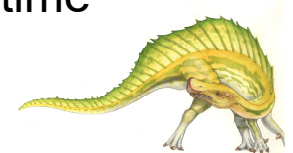
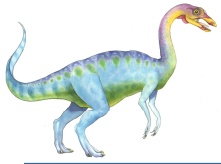


Process Concept

- 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





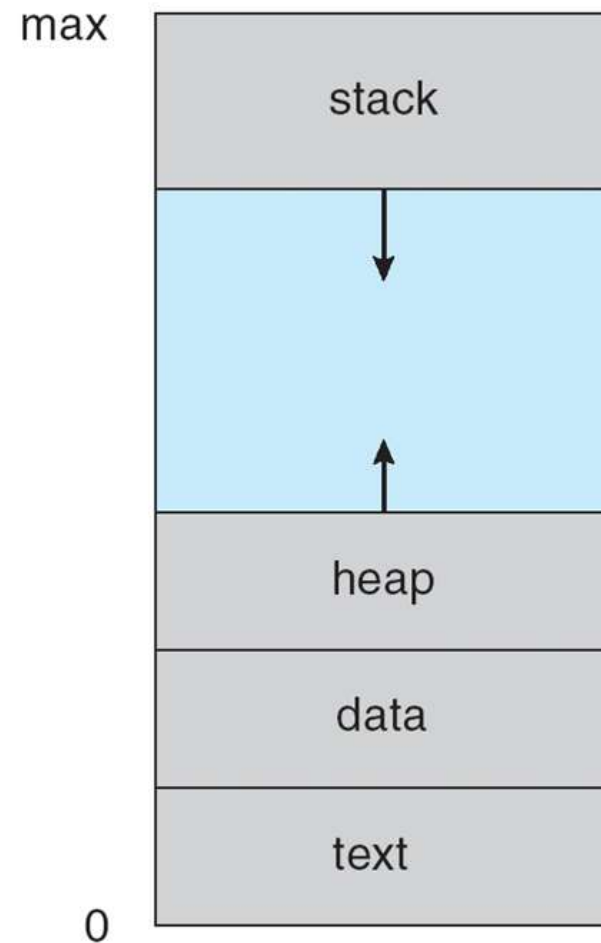
Process Concept (Cont.)

