Chapter 3: Processes

adapted from Silberschatz, Galvin, Gagne

Chapter 3: Processes

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

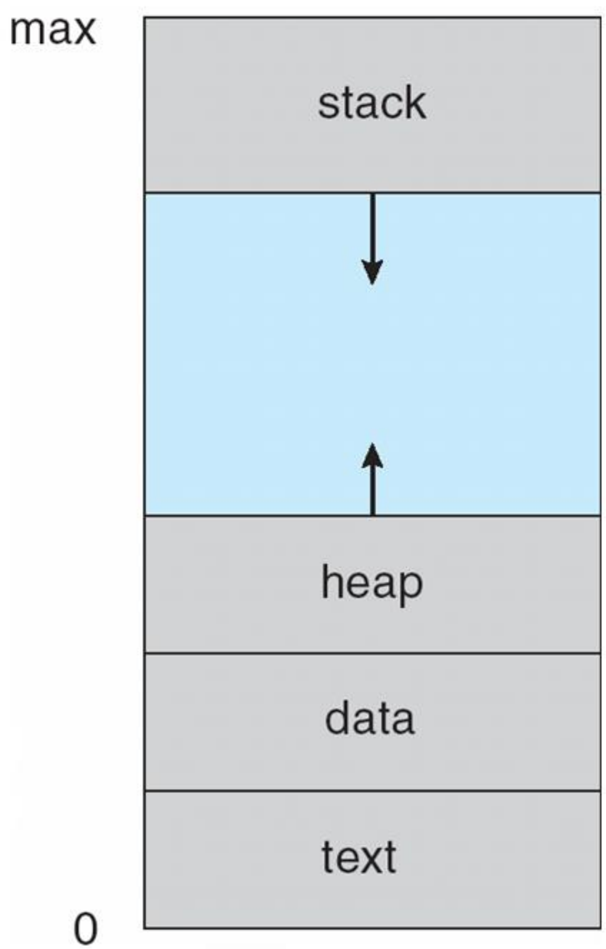
Objectives

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

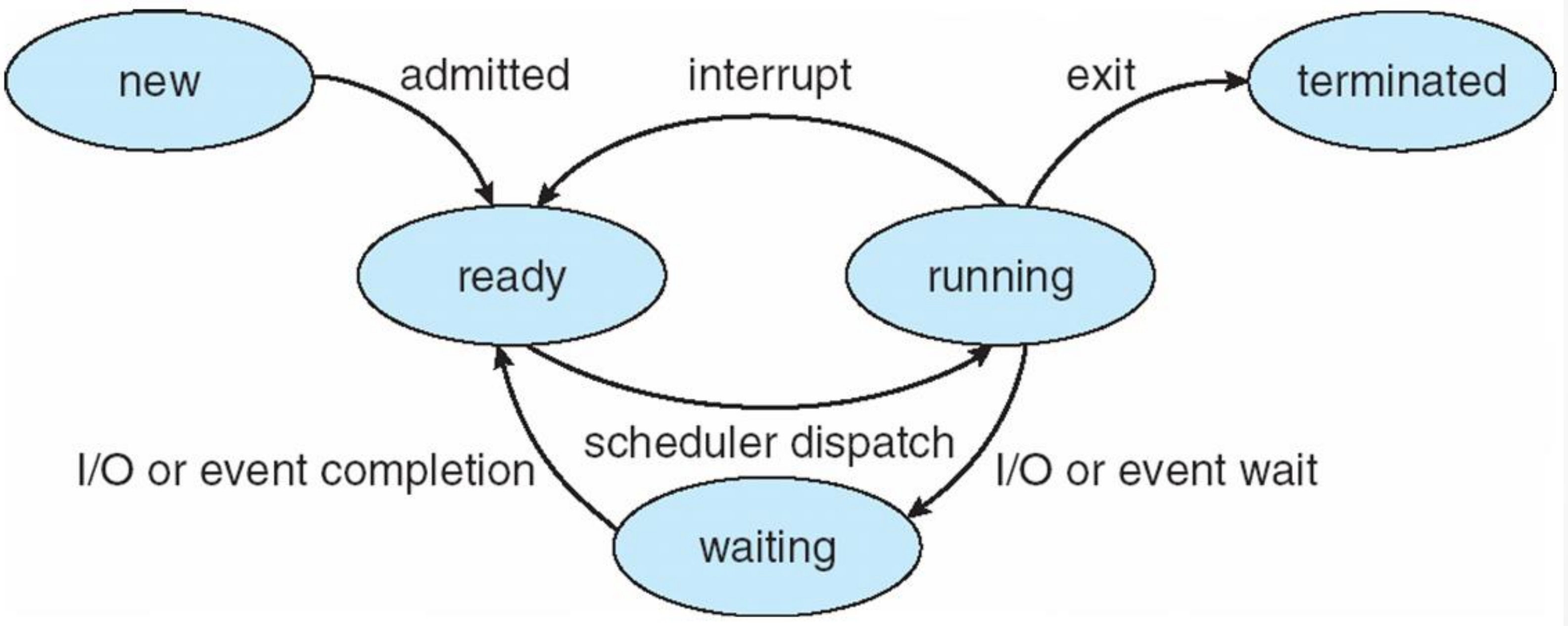
Process in Memory



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

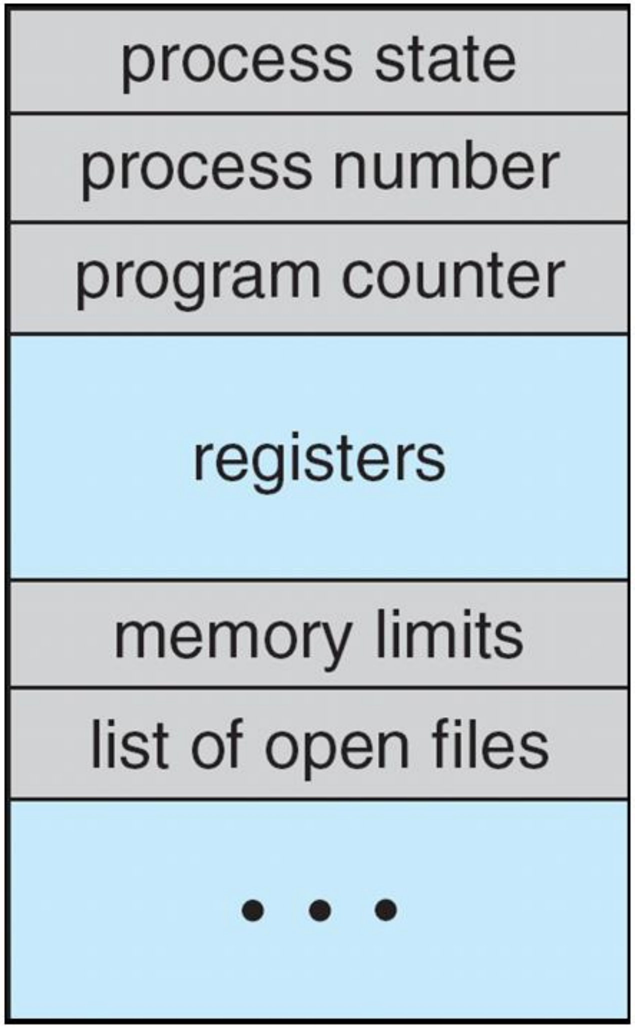


Process Control Block (PCB)

Information associated with each process

