Chapter 3: Processes

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- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication (IPC)
  - 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

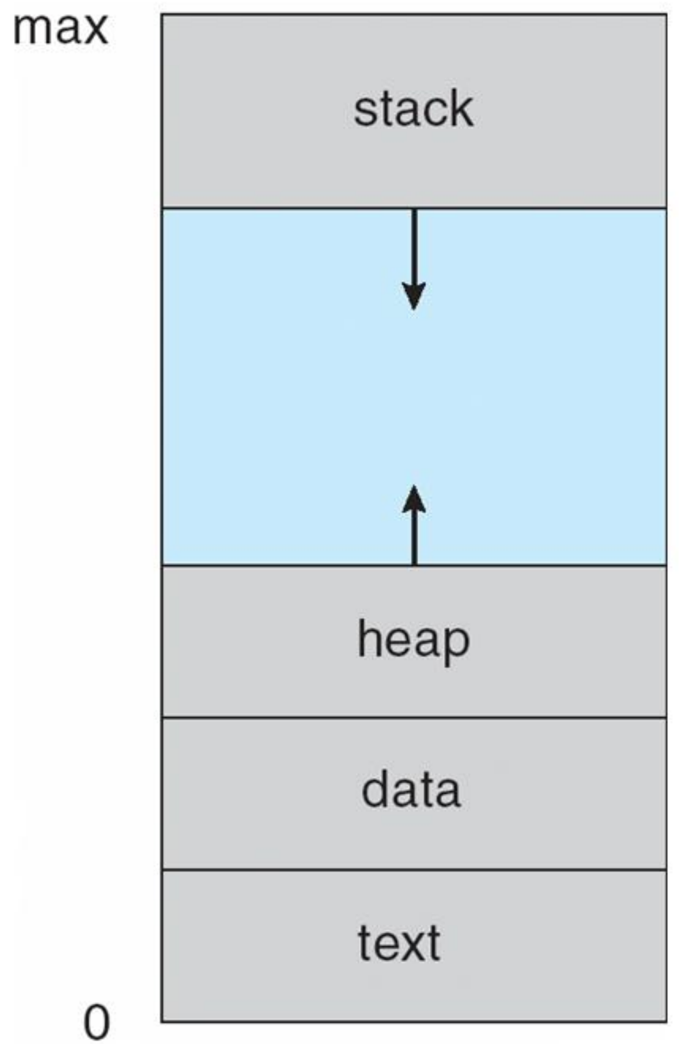
Process Concept

- An operating system executes a variety of programs:
  - Batch system – **jobs**
  - Time-shared systems – **user programs** or **tasks**
- Textbook uses the terms ***job*** and ***process*** almost interchangeably
- 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

Process Concept

- One program can be several processes
  - Consider multiple users executing the same program
- **Process** – a program in execution; process execution must progress in sequential fashion
- Process includes multiple parts
  - The program code, also called **text section**
  - Current activity involving **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

