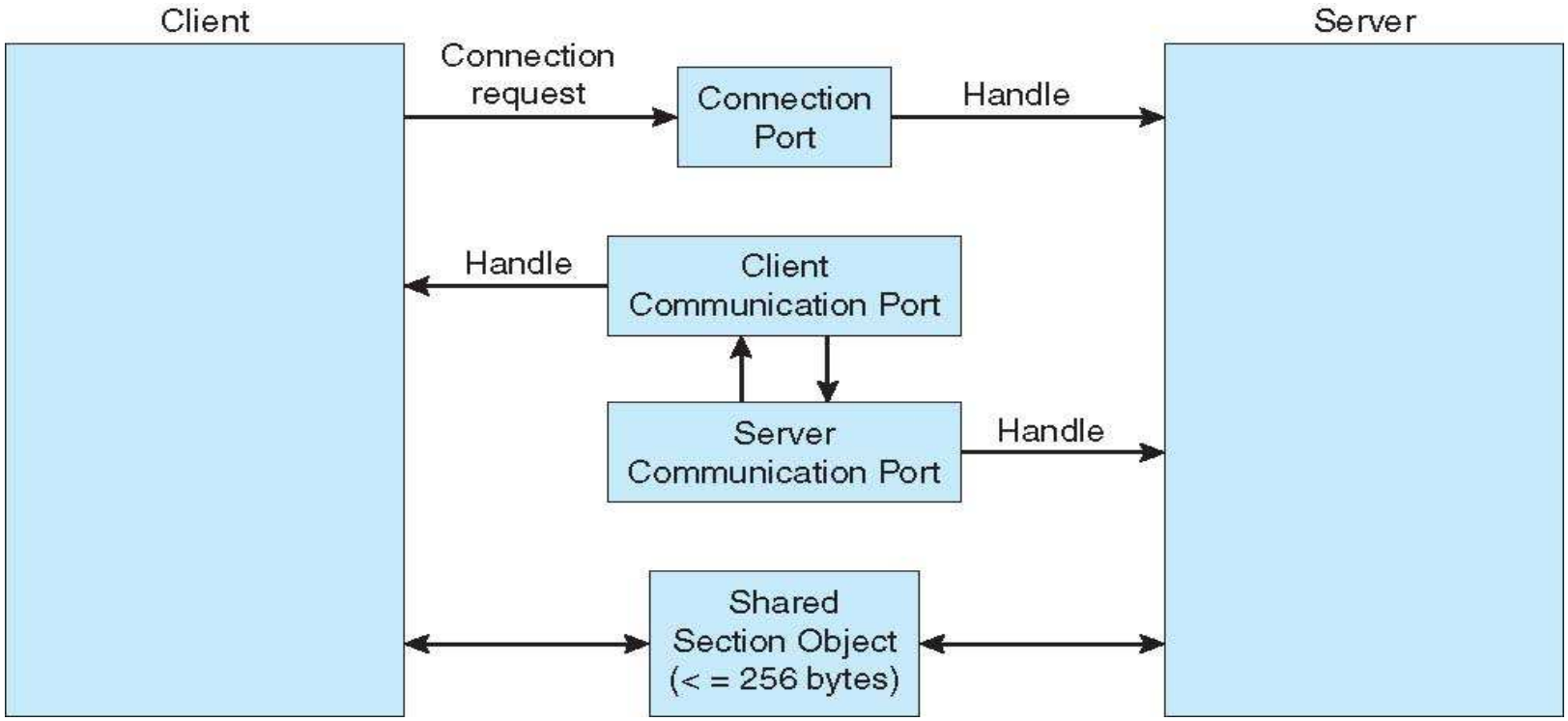


(Callback is a reference to an _____ code, passed as an _____ to other code. lib func to call a subroutine defined in a _____-level layer.)



(With callback, the _____ can be flexible, small, and can be called by _____ app for different use.)