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

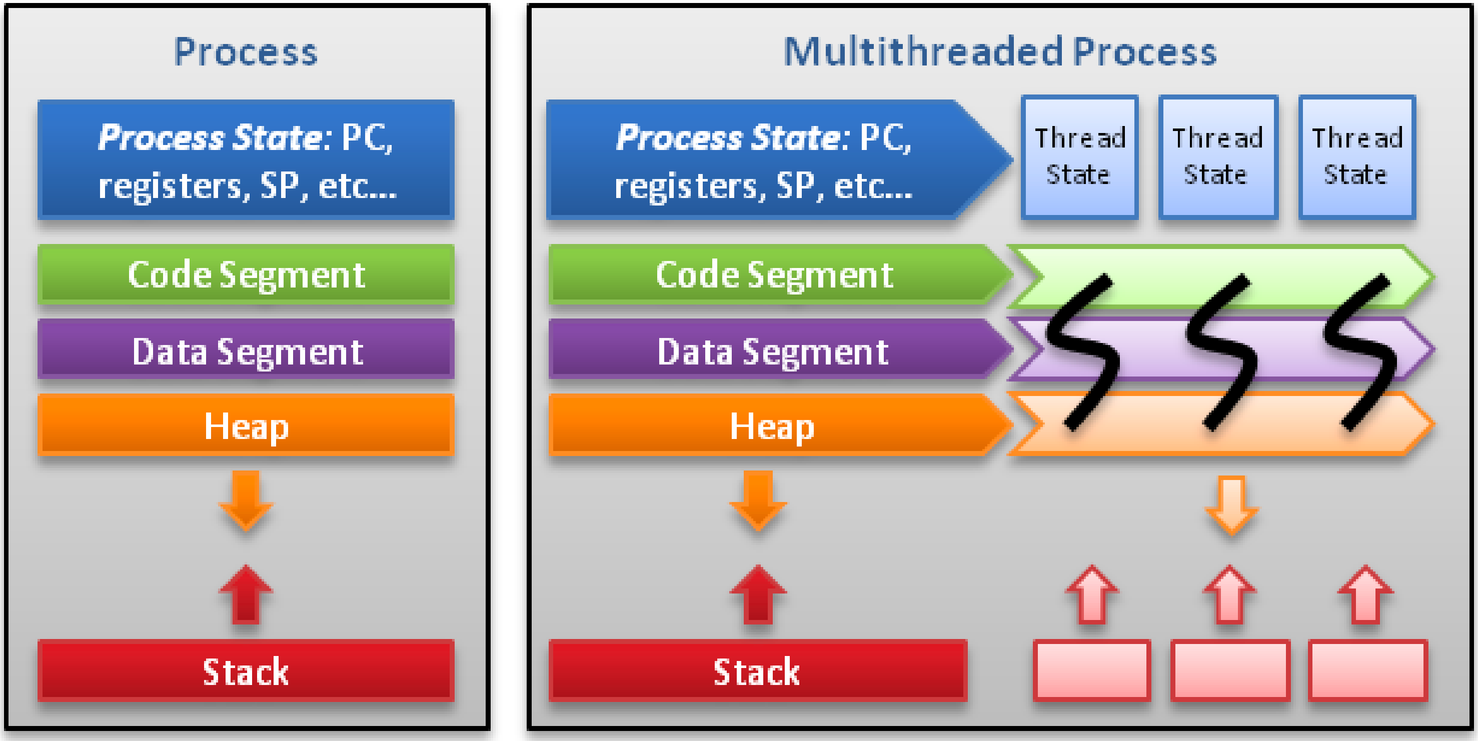
Process Control Block (PCB)



Threads

- One process may have more than one threads
- A single-threaded process performs a single thread of execution
- A multi-threaded process performs multiple threads of execution “concurrently”, thus allowing short response time to user’s input even when the main thread is busy
- PCB is extended to include information about each thread
- Threads are detailed in chapter 4.

