CS370 Operating Systems

Colorado State University
Yashwant K Malaiya

Spring 22 Lecture 5
OS Structures/Processes

Slides based on
- Text by Silberschatz, Galvin, Gagne
- Various sources

FAQ

- API vs system call User programs in a high level language use APIs, APIs are wrappers for system calls that call system routines. [Example Linux x-86 system call code].
- System call examples: soon in the class
- Why do we need API (application programing interface)? So that we don't have to write the code in assembly. [Example]
- Who came up with API standard POSIX? Committees of experts.
- Is Windows POSIX compliant? Yes, ..

Course notes

- HW2 available due Feb 10.
  - Help Session 2: This wed 5:30 PM Room CSB 425
- Self exercises in Teams
- TA: Office hours course website/TEAMSs
  - Available on Help Desk in TEAMs

CS370 Operating Systems

Colorado State University
Yashwant K Malaiya

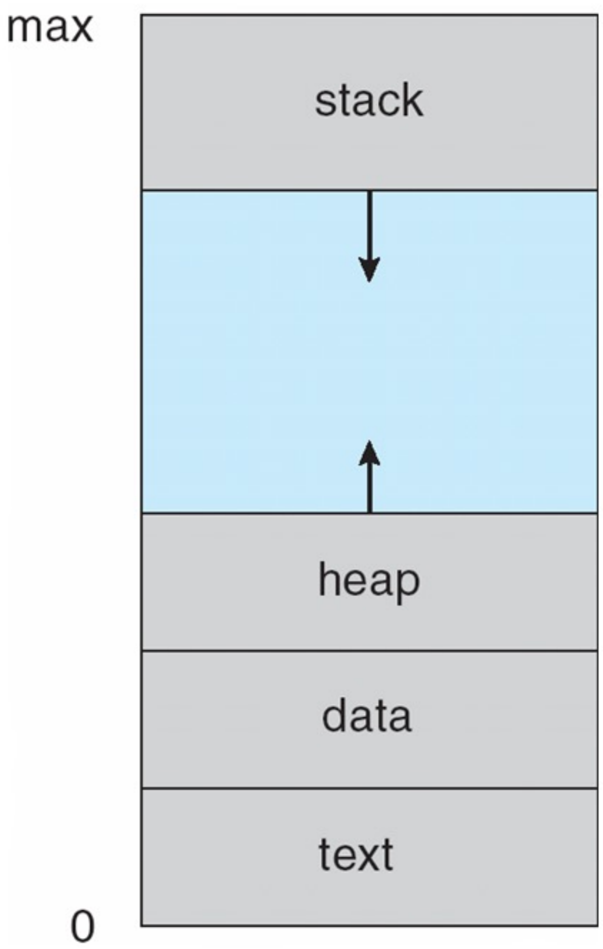
ICQ 9/7/21

CS370 OS Ch3 Processes

- Process Concept: a program in execution
- Process Scheduling
- Processes creation and termination
- Interprocess Communication using shared memory and message passing

