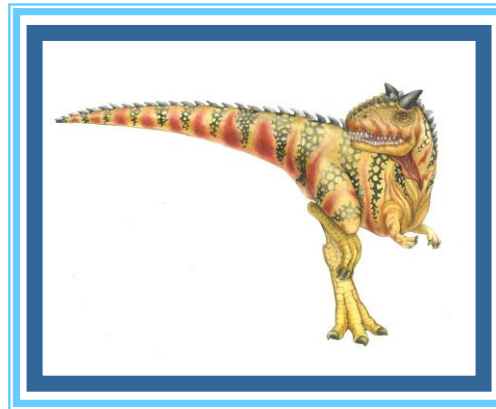


Winona State University
CS405 – Operating System
Spring 2024

Chapter 3: Processes





Outline

- Process Concept
- Process Scheduling
- Operations on Processes
- Interprocess Communication
- IPC in Shared-Memory Systems
- IPC in Message-Passing Systems





Objectives

- Identify the separate components of a process and illustrate how they are represented and scheduled in an operating system.
- Describe how processes are created and terminated in an operating system, including developing programs using the appropriate system calls that perform these operations.
- Describe and contrast interprocess communication using shared memory and message passing.
- Design programs that use pipes and POSIX shared memory to perform interprocess communication.
- Describe client-server communication using sockets and remote procedure calls.
- Design kernel modules that interact with the Linux operating system.





3.1 Process Concept

- An operating system executes a variety of programs that run as a process.
- **Process** – a program in execution; process execution must progress in sequential fashion. No parallel execution of instructions of a single process
- Multiple parts
 - The program code, also called **text section**
 - Current activity including **program counter**, processor registers
 - **Stack** containing temporary data
 - ▶ Function parameters, return addresses, local variables
 - **Data section** containing global variables
 - **Heap** containing memory dynamically allocated during run time

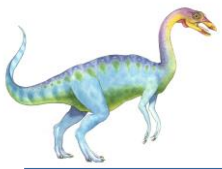




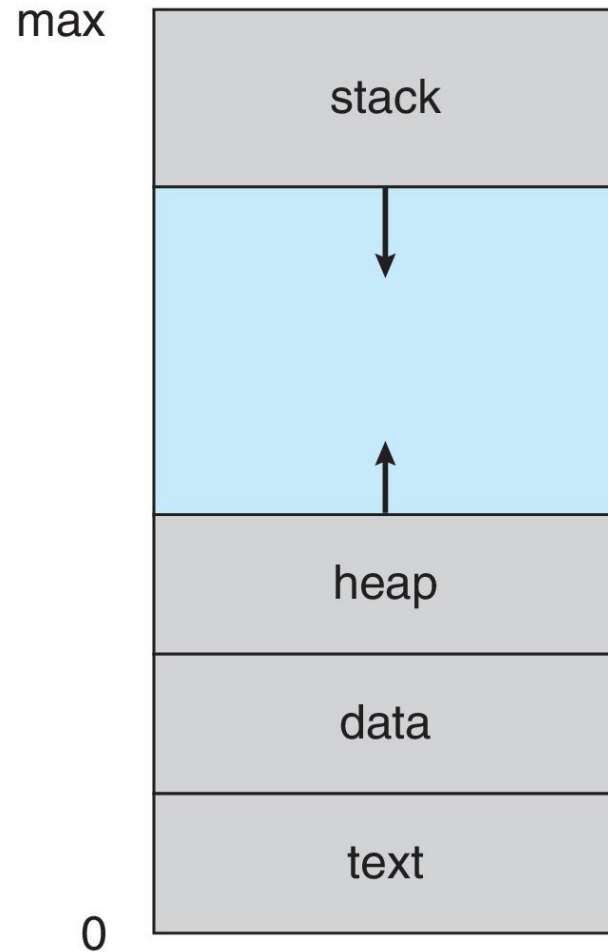
Process Concept (Cont.)

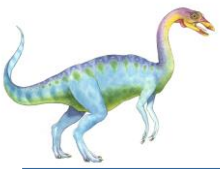
- Program is **passive** entity stored on disk (**executable file**); process is **active**
 - Program becomes process when an executable file is loaded into memory
- Execution of program started via GUI mouse clicks, command line entry of its name, etc.
- One program can be several processes
 - Consider multiple users executing the same program