Process and Thread

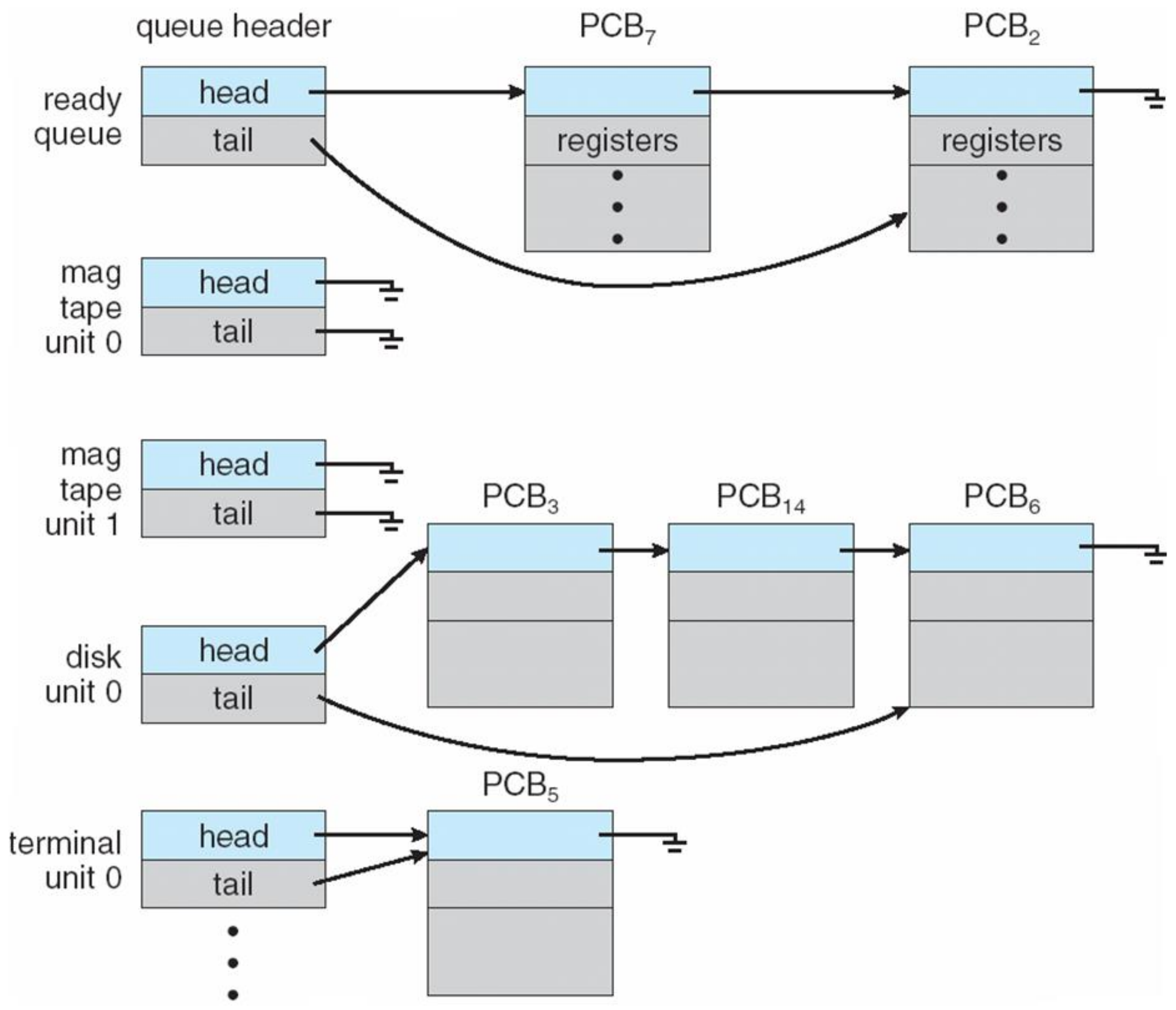


Threads contain only necessary information, such as a stack (for local variables, function arguments, return values), a copy of the registers, program counter and any thread-specific data to allow them to be scheduled individually. Other data is shared within the process between all threads.