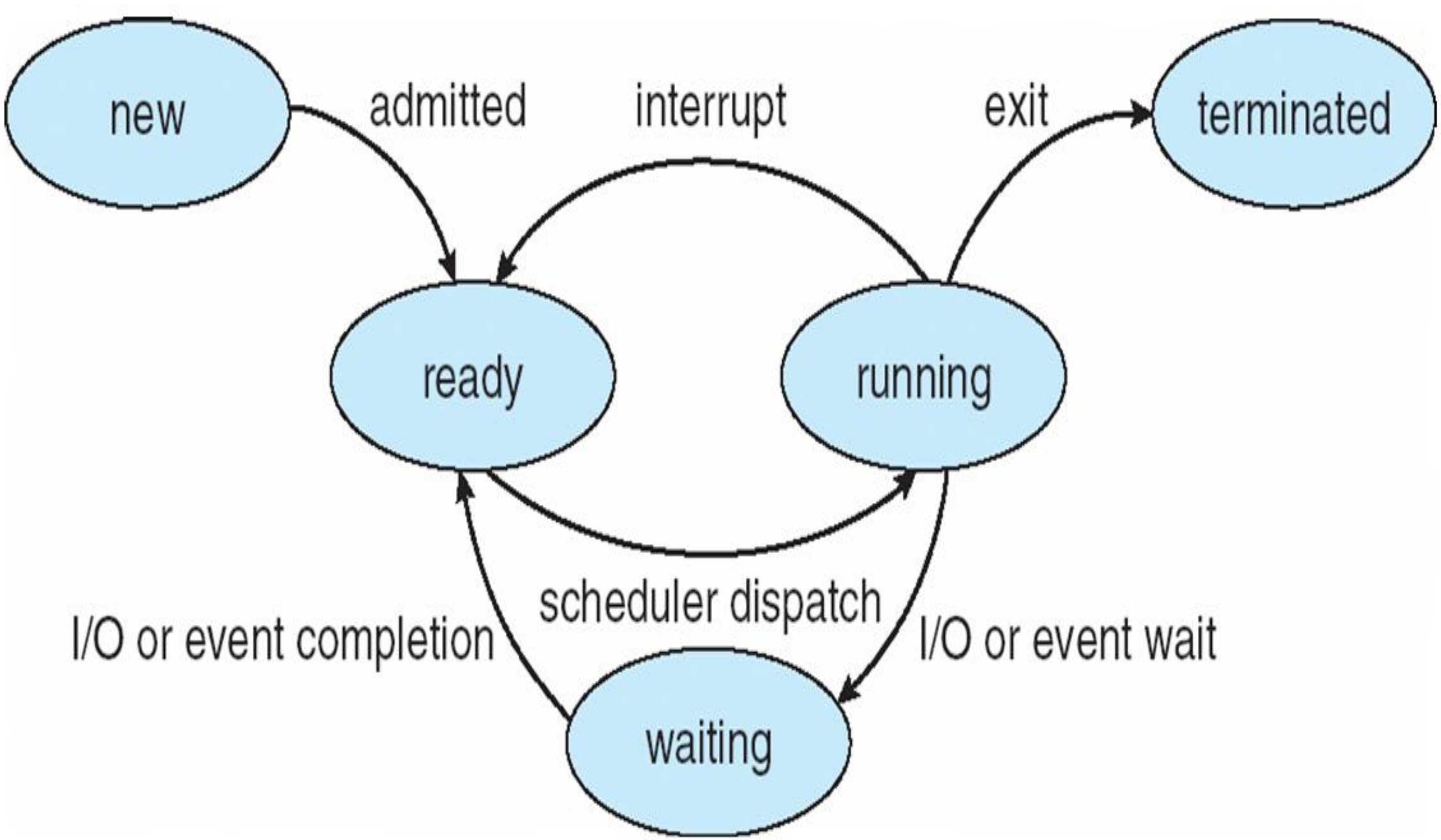
Process in Memory



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

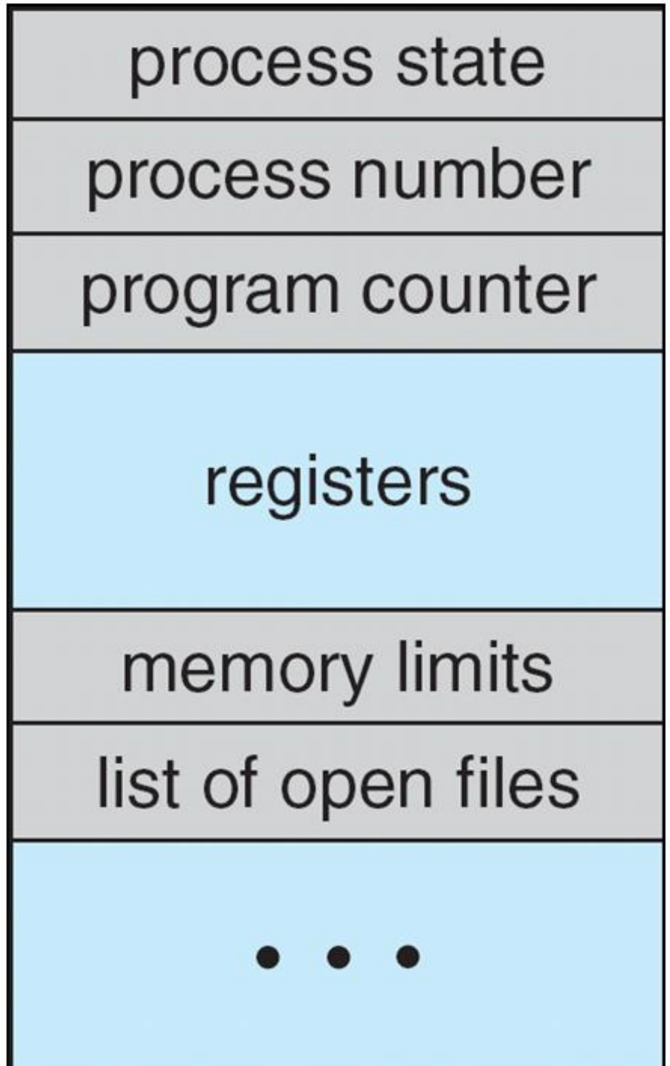
Diagram of Process State



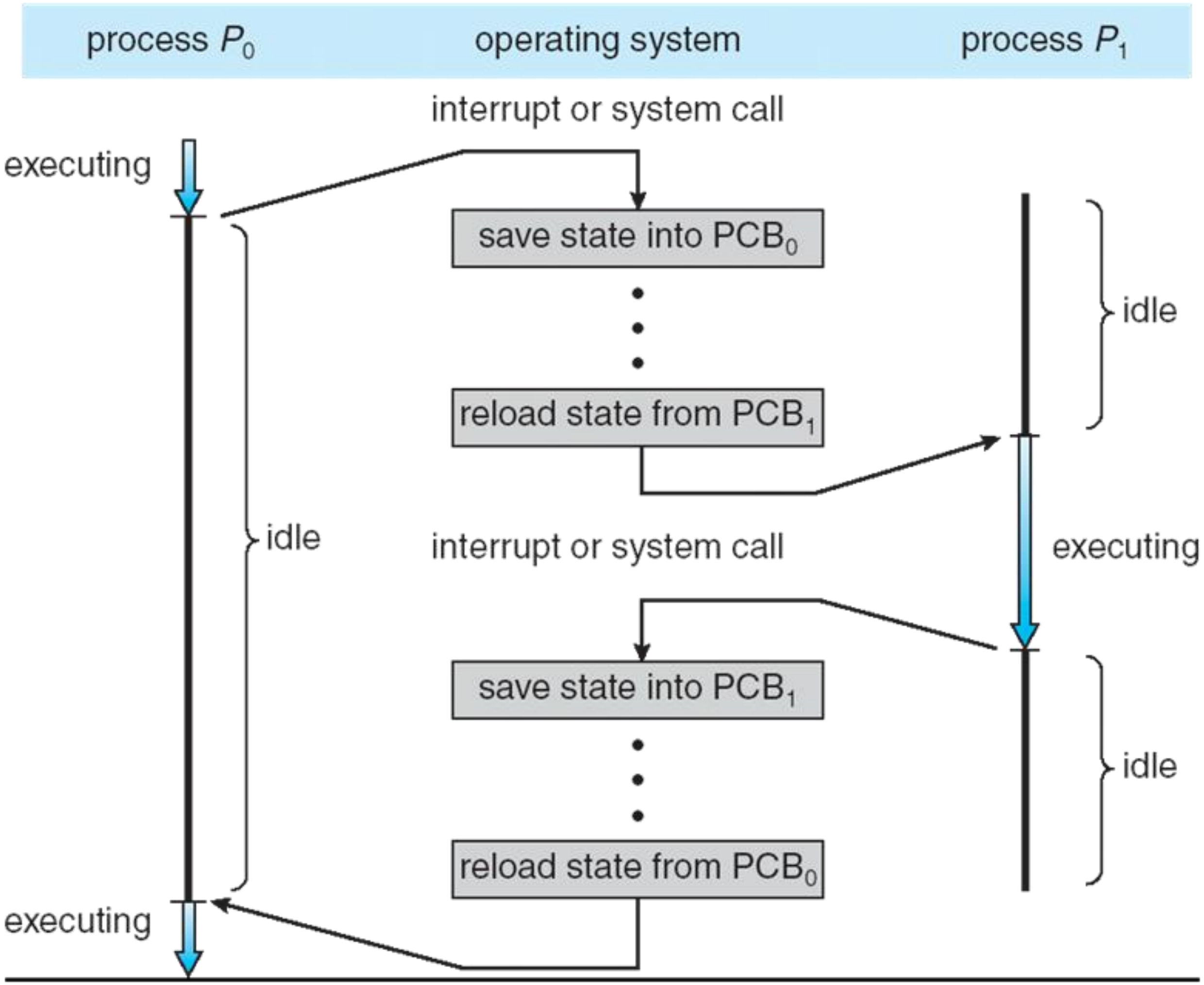
Process Control Block (PCB)

- Information associated with each process
  - **Process state** – 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
  - **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

Process Control Block (PCB)



