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

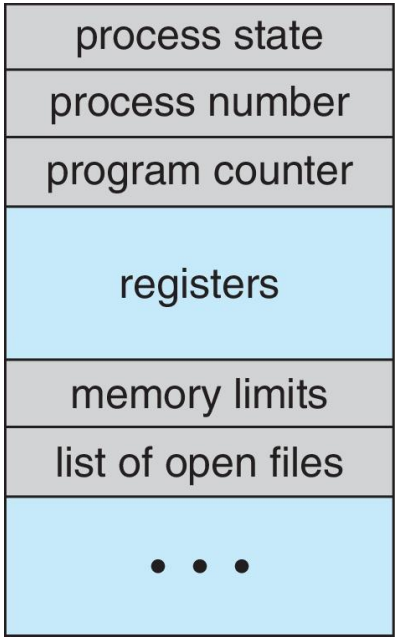
Process Concept (Cont.)

- 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

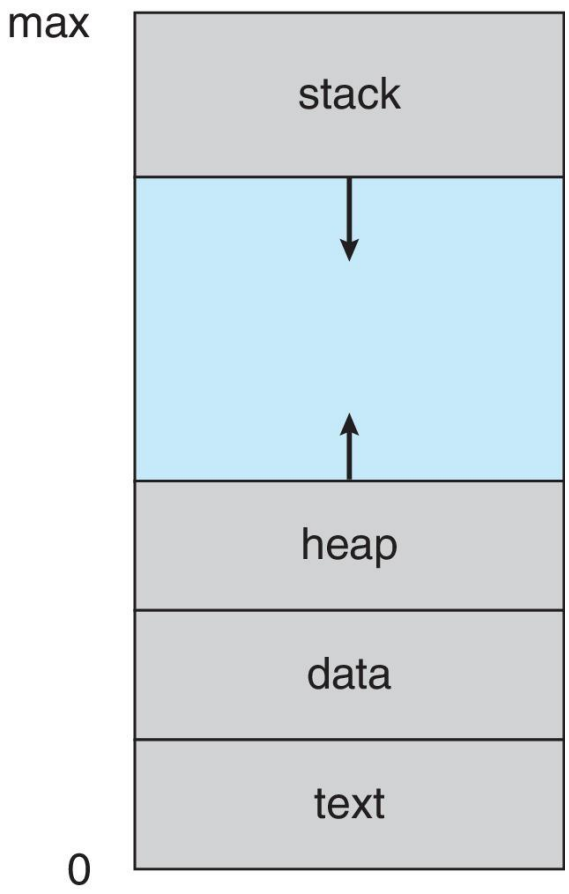
Process Control Block (PCB)

Information associated with each process

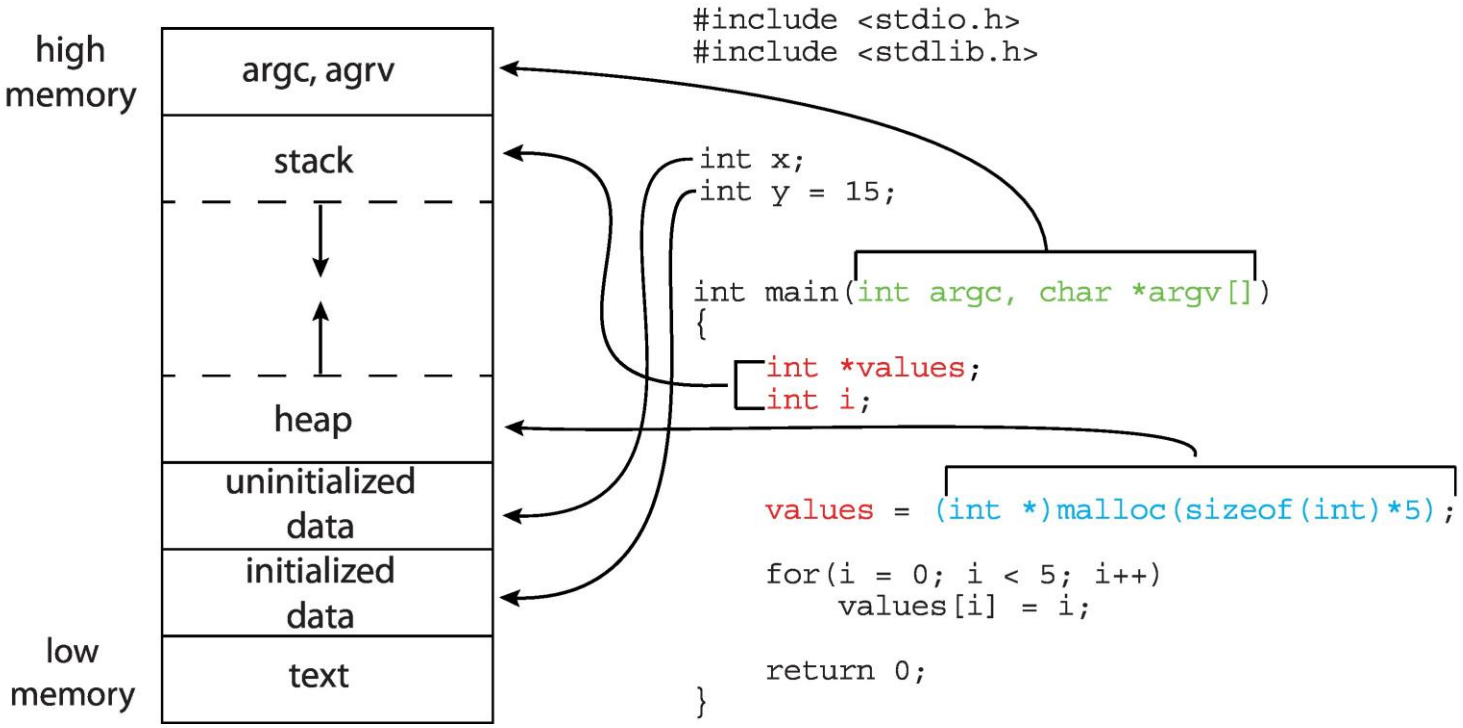
- Process state – running, waiting, etc.
- Program counter – location of instruction to next execute
- CPU registers – contents of all process-centric registers
- CPU scheduling information- priorities, scheduling queue pointers
- Memory-management information – memory allocated to the process
- Accounting information – CPU used, clock time elapsed since start, time limits
- I/O status information – I/O devices allocated to process, list of open files