- 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 in Memory





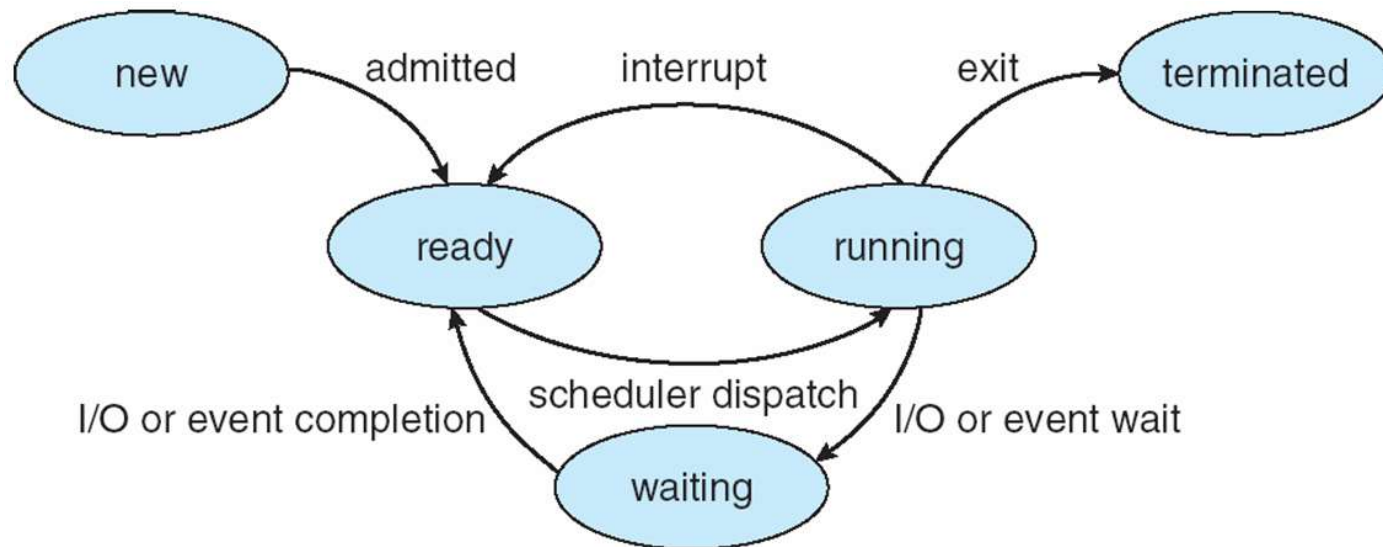
Process State

- 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

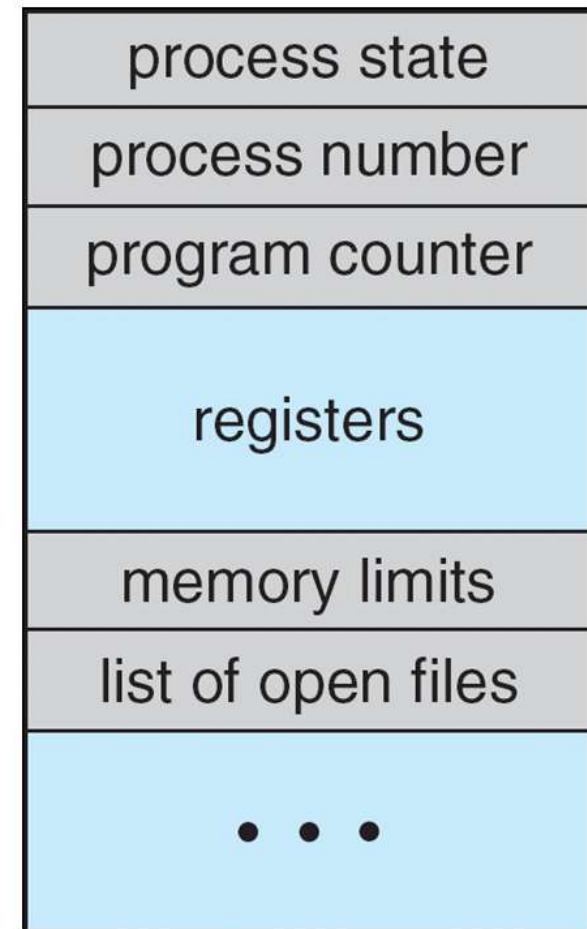




Process Control Block (PCB)