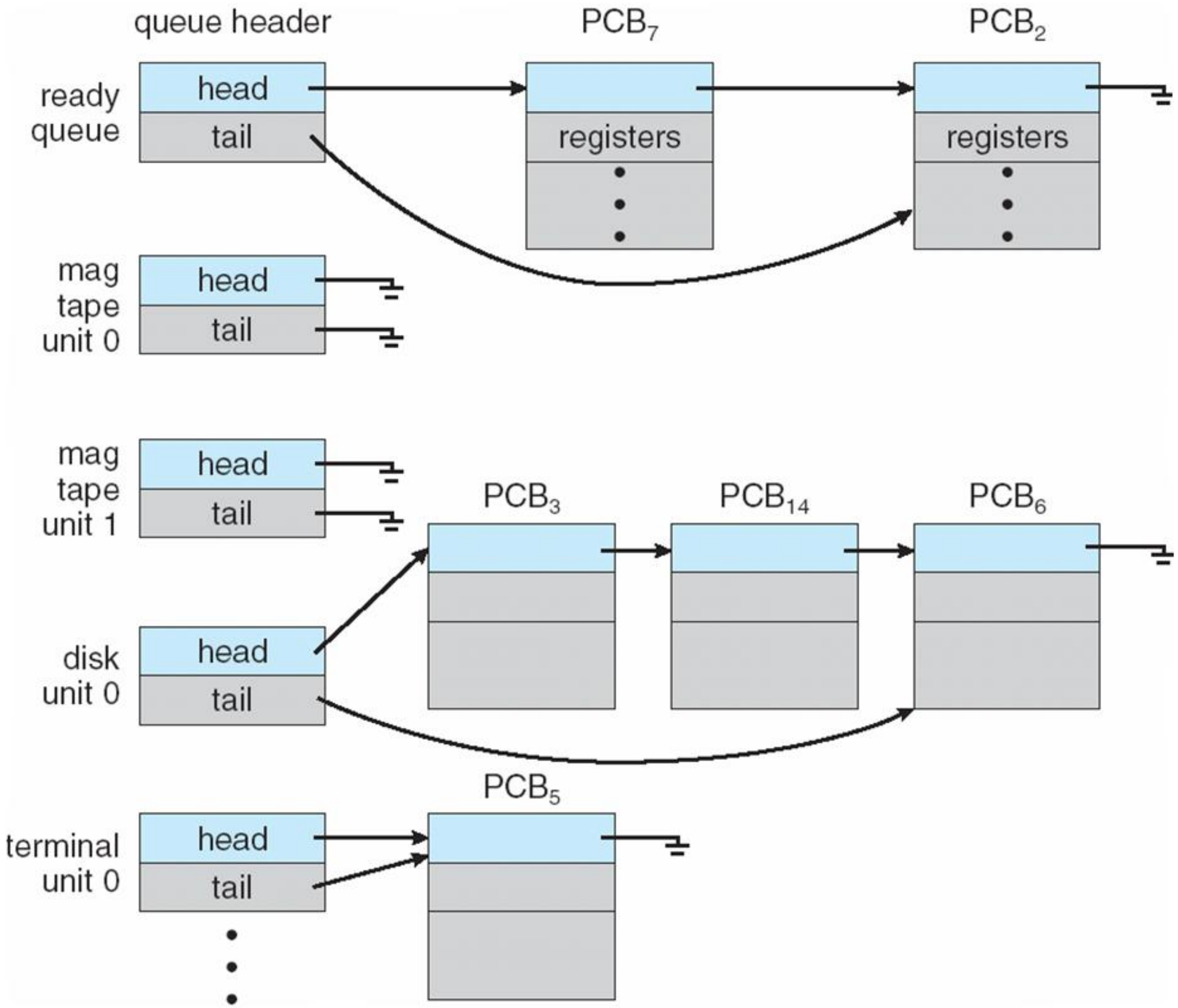
CPU Switch From Process to Process



Process Scheduling

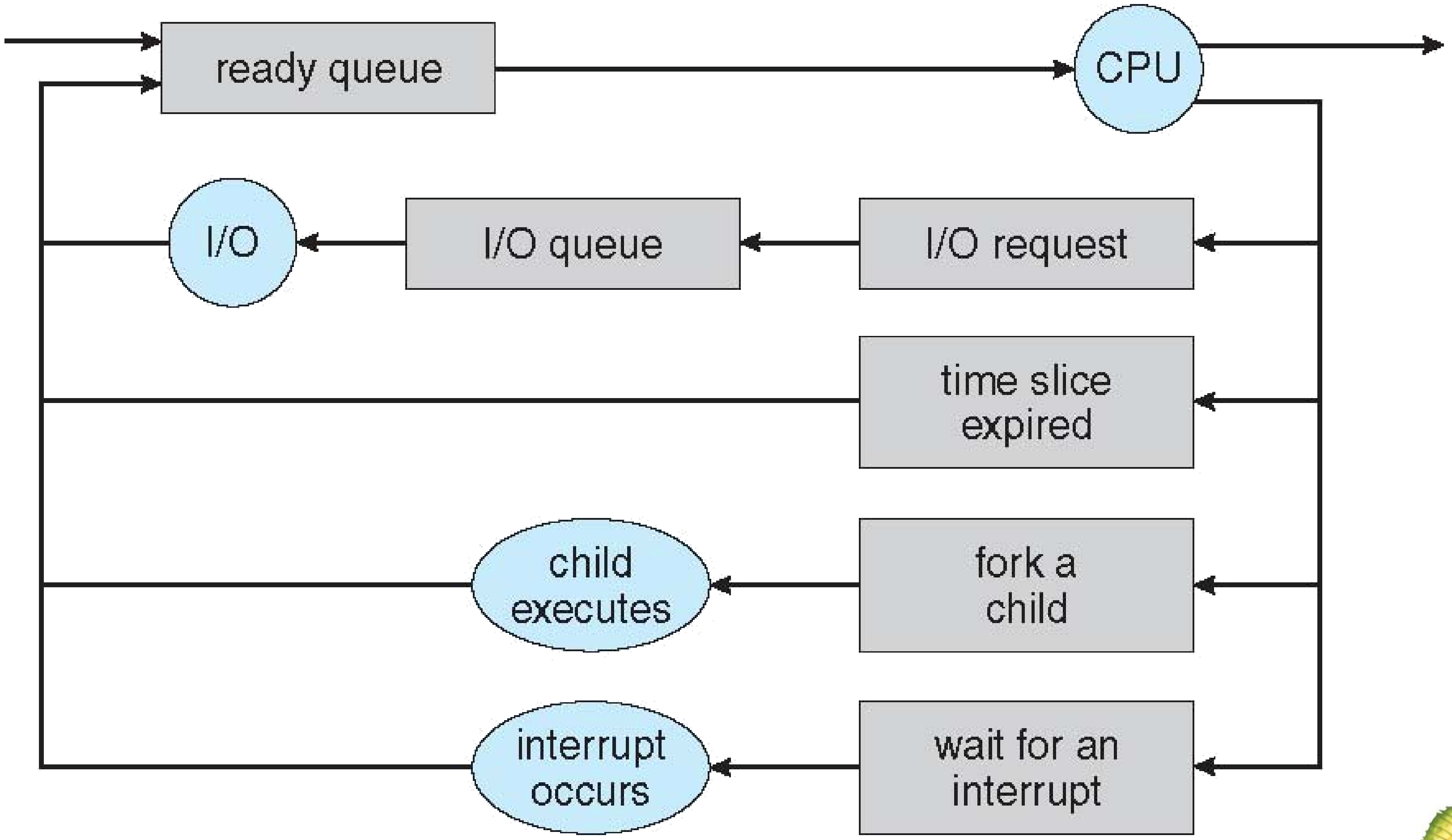
- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the system
  - **Ready queue** – set of all processes residing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