Process in Memory





Memory Layout of a C Program

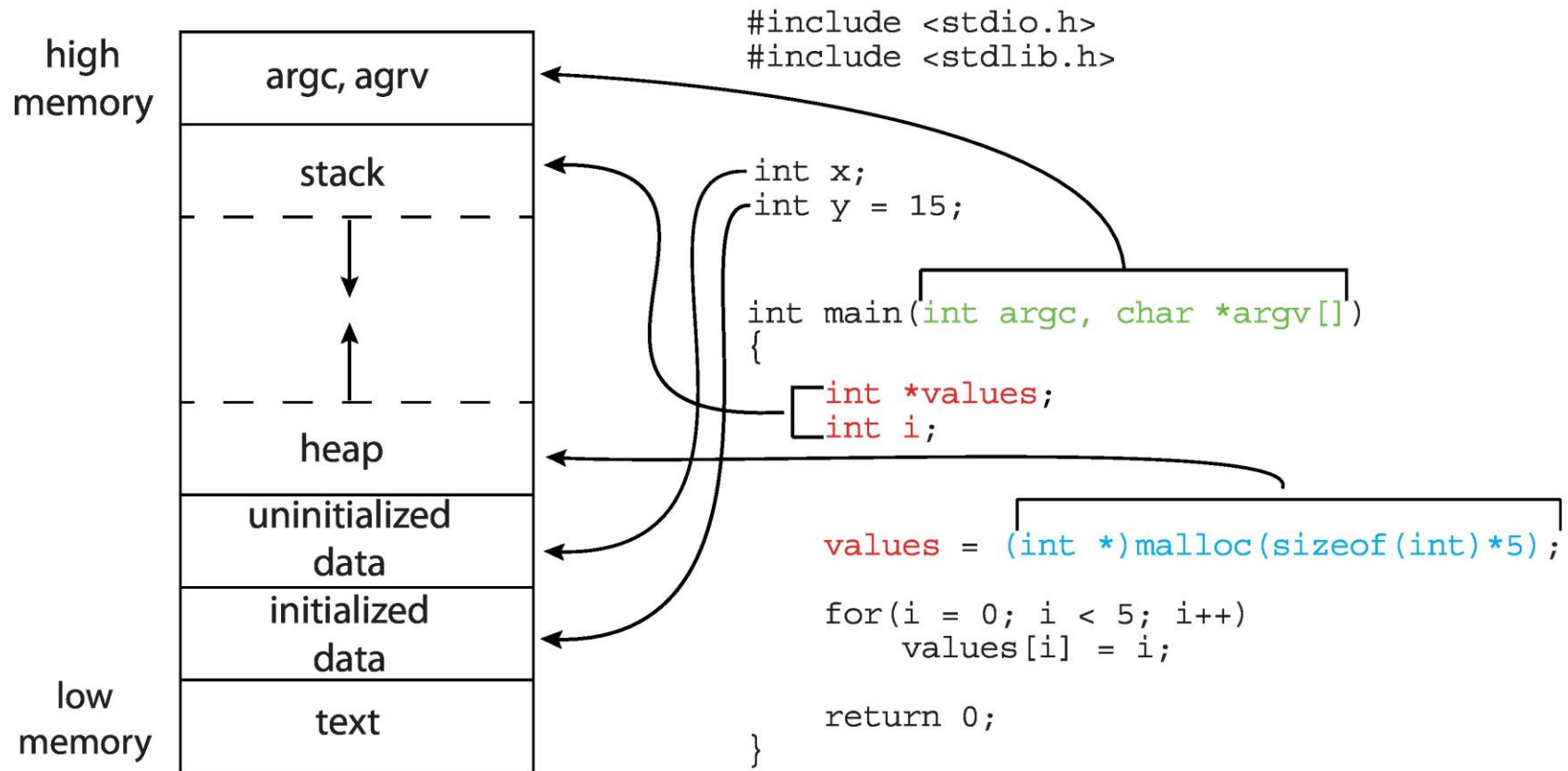
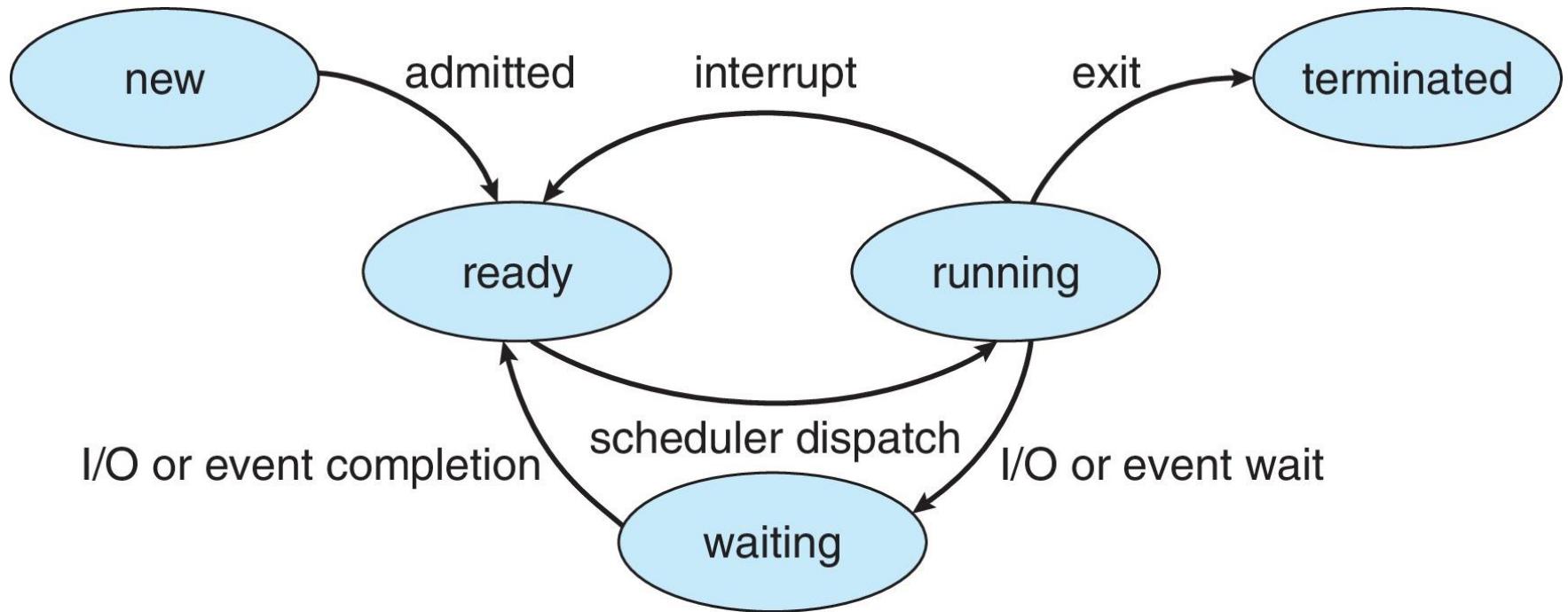




Diagram of Process State



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

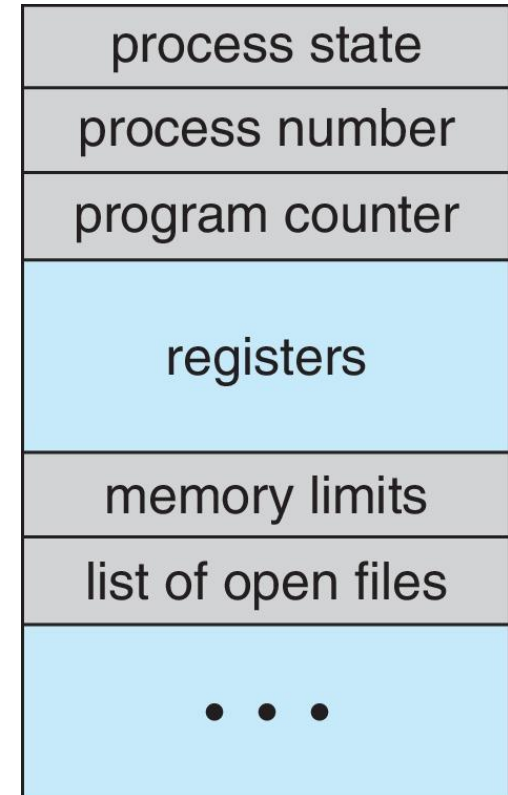




Process Control Block (PCB)

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
- **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