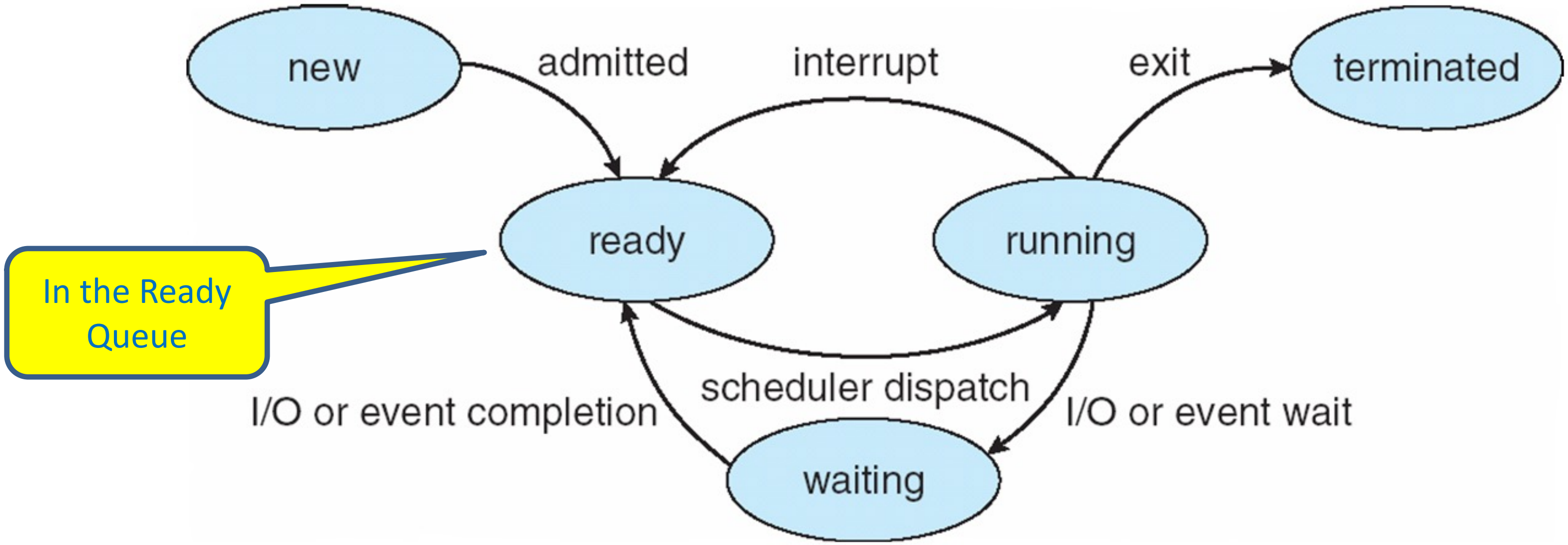
Process Concept

- 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. Includes
  - 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



Colorado State University

Diagram of Process State



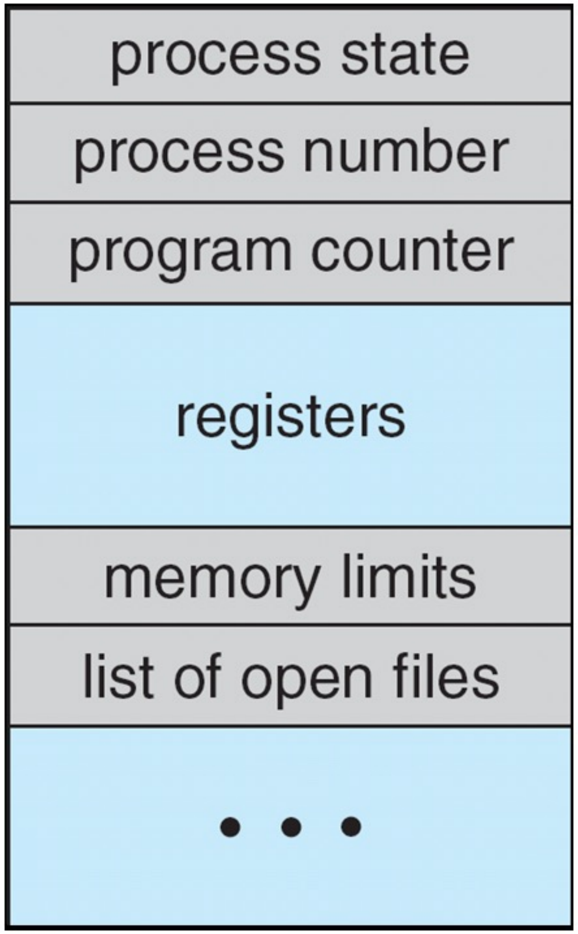
Transitions:
Ready to Running: scheduled by scheduler
Running to Ready: scheduler picks another process, back in ready queue

Running to Waiting (Blocked) : process blocks for input/output
Waiting to Ready: I/O or event done