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** – 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**

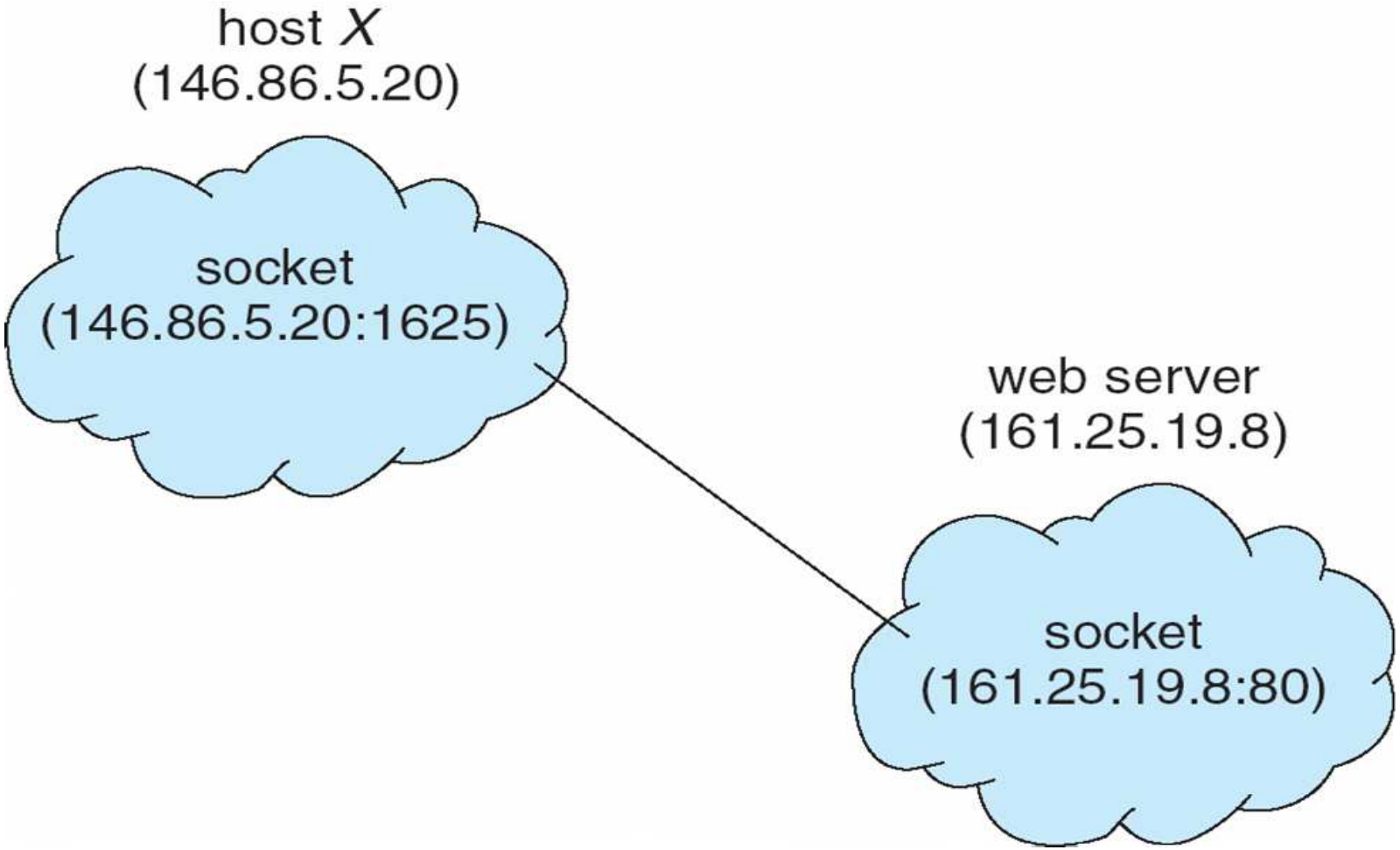
Communication consists between a pair of sockets

All ports below 1024 are ***well known***, used for standard services

* (telnet port: __, ftp: __, web(http): __)

Special IP address 127.0.0.1 (**loopback**) to refer to system on which process is running