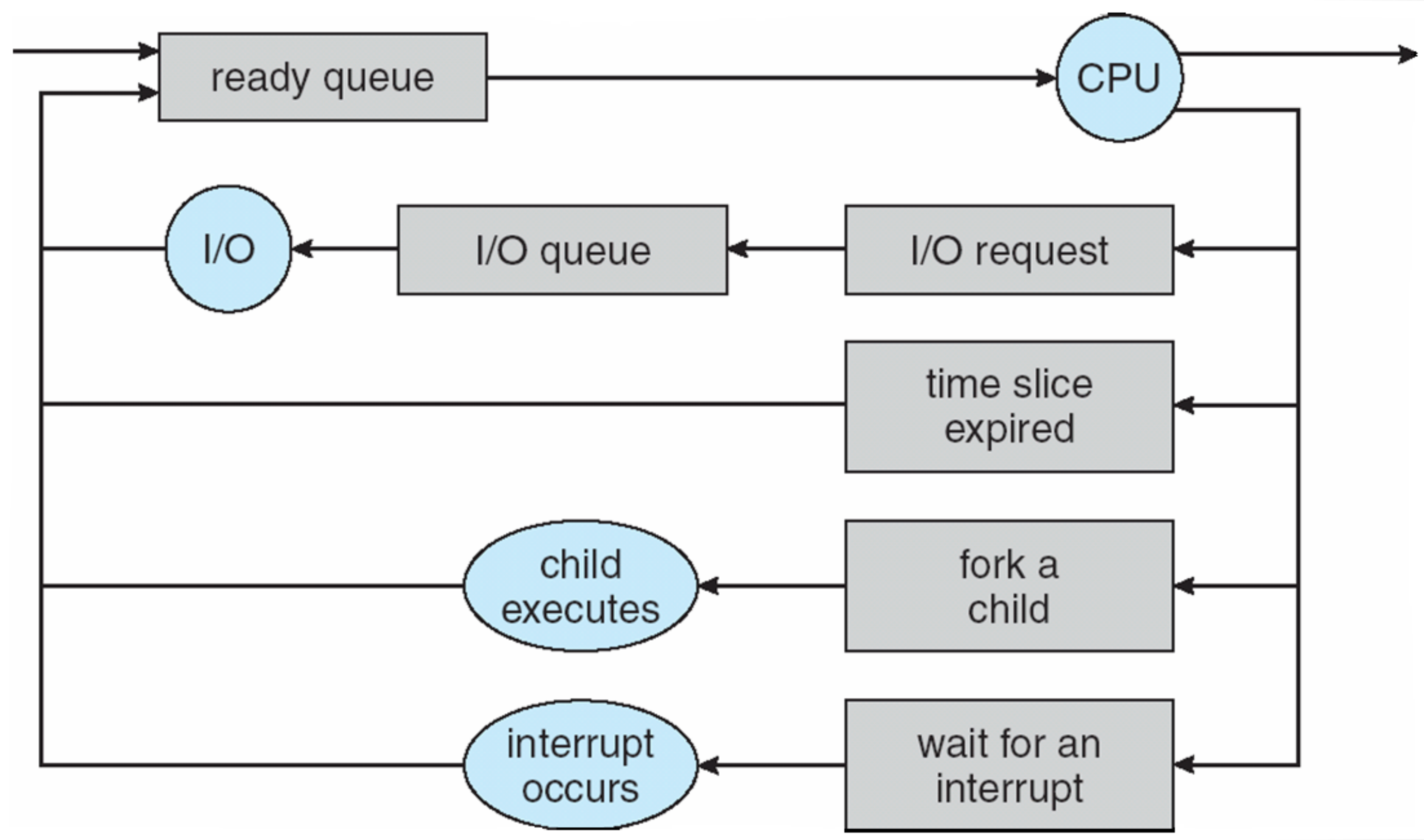
Process Scheduling Queues

- **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 the various queues

Ready Queue And Various I/O Device Queues



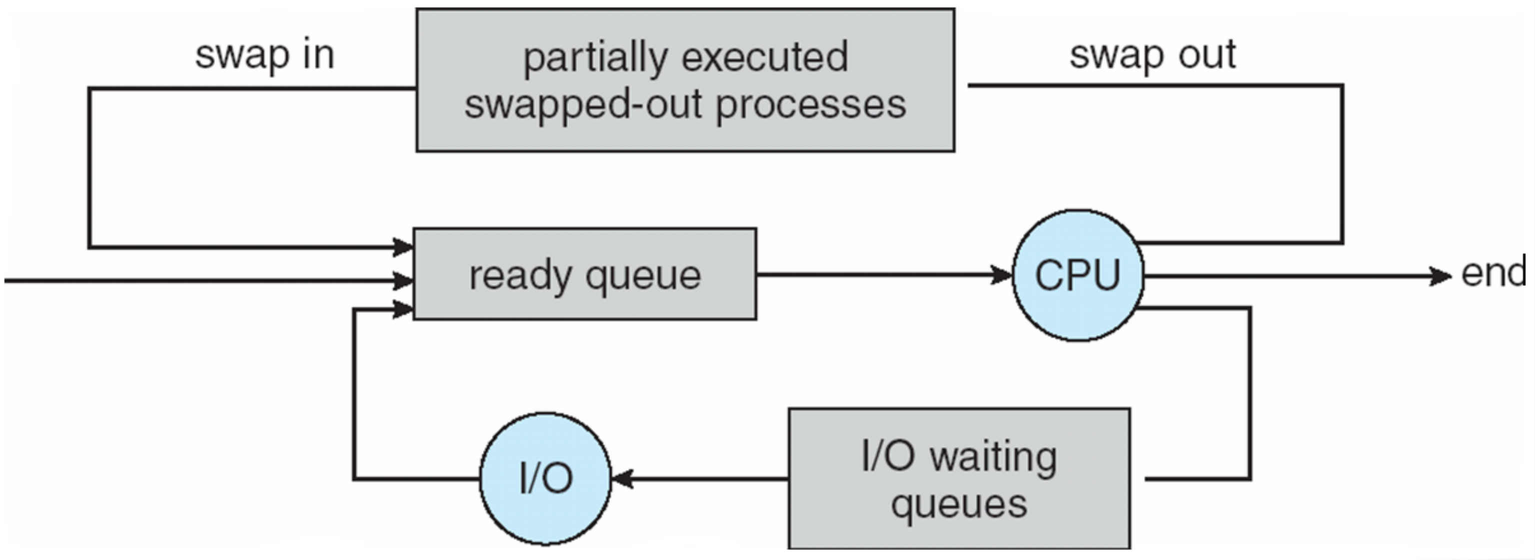
Representation of Process Scheduling



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



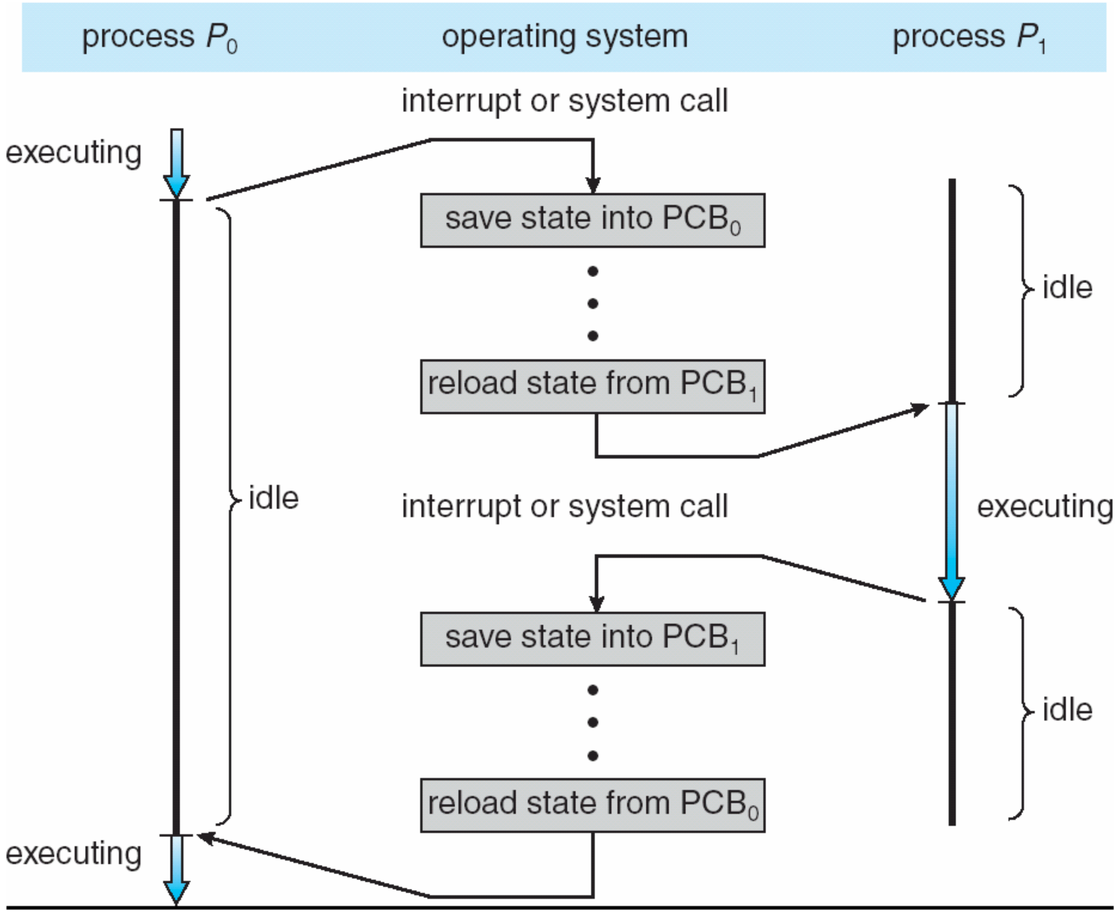
Schedulers (Cont)