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
- Explore in detail in Chapter 4

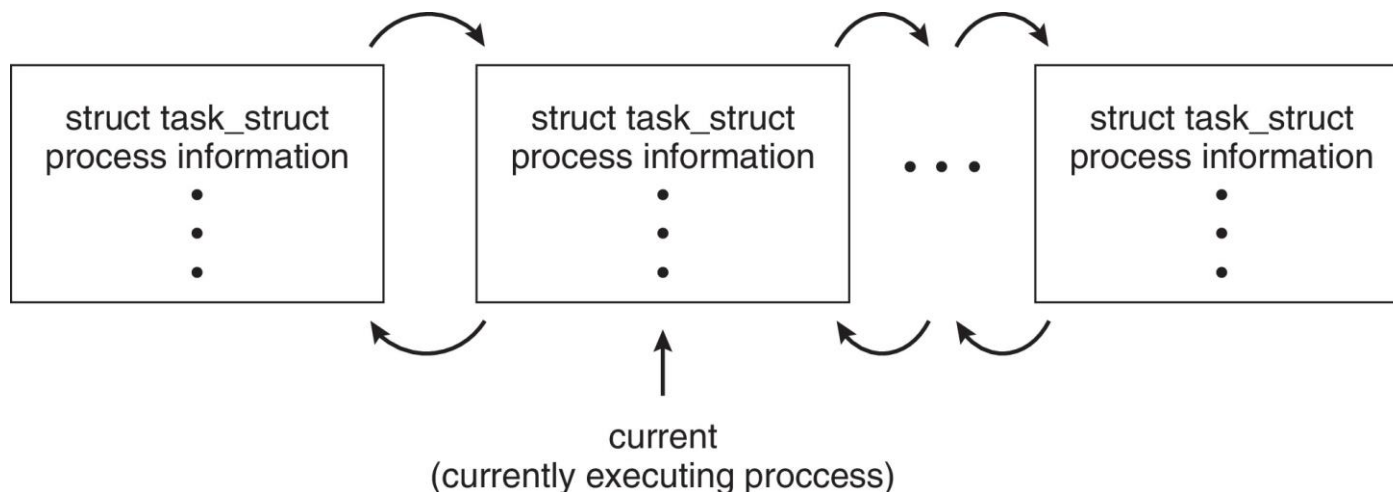




Process Representation in Linux

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 */
```





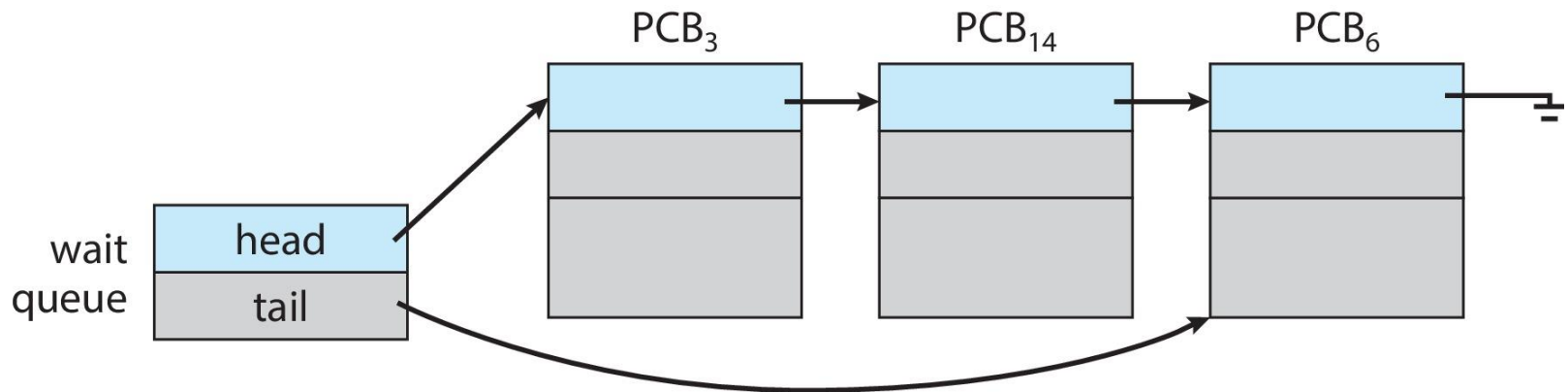
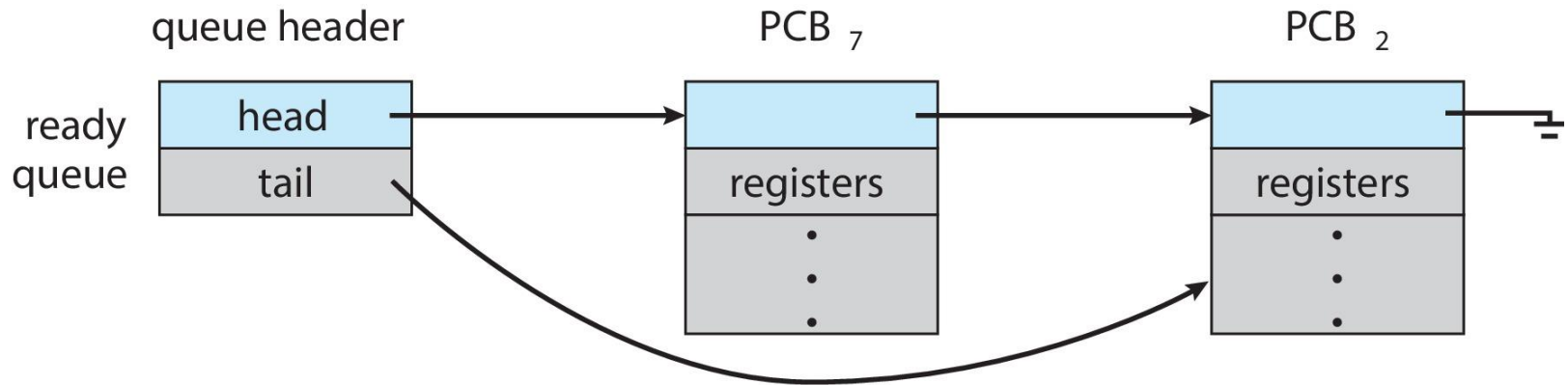
3.2 Process Scheduling

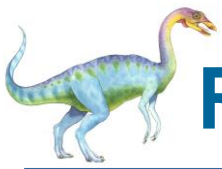
- **Process scheduler** selects among available processes for next execution on CPU core
- Goal -- Maximize CPU use, quickly switch processes onto CPU core
- Maintains **scheduling queues** of processes
 - **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
 - **Wait queues** – set of processes waiting for an event (i.e., I/O)
 - Processes migrate among the various queues