Socket Communication



Sockets in Java

Three types of sockets

- **Connection-oriented** (**TCP**)
- **Connectionless** (**UDP**)
- **`MulticastSocket`** class– data can be sent to multiple recipients

Consider this “Date” server:

```
import java.net.*;
import java.io.*;

public class DateServer
{
   public static void main(String[] args) {
      try {
         ServerSocket sock = new ServerSocket(6013);

         /* now listen for connections */
         while (true) {
            Socket client = sock.accept();

            PrintWriter pout = new
             PrintWriter(client.getOutputStream(), true);

            /* write the Date to the socket */
            pout.println(new java.util.Date().toString());

            /* close the socket and resume */
            /* listening for connections */
            client.close();
         }
      }
      catch (IOException ioe) {
         System.err.println(ioe);
      }
   }
}
```

Remote Procedure Calls

* (sync. comm with msg as _____ and return msg as _____ of subr)

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* (a separate stub for each separate _____ procedure)

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**)

*(machine _____ representation)

Data representation handled via **External Data Representation** (**XDR**) format to account for different architectures * (sender converts data into _____ before trans, and then receiver converts it to original data)

- **Big-endian** and **little-endian**

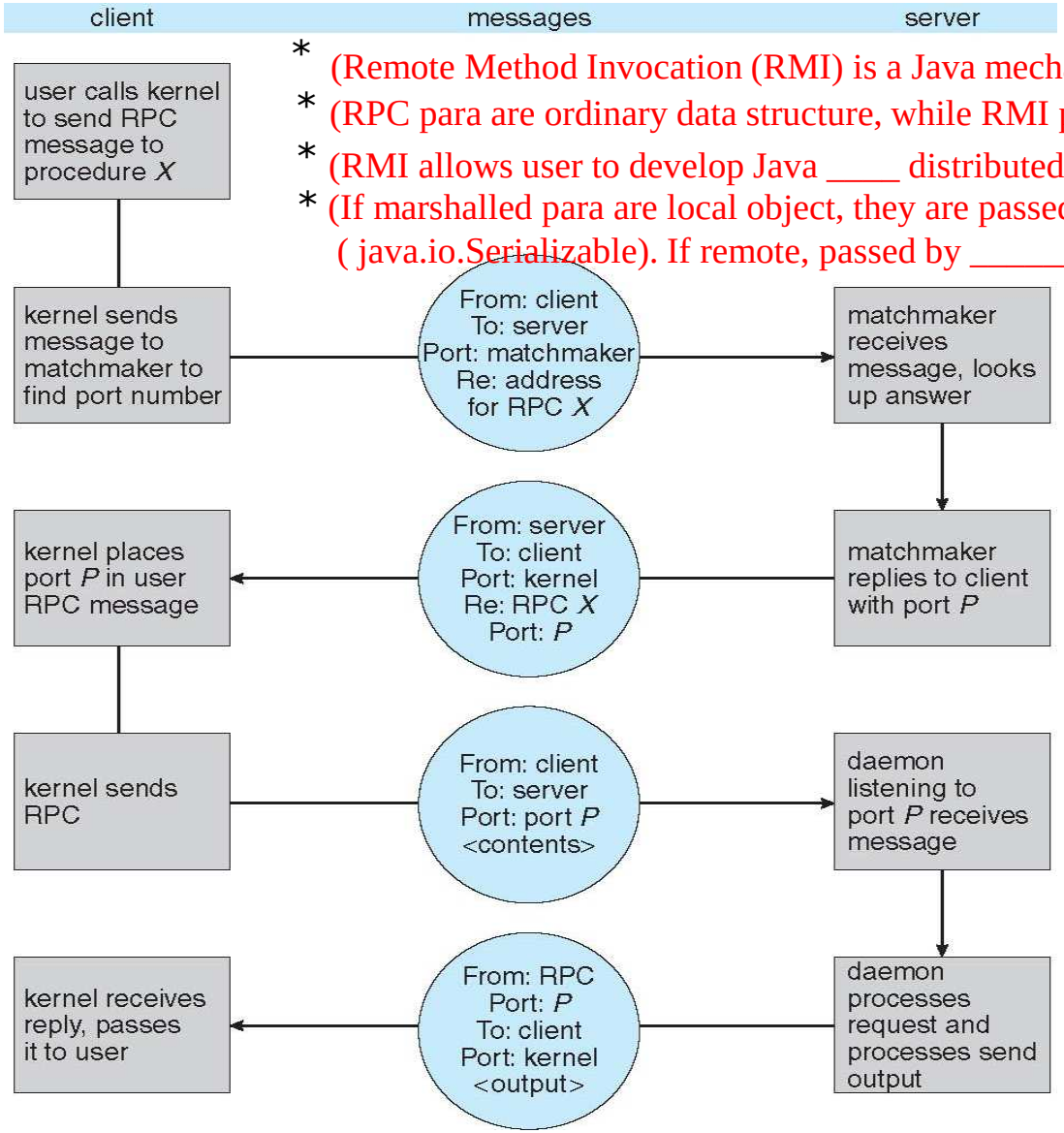
Remote communication has more failure scenarios than local* (duplicated/failed msg problem (sol) _____ /ACK)

