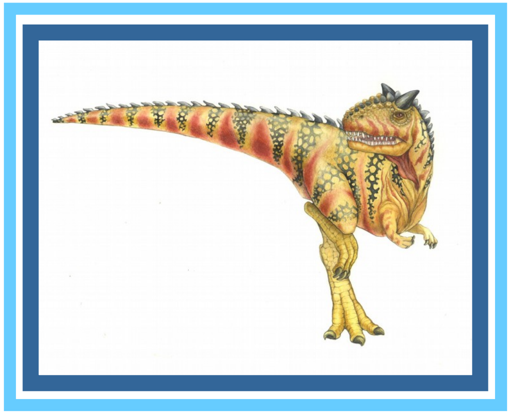
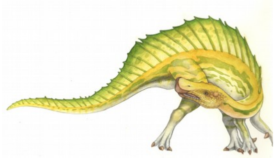
Chapter 3: Processes



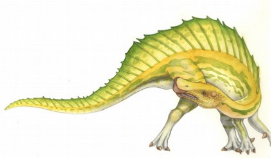
Chapter 3: Processes

- Process Concept
- Process Scheduling
- Operations on Processes
- Inter-process 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

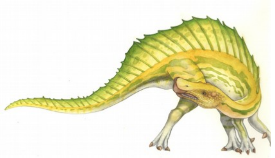


Process Concept

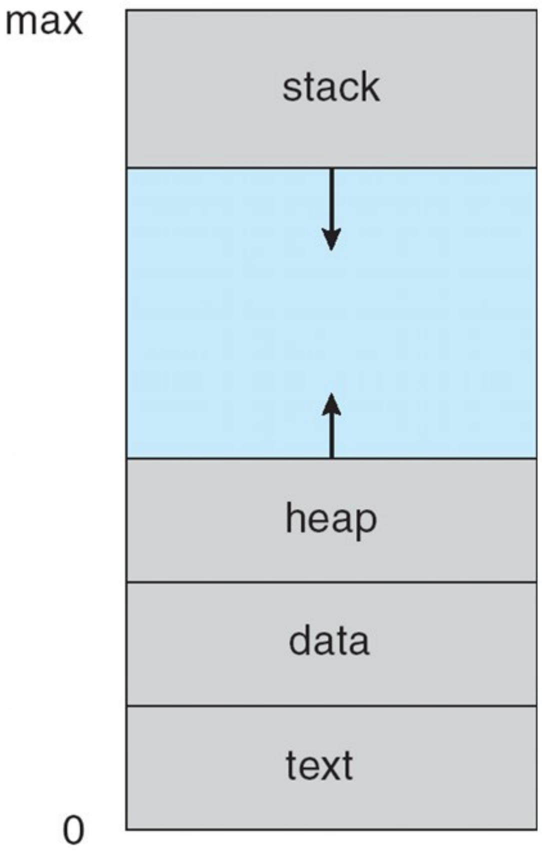
- **Process** – a program in execution; process execution must progress in sequential fashion
- Program is ***passive*** entity stored on disk (**executable file**), process is ***active***
  - Program becomes process when executable file loaded into memory
- Execution of program started via:
  - GUI mouse clicks,
  - command line entry of its name,
  - etc
- One program can be several processes
  - Consider multiple users executing the same program

Process Structure

- A process is more than the program code, which is sometimes known as the **text** section.
- It also includes the current activity:
  - The value of the **program counter**
  - The contents of the **processor's registers**.
- It also includes the process **stack**, which contains temporary data (such as function parameters, return addresses, and local variables)
- It also includes the **data section**, which contains global variables.
- It may also include a **heap**, which is memory that is dynamically allocated during process run time.

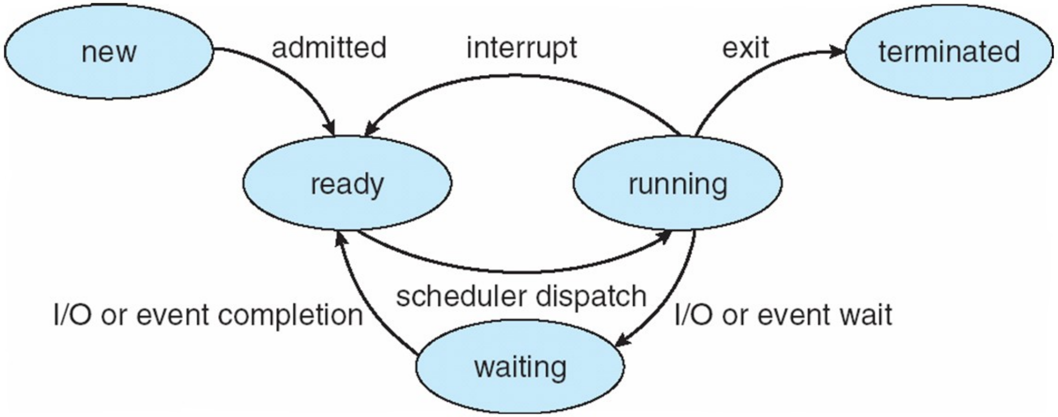


Process in Memory



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

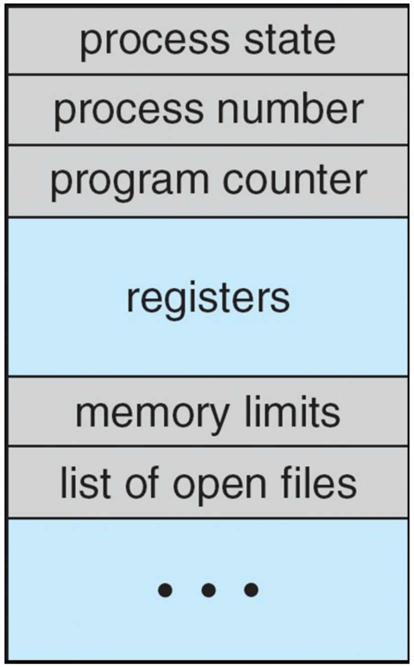


Process Control Block (PCB)

Information associated with each process

(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



process state

process number

program counter

registers

memory limits

list of open files

• • •

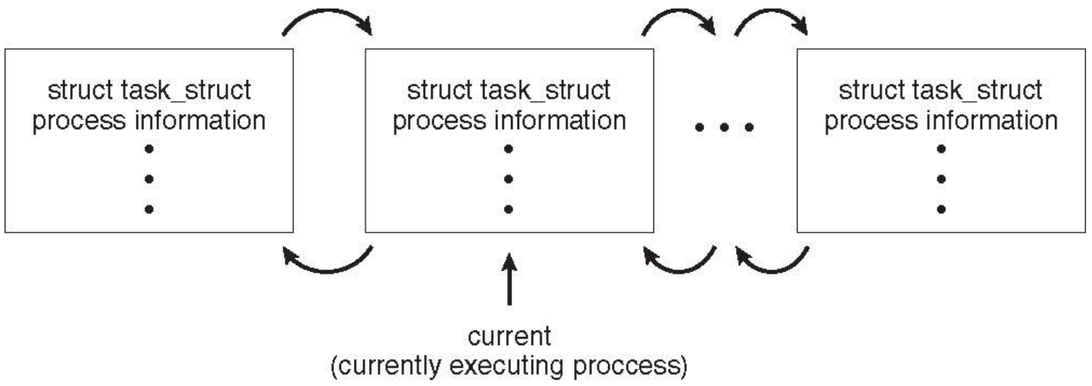
Threads

- 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**
- Need storage for thread details, multiple program counters in PCB
- Covered in the next chapter

