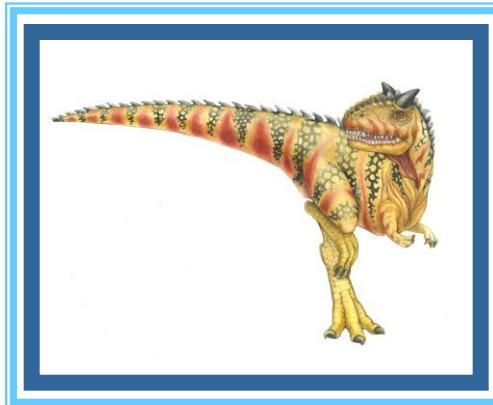


Chapter 3: Processes





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





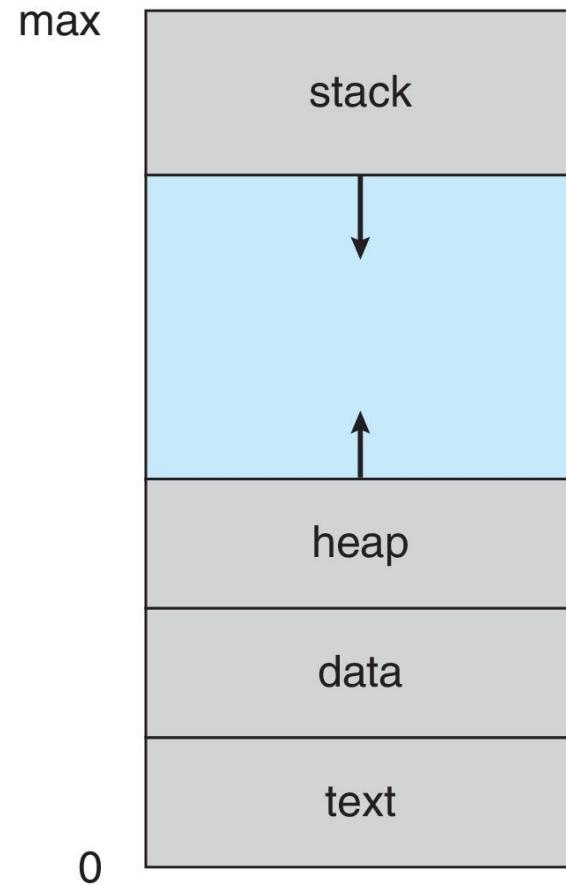
Process Concept (Cont.)