Process in Memory

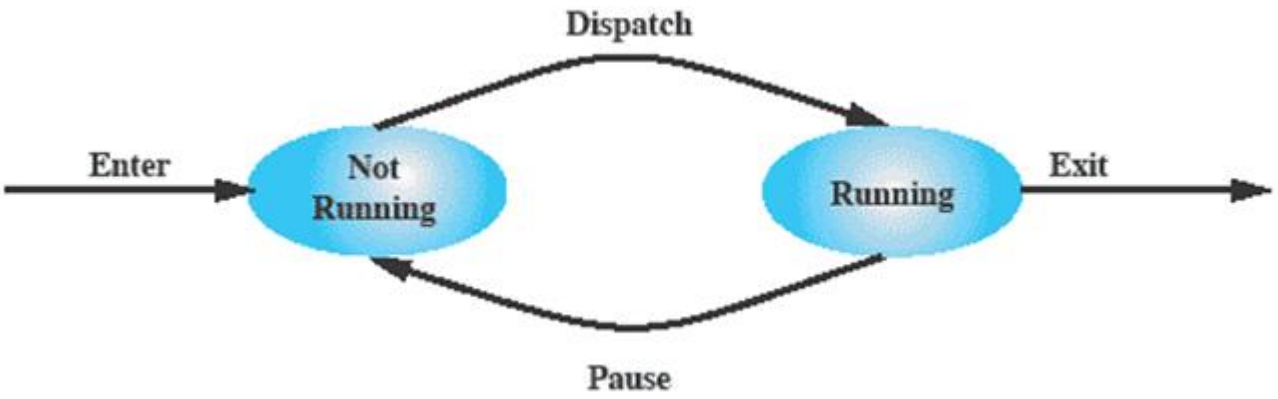


Memory Layout of a C Program



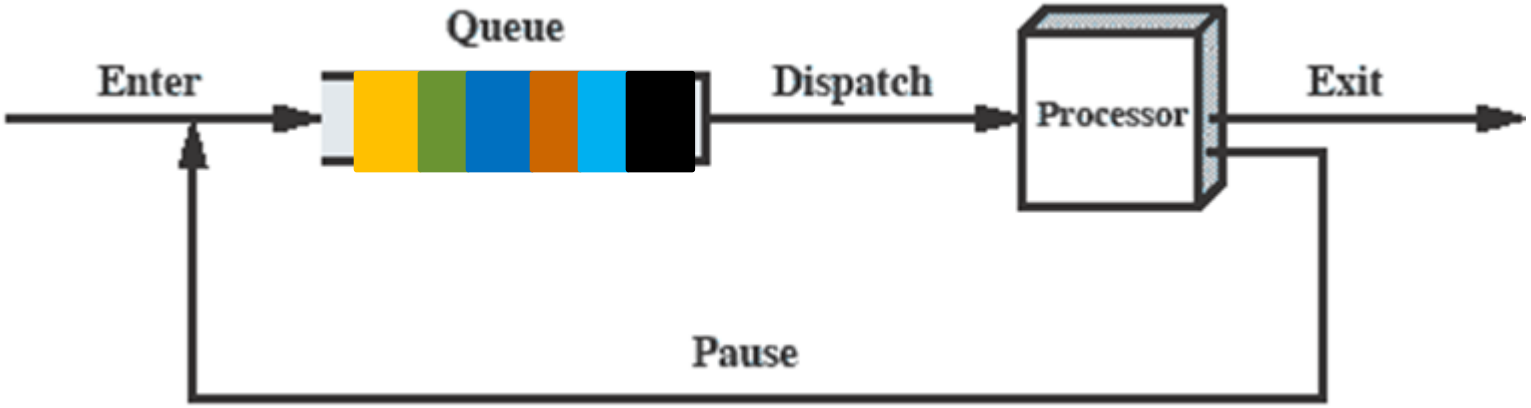
Two-State Process Model

- A process may be in one of two states:
  - running
  - not-running



Two-State Process Model (cont.)

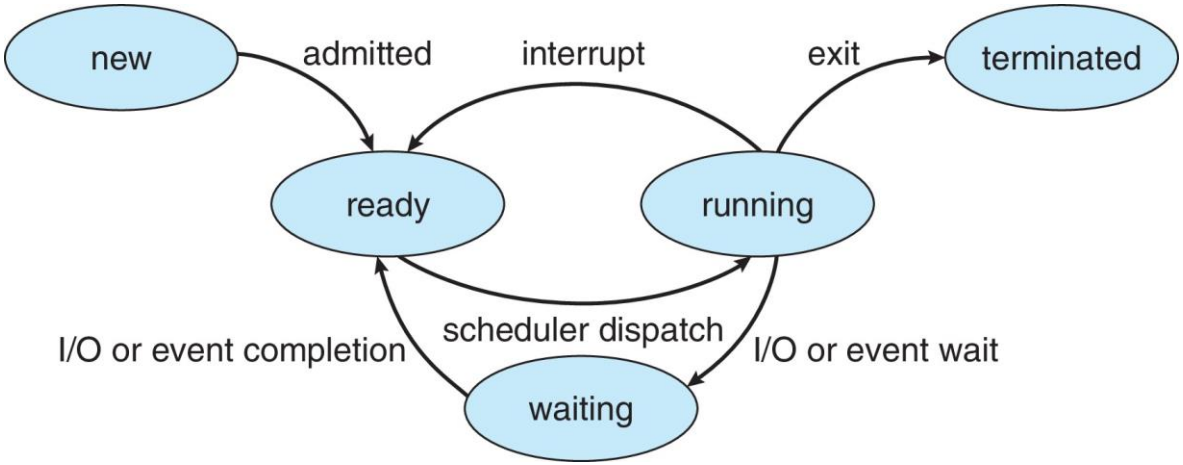
- Queuing Diagram



Five-State Process Model

- Process states
  - 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

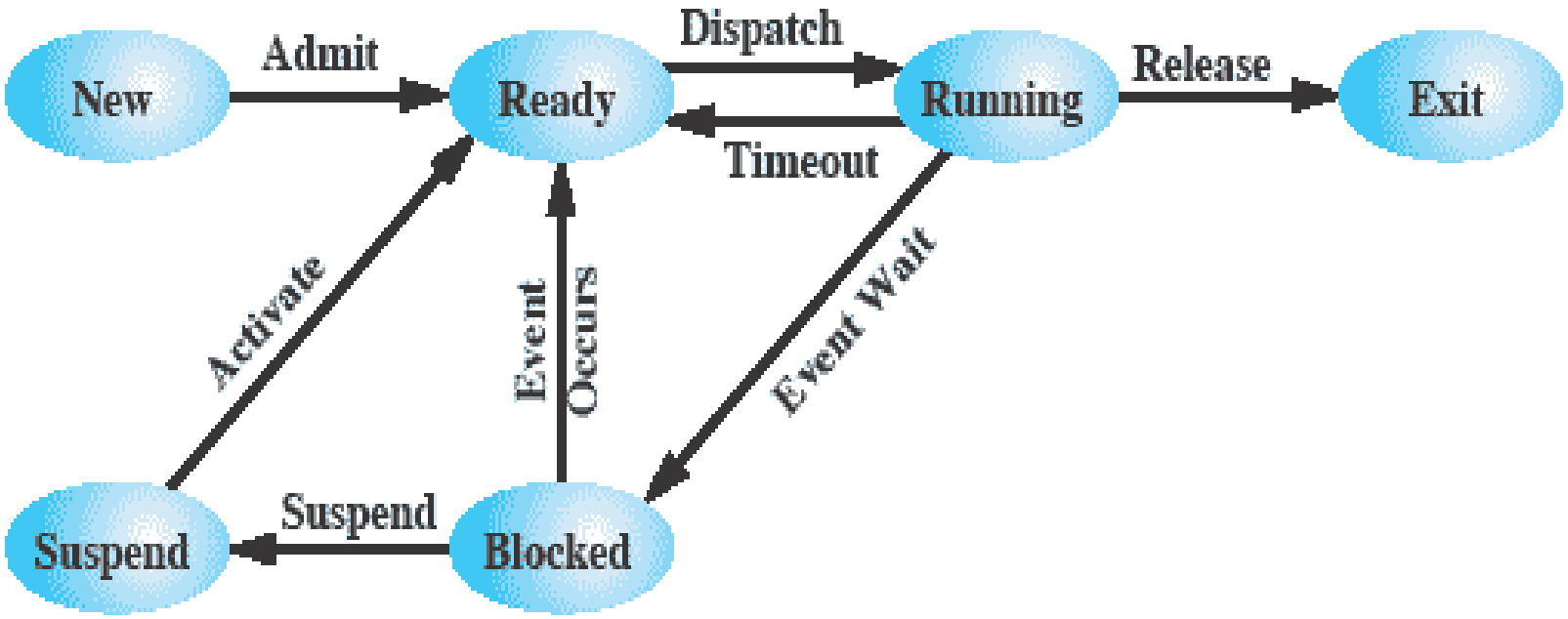
Five-State Process Model (cont.)