Process Representation in Linux

Represented by the C structure `task_struct`

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



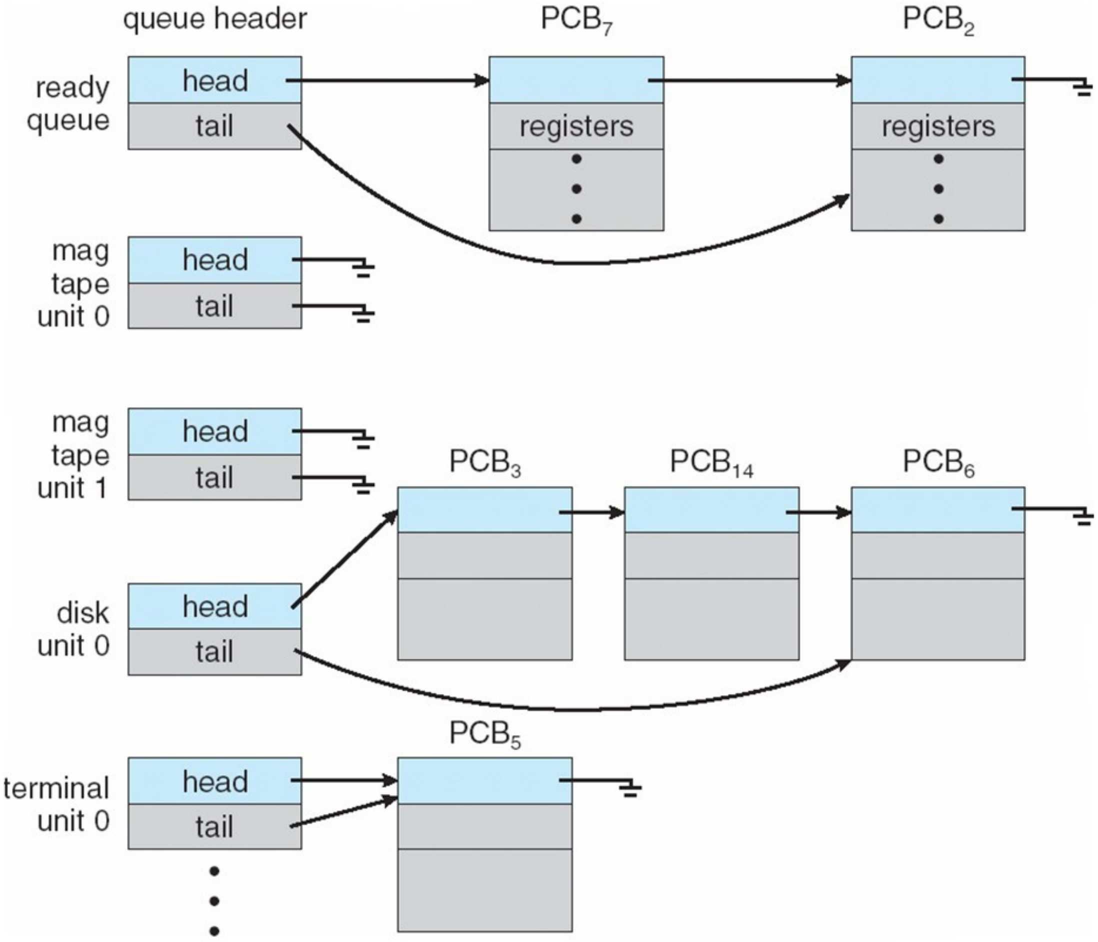
Process Scheduling

- Maximize CPU use
  - Quickly switch processes onto CPU for time sharing
- Process "gives" up then CPU under two conditions:
  - I/O request
  - After N units of time have elapsed (need a timer)
- Once a process gives up the CPU it is added to the "ready queue"
- **Process scheduler** selects among available processes in the ready queue for next execution on CPU

Scheduling Queues

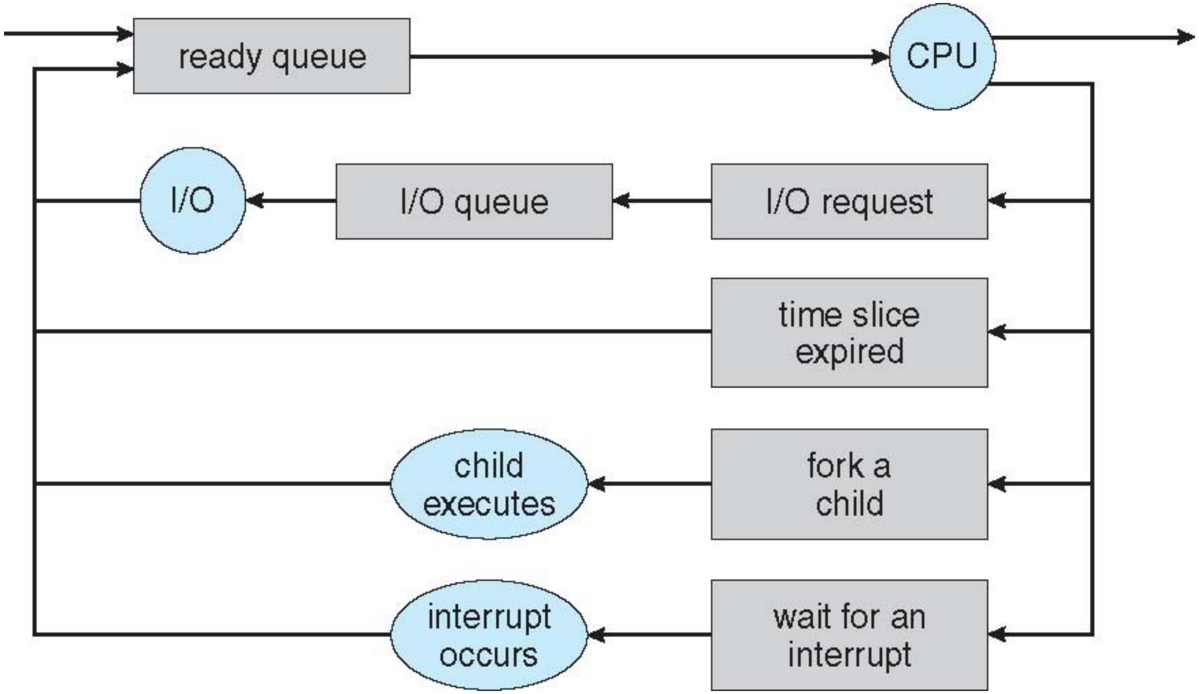
- OS Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the system
  - **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
  - **Device queues** – set of processes waiting for an I/O device
  - Processes migrate among the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

Ready Queue And Various I/O Device Queues

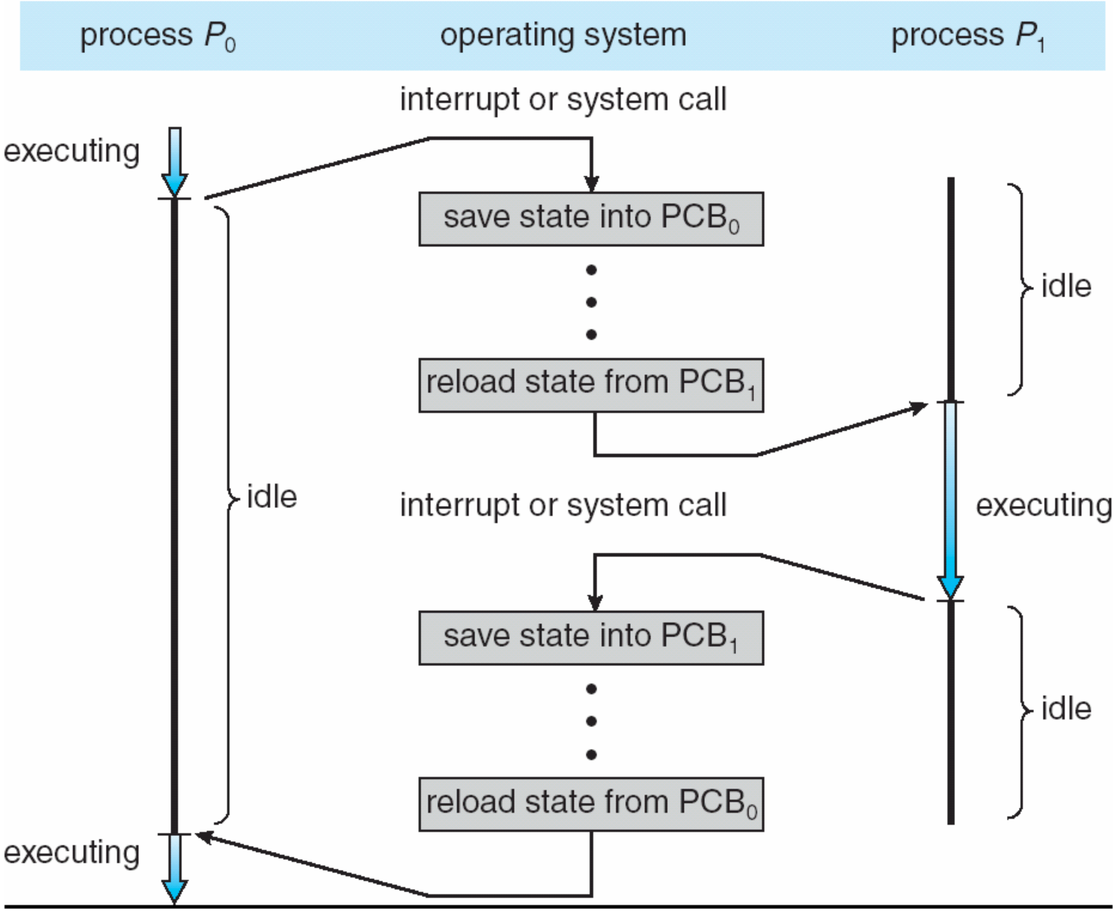


Representation of Process Scheduling

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

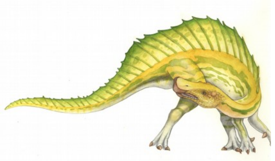


CPU Switch From Process to Process



Schedulers

- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates a CPU
  - Sometimes the only scheduler in a system
  - Short-term scheduler is invoked frequently (milliseconds) ⇒ (must be fast)
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  - Long-term scheduler is invoked infrequently (seconds, minutes) ⇒ (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
- Long-term scheduler strives for good ***process mix***