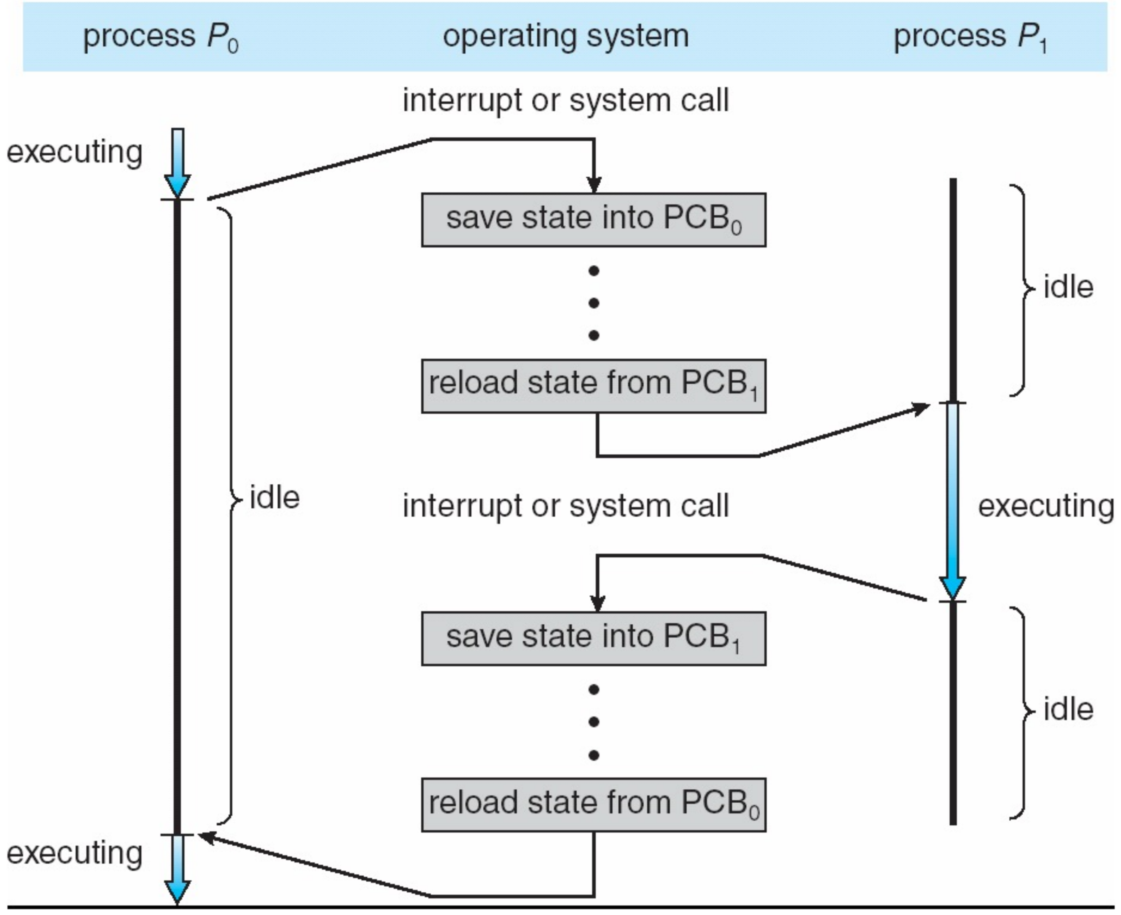
Process Control Block (PCB)

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



CPU Switch From Process to Process



Colorado State University

Processes on my computer

- Mac: apps> utilities> activity monitor > CPU etc.
- https://support.apple.com/guide/activity-monitor/welcome/mac
  - See information about processes
  - Name, PID, threads, details ..

- Windows 10 Ctrl+Alt+Del
- https://www.howtogeek.com/405806/windows-task-manager-the-complete-guide/ : Task manager

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
- Coming up in next chapter