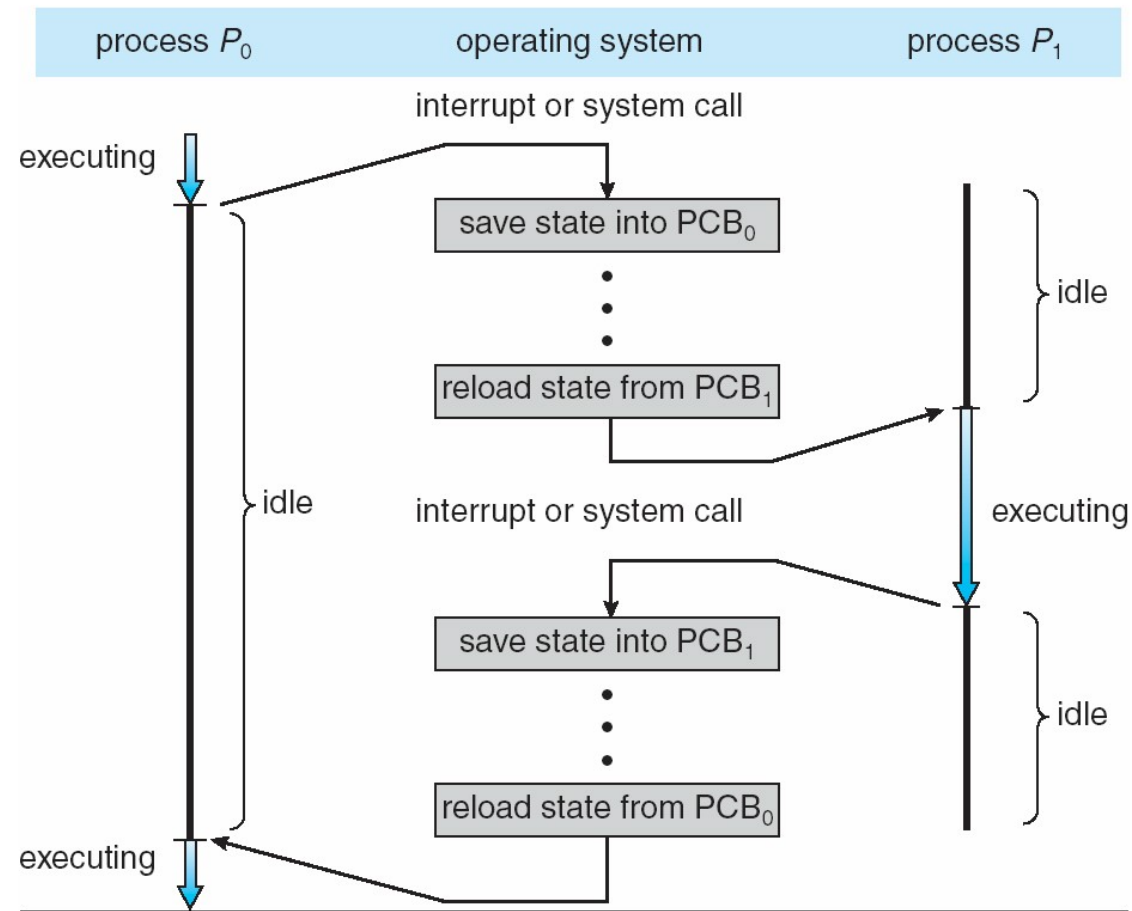
Information associated with each process
(also called **task control block**)

- ❑ 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
- ❑ Memory-management information – memory allocated to the process
- ❑ Accounting information – time limits, clock time elapsed since start
- ❑ I/O status information – I/O devices allocated to process, list of open files