Ready Queue and Various I/O Device Queues



Representation of Process Scheduling

Queuing diagram represents queues, resources, flows



Schedulers

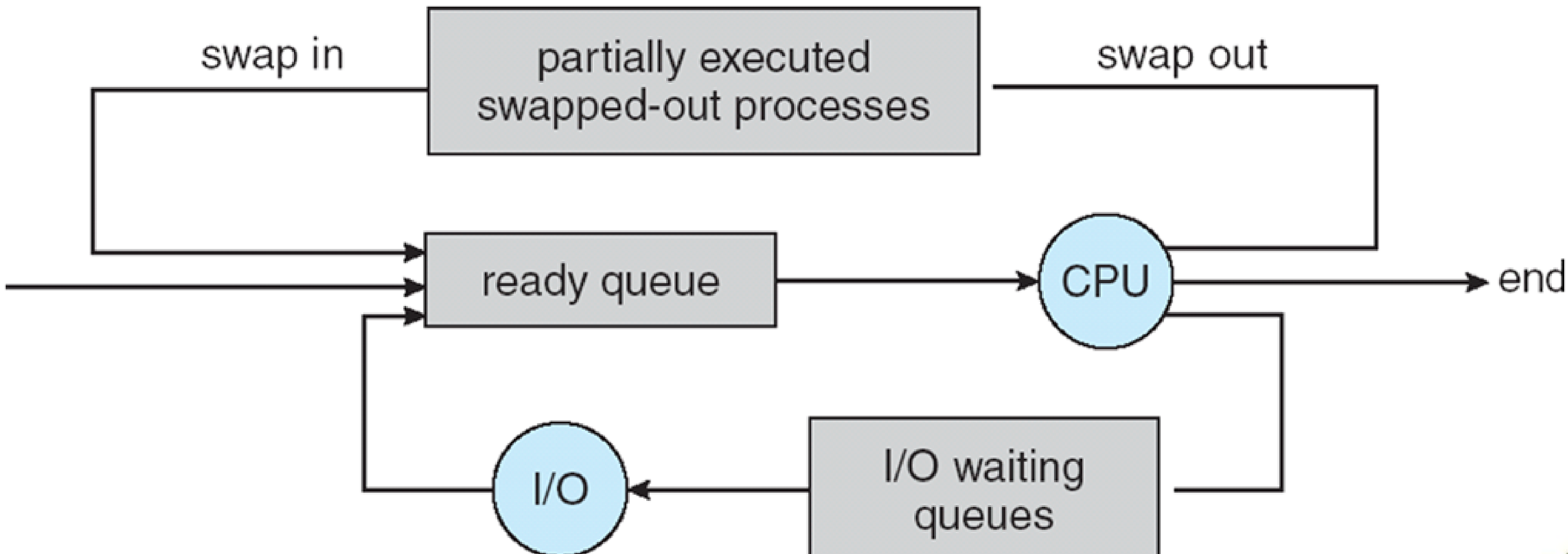
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  - Sometimes the only scheduler in a system
- The long-term scheduler controls the **degree of multiprogramming**

Schedulers

- Short-term scheduler is invoked very frequently (milliseconds) ⇒ (must be fast)
- Long-term scheduler is invoked very infrequently (seconds, minutes) ⇒ (may be slow)
- 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**