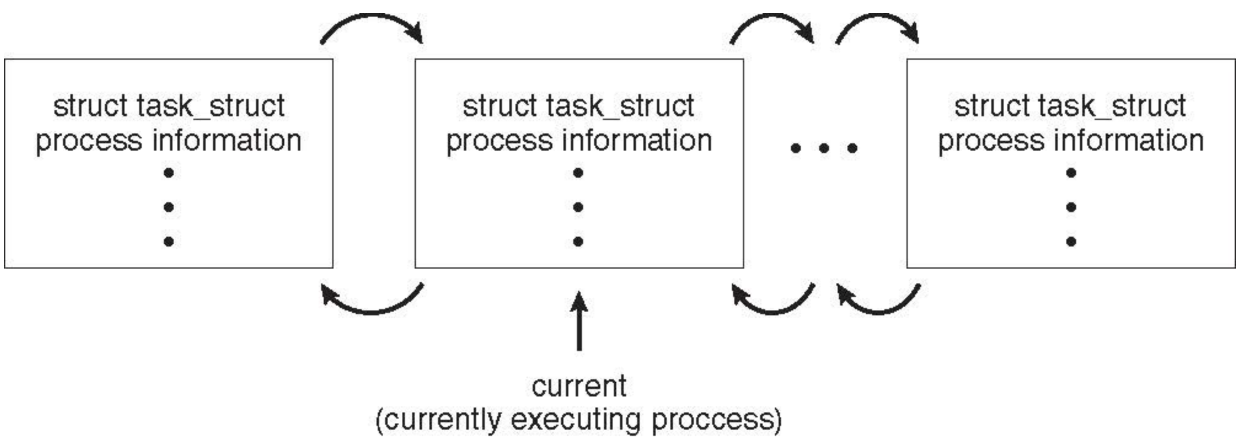
PCB Representation in Linux

Represented by the C structure `task_struct`.

Fields may include

```
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 */
```