CPU Switch From Process to Process

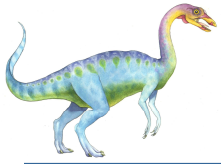




Threads

- 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
- See next chapter





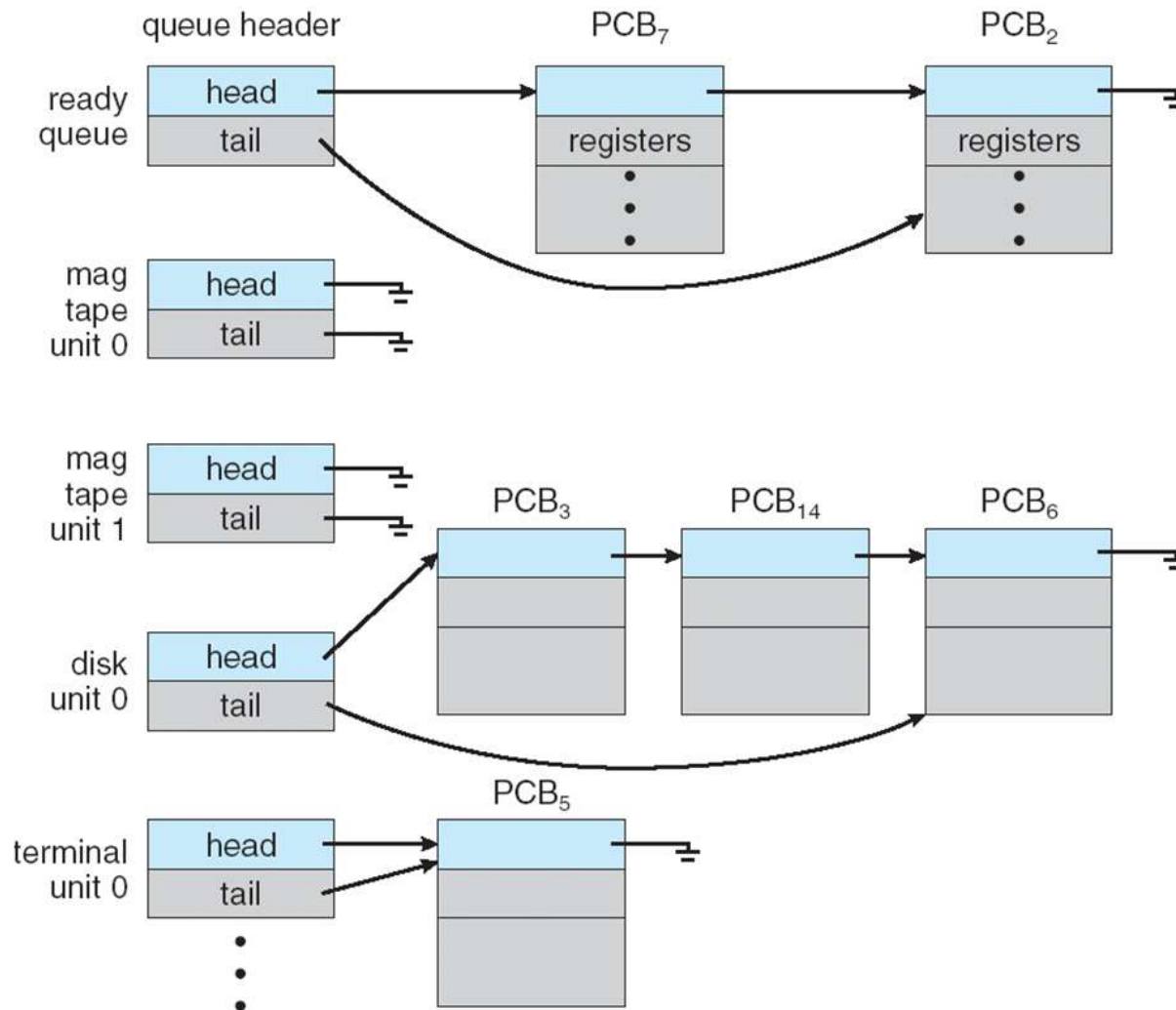
Process Scheduling

- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