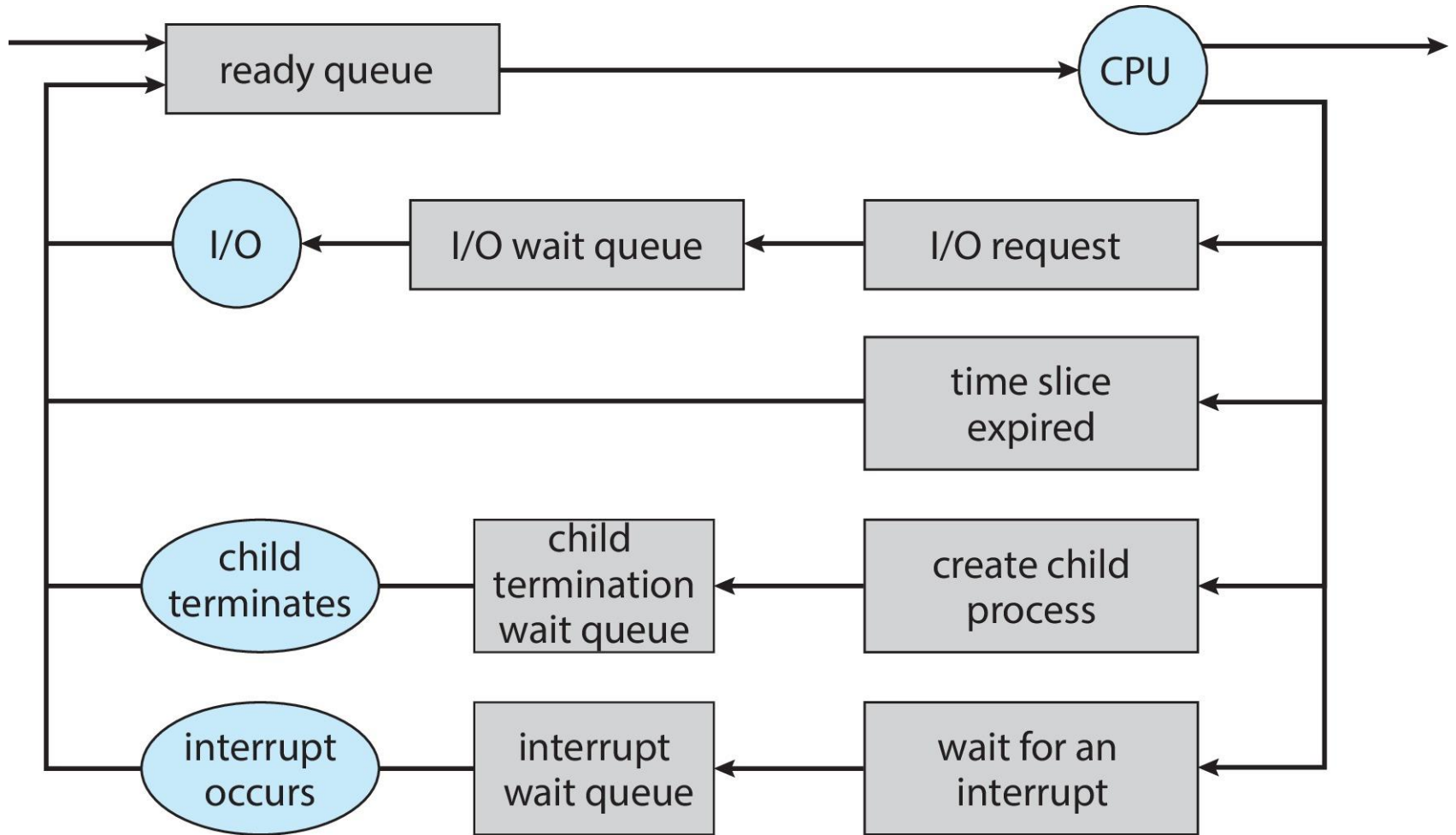


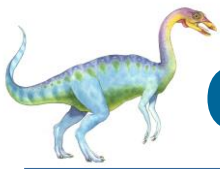
Ready and Wait Queues





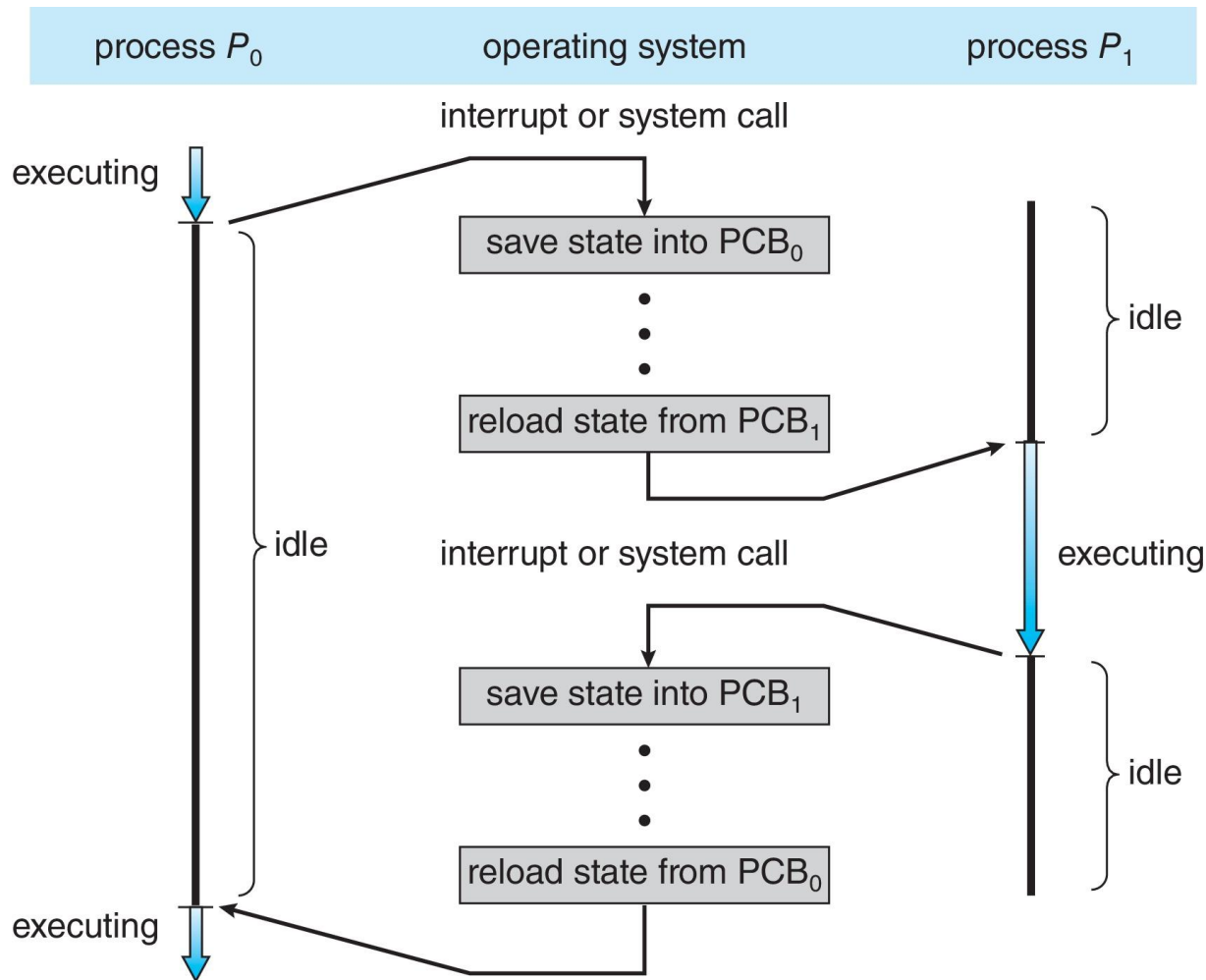
Representation of Process Scheduling





CPU Switch From Process to Process

A **context switch** occurs when the CPU switches from one process to another.





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





Multitasking in Mobile Systems

- Some mobile systems (e.g., early version of iOS) allow only one process to run, others suspended
- Due to screen real estate, user interface limits iOS provides for a
 - Single **foreground** process- controlled via user interface
 - Multiple **background** processes– in memory, running, but not on the display, and with limits
 - Limits include single, 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 even if background process is suspended