- 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



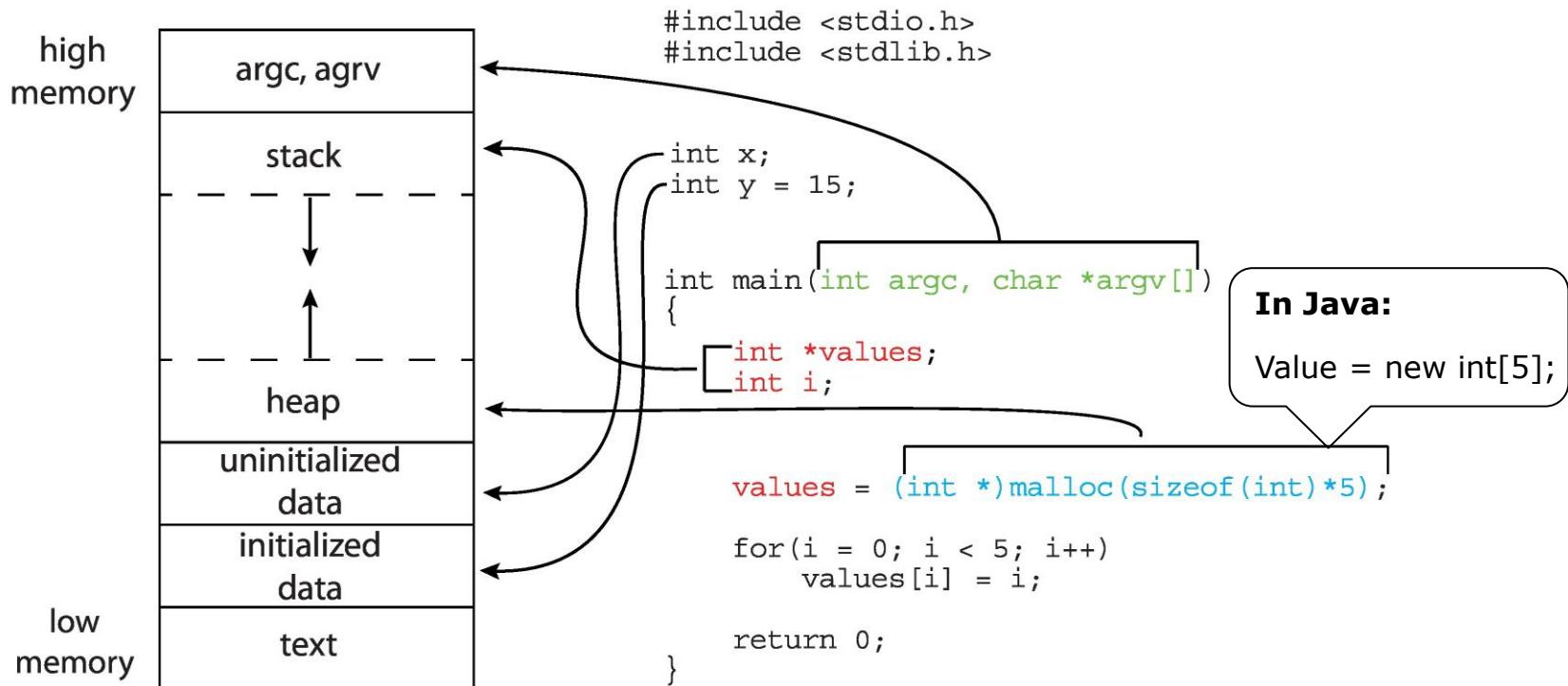


Process in Memory





Memory Layout of a C Program





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



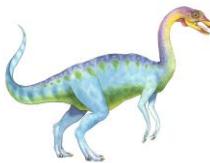
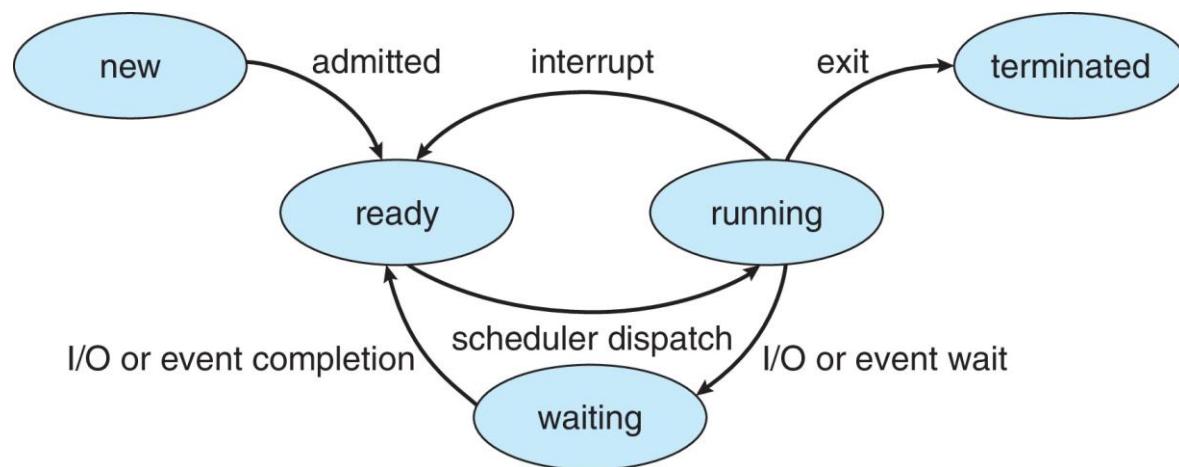
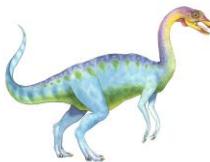