Suspended Processes

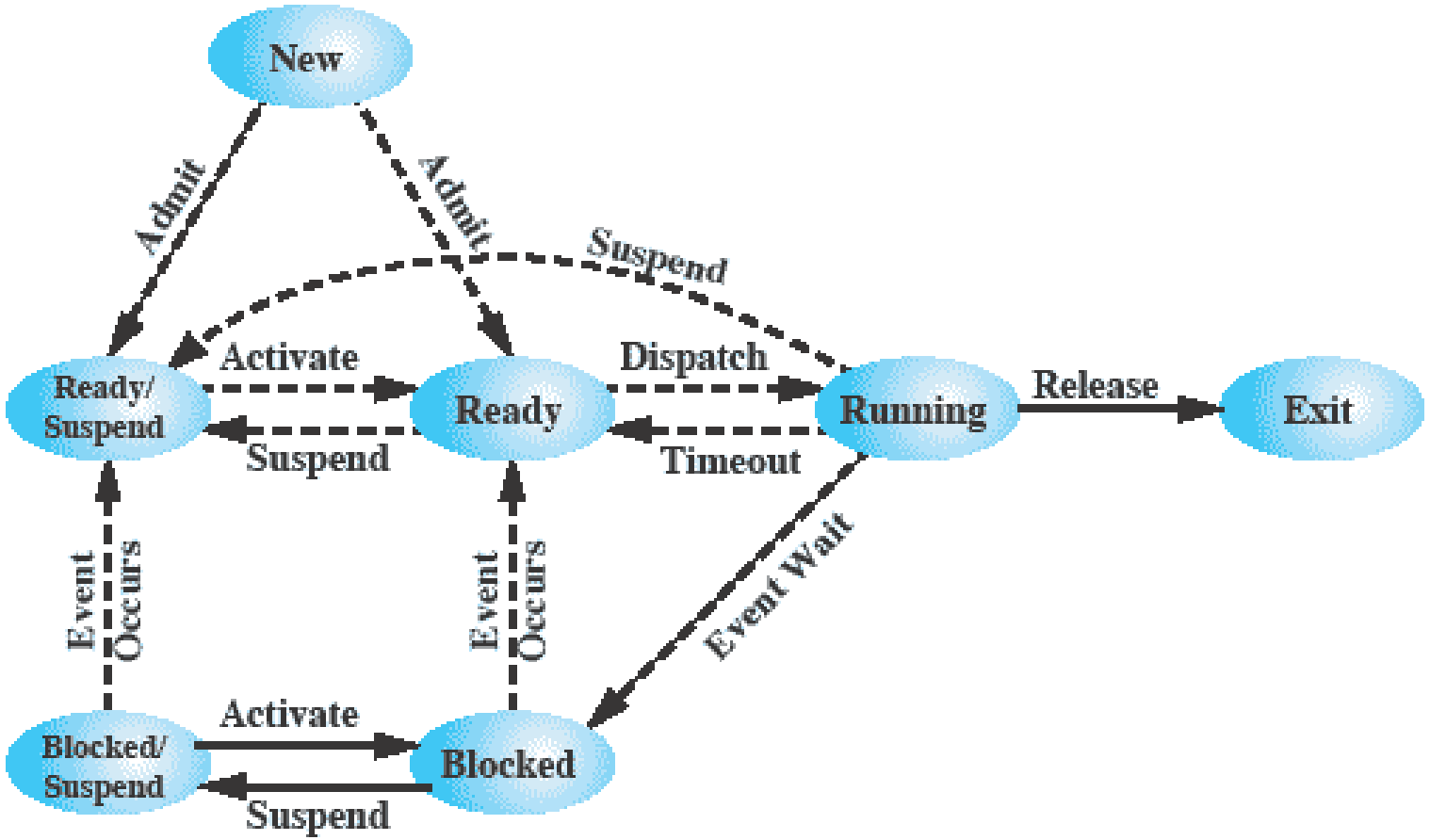
- Swapping
  - involves moving part or all of a process from main memory to disk
  - when none of the processes in main memory is in the Ready state, the OS swaps one of the blocked processes out on to disk into a suspend queue to make room for a new process, or a previously suspended process that is now ready to execute
  - Commonly used in systems that had no virtual memory; less likely to be used with virtual memory since process size can be controlled through the paging mechanism.

One Suspend State



(a) With One Suspend State

Two Suspend States



(b) With Two Suspend States

Characteristics of a Suspended Process

- The process is not immediately available for execution
- The process may or may not be waiting on an event
- The process was placed in a suspended state by an agent: either itself, a parent process, or the OS, for the purpose of preventing its execution
- The process may not be removed from this state until the agent explicitly orders the removal

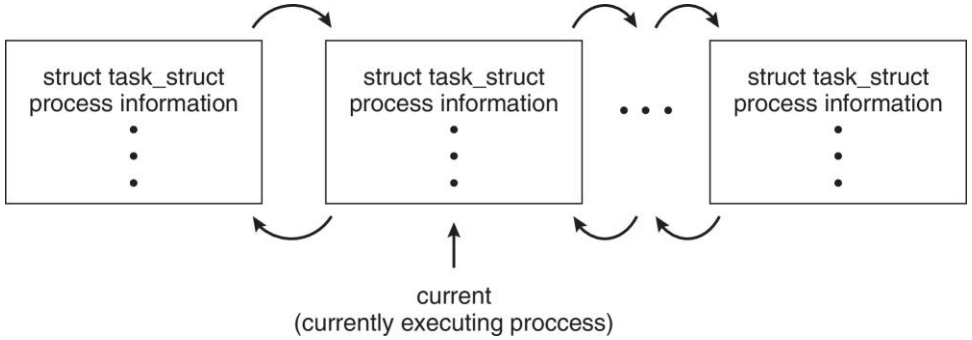
Reasons for Process Suspension

- Swapping
- Other OS reason
- Interactive user request
- Timing
- Parent process request