- Messages can be delivered ***exactly once*** rather than ***at most once***

OS typically provides a rendezvous (or **matchmaker**) service to connect client and server

* (_____ (how does client knows the port no.?)
(sol) 1. fix no. at _____ time 2. _____)

Execution of RPC



* (Remote Method Invocation (RMI) is a Java mechanism similar to ____)
* (RPC para are ordinary data structure, while RMI passes _____ as para)
* (RMI allows user to develop Java ____ distributed across a net)
* (If marshalled para are local object, they are passed by ____ using object serialization (java.io.Serializable). If remote, passed by _____)

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? *(or need to reside on the same machine?)

Ordinary Pipes

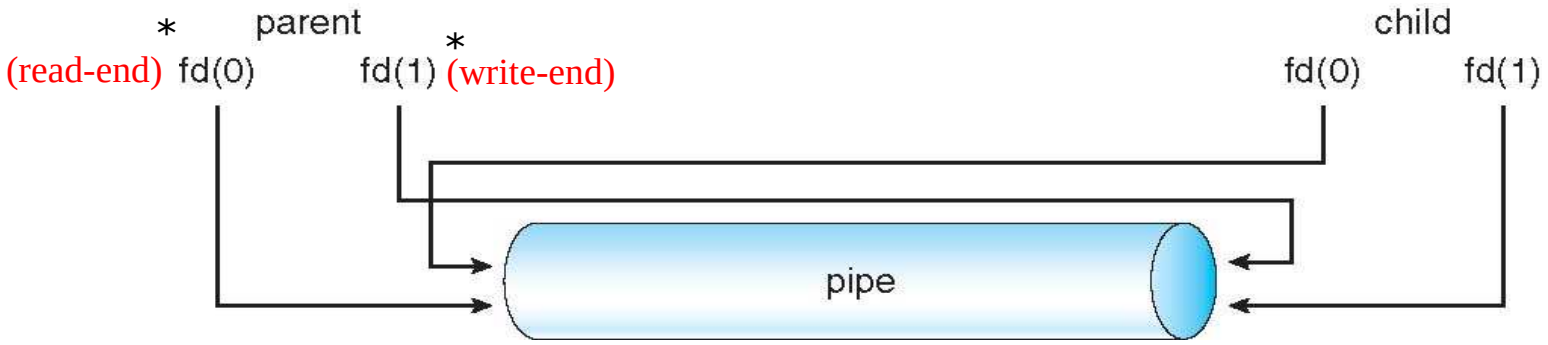
Ordinary Pipes allow communication in standard producer-consumer style

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 * (if they terminate, ordinary pipe ceases to _____)



Windows calls these **anonymous pipes**

See Unix and Windows code samples in textbook

* (Unix treats a pipe as a special type of ____)

Named Pipes

Named Pipes are more powerful than ordinary pipes

Communication is bidirectional

No parent-child relationship is necessary between the communicating processes

* (even though they terminate, named pipe _____)

Several processes can use the named pipe for communication

Provided on both UNIX and Windows systems