- Short-term scheduler 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

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

CPU Switch From Process to Process



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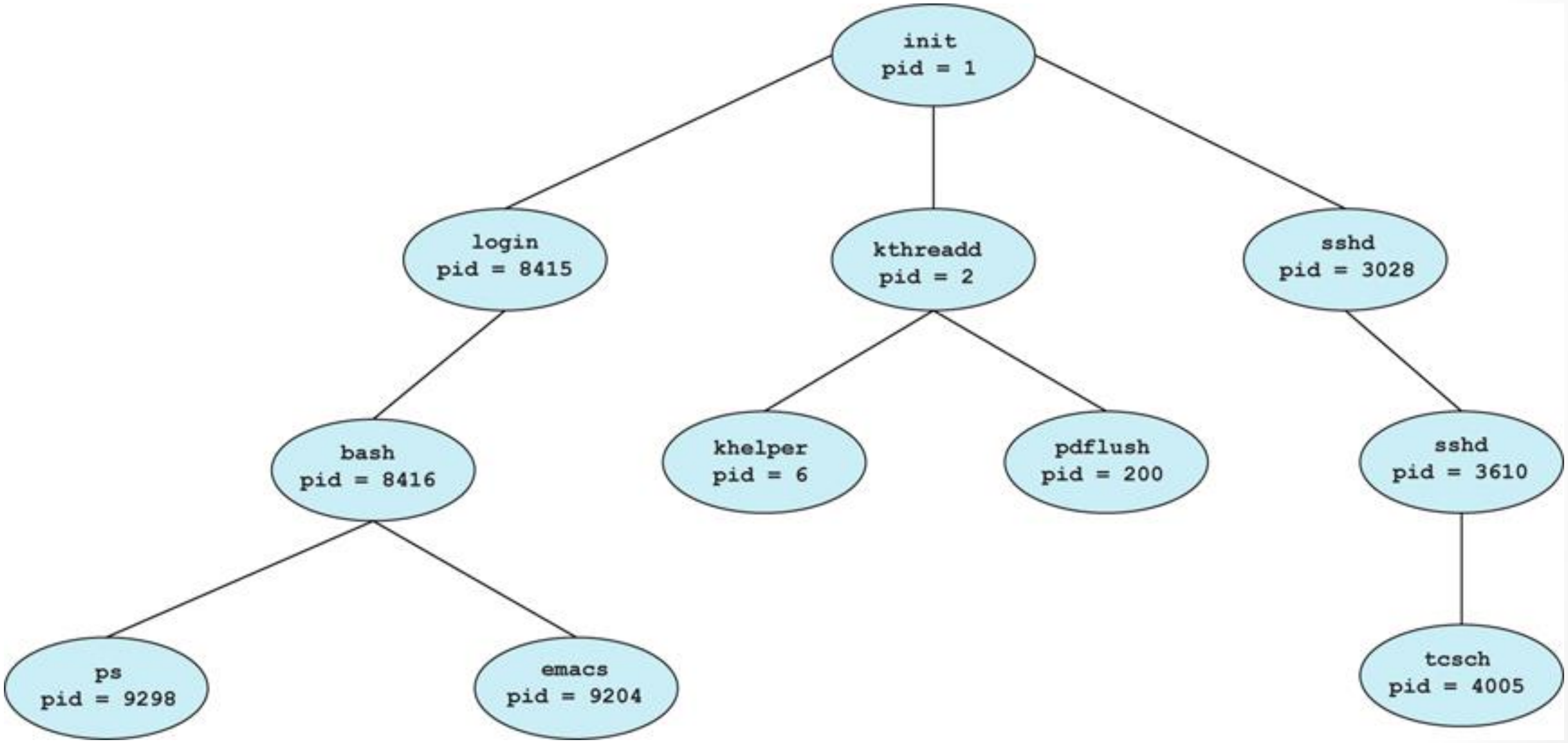
Process Creation

- **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

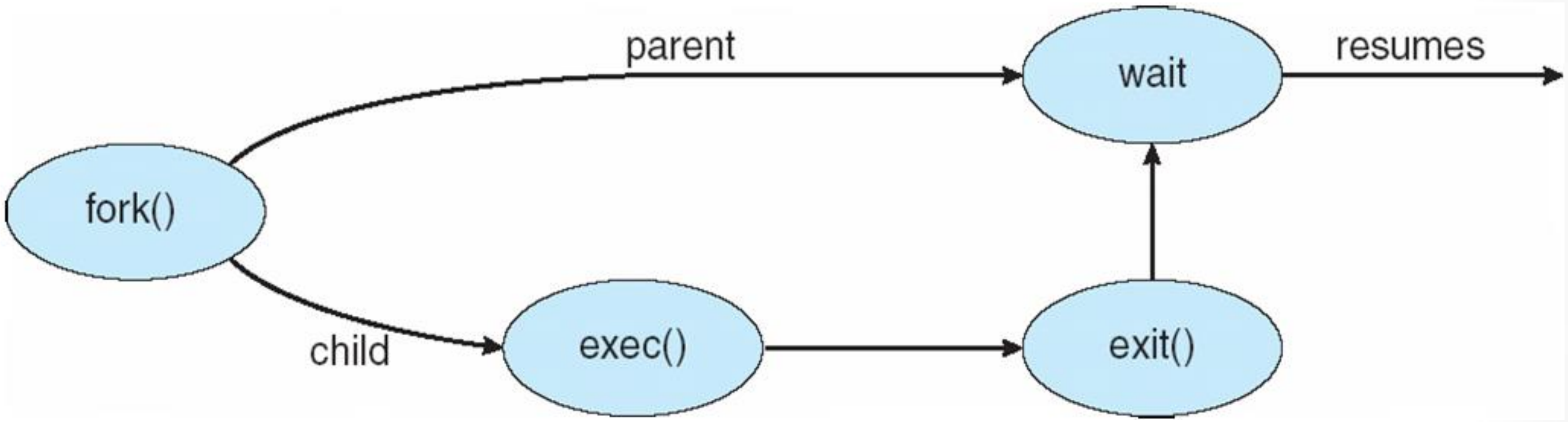
Process Creation (Cont)