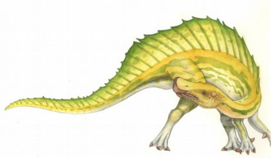


Multitasking in Mobile Systems

- Some mobile systems (e.g., early version of iOS) allow only one process to run, others suspended
- Starting with iOS 4, it 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

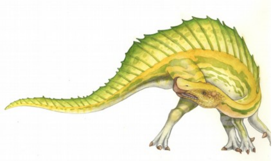
Context Switch

- 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



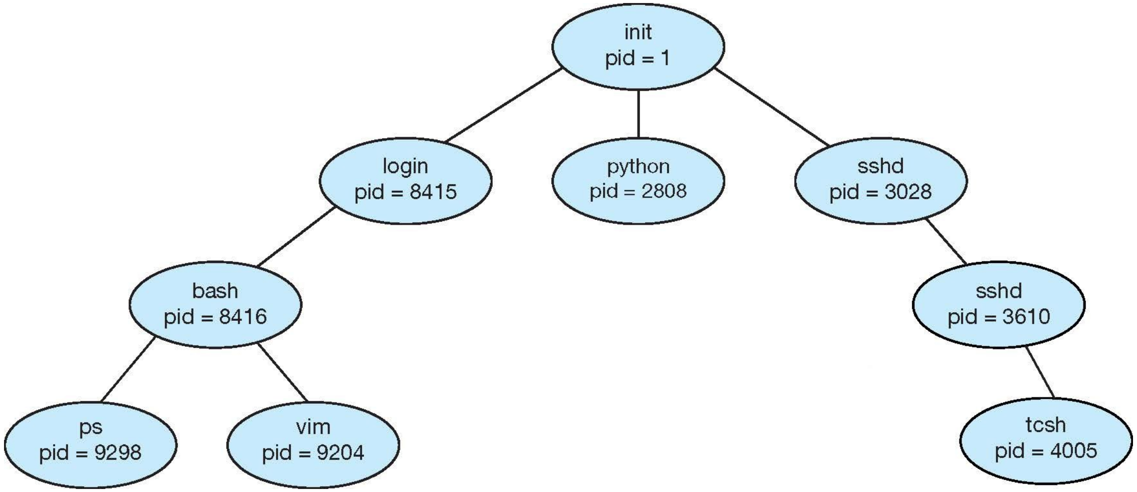
Operations on Processes

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



Process Creation

- A **process** may create other processes.
- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
- Generally, a process is identified and managed via a **process identifier** (**pid**)
- A Tree of Processes in UNIX



init
pid = 1

login
pid = 8415

python
pid = 2808

sshd
pid = 3028

bash
pid = 8416

sshd
pid = 3610

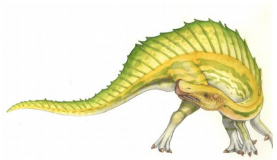
ps
pid = 9298

vim
pid = 9204

tcsh
pid = 4005

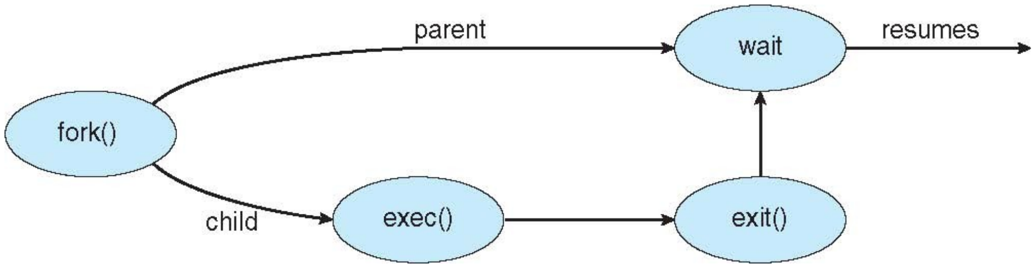
Process Creation (Cont.)

- Resource sharing among parents and children 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
  - A child is a duplicate of the parent address space.
  - A child loads a program into the address space.
- UNIX examples
  - **`fork()`** system call creates new process
  - **`exec()`** system call used after a **`fork()`** replaces the process’ memory space with a new program



C program to create a separate process in UNIX

```
int main()
{
pit.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;
}
```

C Program Forking Separate Process

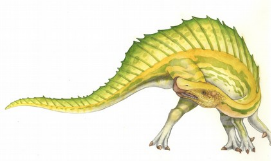
- The C program illustrates how to create a new process UNIX.
- After `fork()` there are two different processes running copies of the same program. The only difference is that the value of pid for the child process is zero, while that for the parent is an integer value greater than zero
- The child process inherits privileges and scheduling attributes from the parent, as well certain resources, such as open files.
- The child process then overlays its address space with the UNIX command “ls” (used to get a directory listing) using the execlp() (a version of the exec() system call).
- The parent waits for the child process to complete with the wait() system call.
- When the child process completes, the parent process resumes from the call to wait(), where it completes using the exit() system call.

Creating a Separate Process via Windows API

```
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 threat handle */
     FALSE, /* disable handle inheritance */
     0, /* no creation flags */
     NULL, /* use parent’s environment block */
     NULL, /* use parent’s existing directory */
     &si,
     &pi))
     {
```

Creating a Separate Process via Windows API (Cont.)

```
     {
     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

- A process terminates when it finishes executing its final statement and it asks the operating system to delete it by using the **`exit()`** system call.
  - At that point, the process may return a status value (typically an integer) to its parent process (via the wait() system call.
  - All the resources of the process are deallocated by the operating system.
- A 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 (Cont.)

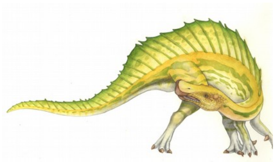
- Some operating systems do not allow a child process to exists if its parent has terminated. If a process terminates, then all its children must also be terminated.
  - **cascading termination.** All children, grandchildren, etc. are terminated.
  - The termination is initiated by the operating system.
- 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 **zombie**
- If parent terminated without invoking **`wait`**, process is **orphan**

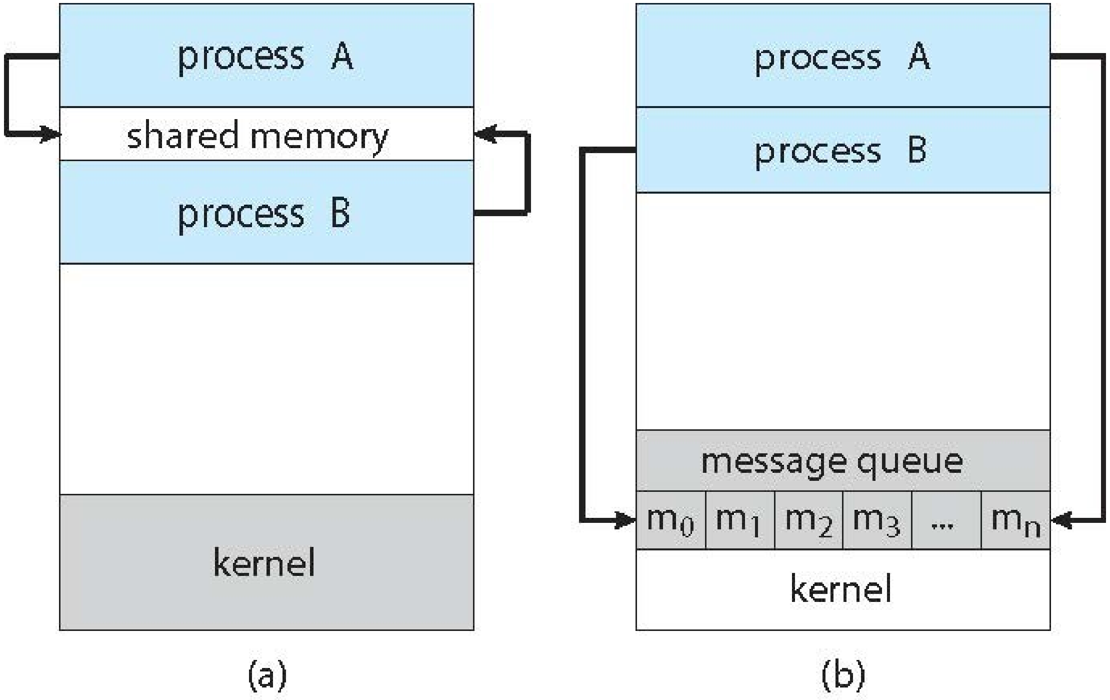
Interprocess Communication

- Processes within a system may be ***independent*** or ***cooperating***
  - Cooperating processes can affect or be affected by other processes, including sharing data
  - Independent processes cannot affect other processes
- Reasons for having cooperating processes:
  - Information sharing
  - Computation speedup (multiple processes running in parallel)
  - Modularity
  - Convenience
- Cooperating processes need **interposes communication** (**IPC**)



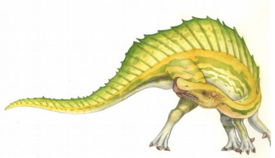
Communications Models

- Two models of IPC
  - **Shared memory**
  - **Message passing**



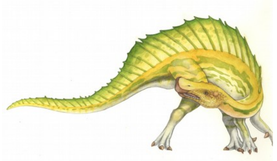
Shared Memory Systems

- 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 is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.



Synchronization

- Cooperating processes that access shared data need to synchronize their actions to ensure data consistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Illustration of the problem – The producer-Consumer problem
  - Producer process produces information that is consumed by a Consumer process.
  - The information is passed from the Producer to the Consumer via a buffer.
  - Two types of buffers can be used:
    - **unbounded-buffer** places no practical limit on the size of the buffer
    - **bounded-buffer** assumes that a fixed buffer size

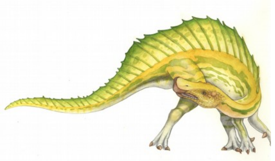


Bounded-Buffer Solution

- Shared data

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

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

- Solution presented in the next two slides is correct, but only 9 out of 10 buffer elements can be used

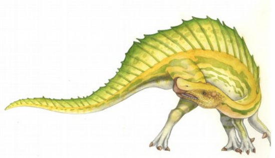


Bounded-Buffer – Producer