 - Service has no user interface, small memory use





3.3 Process Operations - Creation

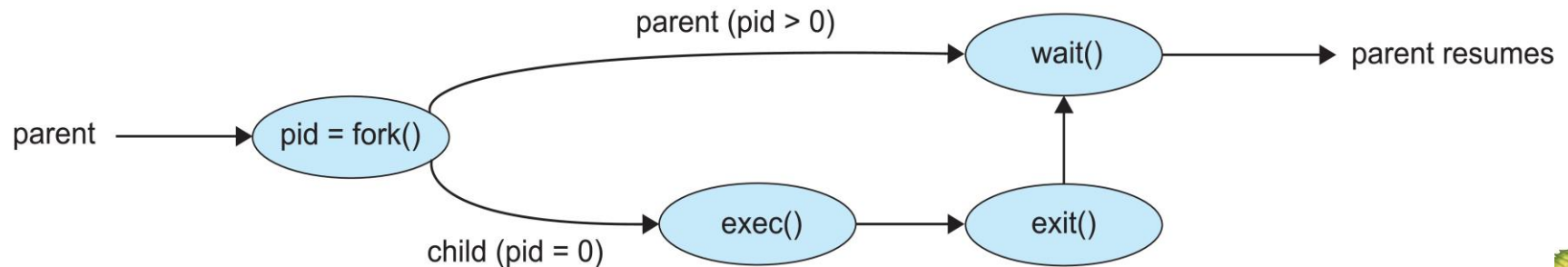
- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- Generally, process identified and managed via a **process identifier (pid)**
- Resource sharing options
 - Parent and children share all resources
 - Children share subset of parent'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





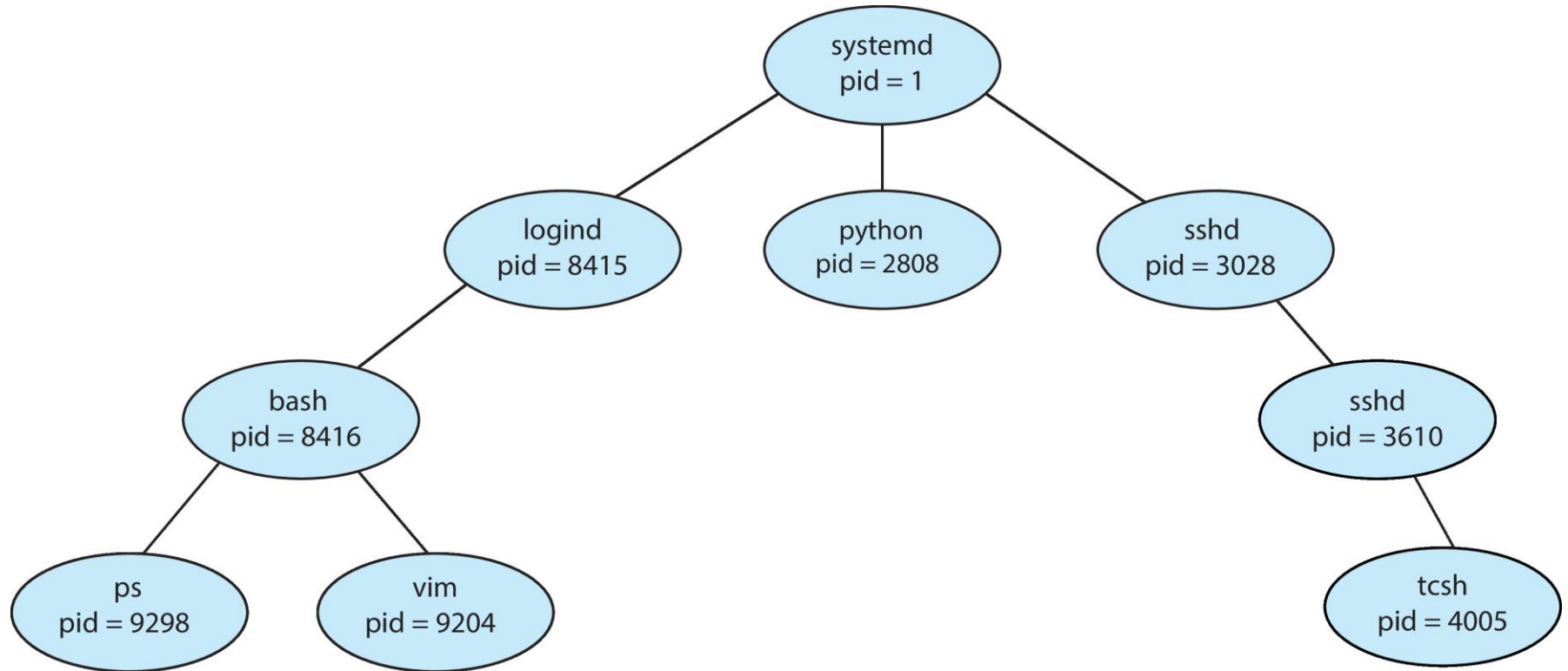
Process Creation (Cont.)

- 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
 - Parent process calls **wait ()** waiting for the child to terminate





A Tree of Processes in Linux





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;
}
```