- 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

A Tree of Processes on Linux



Process Creation



Fork a Child Process in Linux

```
/*** fork.c *****/
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
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 */
		printf ("Child process: %d\n",  (int)getpid());
				sleep(5); //sleep 5 seconds
		printf (”Child Complete!\n");
	}
	else { /* parent process */
		printf ("Parent process: %d\n",  (int)getpid());
		wait (NULL);
		printf ("Parent Complete!\n");
		exit(0);
	}
}
```

Experiment 1

- What is the return value of fork()?
  - In the parent process?
  - In the child process?
- Can the parent process and child process run concurrently in Linux?
- Will the child process be terminated when the parent process exits?
- Will the parent process and child process share the same virtual memory space?
- Will the parent process and child process share the same files descriptors?

Exec() System Call

```
/*** child.c *****/
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
int main()
{
        printf ("Child process: %d\n",  (int)getpid());
        getchar();
        return 0;
}

// gcc –o child child.c
```

Exec() System Call

```
/*** exec.c *****/
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
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 */
                                printf ("Child process: %d\n",  (int)getpid());
                getchar();
                                execlp("./child", "child", NULL);
        }
        else { /* parent process */
                printf ("Parent process: %d\n",  (int)getpid());
                wait (NULL);
                printf ("Parent Complete!\n");
                exit(0);
        }
}
```

Experiment 2

- What happens at exec()?
- Hint: read /proc/<pid>/maps before and after exec().

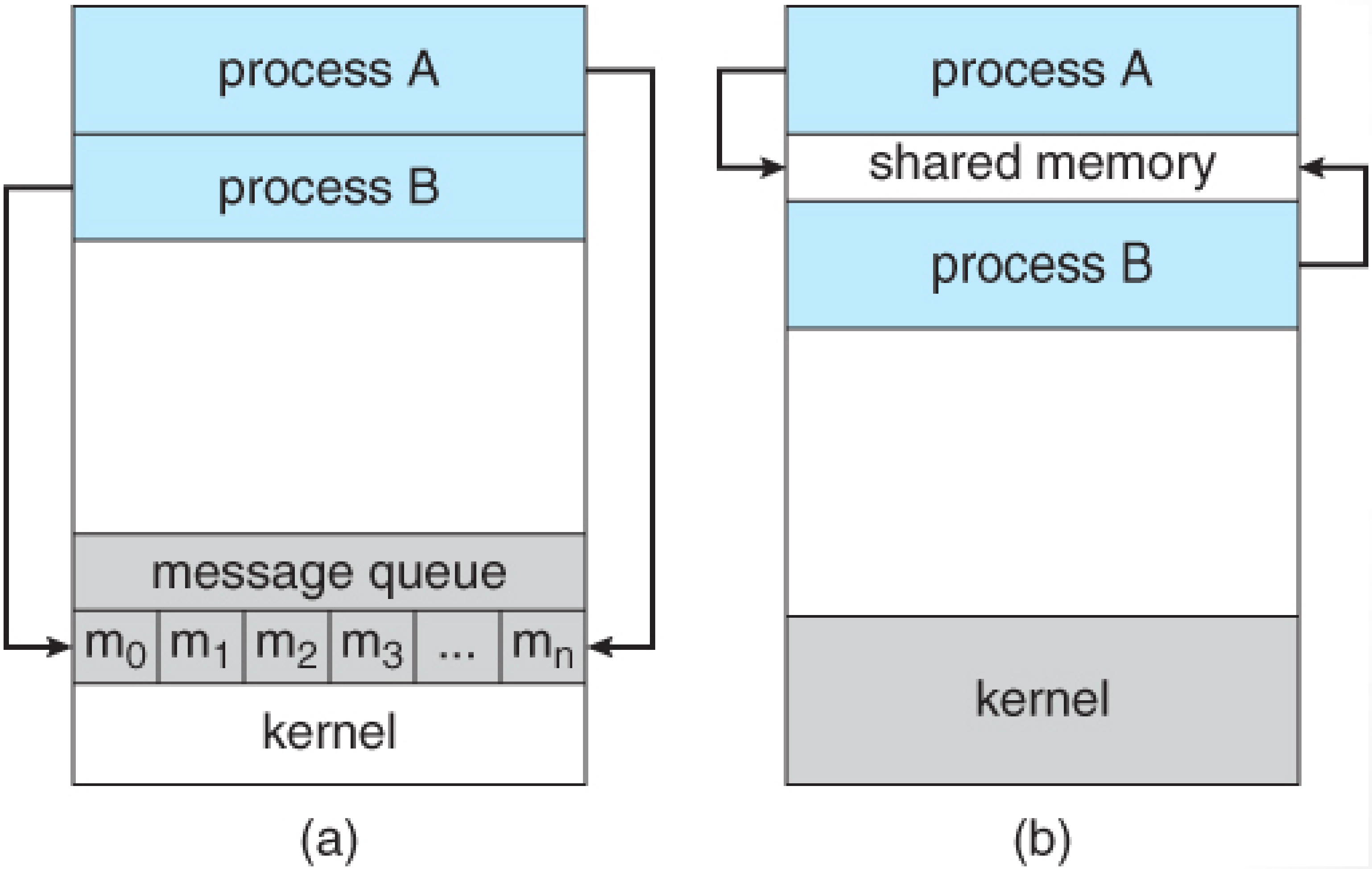
Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**)
  - Output data from child to parent
  - 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**
  - **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
- 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* 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

Example: POSIX IPC

- POSIX shared memory
- POSIX message queue

POSIX Shared Memory

```
/***** headers.h ******/
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <fcntl.h>
#include <sys/shm.h>
#include <sys/stat.h>
#include <sys/mman.h>
```

```
/***** Makefile ********/
all:
	gcc -o producer producer.c -lrt
	gcc -o consumer consumer.c -lrt
```