```
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;
}
```

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 */
}
```



Message Passing Systems

- Mechanism for processes to communicate and to synchronize their actions
  - 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.)

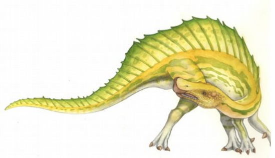
- If processes *P* and *Q* wish to communicate, they need to:
  - Establish a ***communication link*** between them
  - Exchange messages via send/receive
- Implementation issues:
  - How are links established?
  - Can a link be associated with more than two processes?
  - How many links can there be 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

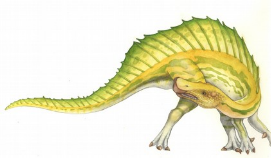
Direct Communication

- 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



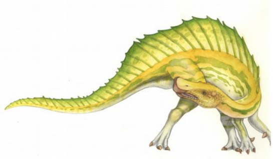
Indirect Communication

- 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
- 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



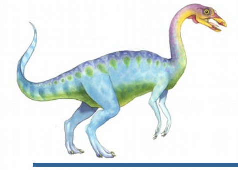
Indirect Communication (Cont.)

- 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



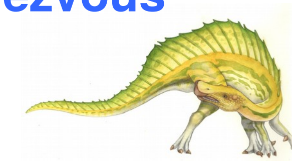
Indirect Communication Issues

- 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.



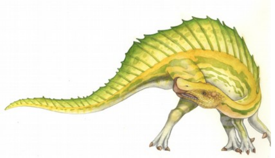
Blocking and Non-blocking schemes

- 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**



Buffering

- Whether communication is direct or indirect, messages exchanged by communicating processes reside in a temporary queue.
- Such queues can be implemented in 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

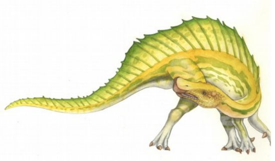


Producer-Consumer with Rendezvous

- Producer-consumer synchronization becomes trivial with rendezvous (blocking send and receive)

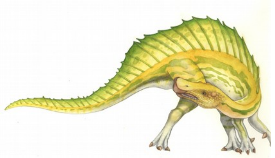
```
message next_produced;
while (true) {
      /* produce an item in next produced */
send(next_produced);
}
```

```
message next_consumed;
while (true) {
   receive(next_consumed);

   /* consume the item in next consumed */
}
```



Example of IPC Systems

- There are four different IPC systems.
  - POSIX API for shared memory
  - Mach operating system, which uses message passing
  - Windows IPC, which uses shared memory as a mechanism for providing certain types of message passing.
  - Pipes, one of the earliest IPC mechanisms on UNIX systems.



POSIX

- POSIX

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

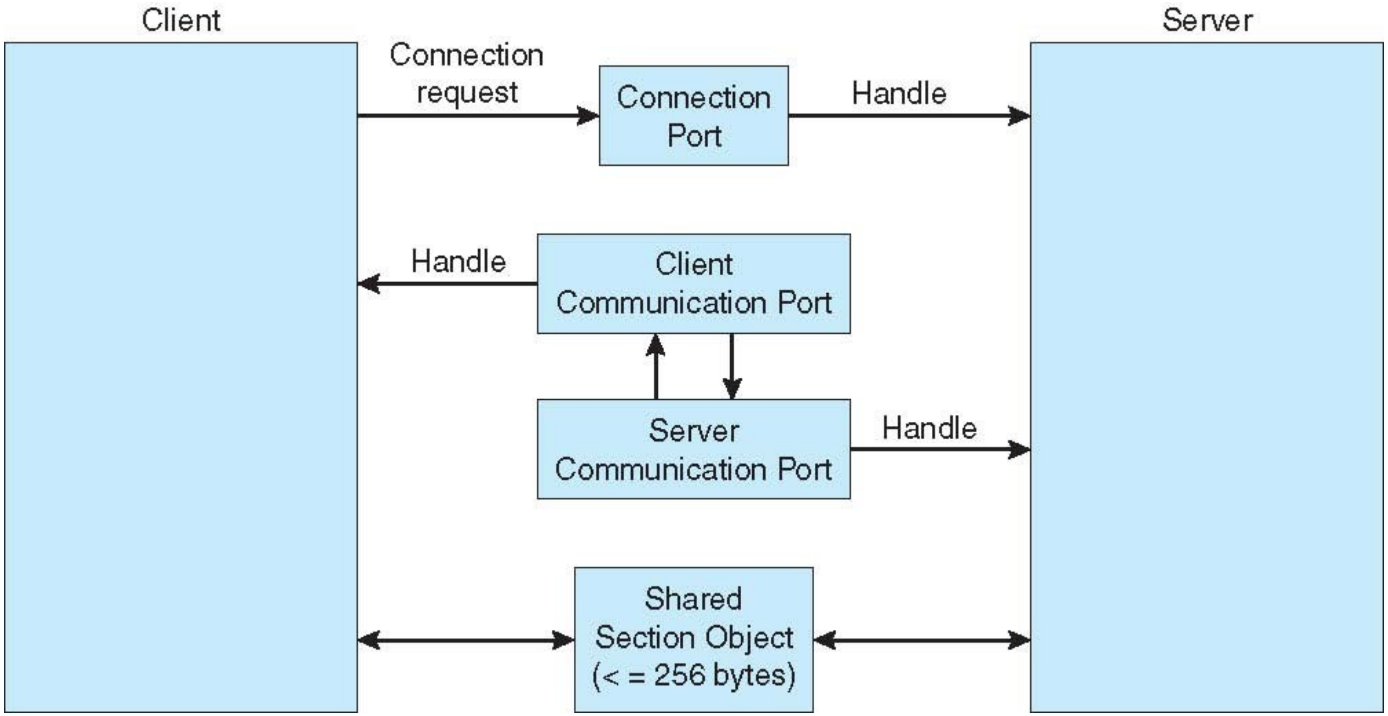
    `msg_send(), msg_receive(), msg_rpc()`
  - Mailboxes needed for commuication, created via

    `port_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

Windows

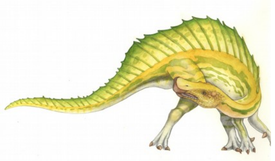
- Message-passing centric via **advanced local procedure call (LPC)** facility
  - Only works between processes on the same system
  - Uses ports (like mailboxes) to establish and maintain communication channels
  - Communication works as follows:
    - The client opens a handle (an abstract reference to a resource) to the subsystem's **connection port** object.
    - The client sends a connection request.
    - The server creates a private **communication port** and returns the handle to the client.
    - The client and server use the corresponding port handle to send messages or callbacks and to listen for replies.

Local Procedure Calls in Windows


Client
Server
Connection request
Connection Port
Handle
Handle
Client Communication Port
Server Communication Port
Handle
Shared Section Object (< = 256 bytes)

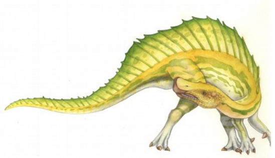
Pipes

- Acts as a conduit allowing two processes to communicate
- Issues:
  - Is communication unidirectional or bidirectional?
  - In the case of two-way communication, is it half or full-duplex?
  - Must there exist a relationship (i.e., ***parent-child***) between the communicating processes?
  - Can the pipes be used over a network?
- Ordinary pipes – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
- Named pipes – can be accessed without a parent-child relationship.