Unlike an array, the elements of a struct can be of different data types



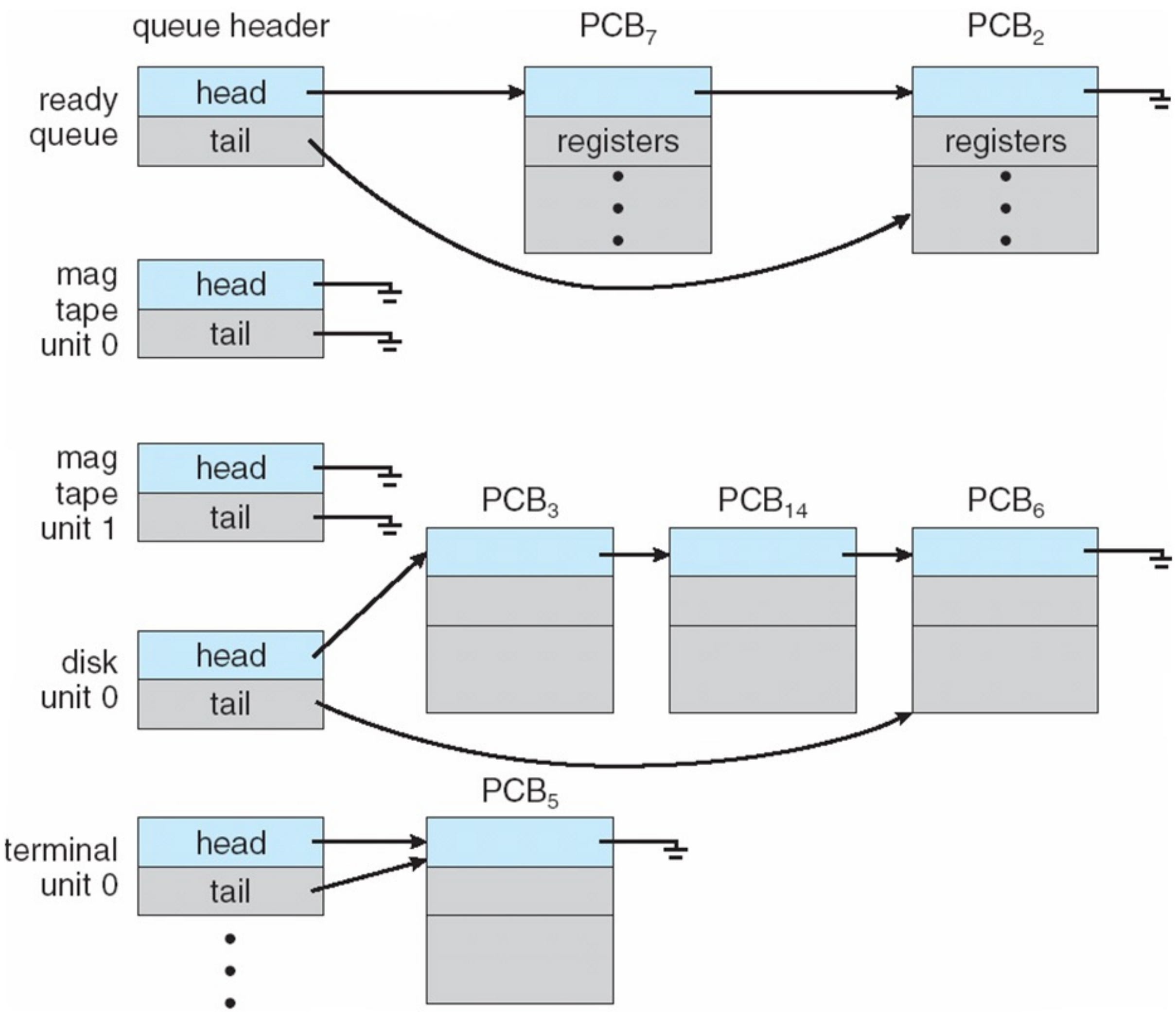
Colorado State University

Process Scheduling

Process Scheduling

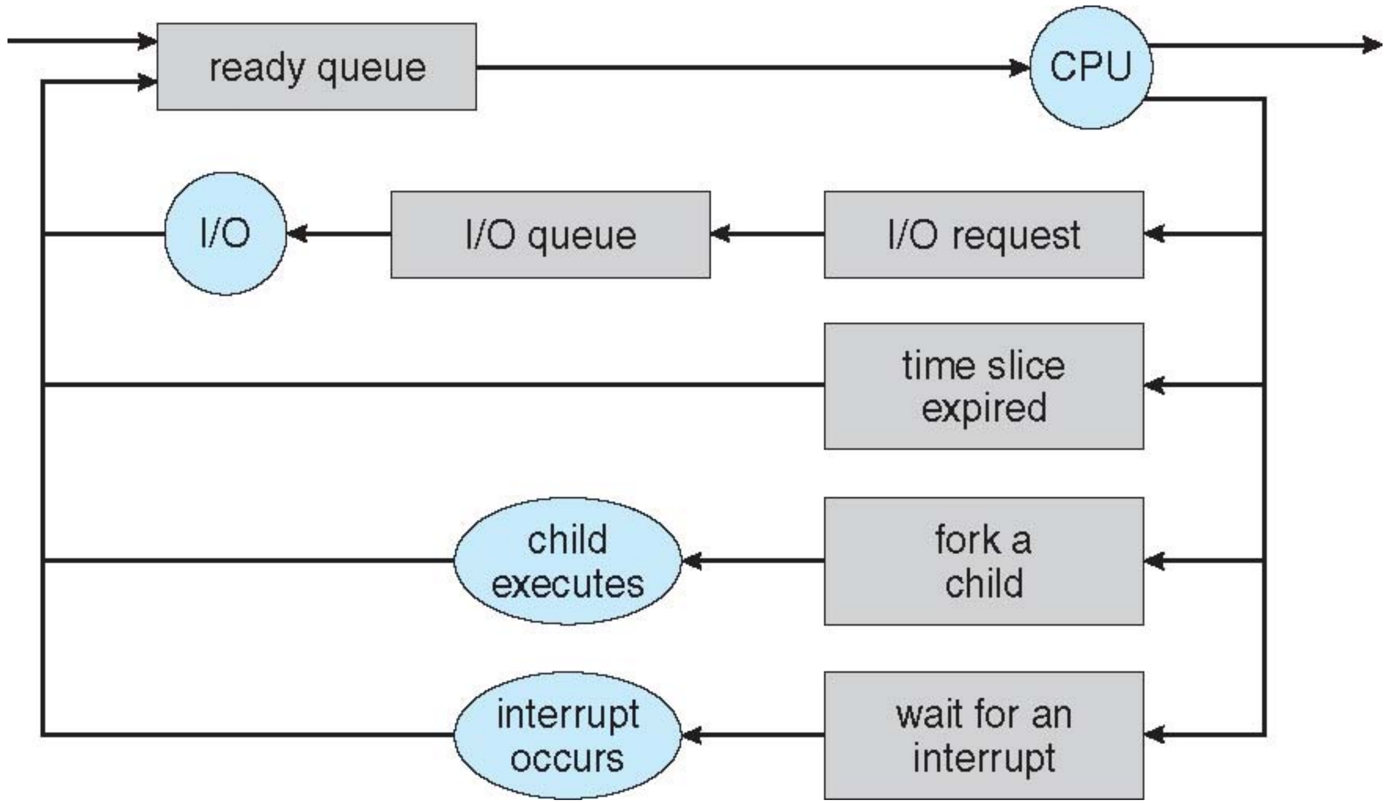
- Maximize CPU use, quickly switch processes onto CPU for time sharing
- **Process scheduler** selects among available processes for next execution on CPU
- Maintains **scheduling queues** of processes
  - **Job queue** – set of all processes in the system
  - **Ready queue** – set of all processes residing 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