Diagram of Process State





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
• • •

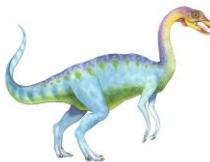




Threads

- 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**
- Must then have storage for thread details, multiple program counters in PCB
- Explore in detail in Chapter 4

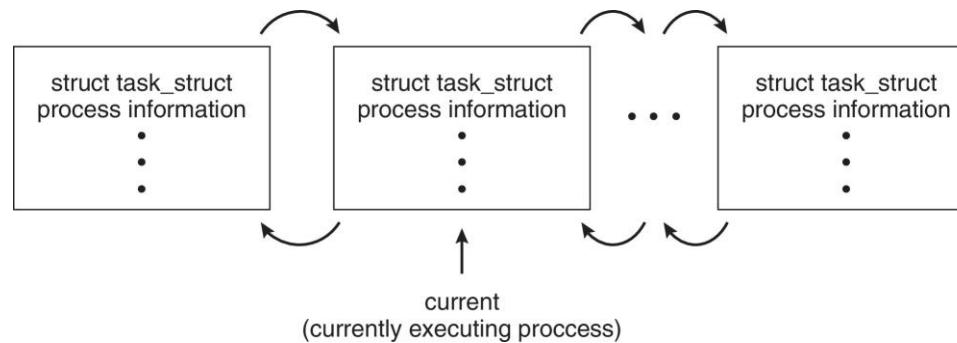


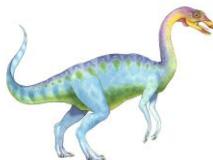


Process Representation in Linux

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 */
```

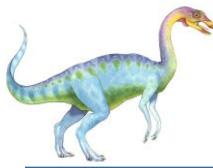




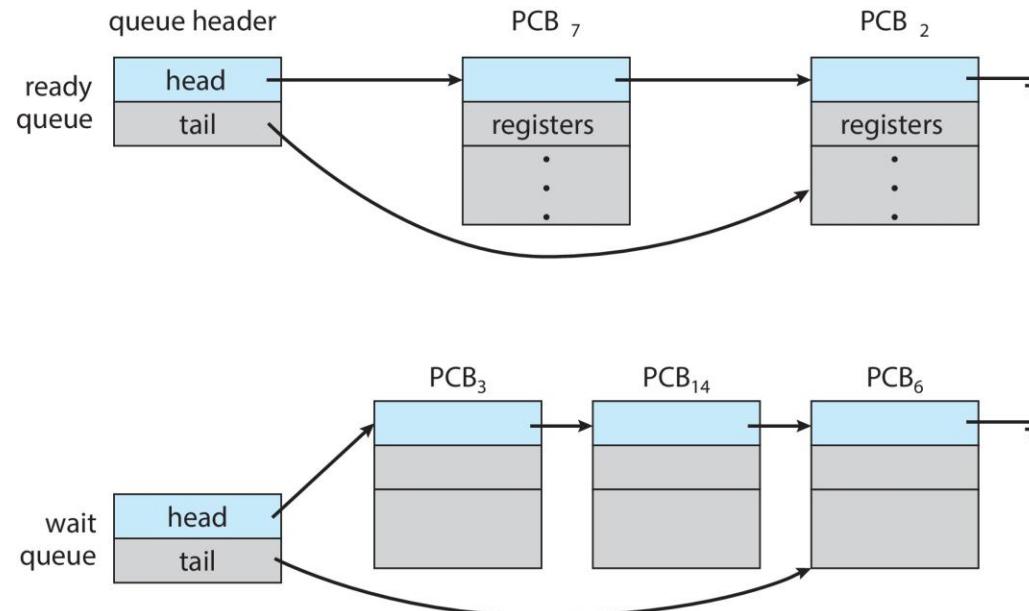
Process Scheduling