Ordinary Pipes

- Ordinary Pipes allow two process to 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 unidirectional, allowing only one-way communication.
- If two-way communication is required, two pipes must be used, with each pipe sending data in a different direction.
- Require parent-child relationship between communicating processes



Ordinary Pipes

- On UNIX systems, ordinary pipes are constructed using the function

  pipe (int fd[])

- This function creates a pipe that is accessed through the

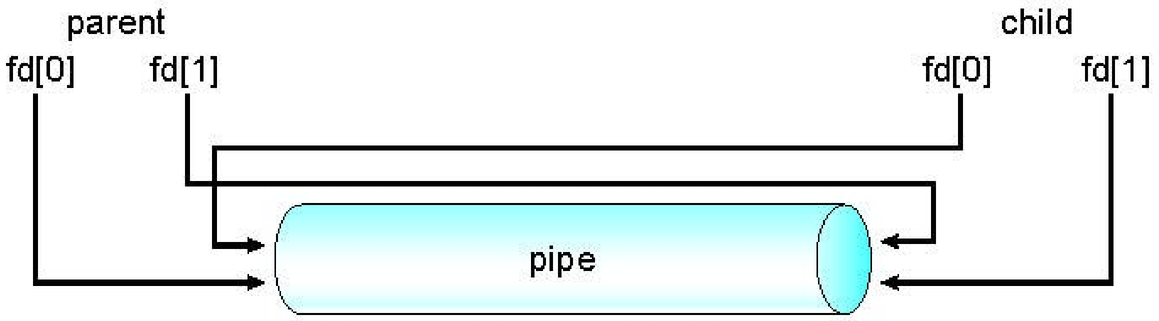
  int fd[]

  file descriptors:

  fd[0] is the read-end of the pipe

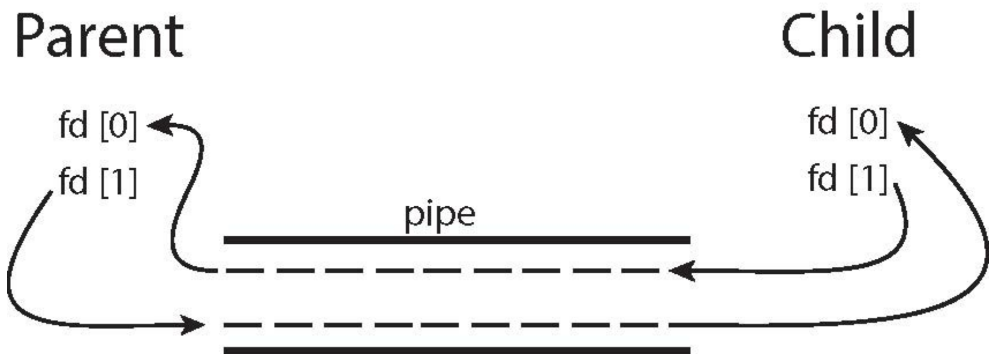
  fd[1]} is the write-end of the pipe

- UNIX treats a pipe as a special type of file. Thus, pipes can be accessed using ordinary read() and write() system calls.



- Window
- See Un

Figure Pipe



Named Pipes

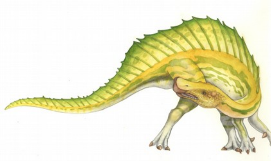
- Named Pipes are more powerful than ordinary pipes
- Communication is bidirectional
- No parent-child relationship is necessary between the communicating processes
- Several processes can use the named pipe for communication
- Provided on both UNIX and Windows systems

Communications in Client-Server Systems

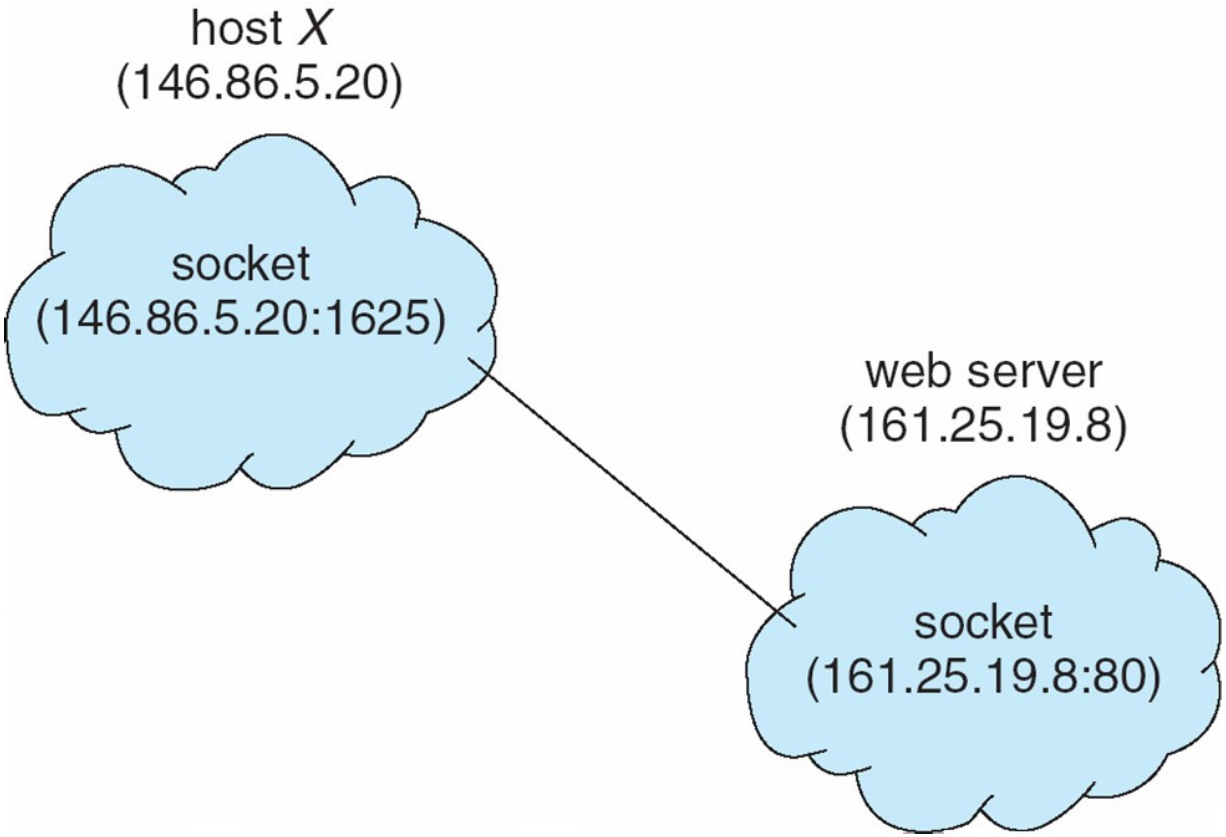
- Sockets
- Remote Procedure Calls
- Remote Method Invocation (Java)

Sockets

- A **socket** is defined as an endpoint for communication
- Concatenation of IP address and **port** – 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**) is used to refer to system on which process is running. That is, when a computer refers to address 127.0.0.1, it is referring to itself.