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

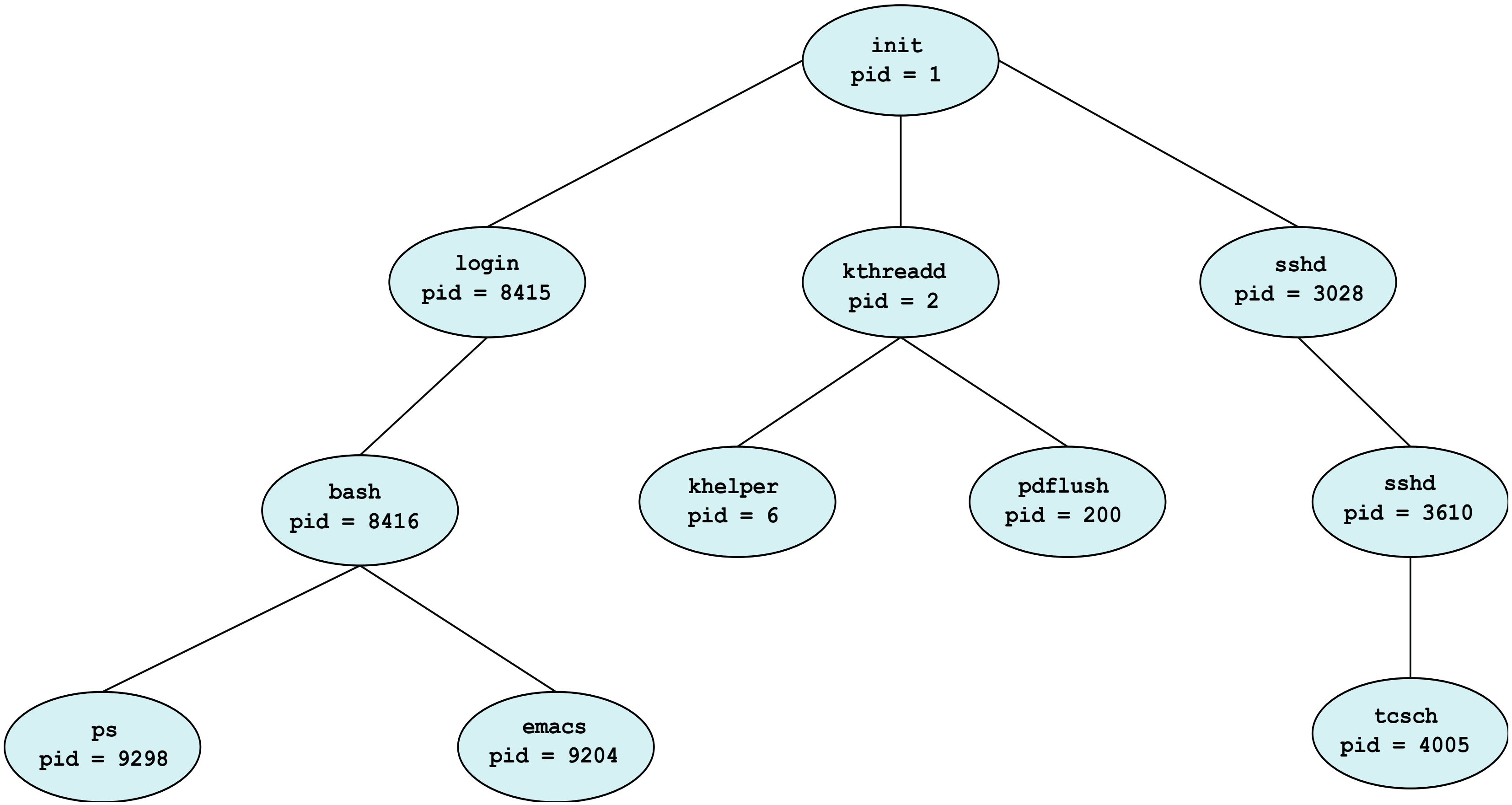
Operations on Processes

- System must provide mechanisms for process creation, termination, and so on as detailed next

Process Creation

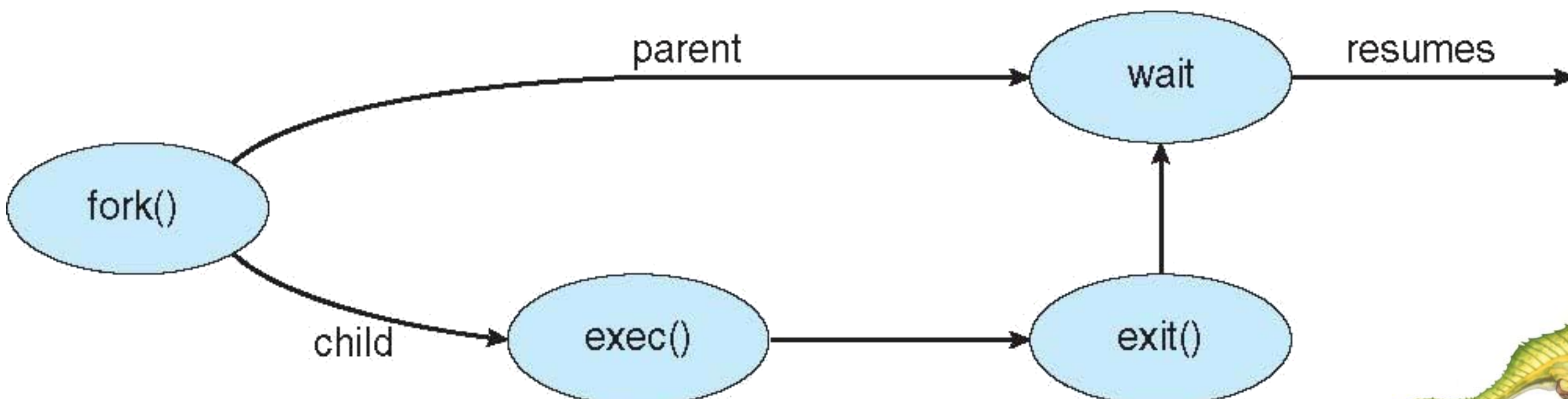
- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
  - Generally, process identified and managed via a **process identifier** (**pid**)
- Resource sharing options
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution options
  - Parent and children execute concurrently
  - Parent waits until all or some children terminate

A Tree of Processes in Linux



Process Creation (Cont.)

- Address space
  - Child duplicate of parent program
  - 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



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);
    }
    else { /* parent process */
       /* parent will wait for the child to complete */
       wait(NULL);
       printf("Child Complete");
    }