 - **Job queue** – set of all processes in the system
 - **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
 - **Device queues** – set of processes waiting for an I/O device
 - Processes migrate among the various queues





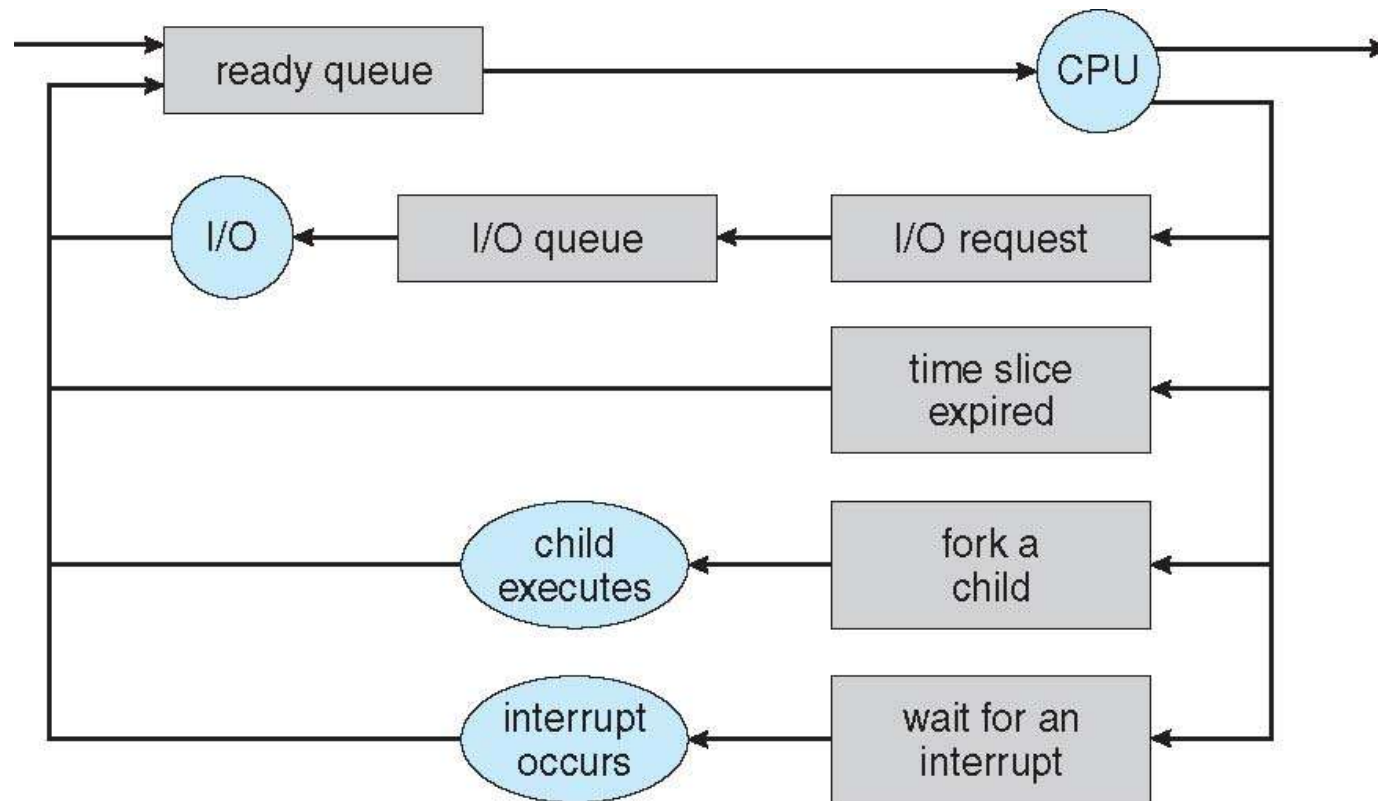
Ready Queue And Various I/O Device Queues