Process Representation in Linux

Represented by the C structure `task_struct`

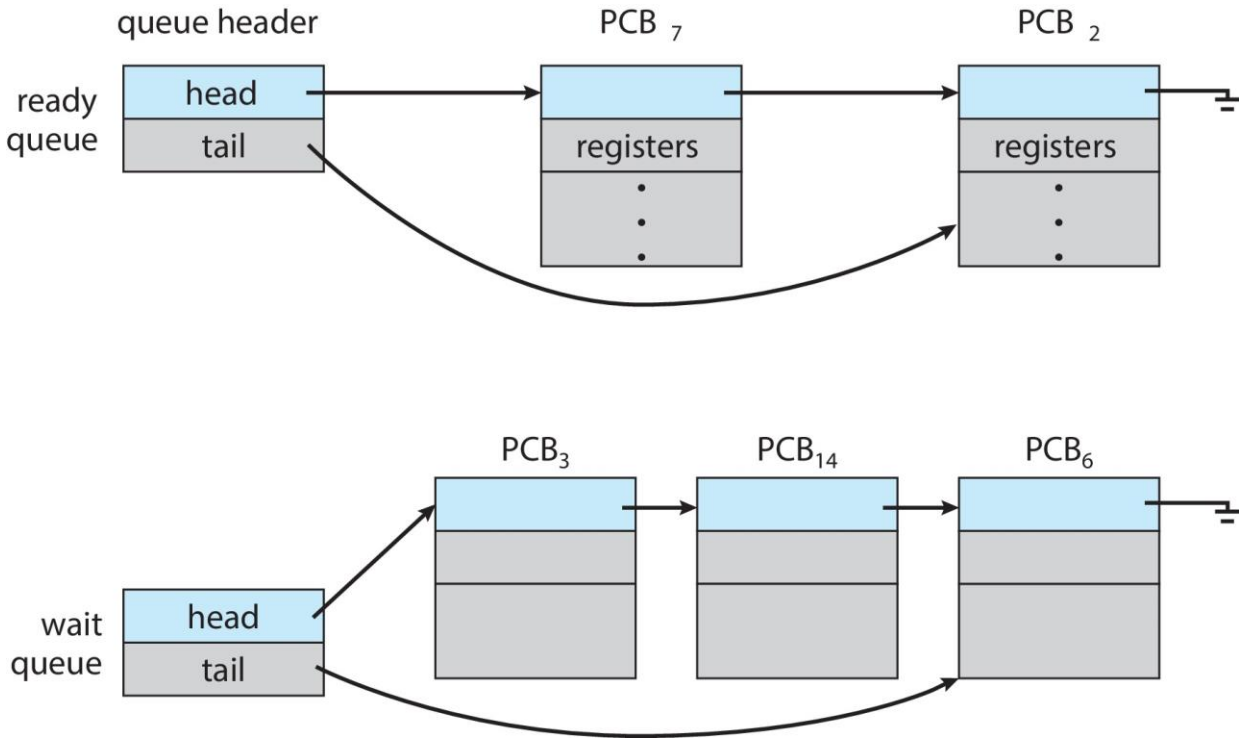
```
pid t_pid;                    /* process identifier */
long state;                   /* state of the process */
unsigned int time_slice       /* scheduling information */
struct task_struct *parent;/* this process's parent */
struct list_head children; /* this process's children */
struct files_struct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



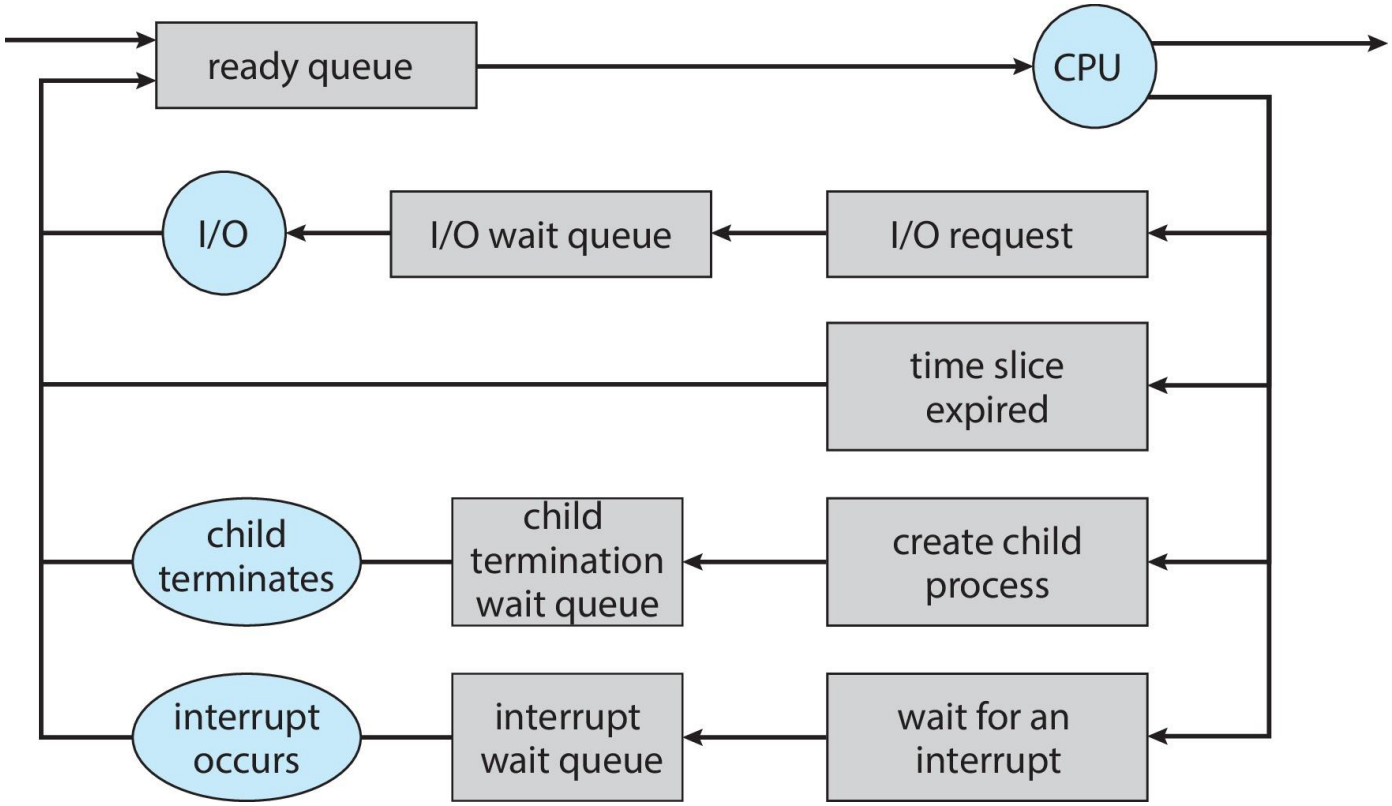
Process Scheduling

- 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

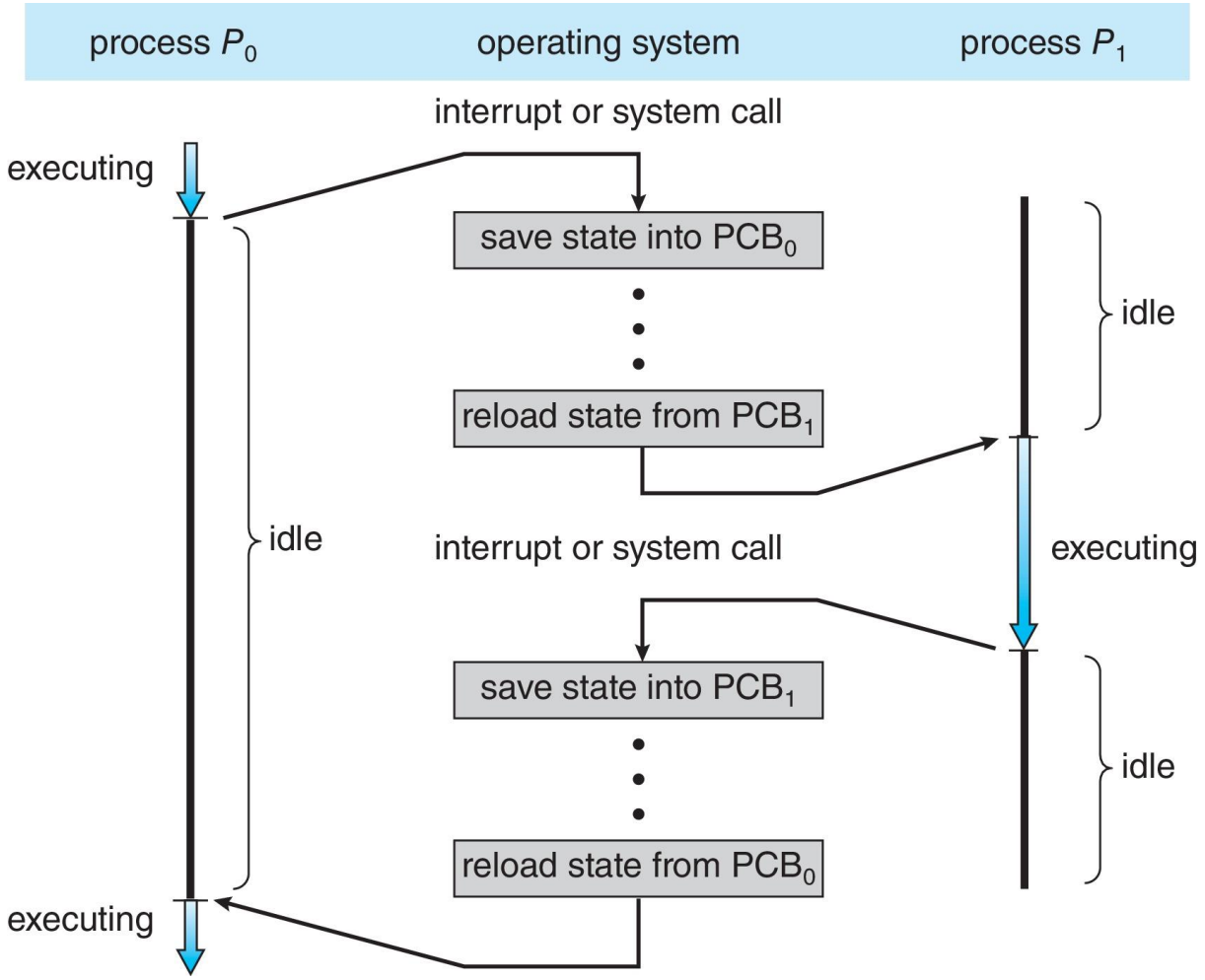


Context Switch

- 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

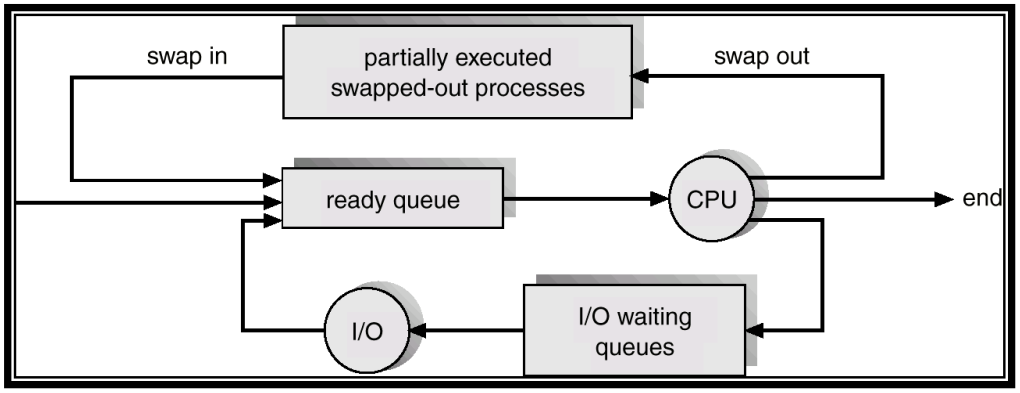
CPU Switch From Process to Process

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



Schedulers

- A process migrates between the various scheduling queues throughout its lifetime.
- The OS must select, for scheduling purposes, processes from these queues in some fashion. The selection process is carried out by the appropriate scheduler.
- Types of scheduler
  - Long-term scheduler
  - Short-term scheduler
  - Medium-term scheduler



Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) $\Rightarrow$ (must be fast).
- Long-term scheduler is invoked very infrequently (seconds, minutes) $\Rightarrow$ (may be slow).
- The long-term scheduler controls the degree of multiprogramming.
- Processes can be described as either:
  - I/O-bound process – spends more time doing I/O than computations, many short CPU bursts.
  - CPU-bound process – spends more time doing computations; few very long CPU bursts.

Multi-tasking 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

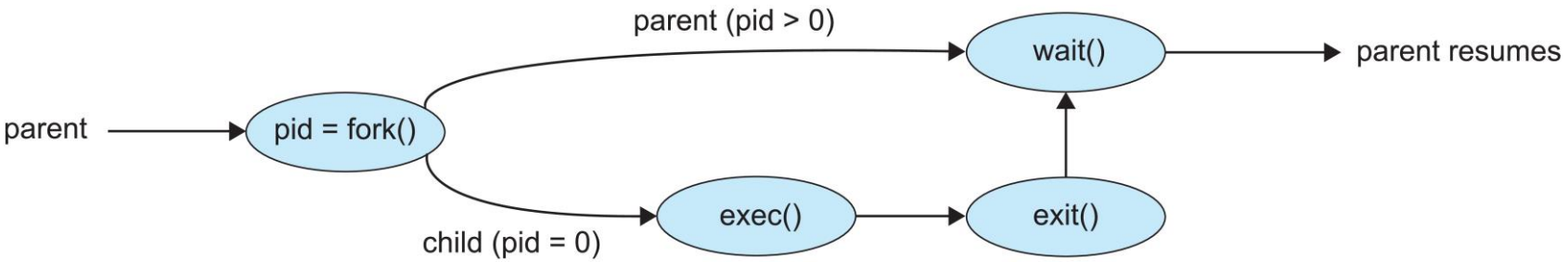
- Reasons for process creation
  - New batch job
  - Interactive logon
  - Created by OS to provide a service
  - Spawned by existing process

Process Creation (cont.)

- Process spawning: when the OS creates a process at the explicit request of another process
- 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



fork() System Call

- System call fork() is used to create processes.
- It takes no arguments and returns a process ID.
- The purpose of fork() is to create a new process, which becomes the child process of the caller.
- After a new child process is created, both processes will execute the next instruction following the fork() system call.
- Therefore, we have to distinguish the parent from the child. This can be done by testing the returned value of fork():
  - If fork() returns a negative value, the creation of a child process was unsuccessful.
  - fork() returns a zero to the newly created child process.
  - fork() returns a positive value, the process ID of the child process, to the parent.

fork() System Call Example

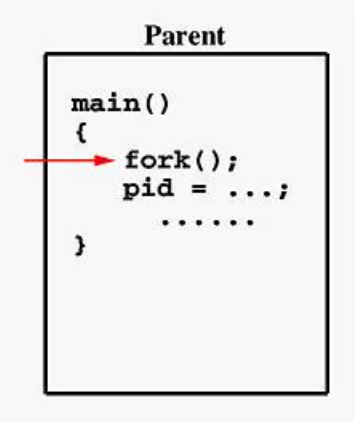
```
#include <sys/types.h>
#include <stdio.h>
#include <unistd.h>