POSIX Shared Memory

```
/******* producer.c *******/
#include "headers.h"

int main()
{
    const char *name = "OS";
  const char *message = "Learning operating system is fun!";
  int shm_fd;
    void *ptr;
    /* create the shared memory segment */
    shm_fd = shm_open(name, O_CREAT|O_RDWR, 0666);

    /* configure the size of the shared memory segment */
    ftruncate(shm_fd, 4096);

    /* now map the shared memory segment in the address space of the process */
    ptr = mmap(0,SIZE, PROT_READ|PROT_WRITE, MAP_SHARED, shm_fd, 0);
    if (ptr == MAP_FAILED) {
            printf("Map failed\n");
            return -1;
    }
    sprintf(ptr,"%s",message);
}
```

POSIX Shared Memory

```
/********* consumer.c ***********/
#include "headers.h"
int main()
{
    const char *name = "OS";
    int shm_fd;                         // file descriptor, from shm_open()
  char *shm_base;      // base address, from mmap()
  /* open the shared memory segment as if it was a file */
  shm_fd = shm_open(name, O_RDONLY, 0666);
  if (shm_fd == -1) {
    printf("Shared memory failed\n");
    exit(1);
  }
  /* map the shared memory segment to the address space of the process */
  shm_base = mmap(0, SIZE, PROT_READ, MAP_SHARED, shm_fd, 0);
  if (shm_base == MAP_FAILED) {
    printf("Map failed\n");
    exit(1);
  }
    /* Read data */
    printf("%s", shm_base);
    /* remove the named shared memory object*/
    shm_unlink(name);
}
```

Practice: Bounded Buffer

- Implement a bounded-buffer producer-consumer model using POSIX shared memory

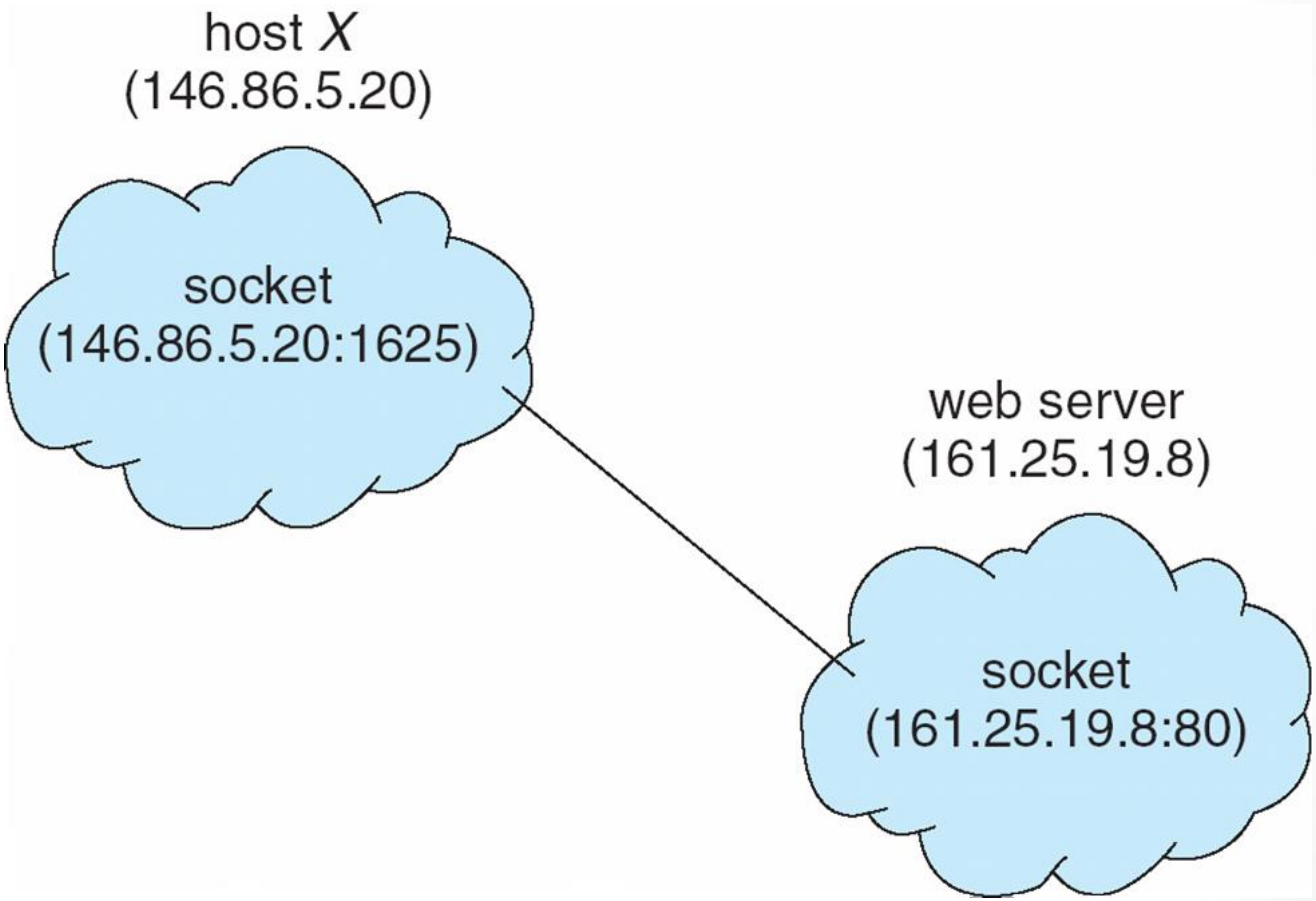
Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls
- 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