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 Operation - Termination

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

- Parent may terminate the execution of children processes using the **abort ()** system call. Some reasons for doing so:
 - Child has exceeded allocated resources
 - Task assigned to child is no longer required
 - The parent is exiting, and the operating systems does not allow a child to continue if its parent terminates





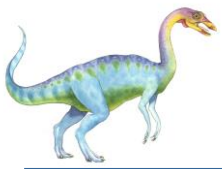
Process Termination

- Some operating systems do not allow child to exist if its parent has terminated. If a process terminates, then all its children must also be terminated.
 - **cascading termination.** All children, grandchildren, etc., are terminated.
 - The termination is initiated by the operating system.
- The parent process may wait for termination of a child process by using the **wait()** system call. The call returns status information and the pid of the terminated process

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

- If no parent waiting (did not invoke **wait()**) process is a **zombie**
- If parent terminated without invoking **wait()**, process is an **orphan**





Android Process Importance Hierarchy

- Mobile operating systems often must terminate processes to reclaim system resources such as memory. From **most** to **least** important:
 - Foreground process
 - Visible process
 - Service process
 - Background process
 - Empty process

- Android will begin terminating processes that are least important.





Practice Question

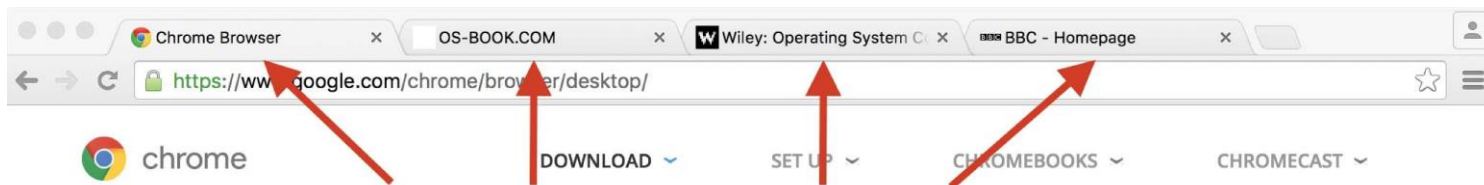
- Original versions of Apple's mobile iOS operating system provided no means of concurrent processing. Discuss three major complications that concurrent processing adds to an operating system.





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 different types of processes:
 - **Browser** process manages user interface, disk and network I/O
 - **Renderer** process renders web pages, deals with HTML, JavaScript. A new renderer created for each website opened
 - ▶ Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
 - **Plug-in** process for each type of plug-in



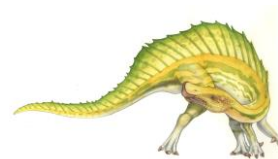
Each tab represents a separate process.





3.4 Interprocess Communication

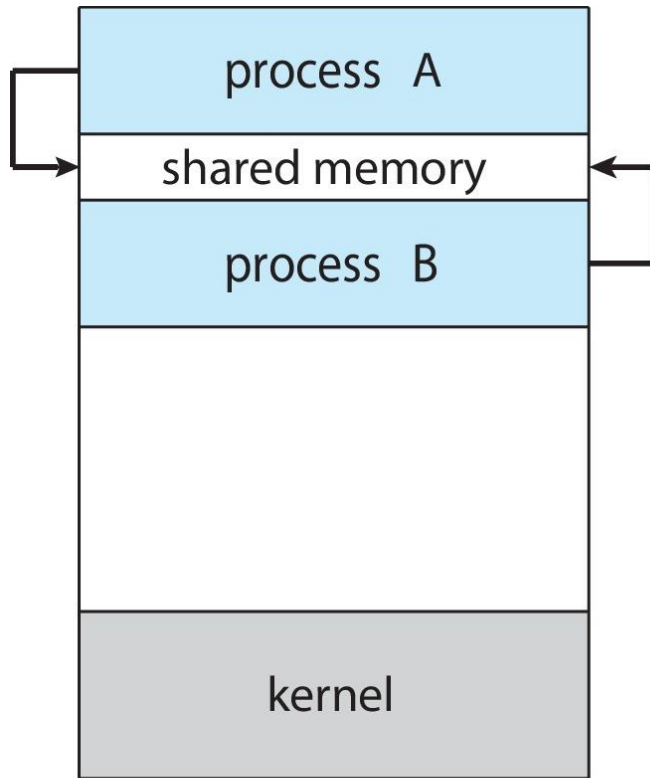
- Processes within a system may be *independent* or *cooperating*
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
 - Information sharing
 - Computation speedup
 - Modularity
 - Convenience
- Cooperating processes need **interprocess communication (IPC)**
- Two models of IPC
 - **Shared memory**
 - **Message passing**