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;
}
```

fork() System Call Example

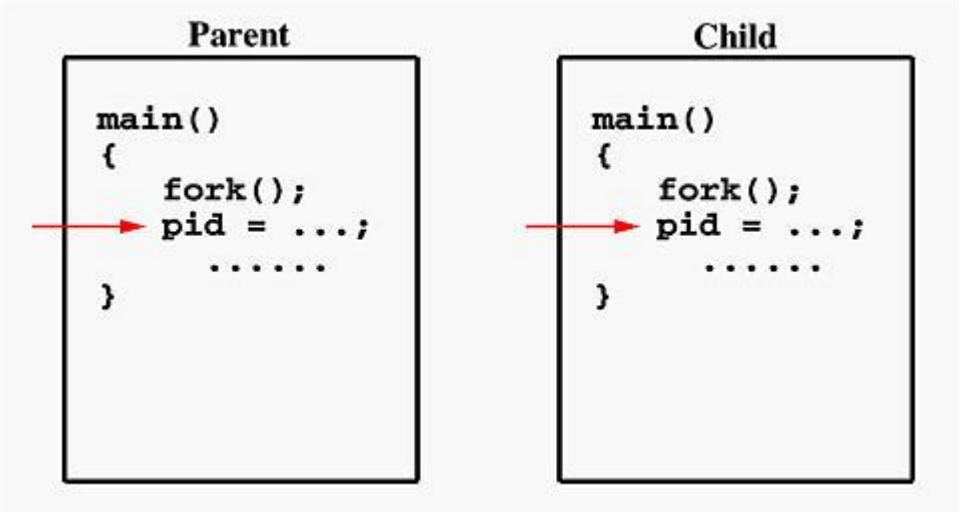
```
/*    This program illustrates the use of fork() and getpid() system */
/* calls.  Note that write() is used instead of printf() since the   */
/* latter is buffered while the former is not.                       */
/* ----------------------------------------------------------------- */

#include  <stdio.h>
#include  <string.h>
#include  <sys/types.h>

#define   MAX_COUNT  200
#define   BUF_SIZE   100

void  main(void)
{
     pid_t  pid;
     int    i;
     char   buf[BUF_SIZE];

     fork();
     pid = getpid();
     for (i = 1; i <= MAX_COUNT; i++) {
          sprintf(buf, "This line is from pid %d, value = %d\n", pid, i);
          write(1, buf, strlen(buf));
     }
}
```

fork() System Call Example

- Suppose the previous program executes up to the point of the call to fork()

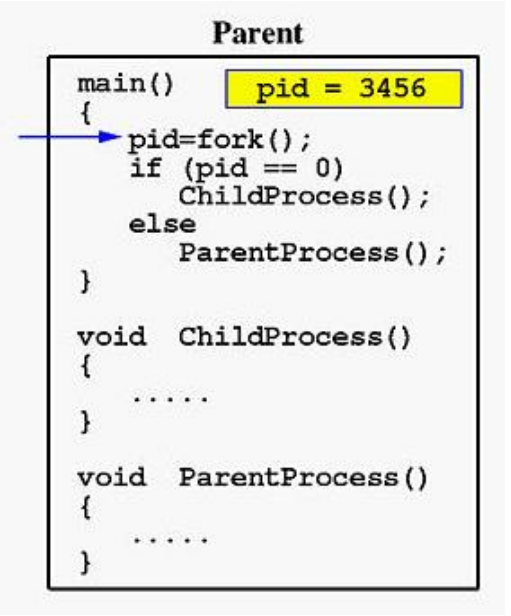


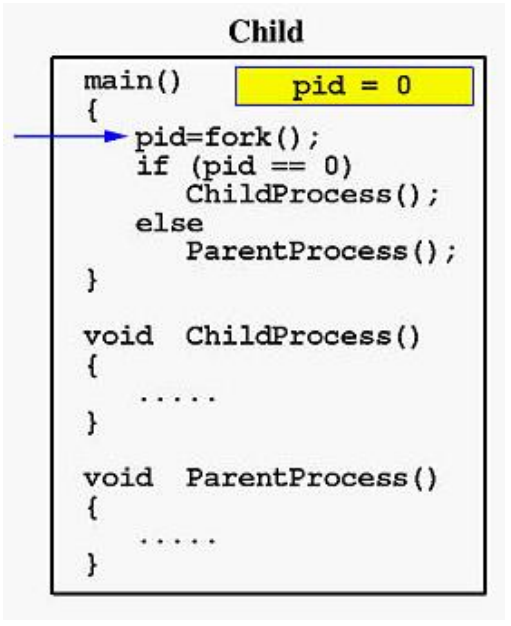
- If the call to fork() is executed successfully, Unix will
  - make two identical copies of address spaces, one for the parent and the other for the child.
  - Both processes will start their execution at the next statement following the fork() call as shown in the second figure:



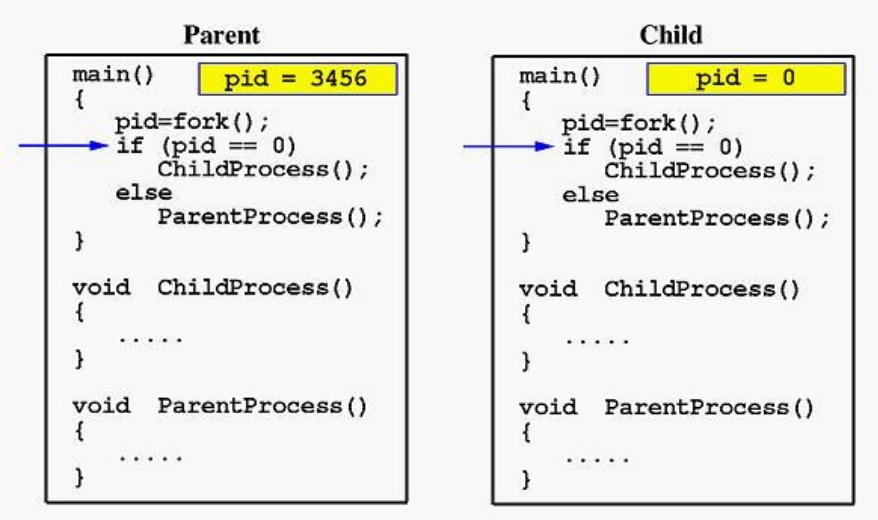
fork() System Call Example

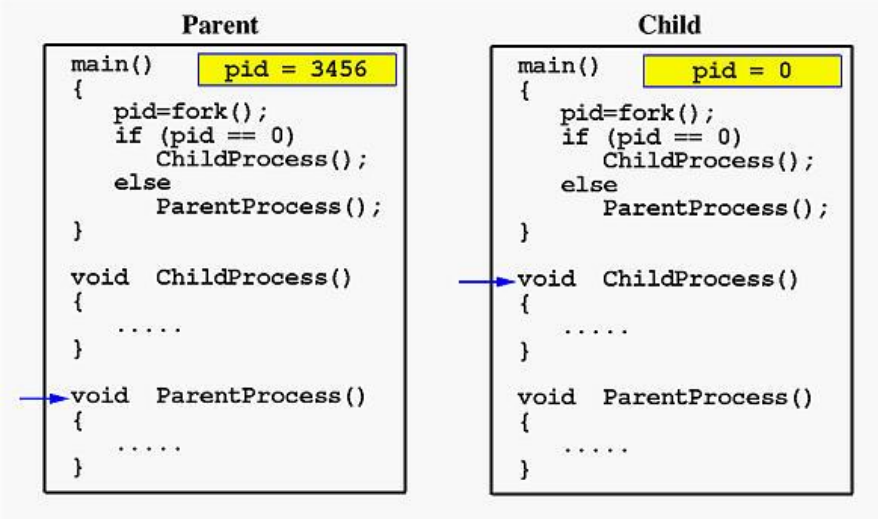
```
/*   This program runs two processes, a parent and a child.  Both of */
/* them run the same loop printing some messages.  Note that printf()*/
/* is used in this program.                                          */
/* ----------------------------------------------------------------- */