    return 0;
}
```

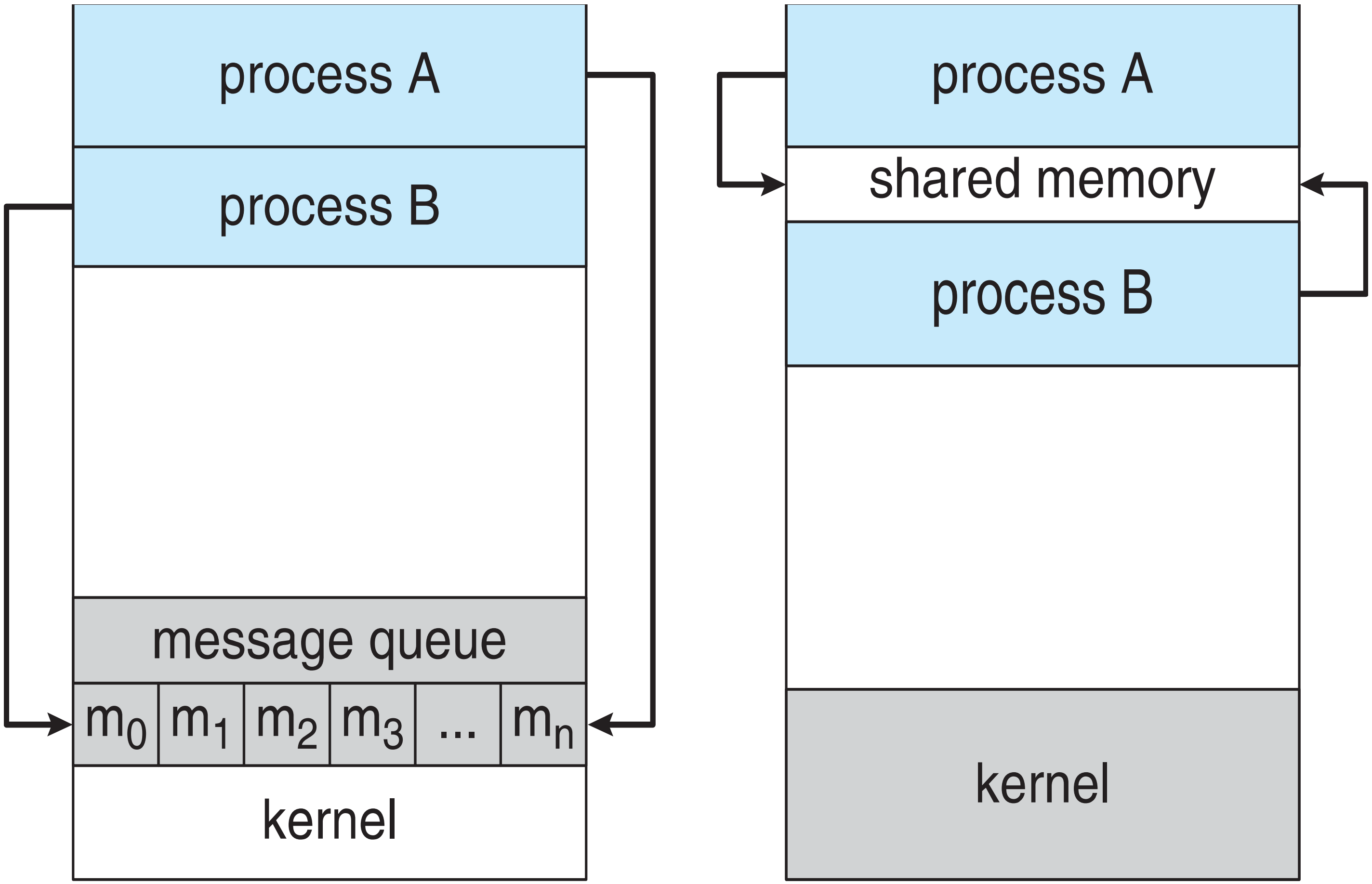
Process Termination

- Process executes last statement and asks the operating system to delete it (**`exit()`**)
  - Child process return its status to parent (via **`wait()`**)
  - Process' resources are deallocated by the operating system
- Parent may terminate execution of its children processes (**`abort()`**) for a variety of reasons:
  - 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 must also 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 require an **interprocess communication** (**IPC**) mechanism
  - Two models of IPC:
    a) **Message passing**
    b) **Shared memory**

Communications Models



(a) (b)

Producer-Consumer Problem

- Paradigm for cooperating processes, a **producer** process produces information that is consumed by a **consumer** process:
  - A compiler may produce assembly code that is consumed by an assembler
  - A web server produces HTML files which are consumed by the client web browser
- One solution to allow them to run concurrently, uses a buffer of items (**shared memory**) that can be filled by producer and emptied by consumer:
  - **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

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

Bounded-Buffer – Consumer

```
item next_consumed;
while (true) {
      while (in == out)
          ;   /* do nothing - empty buffers */
      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 at least 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
  - 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?
- 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
    - A mailbox may be created (and then owned) either by a process or by the operating system
  - Send and receive messages through mailbox
    - Only owner process can receive messages through its mailbox
  - Destroy a mailbox by the owner
- 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 owned by OS
  - 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

Synchronization (Cont.)

- Different combinations possible
  - If both send and receive are blocking, we have a **rendezvous**
- Producer-consumer problem becomes trivial