- **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



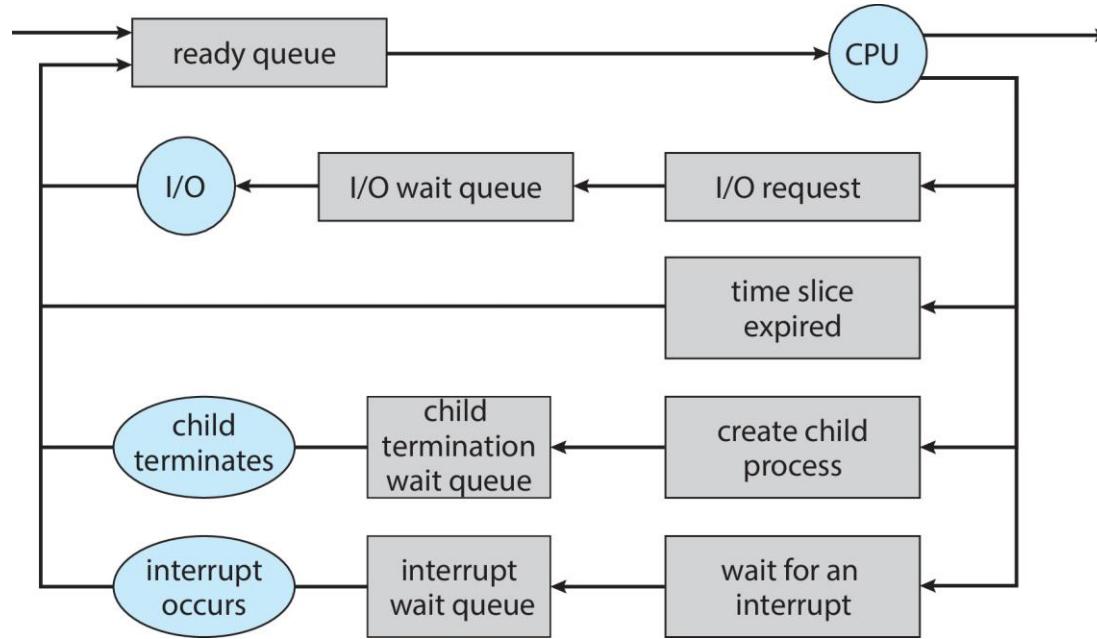


Ready and Wait Queues





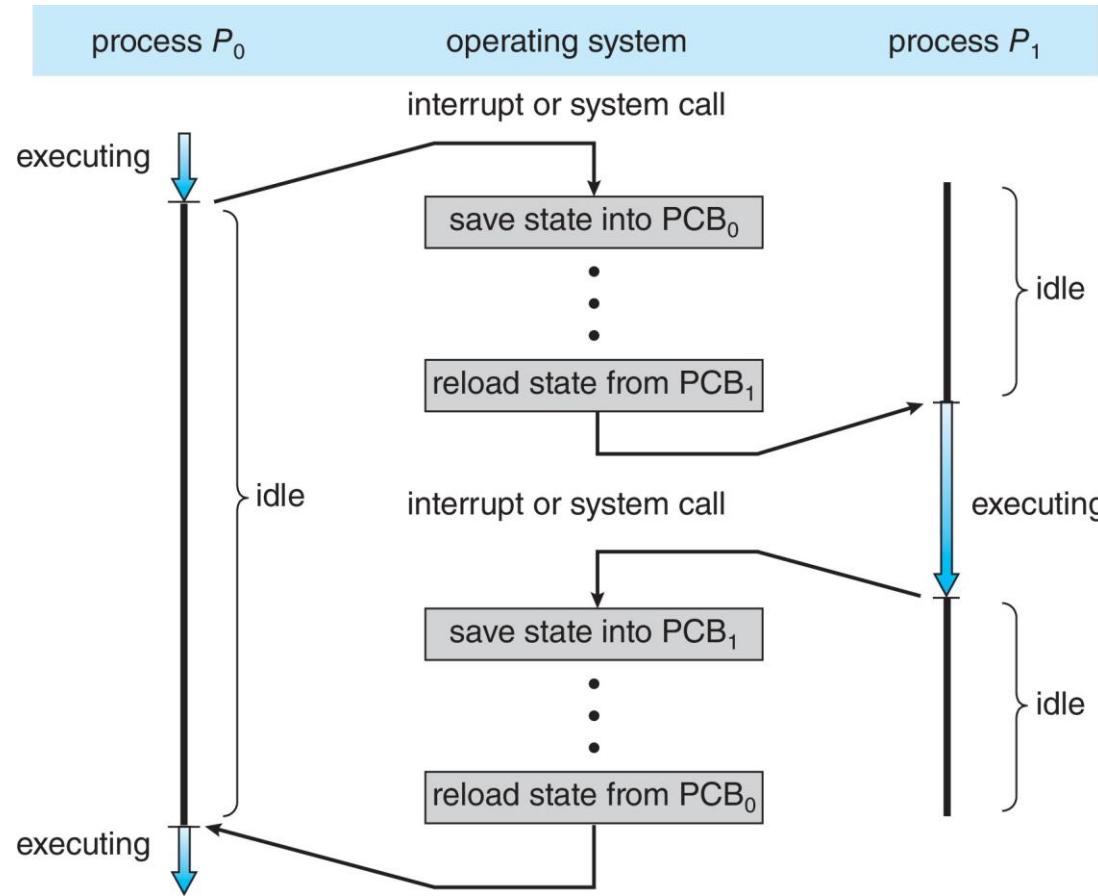
Representation of Process Scheduling

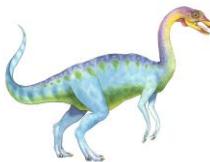




CPU Switch From Process to Process

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

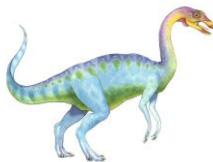




Operations on Processes

- System must provide mechanisms for:
 - Process creation
 - Process termination





Process Creation

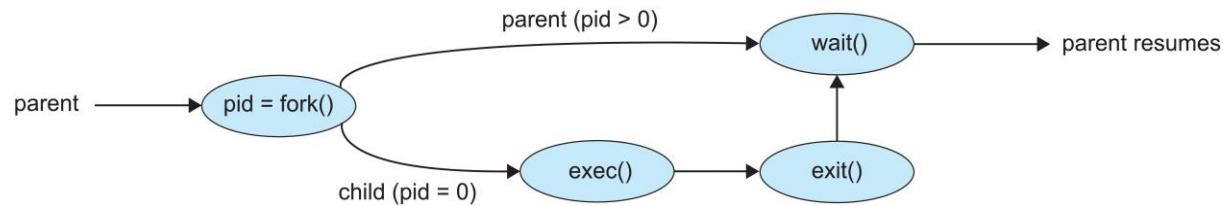
- Parent process create children processes, which, in turn create other processes, forming a tree of processes
- Generally, process identified and managed via a process identifier (pid)
- Resource sharing options
 - Parent and children share all resources
 - Children share subset of parent's resources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

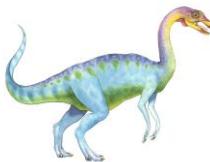




Process Creation (Cont.)

- 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





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>

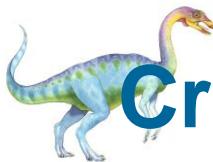
int main(VOID)
{
    STARTUPINFO si;
    PROCESS_INFORMATION pi;

    /* 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);
}
```