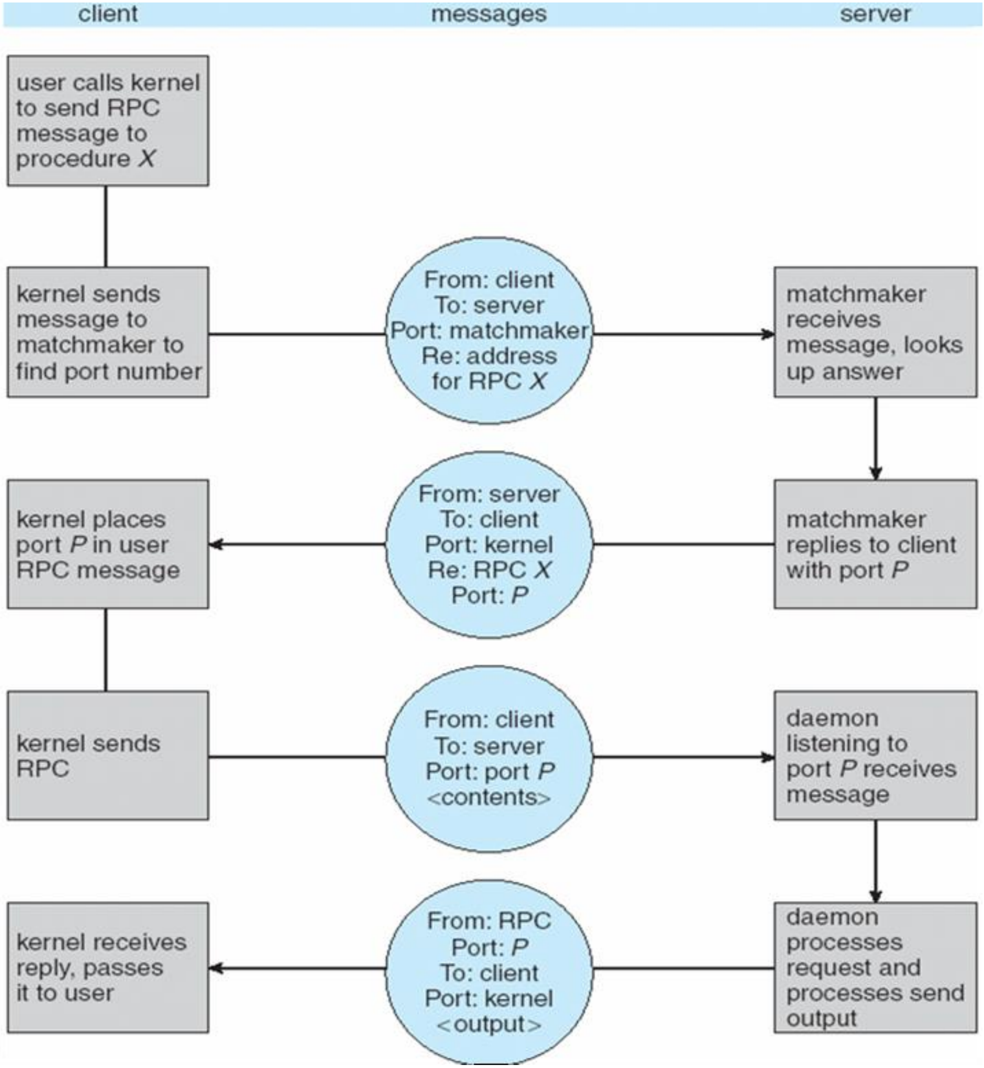
Socket Communication



Remote Procedure Calls

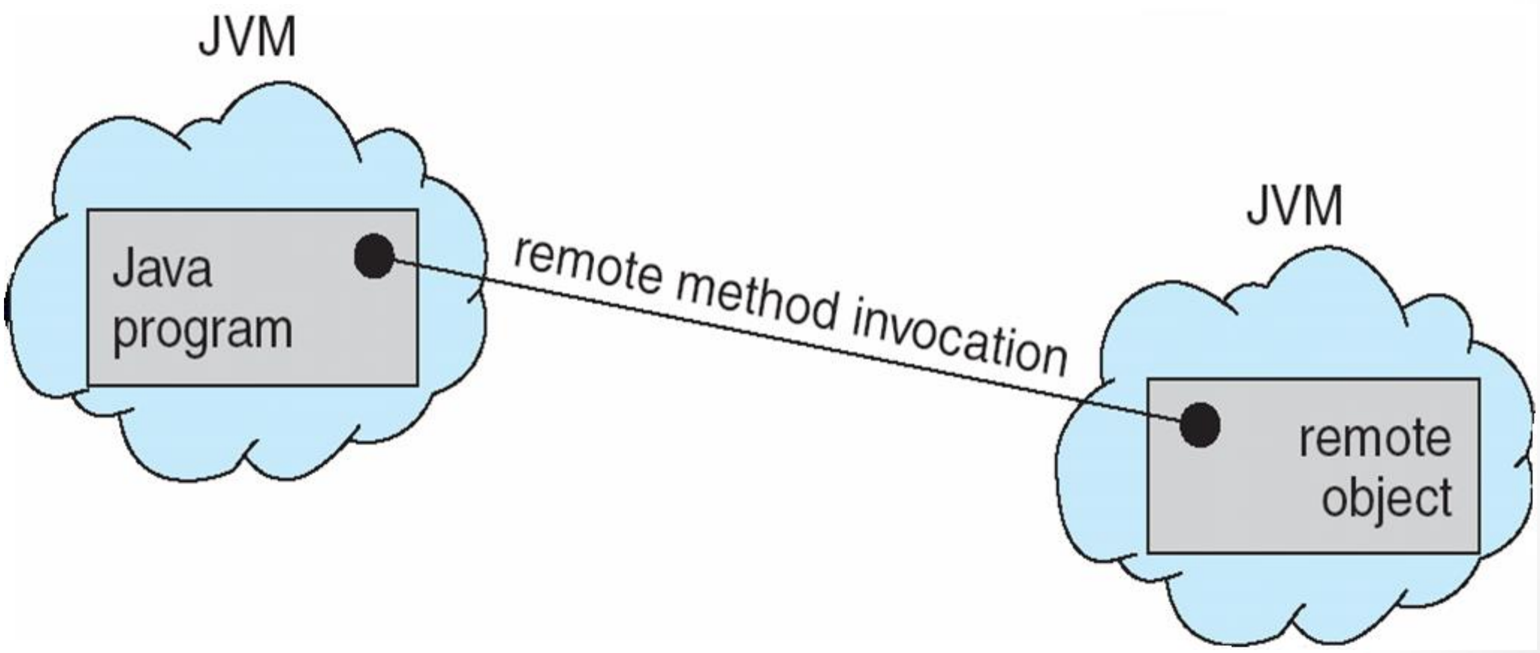
- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and *marshalls* the parameters
- The server-side stub receives this message, unpacks the marshalled parameters, and peforms the procedure on the server

Execution of RPC



Remote Method Invocation

- Remote Method Invocation (RMI) is a Java mechanism similar to RPCs
- RMI allows a Java program on one machine to invoke a method on a remote object



End of Chapter 3