#include  <stdio.h>
#include  <sys/types.h>

#define   MAX_COUNT  200

void  ChildProcess(void);               /* child process prototype  */
void  ParentProcess(void);              /* parent process prototype */

void  main(void)
{
     pid_t  pid;

     pid = fork();
     if (pid == 0)
          ChildProcess();
     else
          ParentProcess();
}

void  ChildProcess(void)
{
     int   i;

     for (i = 1; i <= MAX_COUNT; i++)
          printf("   This line is from child, value = %d\n", i);
     printf("   *** Child process is done ***\n");
}

void  ParentProcess(void)
{
     int   i;

     for (i = 1; i <= MAX_COUNT; i++)
          printf("This line is from parent, value = %d\n", i);
     printf("*** Parent is done ***\n");
}
```





fork() System Call Example





fork() System Call Example

- (i)

```c
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
int main()
{

    // make two process which run same
    // program after this instruction
    fork();

    printf("Hello world!\n");
    return 0;
}
```

- (ii)

```c
#include <stdio.h>
#include <sys/types.h>
int main()
{
    fork();
    fork();
    fork();
    printf("hello\n");
    return 0;
}
```

fork() System Call Example

- (iii)

```c
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
void forkexample()
{
    // child process because return value zero
    if (fork() == 0)
        printf("Hello from Child!\n");

    // parent process because return value non-
    else
        printf("Hello from Parent!\n");
}
int main()
{
    forkexample();
    return 0;
}
```

- (iv)

```c
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>

void forkexample()
{
    int x = 1;

    if (fork() == 0)
        printf("Child has x = %d\n", ++x);
    else
        printf("Parent has x = %d\n", --x);
}
int main()
{
    forkexample();
    return 0;
}
```

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 (cont.)

- 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

Process Termination (cont.)

- Reasons for process termination
  - Normal completion
  - Time limit exceeded
  - Memory unavailable
  - Bounds violation
  - Protection error
  - Arithmetic error
  - I/O failure
  - Invalid instruction
  - Parent termination

Zombie and Orphan Processes

- Zombie process
  - A process which has finished the execution but still has entry in the process table to report to its parent process.
  - A child process always first becomes a zombie before being removed from the process table.
  - The parent process reads the exit status of the child process which reaps off the child process entry from the process table.

- Orphan process
  - A process whose parent process no more exists i.e. either finished or terminated without waiting for its child process to terminate.

Code of Zombie and Orphan Processes

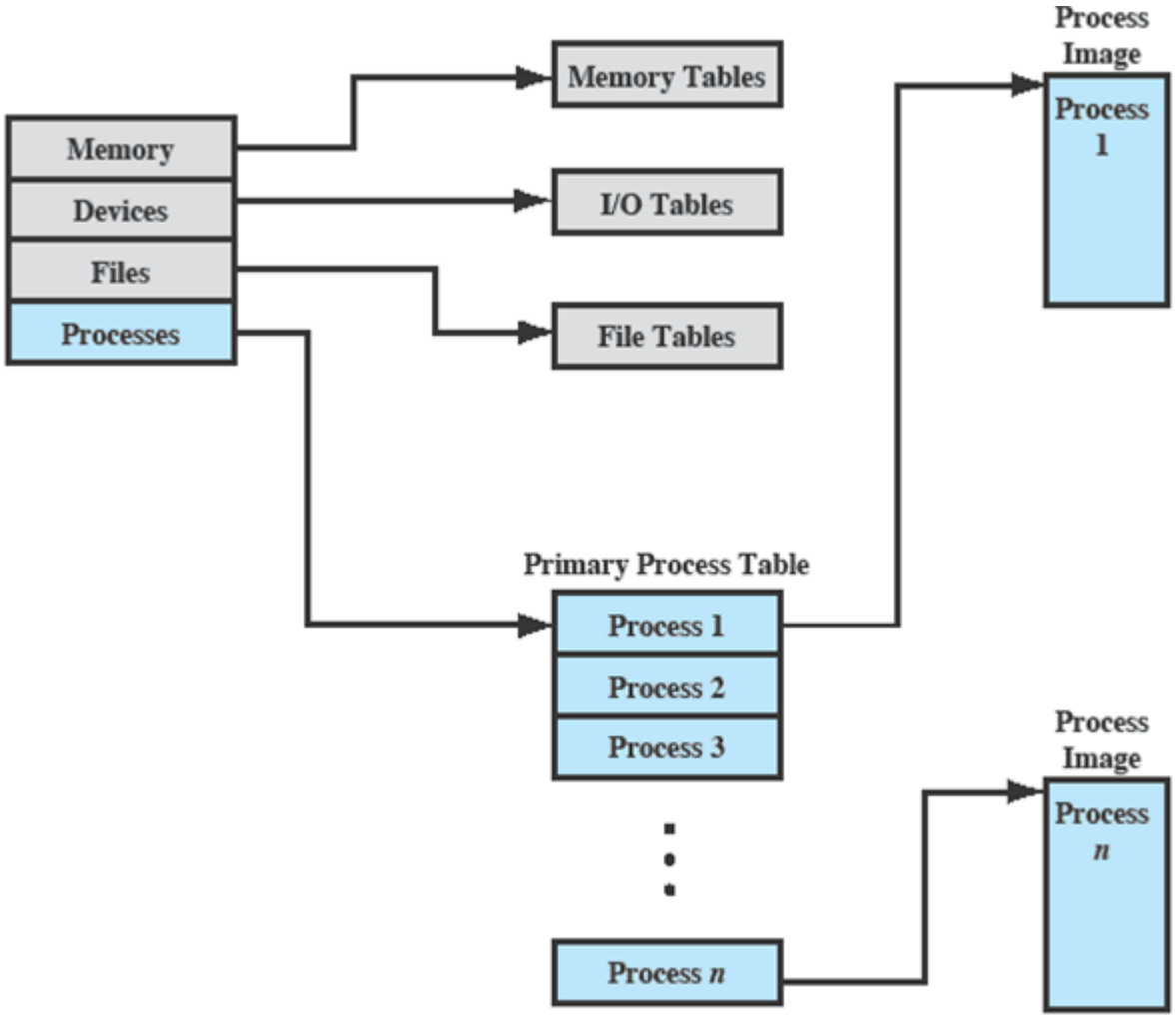
- Code of zombie process

```c
#include <stdlib.h>
#include <sys/types.h>
#include <unistd.h>
int main()
{
    // Fork returns process id
    // in parent process
    pid_t child_pid = fork();

    // Parent process
    if (child_pid > 0)
        sleep(50);

    // Child process
    else
        exit(0);

    return 0;
}
```

- Code of orphan process

```c
#include<stdio.h>
#include <sys/types.h>
#include <unistd.h>

int main()
{
    // Create a child process
    int pid = fork();

    if (pid > 0)
        printf("in parent process");