Representation of Process Scheduling

- Queueing diagram represents queues, resources, flows





Schedulers

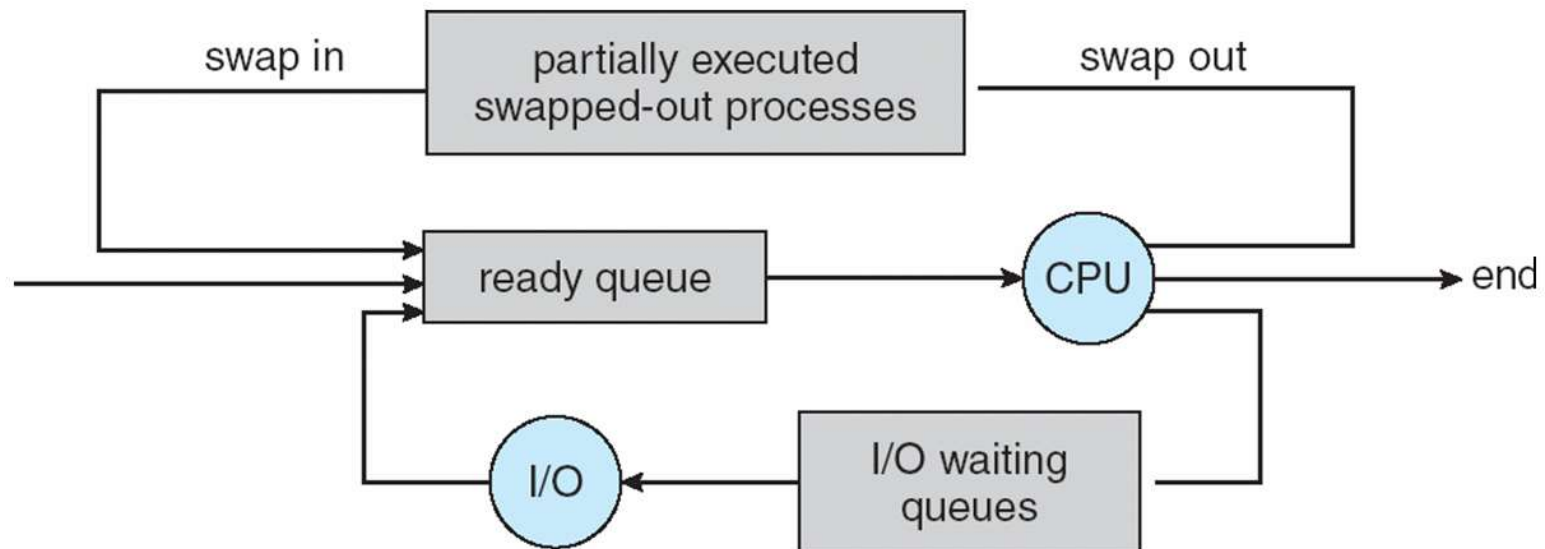
- **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
 - Sometimes the only scheduler in a system
 - Short-term scheduler is invoked frequently (milliseconds) \Rightarrow (must be fast)
- **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
 - Long-term scheduler is invoked infrequently (seconds, minutes) \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
- Long-term scheduler strives for good **process mix**
- CPU burst: a time period during which the process wants to continuously run in the CPU without making I/O