Assumes a single CPU. Common until recently

Colorado State University

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***

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
- Newer iOS supports multitasking better. iOS 14: picture in picture
- 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.

www.jklossner.com
ARE YOU SURE YOU WANT TO SIT AT THE KIDS TABLE?
Window Phone 7
the ENTERPRISE
Mobile OSs

Context Switch

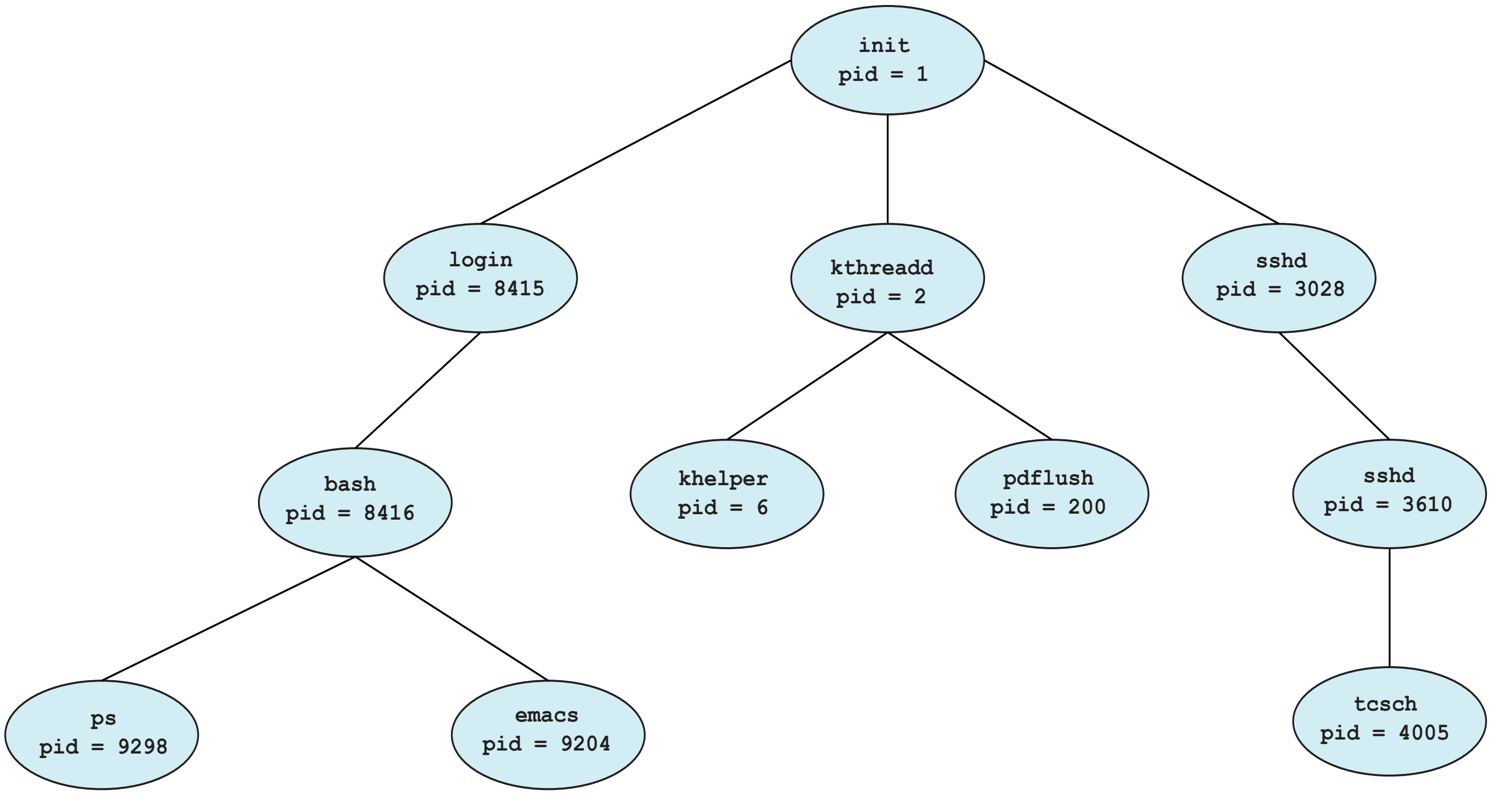
- When CPU switches to another process, the system must **save the state** of the old process and load the **saved state** for the new process via a **context switch**
- **Context** of a process represented in the PCB
- Context-switch time is overhead; the system does no useful work while switching
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