    // Note that pid is 0 in child process
    // and negative if fork() fails
    else if (pid == 0)
    {
        sleep(30);
        printf("in child process");
    }

    return 0;
}
```

OS Control Tables



OS Control Tables (cont.)

- Memory tables
  - Used to keep track of both main (real) and secondary (virtual) memory
- I/O tables
  - Used by the OS to manage the I/O devices and channels of the computer system
  - At any given time, an I/O device may be available or assigned to a particular process
- File tables
  - Provide information about existence of files, location on secondary, memory, current status, other attributes
- Process tables
  - Must be maintained to manage processes
  - Must have some reference to memory, I/O, and file tables

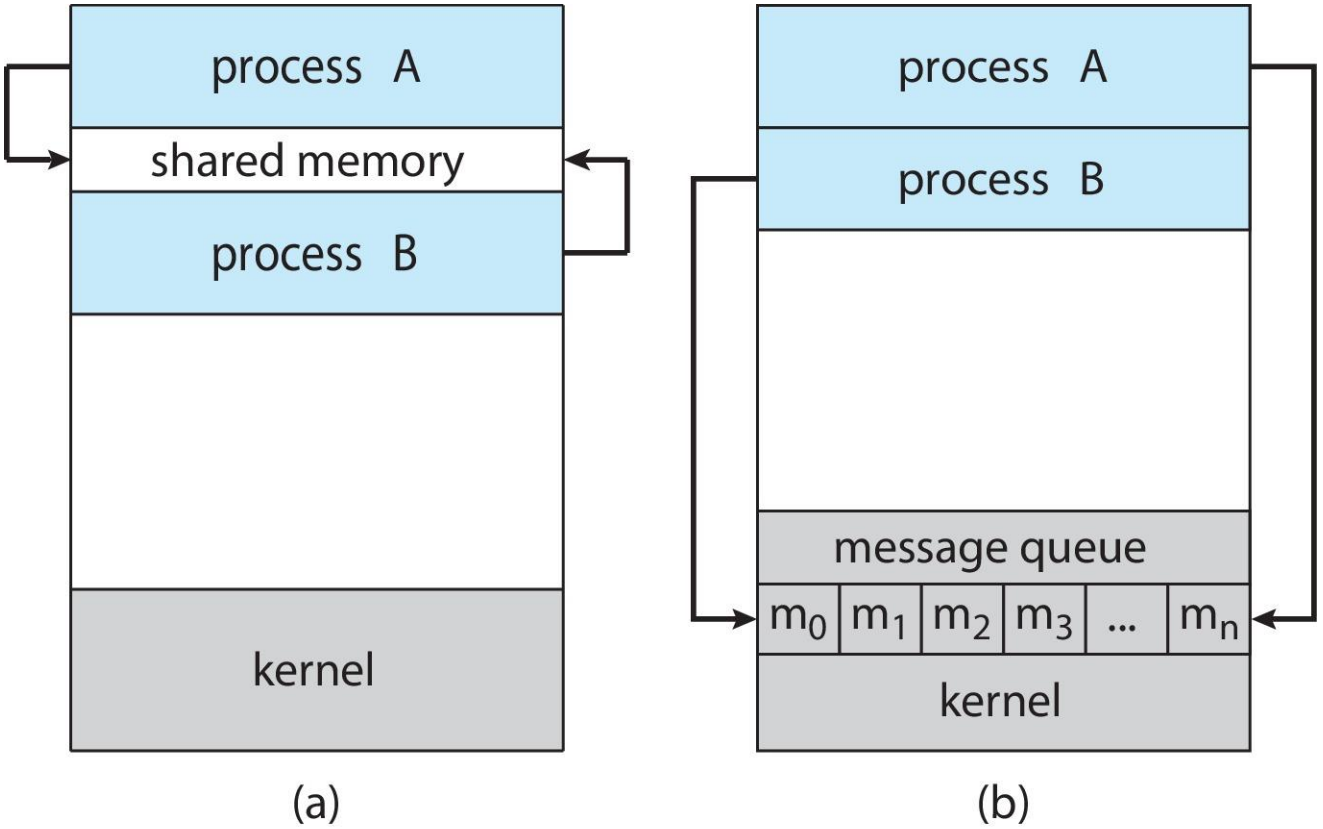
Interprocess Communication

- 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
- Cooperating processes need interprocess communication (IPC)
- Two models of IPC
  - Shared memory
  - Message passing

Communications Models

(a) Shared memory.

(b) Message passing.



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.

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 */
}
```

What about Filling all the Buffers?

- Suppose that we wanted to provide a solution to the consumer-producer problem that fills all the buffers.
- 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 and is decremented by the consumer after it consumes a buffer.

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 `register1 = counter` {register1 = 5}
S1: producer execute `register1 = register1 + 1` {register1 = 6}
S2: consumer execute `register2 = counter` {register2 = 5}
S3: consumer execute `register2 = register2 – 1` {register2 = 4}
S4: producer execute `counter = register1` {counter = 6 }
S5: consumer execute `counter = register2` {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?

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

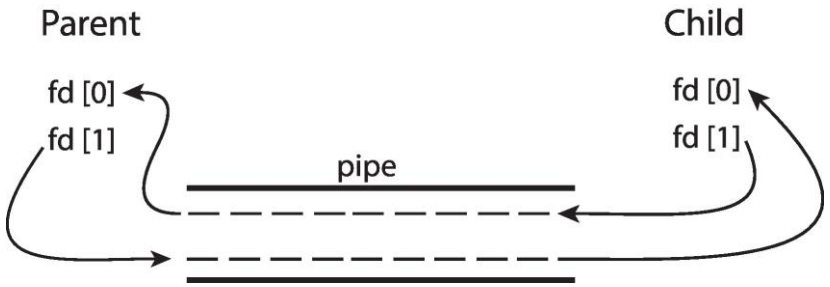
- Queue of messages attached to the link.
- Implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.
     Sender must wait for receiver (rendezvous)
  2. Bounded capacity – finite length of *n* messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits

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 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 therefore unidirectional
- Require parent-child relationship between communicating processes



- Windows calls these anonymous pipes

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

Case Study: UNIX SVR4

- Uses the model where most of the OS executes within the environment of a user process
- Two process categories: system processes and user processes
- System processes run in kernel mode
  - executes operating system code to perform administrative and housekeeping functions independent of any specific user process.
- User Processes
  - operate in user mode to execute user programs and utilities
  - operate in kernel mode to execute instructions that belong to the kernel
  - enter kernel mode by issuing a system call, when an exception is generated, or when an interrupt occurs

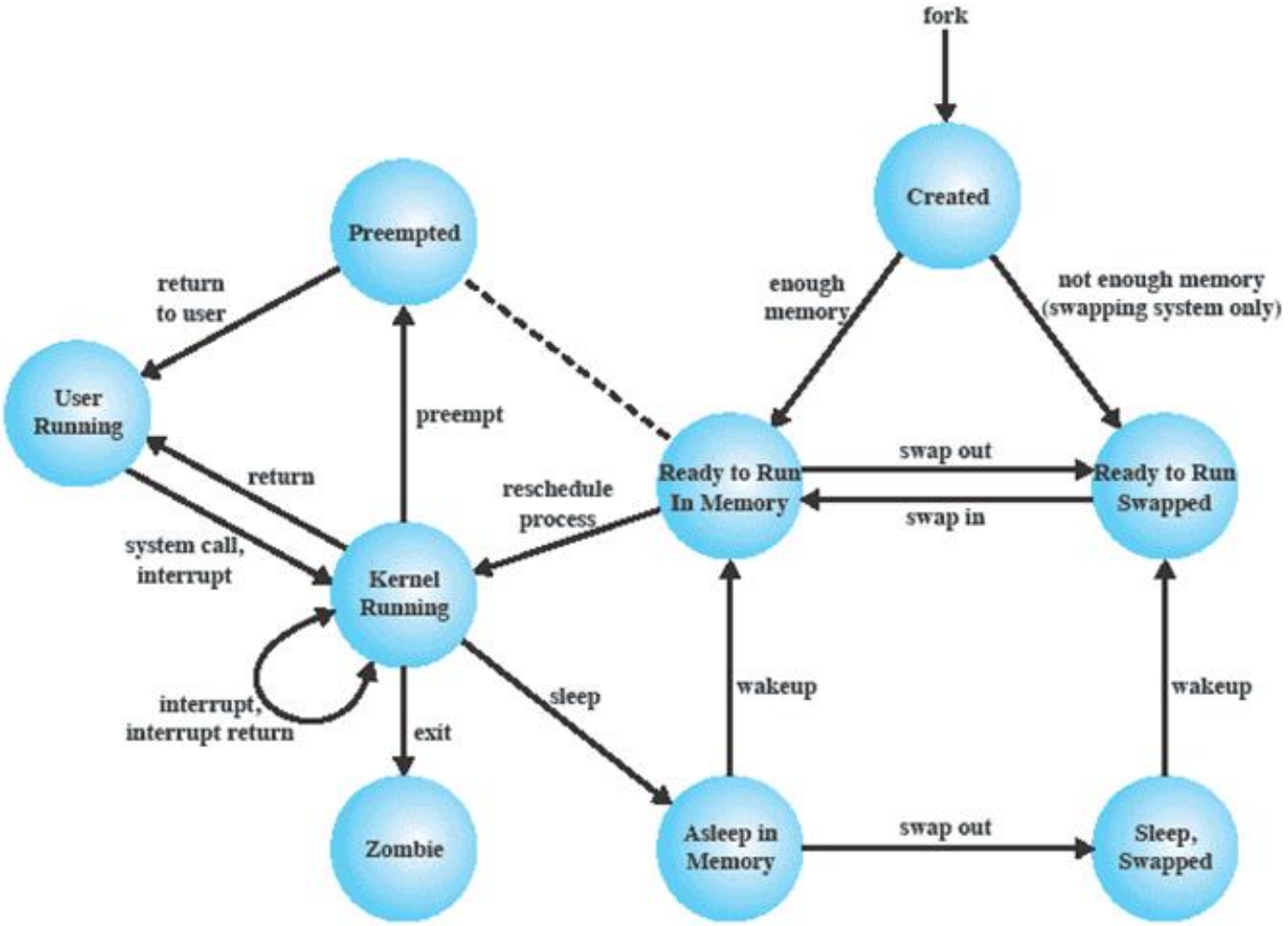
Case Study: UNIX SVR4 (cont.)