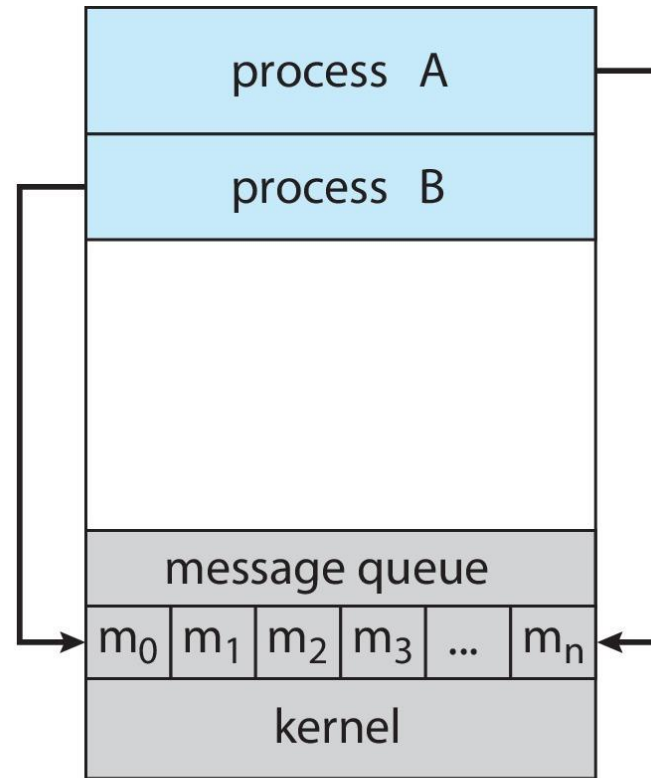
Communications Models

(a) Shared memory.



(a)

(b) Message passing.



(b)





Producer-Consumer Problem

- Paradigm for cooperating processes:
 - *producer* process produces information that is consumed by a *consumer* process
- Two variations:
 - **unbounded-buffer** places no practical limit on the size of the buffer:
 - ▶ Producer never waits
 - ▶ Consumer waits if there is no buffer to consume
 - **bounded-buffer** assumes that there is a fixed buffer size
 - ▶ Producer must wait if all buffers are full
 - ▶ Consumer waits if there is no buffer to consume





3.5 IPC – Shared Memory

- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the users processes not the operating system.
- Major issues are 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 Chapters 6 & 7.





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





Producer Process – Shared Memory

```
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;
}
```





Consumer Process – Shared Memory

```
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 */
}
```





3.6 IPC – Message Passing

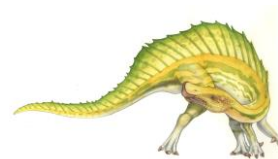
- Processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
 - **send**(*message*)
 - **receive**(*message*)
- The *message* size is either fixed or variable





Message Passing (Cont.)

- If processes P and Q wish to communicate, they need to:
 - Establish a **communication link** between them
 - Exchange messages via send/receive
- 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**?





Implementation of Communication Link

- **Physical:**
 - Shared memory
 - Hardware bus
 - Network

- **Logical:**
 - Direct or indirect
 - Synchronous or asynchronous
 - Automatic or explicit buffering





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



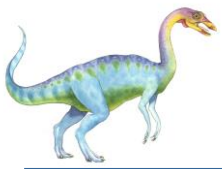


Indirect Communication (Cont.)

- Operations
 - Create a new mailbox (port)
 - Send and receive messages through mailbox
 - Delete 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 (Cont.)

- 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** -- the sender is blocked until the message is received
 - **Blocking receive** -- the receiver is blocked until a message is available
- **Non-blocking** is considered **asynchronous**
 - **Non-blocking send** -- the sender sends the message and continue
 - **Non-blocking receive** -- the receiver receives:
 - ▶ A valid message, or
 - ▶ Null message
- Different combinations possible
 - If both send and receive are blocking, we have a **rendezvous**





Producer-Consumer: Message Passing

- Producer

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

- Consumer

```
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** – no messages are queued on a link.
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





3.8 Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls

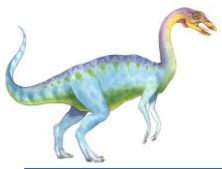




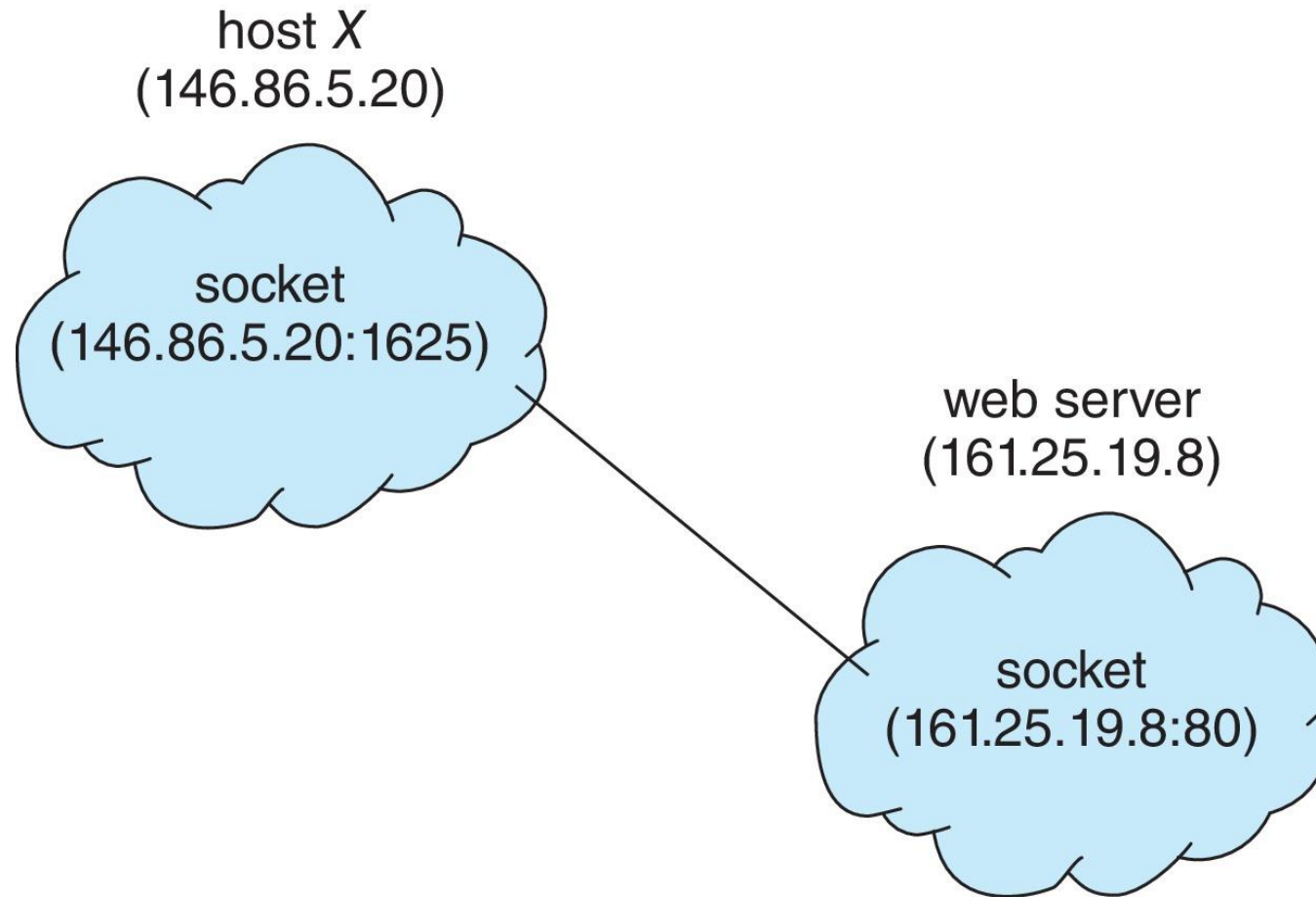
Sockets

- 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
- 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 in Java:

```
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);
        }
    }
}
```





Sockets in Java

The equivalent Date client

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

public class DateClient
{
    public static void main(String[] args) {
        try {
            /* make connection to server socket */
            Socket sock = new Socket("127.0.0.1",6013);

            InputStream in = sock.getInputStream();
            BufferedReader bin = new
                BufferedReader(new InputStreamReader(in));

            /* read the date from the socket */
            String line;
            while ( (line = bin.readLine()) != null)
                System.out.println(line);

            /* close the socket connection*/
            sock.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
- On Windows, stub code compile from specification written in **Microsoft Interface Definition Language (MIDL)**





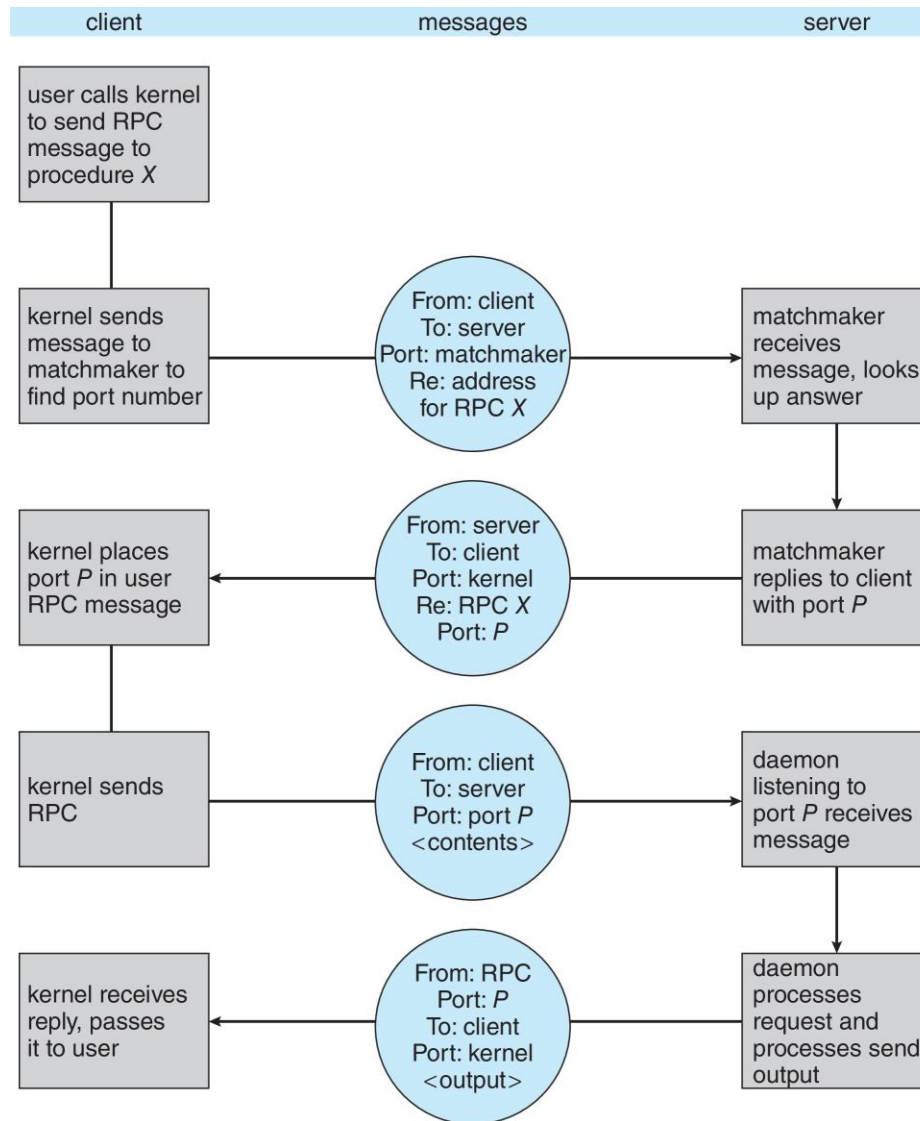
Remote Procedure Calls (Cont.)

- Data representation handled via **External Data Representation (XDL)** format to account for different architectures
 - **Big-endian** and **little-endian**
- Remote communication has more failure scenarios than local
 - Messages can be delivered ***exactly once*** rather than ***at most once***
- OS typically provides a rendezvous (or **matchmaker**) service to connect client and server





Execution of RPC





Practice Question

Determine the output in LINE A and B?

```
#include <stdio.h> LF
#include <sys/types.h> LF
#include <sys/wait.h> LF
#include <unistd.h> LF
LF
int value = 5; LF
LF
int main() LF
{ LF
    pid_t pid; LF
    LF
    pid = fork(); LF
    LF
    if (pid == 0) { /* child process */ LF
        value += 15; LF
        printf("CHILD: value = %d\n", value); /* LINE B */ LF
        return 0; LF
    } LF
    else if (pid > 0) { /* parent process */ LF
        wait(NULL); LF
        printf("PARENT: value = %d\n", value); /* LINE A */ LF
        return 0; LF
    } LF
} LF
```





Practice Question

Determine how many processes will be created including this program process?

```
#include <stdio.h>
#include <unistd.h>
int main()
{
    printf("%d*\n", getpid());
    fork();
    printf("%d**\n", getpid());
    fork();
    printf("%d***\n", getpid());
    fork();
    printf("%d****\n", getpid());
    return 0;
}
```



End of Chapter 3