<u>Producer</u>

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

<u>Consumer</u>

```
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

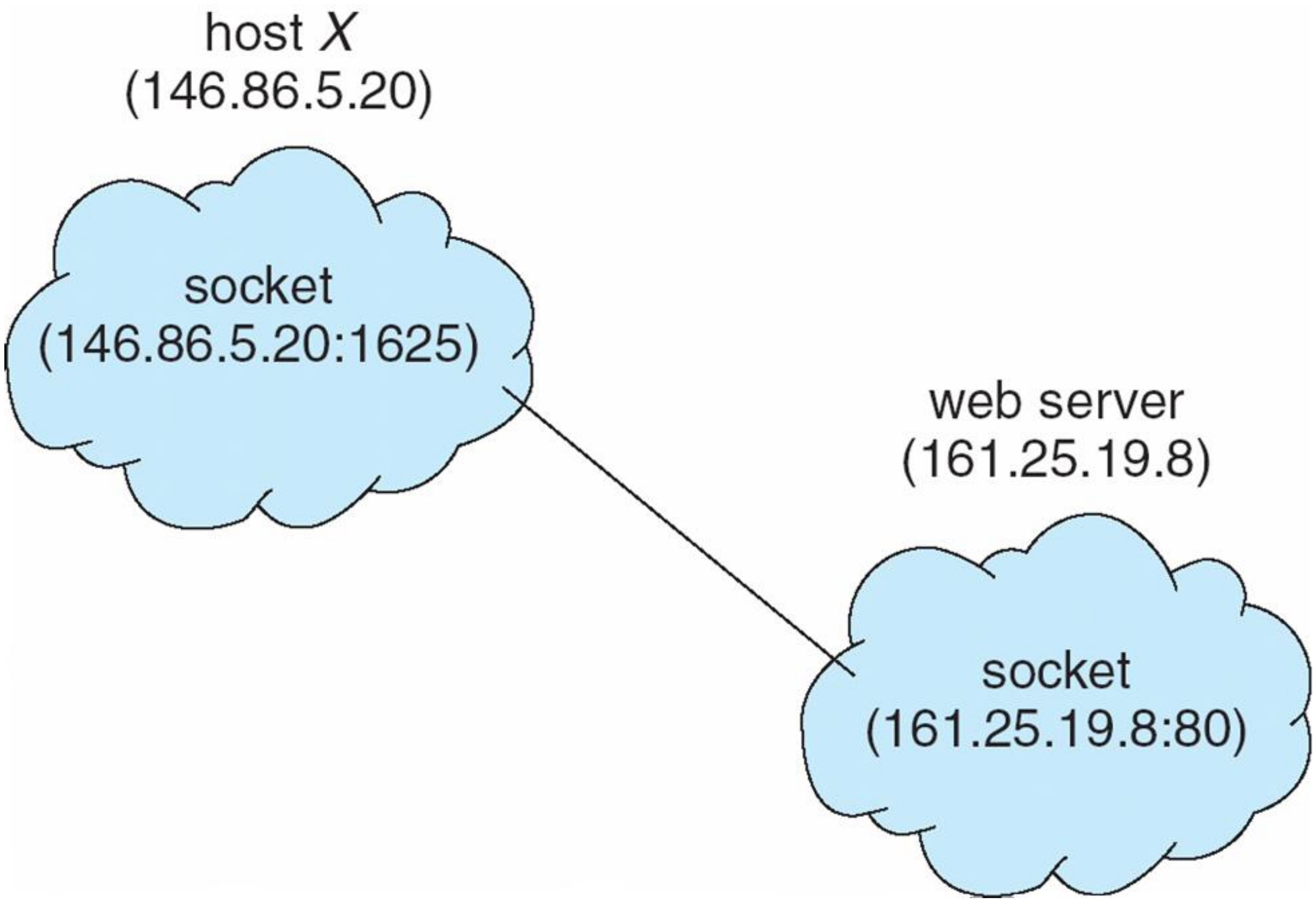
Communications in Client-Server Systems

- Shared memory and message passing strategies can be used for communication in client–server systems as well
- Four other used techniques for communication in client–server systems:
  - Sockets
  - Remote Procedure Calls
  - Pipes
  - Remote Method Invocation (Java)

Sockets

- A **socket** is an endpoint for communication
  - A pair of processes communicating over a network employs a pair of sockets
- A socket is identified by an IP address concatenated with a **port** number.
  - The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**
- The server waits for incoming client requests by listening to a specified port
  - All ports below 1024 are **well known**, used for standard services
  - To allow a client and server on the same host to communicate, a special IP address 127.0.0.1 (**loopback**) is used to refer to itself

Socket Communication



Sockets in Java

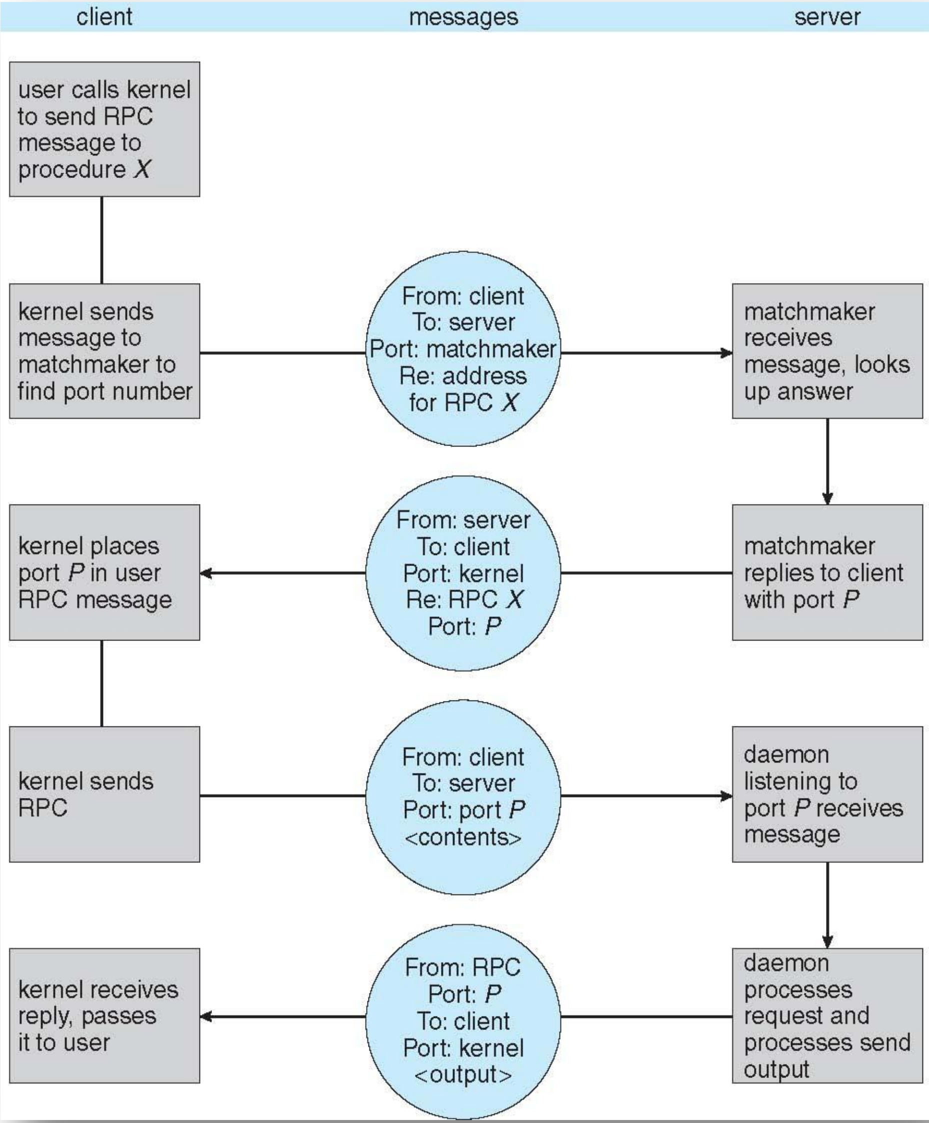
- Three different types of sockets:
  - **Connection-oriented** (**TCP**) `Socket` class
  - **Connectionless** (**UDP**) `DatagramSocket` class
  - `MulticastSocket` class – data can be sent to multiple recipients
- Consider this "Date" server:

```
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

- 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

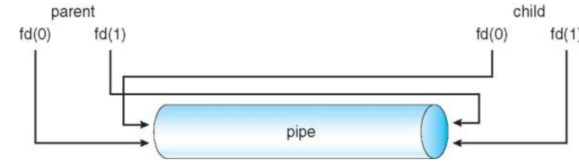
Execution of RPC



Pipes

- Acts as a channel allowing two processes to communicate
- Simpler ways for communication but have some limitations
- **Issues**
  - Is communication unidirectional or bidirectional?
  - In the case of two-way communication, is it half or full-duplex?
  - Must there exist a relationship (as **parent-child**) between the communicating processes?
  - Can be used over a network or must reside on the same machine?