- UNIX process states

User Running	Executing in user mode.
Kernel Running	Executing in kernel mode.
Ready to Run, in Memory	Ready to run as soon as the kernel schedules it.
Asleep in Memory	Unable to execute until an event occurs; process is in main memory (a blocked state).
Ready to Run, Swapped	Process is ready to run, but the swapper must swap the process into main memory before the kernel can schedule it to execute.
Sleeping, Swapped	The process is awaiting an event and has been swapped to secondary storage (a blocked state).
Preempted	Process is returning from kernel to user mode, but the kernel preempts it and does a process switch to schedule another process.
Created	Process is newly created and not yet ready to run.
Zombie	Process no longer exists, but it leaves a record for its parent process to collect.

Case Study: UNIX SVR4 (cont.)

- UNIX Process State Transition Diagram



Case Study: UNIX SVR4 (cont.)

- A Unix Process

User-Level Context	
Process text	Executable machine instructions of the program
Process data	Data accessible by the program of this process
User stack	Contains the arguments, local variables, and pointers for functions executing in user mode
Shared memory	Memory shared with other processes, used for interprocess communication
Register Context	
Program counter	Address of next instruction to be executed; may be in kernel or user memory space of this process
Processor status register	Contains the hardware status at the time of preemption; contents and format are hardware dependent
Stack pointer	Points to the top of the kernel or user stack, depending on the mode of operation at the time or preemption
General-purpose registers	Hardware dependent
System-Level Context	
Process table entry	Defines state of a process; this information is always accessible to the operating system
U (user) area	Process control information that needs to be accessed only in the context of the process
Per process region table	Defines the mapping from virtual to physical addresses; also contains a permission field that indicates the type of access allowed the process: read-only, read-write, or read-execute
Kernel stack	Contains the stack frame of kernel procedures as the process executes in kernel mode

Case Study: UNIX SVR4 (cont.)

- UNIX Process Table Entry

Process status	Current state of process.
Pointers	To U area and process memory area (text, data, stack).
Process size	Enables the operating system to know how much space to allocate the process.
User identifiers	The **real user ID** identifies the user who is responsible for the running process. The **effective user ID** may be used by a process to gain temporary privileges associated with a particular program; while that program is being executed as part of the process, the process operates with the effective user ID.
Process identifiers	ID of this process; ID of parent process. These are set up when the process enters the Created state during the fork system call.
Event descriptor	Valid when a process is in a sleeping state; when the event occurs, the process is transferred to a ready-to-run state.
Priority	Used for process scheduling.
Signal	Enumerates signals sent to a process but not yet handled.
Timers	Include process execution time, kernel resource utilization, and user-set timer used to send alarm signal to a process.
P_link	Pointer to the next link in the ready queue (valid if process is ready to execute).
Memory status	Indicates whether process image is in main memory or swapped out. If it is in memory, this field also indicates whether it may be swapped out or is temporarily locked into main memory.

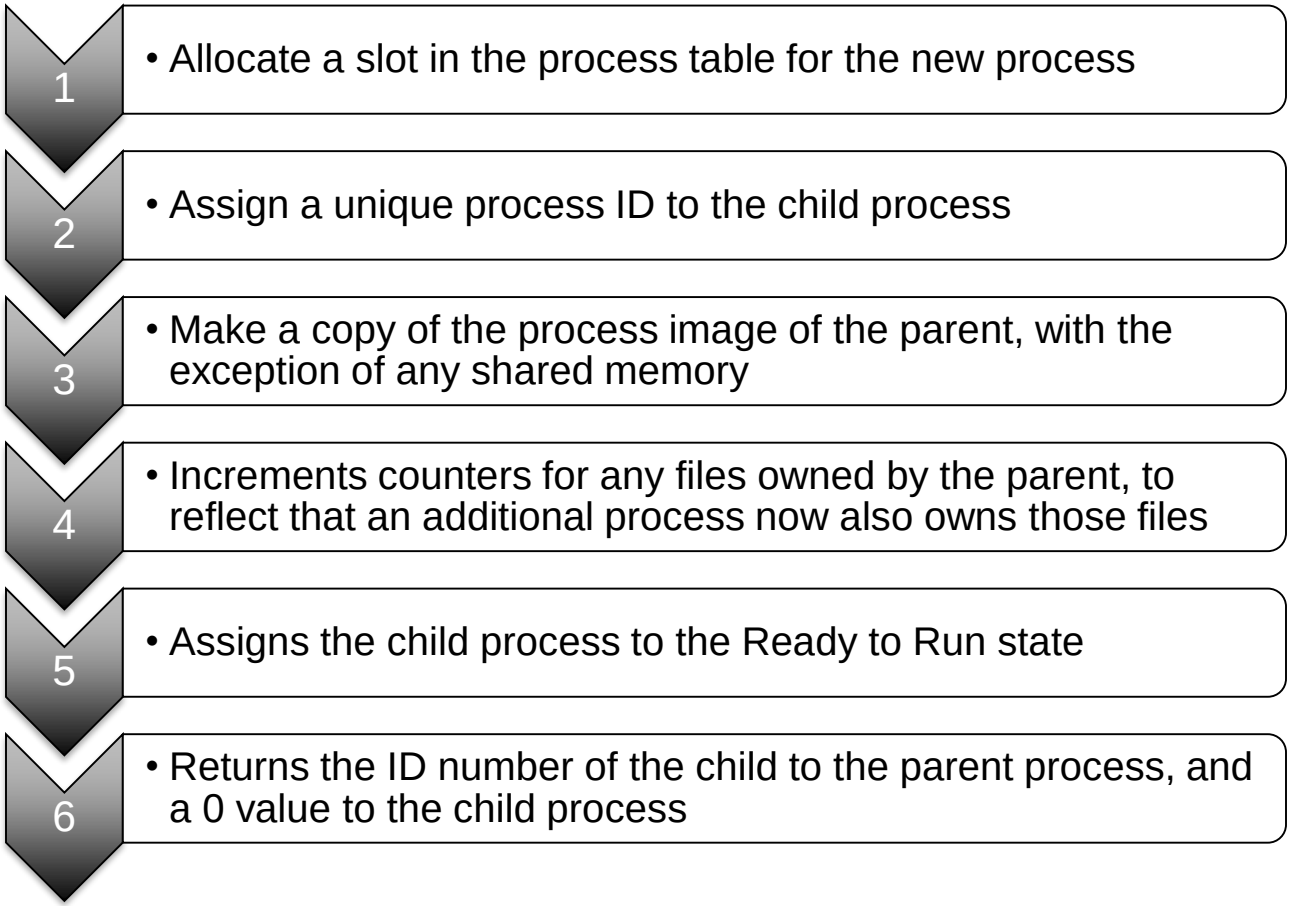
Case Study: UNIX SVR4 (cont.)

- UNIX User area

Process table pointer	Indicates entry that corresponds to the U area.
User identifiers	Real and effective user IDs. Used to determine user privileges.
Timers	Record time that the process (and its descendants) spent executing in user mode and in kernel mode.
Signal-handler array	For each type of signal defined in the system, indicates how the process will react to receipt of that signal (exit, ignore, execute specified user function).
Control terminal	Indicates login terminal for this process, if one exists.
Error field	Records errors encountered during a system call.
Return value	Contains the result of system calls.
I/O parameters	Describe the amount of data to transfer, the address of the source (or target) data array in user space, and file offsets for I/O.
File parameters	Current directory and current root describe the file system environment of the process.
User file descriptor table	Records the files the process has opened.
Limit fields	Restrict the size of the process and the size of a file it can write.
Permission modes fields	Mask mode settings on files the process creates.

Case Study: UNIX SVR4 (cont.)

- Process creation is by means of the kernel system call, fork( )
- This causes the OS, in Kernel Mode, to:



Case Study: UNIX SVR4 (cont.)

- After creation of process
  - After creating the process the Kernel can do one of the following, as part of the dispatcher routine:
    - stay in the parent process
    - transfer control to the child process
    - transfer control to another process