Processes creation & 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

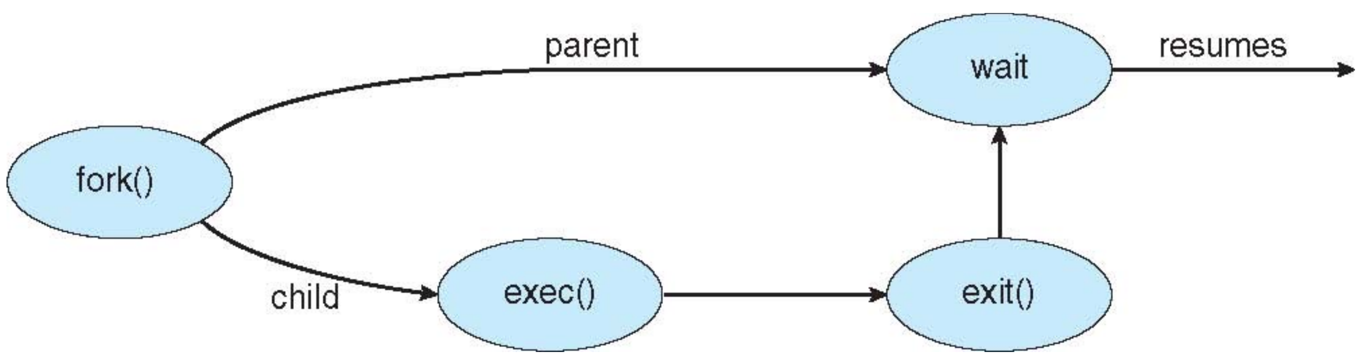
A Tree of Processes in Linux



Colorado State University

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



Colorado State University

Fork ( ) to create a child process

- Fork creates a copy of process
- Return value from fork (): integer
  - When > 0:
    - Running in (original) Parent process
    - return value is pid of new child
  - When = 0:
    - Running in new Child process
  - When < 0:
    - Error! Perhaps exceeds resource constraints. sets errno (a global variable in errno.h)
    - Running in original process
- All of the state of original process duplicated in both Parent and Child! Almost ..
  - Memory, File Descriptors (next topic), etc…