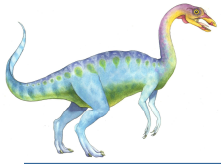




Addition of Medium Term Scheduling

- **Medium-term scheduler** can be added if degree of multiple programming needs to decrease
 - Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**

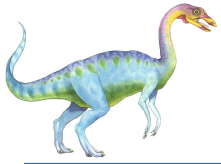




Context Switch

- When CPU switches to another process, the system must **save the state** of the old process and load the **saved state** for the new process via a **context switch**
- **Context** of a process represented in the PCB
- Context-switch time is overhead; the system does no useful work while switching
 - The more complex the OS and the PCB → the longer the context switch
- Time dependent on hardware support





Operations on Processes

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





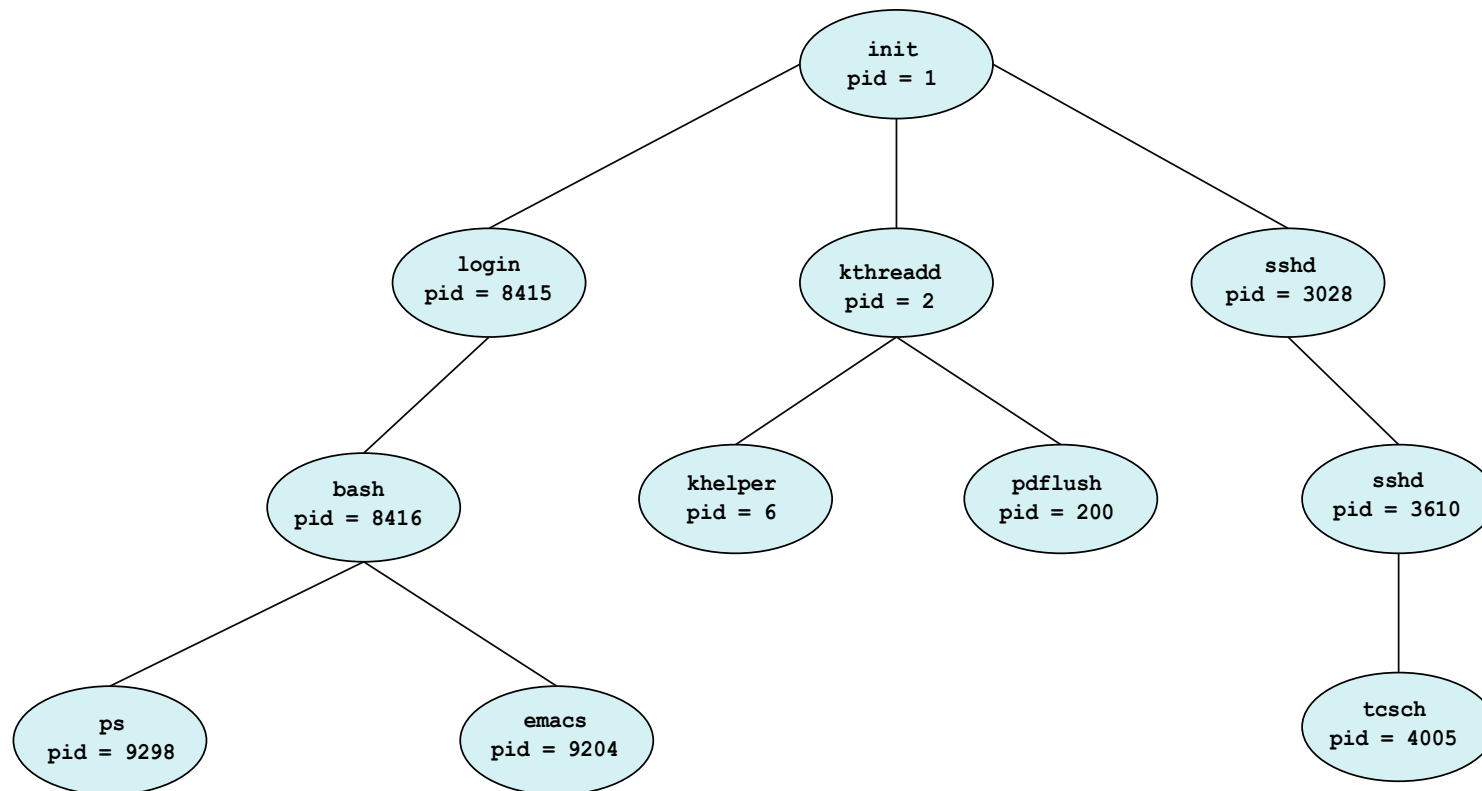
Process Creation

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





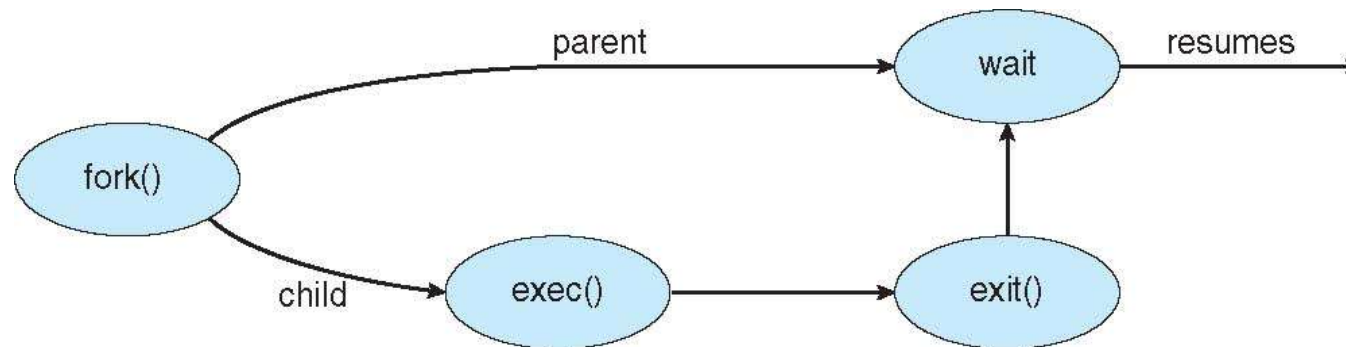
A Tree of Processes in Linux





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





C Program Forking Separate Process

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

int main()
{
    pid_t pid;

    /* fork a child process */
    pid = fork();

    if (pid < 0) { /* error occurred */
        fprintf(stderr, "Fork Failed");
        return 1;
    }
    else if (pid == 0) { /* child process */
        execlp("/bin/ls", "ls", NULL);
    }
    else { /* parent process */
        /* parent will wait for the child to complete */
        wait(NULL);
        printf("Child Complete");
    }

    return 0;
}
```

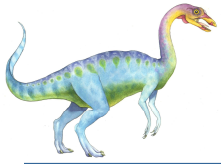




Process Termination

- Process executes last statement and then asks the operating system to delete it using the **exit()** system call.
 - Returns status data from child to parent (via **wait()**)
 - Process' resources are deallocated by operating system
- Parent may terminate the execution of children processes using the **abort()** system call. Some reasons for doing so:
 - Child has exceeded allocated resources
 - Task assigned to child is no longer required
 - The parent is exiting and the operating systems does not allow a child to continue if its parent terminates





Process Termination

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

```
pid = wait(&status);
```
- If no parent waiting (did not invoke `wait()`) process is a **zombie**
- If parent terminated without invoking `wait`, process is an **orphan**