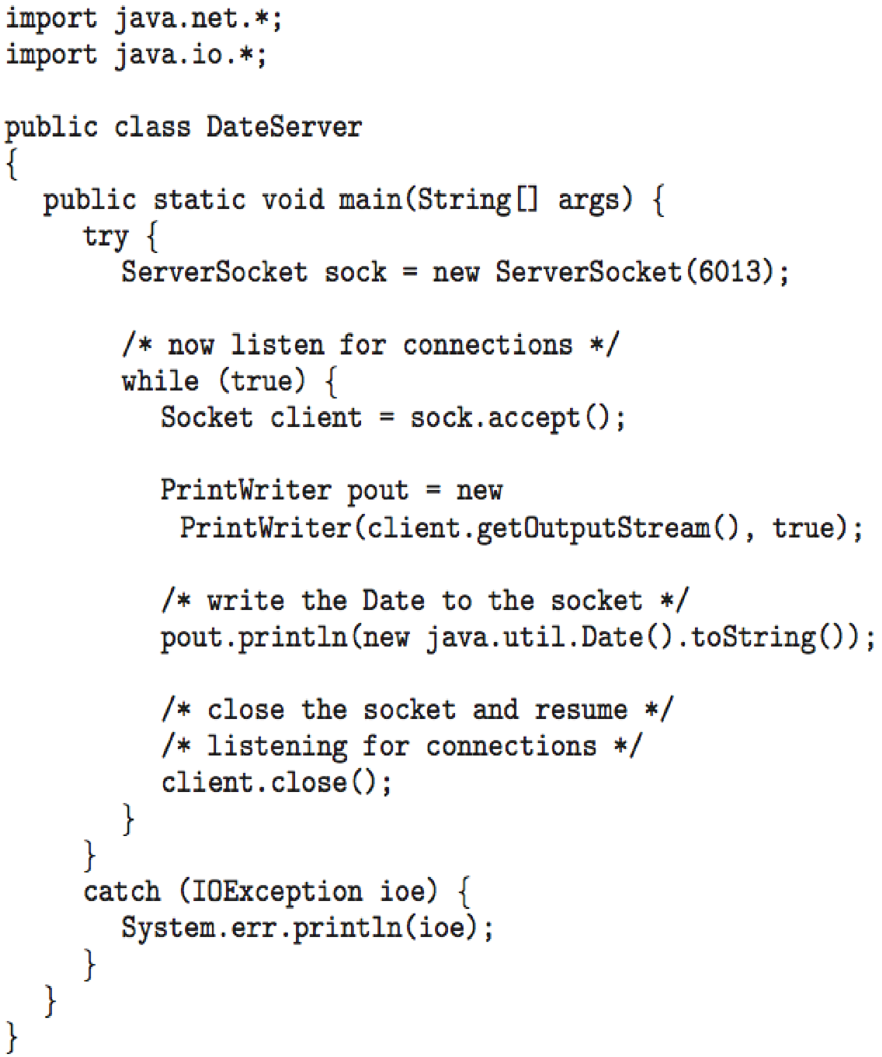


Socket Communication



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);
      }
   }
}
```

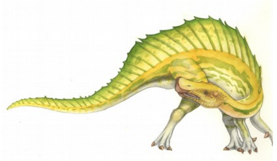
Remote Procedure Calls

- 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 (marshalling involves packaging the parameters into a form that can be transmitted over a network).
- 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**)

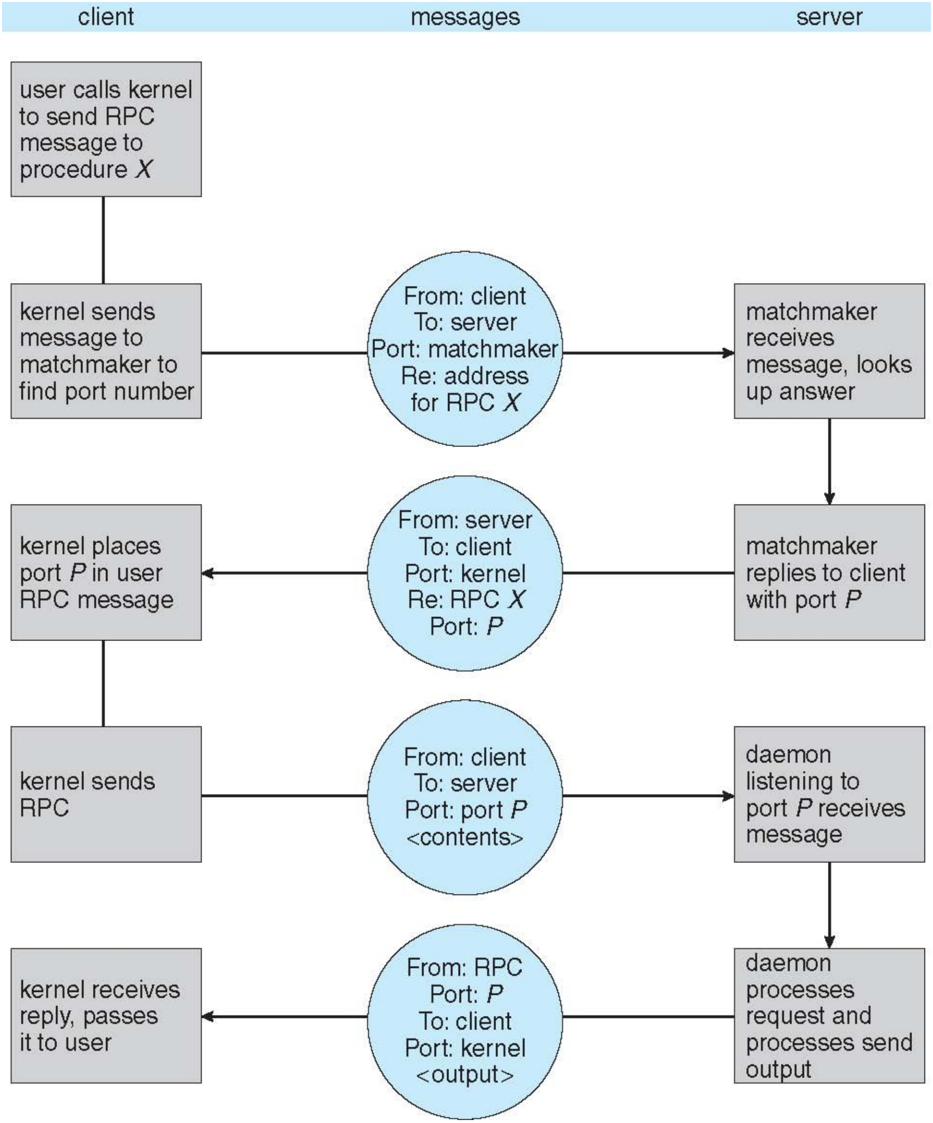
Remote Procedure Calls (Cont.)

- Data representation handled via **External Data Representation** (**XDL**) format to account for different architectures.
- Must be dealt with concerns differences in data representation on the client and server machines.
- Consider the representation of 32-bit integers.
  - **Big-endian.** Store the most significant byte first
  - **Little-endian.** Store the least significant byte first.

  Big-endian is the most common format in data networking . It is also referred to as **network byte order**.
- 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



client

messages

server

user calls kernel to send RPC message to procedure *X*

kernel sends message to matchmaker to find port number

From: client
To: server
Port: matchmaker
Re: address for RPC *X*

matchmaker receives message, looks up answer

matchmaker replies to client with port *P*

From: server
To: client
Port: kernel
Re: RPC *X*
Port: *P*

kernel places port *P* in user RPC message

kernel sends RPC

From: client
To: server
Port: port *P*
<contents>

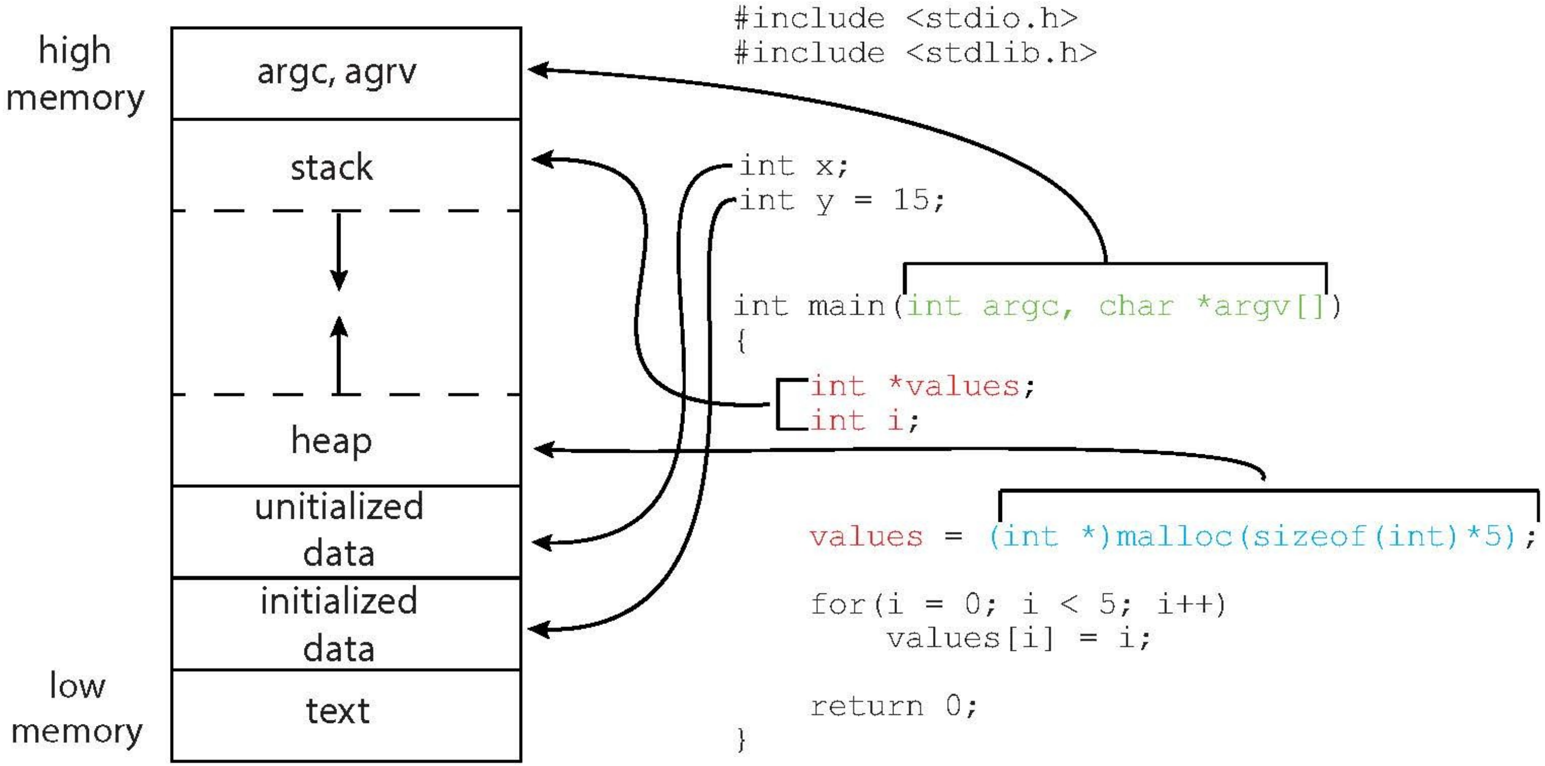
daemon listening to port *P* receives message

daemon processes request and processes send output

From: RPC
Port: *P*
To: client
Port: kernel
<output>

kernel receives reply, passes it to user

Memory Layout



high memory

argc, agrv

stack

heap

unitialized data

initialized data

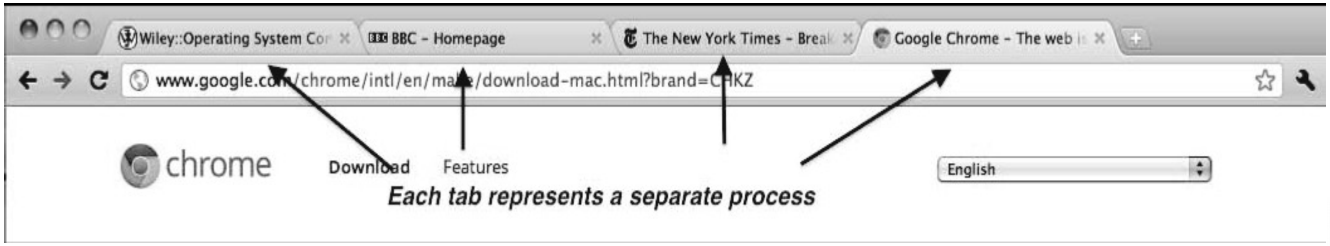
text

low memory