Creating a Separate Process via Java

```
Process process;  
try {  
    // Create child process  
    process = Runtime.getRuntime().exec("c:\\windows\\mspaint.exe");  
  
    // Parent will wait child to complete  
    int exitCode = process.waitFor();  
    System.out.println(String.format("ExitCode=%d",exitCode));  
  
} catch (Exception ex) {  
    System.out.println("Error: "+ex.getMessage());  
}
```

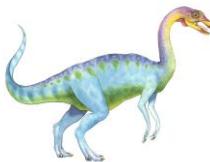




Process Termination

- 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





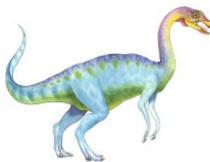
Process Termination

- Some operating systems do not allow child to 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 a **zombie**
- If parent terminated without invoking **wait()** , process is an **orphan**
- **When zombie and orphan processes will be terminated?**





Android Process Importance Hierarchy

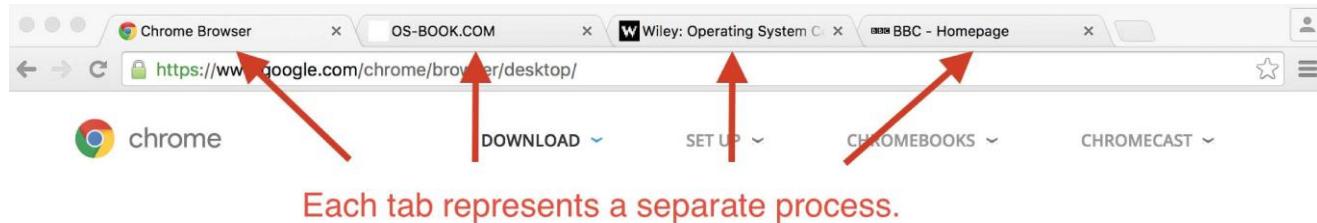
- Mobile operating systems often have to terminate processes to reclaim system resources such as memory. From **most** to **least** important:
 - Foreground process
 - Visible process
 - Service process
 - Background process
 - Empty process
- Android will begin terminating processes that are least important.





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





Interprocess Communication

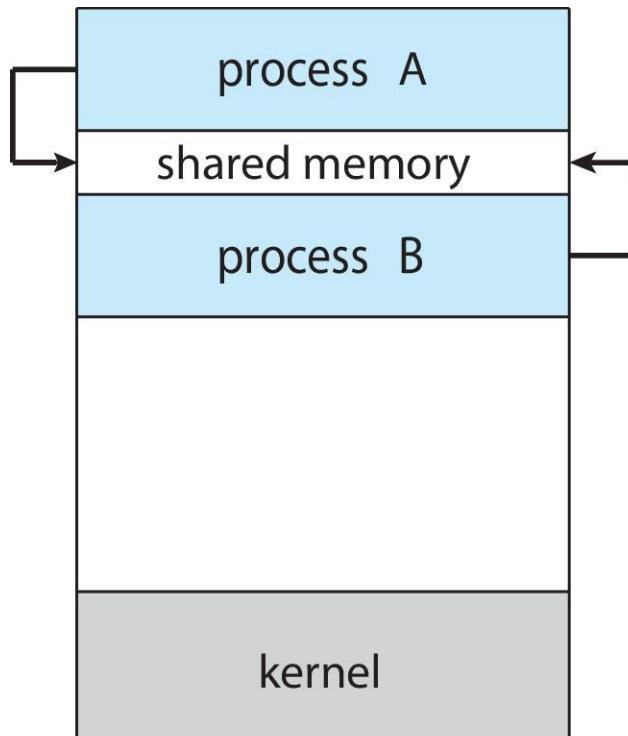
- Processes within a system may be ***independent*** or ***cooperating***
- Cooperating process can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
 - Information sharing
 - Computation speedup
 - Modularity
 - Convenience
- Cooperating processes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