Ordinary Pipes



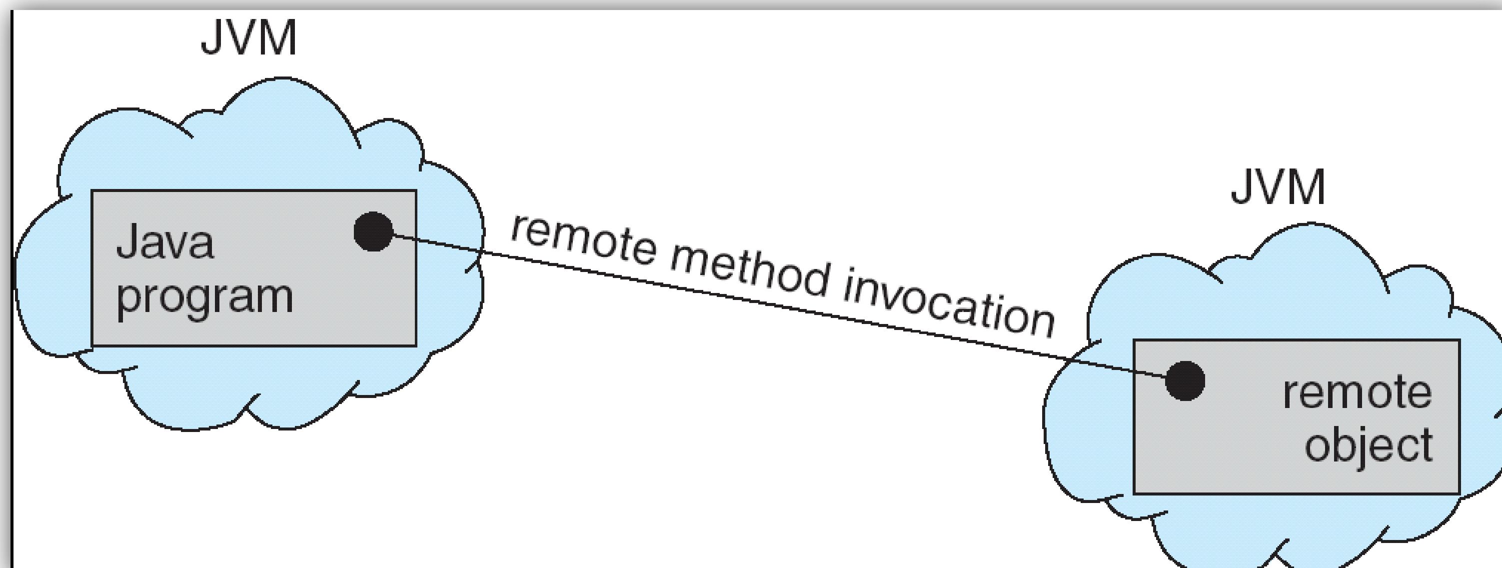
- Ordinary Pipes allow communication in standard producer-consumer style
  - Producer writes to one end (the **write-end** of the pipe)
  - Consumer reads from the other end (the **read-end** of the pipe)
  - So, they allow only unidirectional communication
- Require parent-child relationship between communicating processes
  - A parent process creates a pipe and uses it to communicate with its child process
- UNIX treats it as a special type of file and can be accessed using read() and write() system calls

Named Pipes

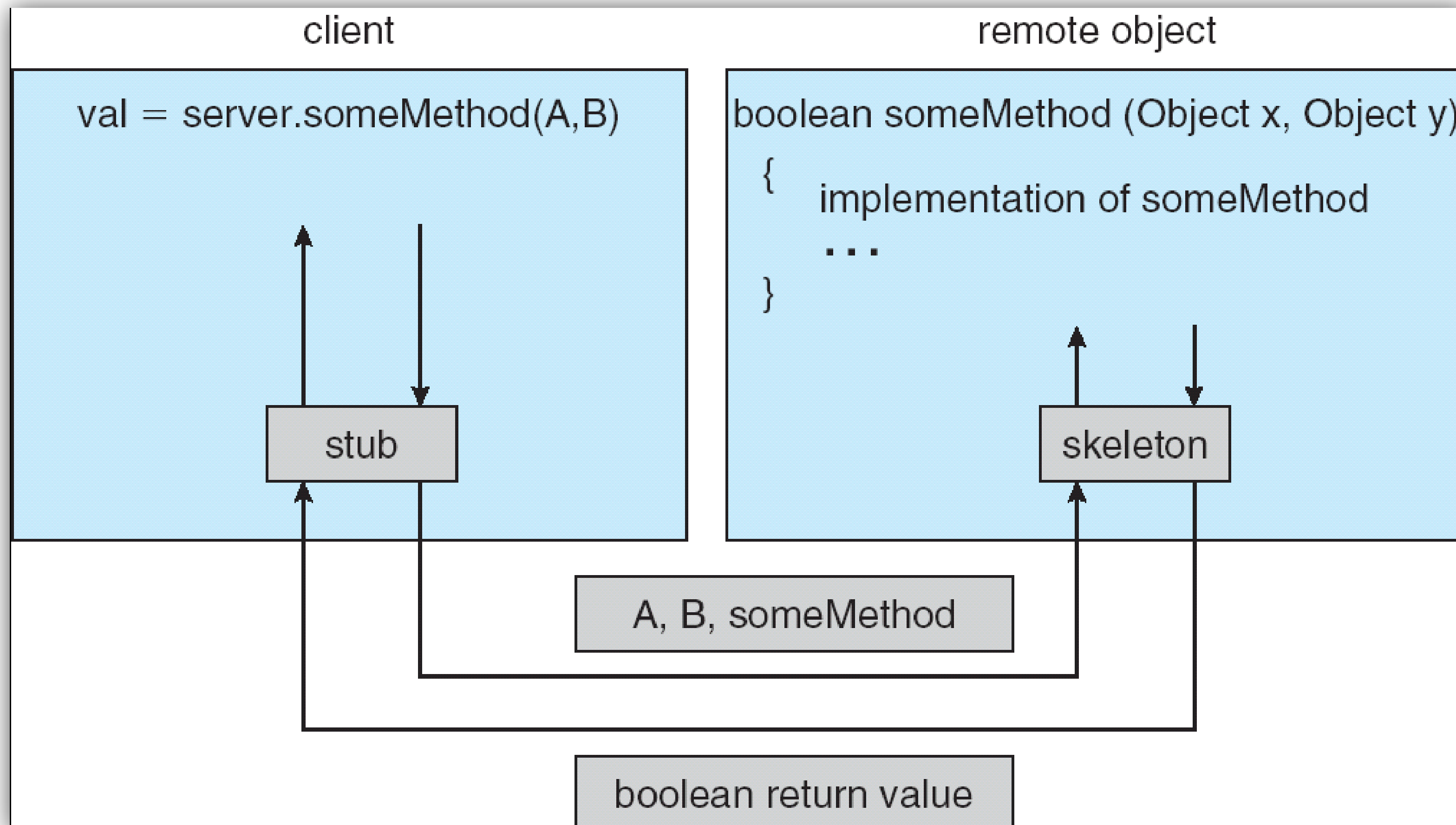
- More powerful tool than ordinary pipes
  - Communication can be bidirectional
  - No parent–child relationship is required.
  - Several processes can use it for communication
- Both UNIX and Windows systems support it, although implementation details differ greatly
  - Referred to as FIFOs in UNIX and once created, they appear as typical files and manipulated with ordinary open(), read(), write(), and close() system calls
  - Windows provide a richer communication mechanism
    - Full-duplex communication is allowed
    - May reside on either the same or different machines
    - Allow either byte- or message-oriented data

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.



Marshalling Parameters



End of Chapter 3