```
#include <stdio.h>
#include <stdlib.h>

int x;
int y = 15;

int main(int argc, char *argv[])
{
    int *values;
    int i;

    values = (int *)malloc(sizeof(int)*5);

    for(i = 0; i < 5; i++)
        values[i] = i;

    return 0;
}
```

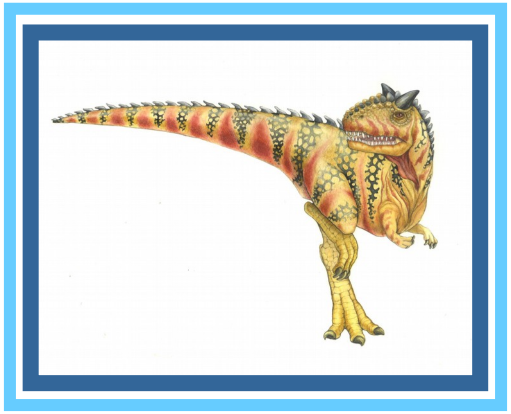
Multiprocess Architecture – Chrome Browser

- 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


Wiley::Operating System Co
BBC – Homepage
The New York Times – Break
Google Chrome – The web i
www.google.com/chrome/intl/en/make/download-mac.html?brand=CHKZ
chrome
Download
Features
English

Each tab represents a separate process

End of Chapter 3



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; 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

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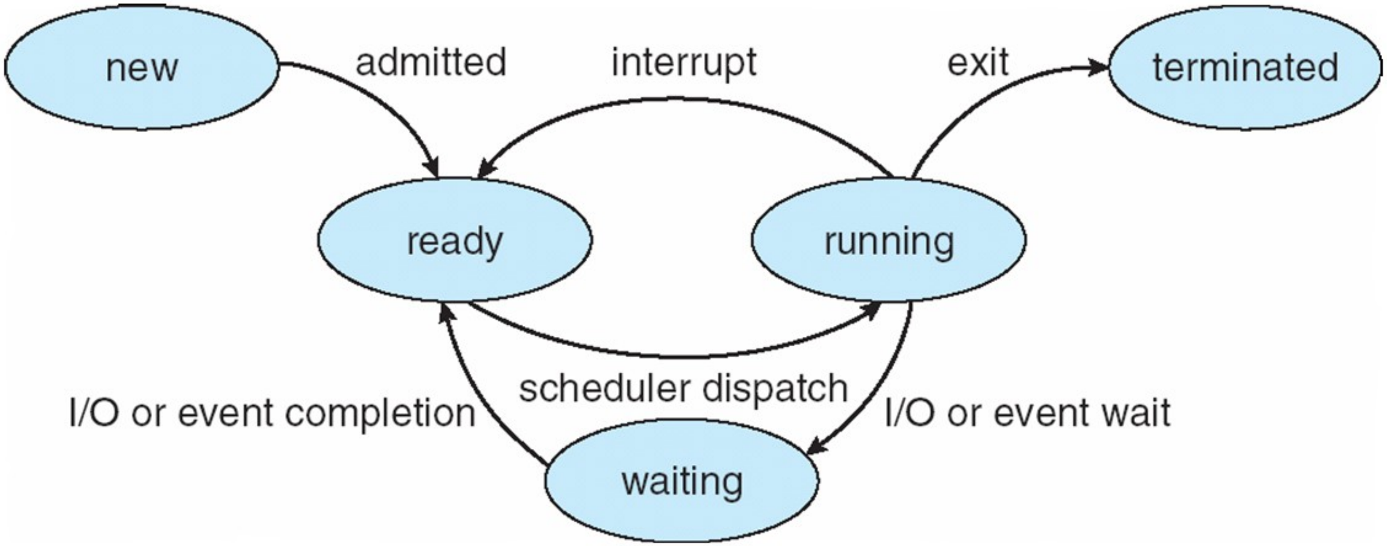
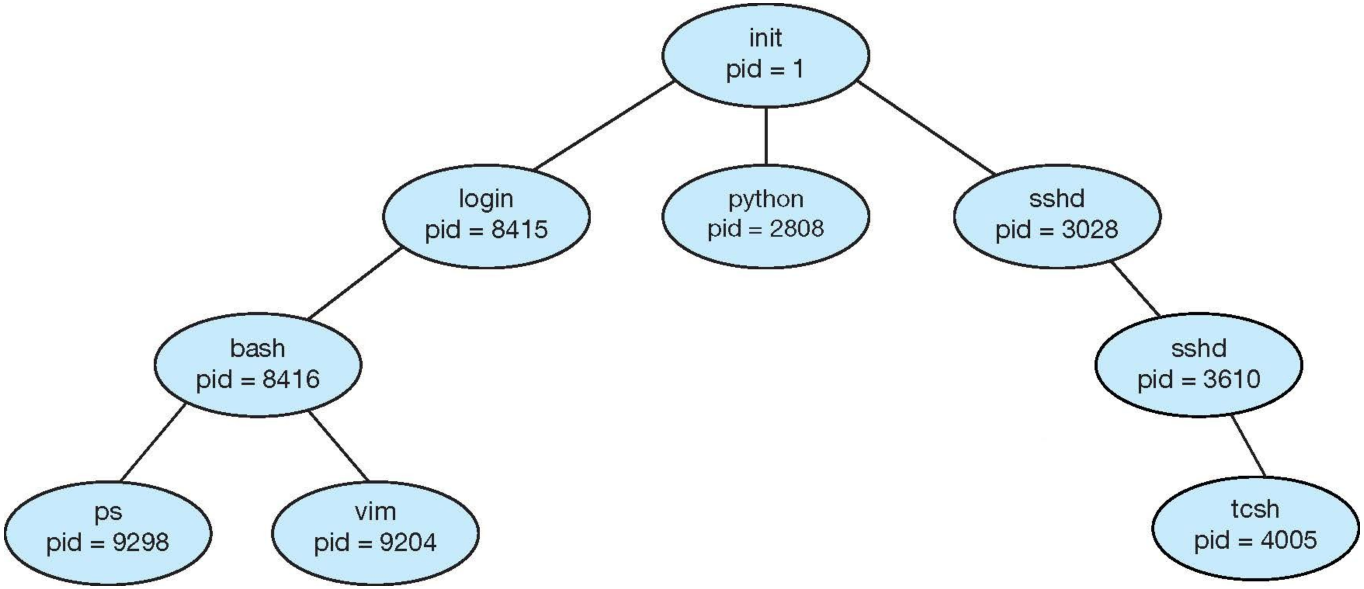
Diagram of Process State

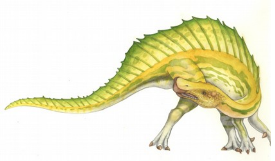


A Tree of Processes in UNIX



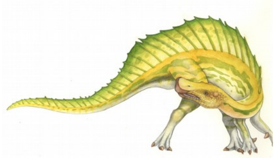
Synchronization

- Cooperating process must synchronize their actions
- To illustrate the concept of cooperating processes, we will consider the producer-consumer problem, which is a common paradigm for cooperating processes.
- A producer process produces information that is consumed by a consumer process.
- For example, a compiler may produce assembly code that is consumed by an assembler. The assembler, in turn, may produce object modules that are consumed by the loader.
- The producer-consumer problem also provides a useful metaphor for the client-server paradigm. We generally think of a server as a producer and a client as a consumer. For example, a web server produces (that is, provides) web content such as HTML files and images, which are consumed (that is, read) by the client web browser requesting the resource.



Synchronization

- Cooperating processes Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Illustration of the problem – The producer-Consumer problem
  - Producer process produces information that is consumed by a Consumer process.
  - The information is passed from the Producer to the Consumer via a buffer.
  - Two types of buffers can be used:
    - **unbounded-buffer** places no practical limit on the size of the buffer
    - **bounded-buffer** assumes that a fixed buffer size



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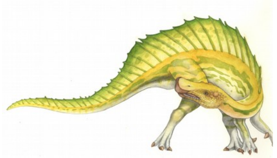

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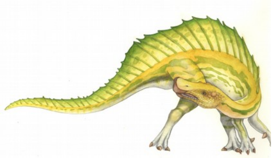


Bounded-Buffer Solution – Shared Memory

- Shared data

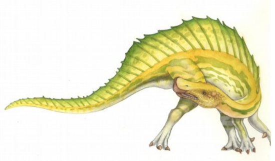
```
#define BUFFER_SIZE 10
typedef struct {
  . . .
} item;