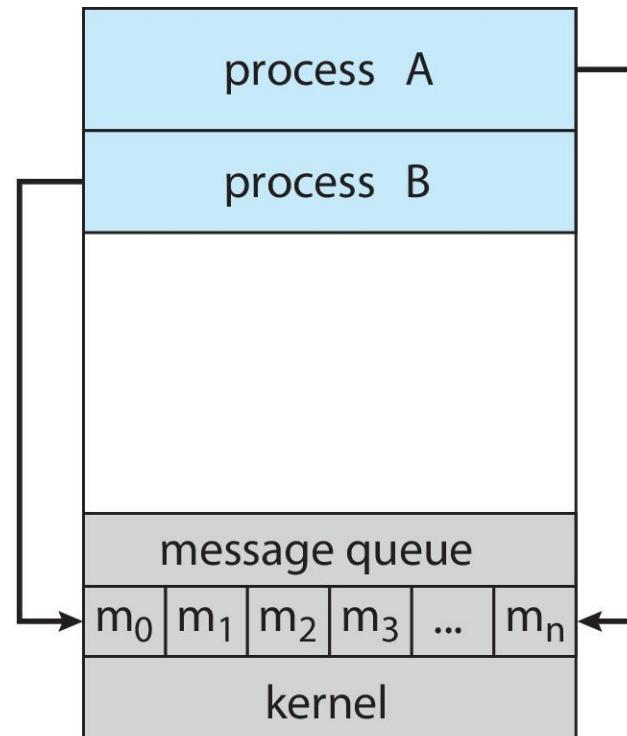
Communications Models

(a) Shared memory.



(a)

(b) Message passing.



(b)

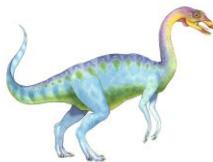




Producer-Consumer Problem

- 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

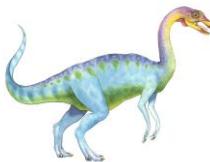




IPC – Shared Memory

- 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 is 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.





Producer-Consumer Solution

- Suppose that we wanted to provide a solution to the consumer-producer problem.
- We can do so by having an integer **counter** that keeps track of the number of full buffers.
- Initially, **counter** is set to 0.
- The integer **counter** is incremented by the producer after it produces a new buffer.
- The integer **counter** is decremented by the consumer after it consumes a buffer.





Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10

typedef struct {

    . . .

} item;

item buffer[BUFFER_SIZE];
int counter = 0;
```





Producer

```
while (true) {  
    /* produce an item in next_produced */  
  
    while (counter == BUFFER_SIZE)  
        ; /* do nothing */  
    buffer[in] = next_produced;  
    in = (in + 1) % BUFFER_SIZE;  
    counter++;  
}
```





Consumer

```
while (true) {  
    while (counter == 0)  
        ; /* do nothing */  
    next_consumed = buffer[out];  
    out = (out + 1) % BUFFER_SIZE;  
    counter--;  
    /* consume the item in next_consumed */  
}
```





Race Condition

- `counter++` could be implemented as

```
register1 = counter  
register1 = register1 + 1  
counter = register1
```

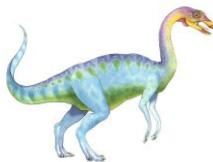
- `counter--` could be implemented as

```
register2 = counter  
register2 = register2 - 1  
counter = register2
```

- Consider this execution interleaving with “count = 5” initially:

S0: producer execute <code>register1 = counter</code>	{register1 = 5}
S1: producer execute <code>register1 = register1 + 1</code>	{register1 = 6}
S2: consumer execute <code>register2 = counter</code>	{register2 = 5}
S3: consumer execute <code>register2 = register2 - 1</code>	{register2 = 4}
S4: producer execute <code>counter = register1</code>	{counter = 6 }
S5: consumer execute <code>counter = register2</code>	{counter = 4}





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

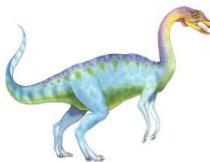




Message Passing (Cont.)

- 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?





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 */

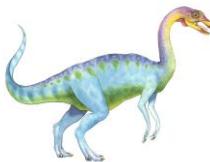
    send(next_produced);
}
```

- Consumer

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

    /* consume the item in next_consumed */
}
```

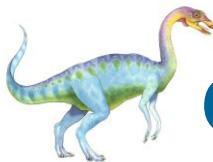




Buffering

- 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

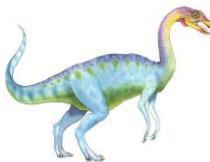




Communications in Client-Server Systems

- **Sockets:** is defined as an endpoint for communication between two programs running on the network
- **Remote Procedure Calls (RPC):** abstract procedure calls between processes on networked systems





Socket Communication