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

- Solution presented in the next two slides is correct, but only 9 out of 10 buffer elements can be used

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;
}
```



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 */
}
```

Producer-Consumer with Rendezvous

- Producer-consumer synchronization becomes trivial with rendezvous (blocking send and receive)

```
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 */
}
```

Examples of IPC Systems - Mach

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  - 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()`
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    - Wait indefinitely
    - Wait at most *n* milliseconds
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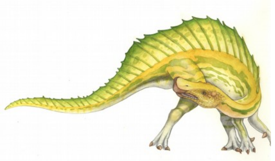
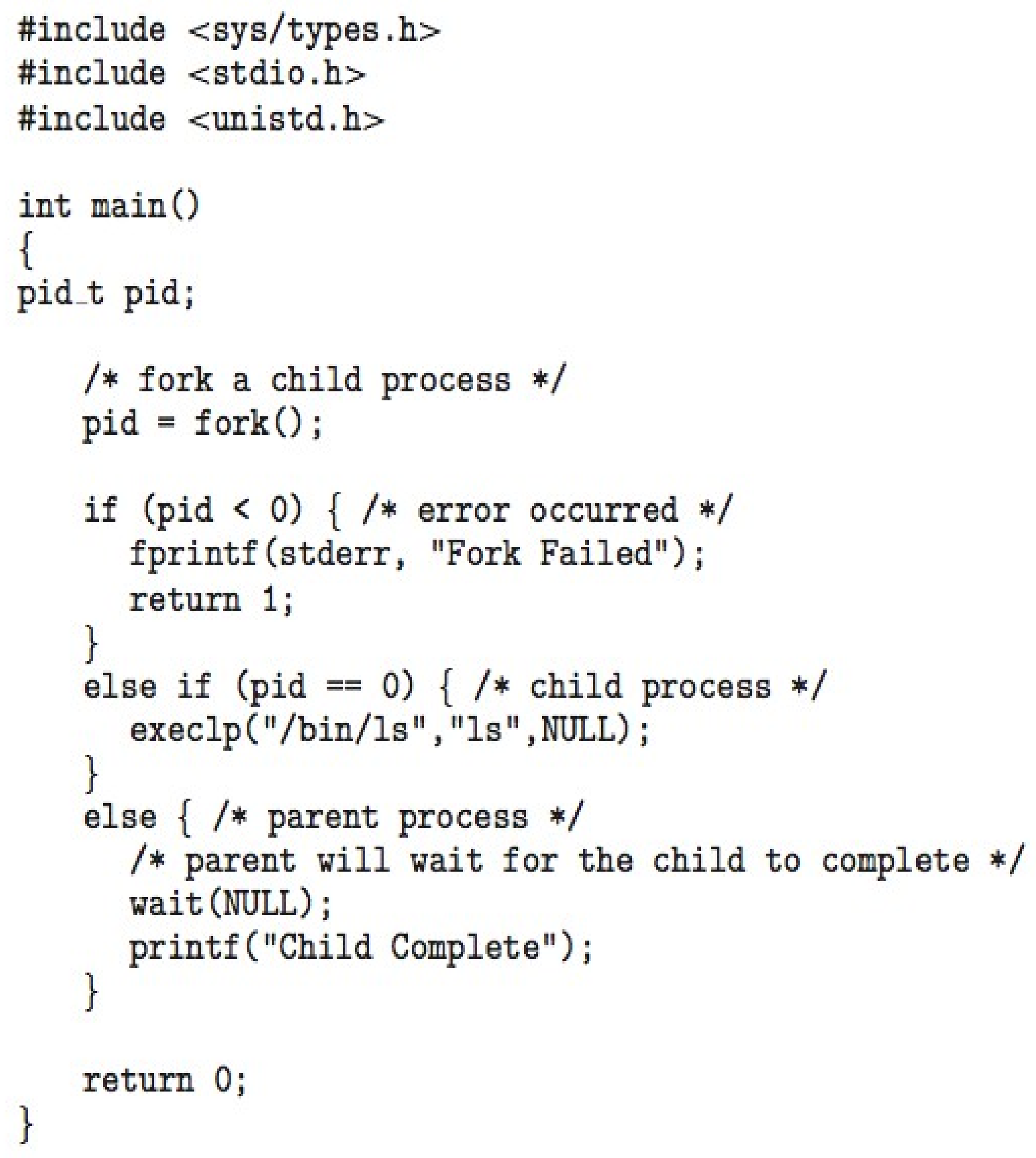
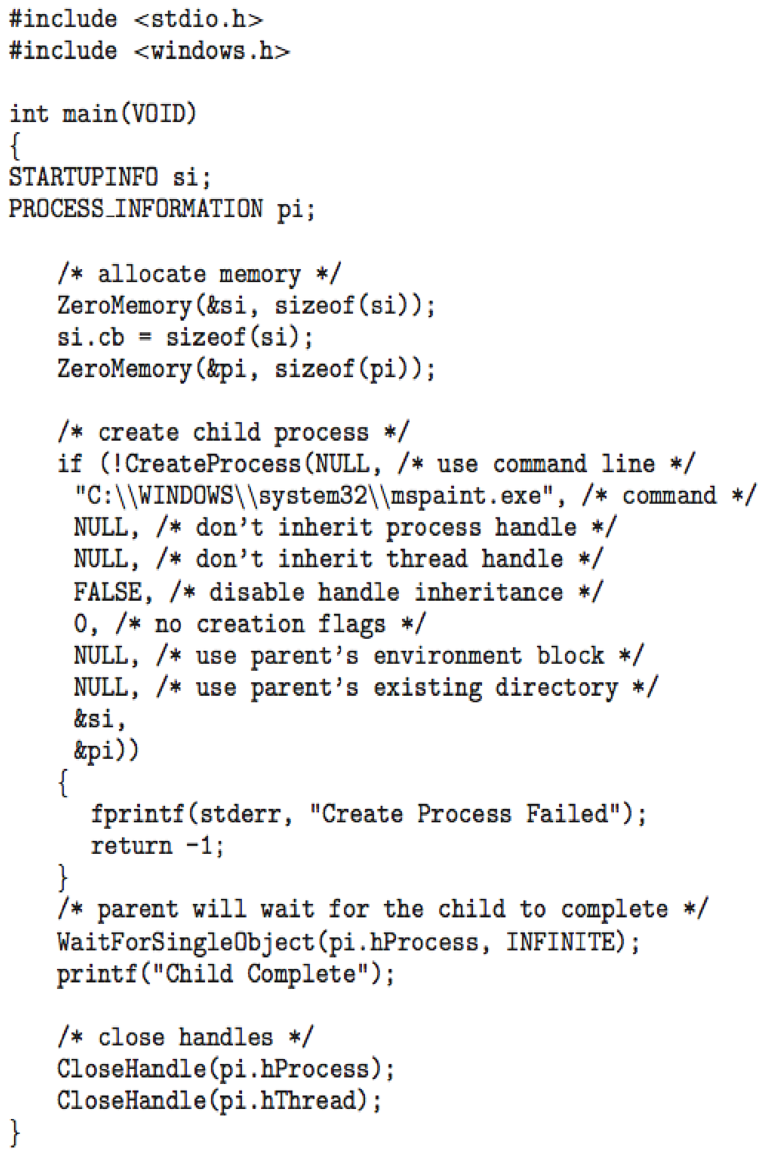


C program to create a separate process in UNIX



```
#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);
}
```