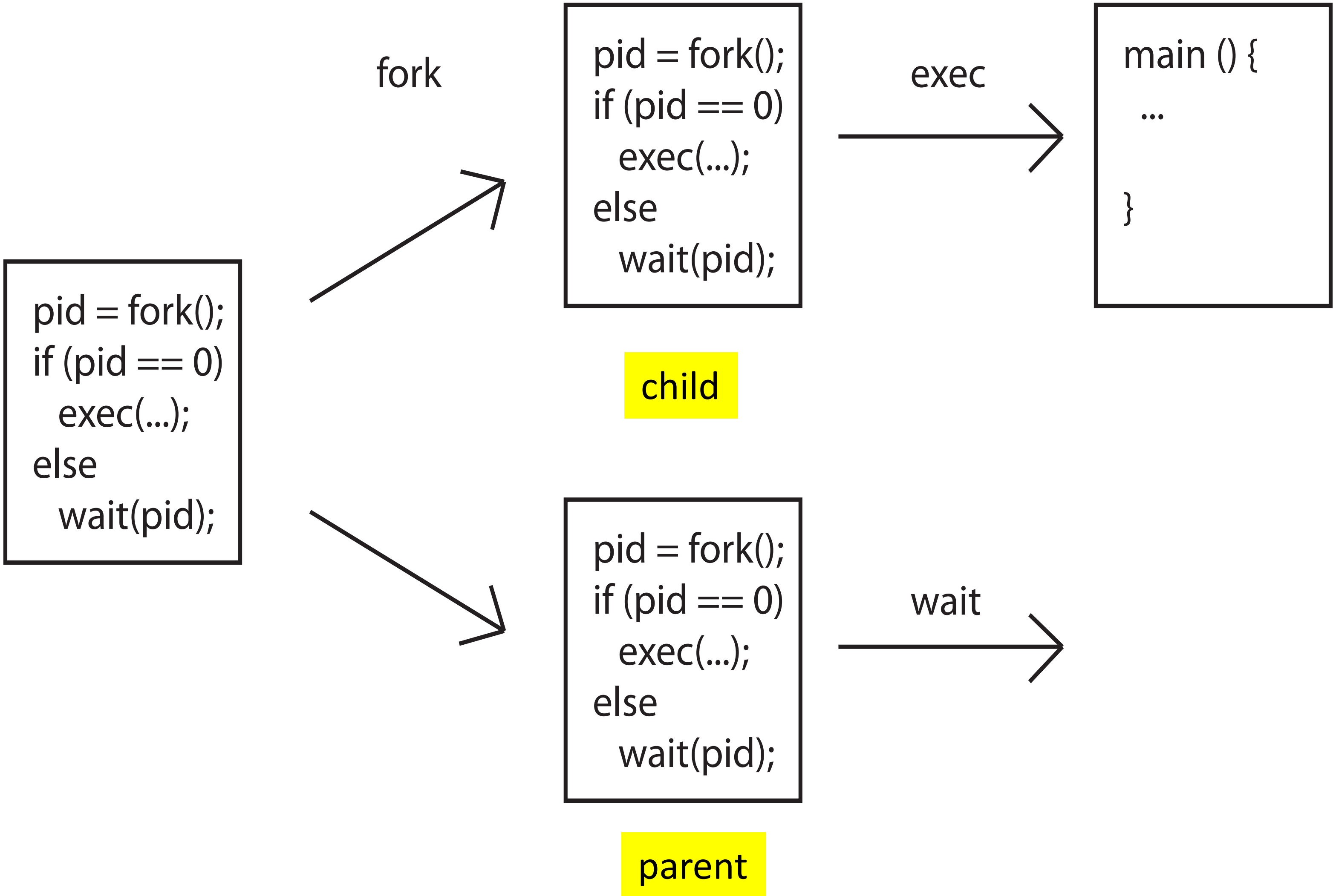
Process Management System Calls

- UNIX fork – system call to create a copy of the current process, and start it running
  - No arguments!
- UNIX exec – system call to *change the program* being run by the current process. Several variations.
- UNIX wait – system call to wait for a process to finish
- Details: see man pages

Some examples:

```
pid_t pid = getpid();   /* get current processes PID */;
waitpid(cid, 0, 0);   /* Wait for my child to terminate. */
exit (0);   /* Quit*/
kill(cid, SIGKILL);   /* Kill child*/
```

UNIX Process Management



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;
}
```

<sys/types.h> definitions of derived types
<unistd.h> POSIX API

execlp(3) - Linux man page
http://linux.die.net/man/3/execlp

Forking PIDs

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

        /* fork a child process */
        cid = fork();
        if (cid < 0) { /* error occurred */
            fprintf(stderr, "Fork Failed\n");
           return 1;
        }
        else if (cid == 0) { /* child process */
            printf("I am the child %d, my PID is %d\n", cid, getpid());
             execlp("/bin/ls","ls",NULL);
        }
        else { /* parent process */
             /* parent will wait for the child to complete */
             printf("I am the parent with PID %d, my parent is %d, my child is %d\n",getpid(), getppid(), cid);
             wait(NULL);

             printf("Child Complete\n");
        }

  return 0;
}
```

```
Ys-MacBook-Air:ch3 ymalaiya$ ./newproc-posix_m
I am the parent with PID 494, my parent is 485, my child is 496
I am the child 0, my PID is 496
DateClient.java                    newproc-posix_m

Child Complete
Ys-MacBook-Air:ch3 ymalaiya$
```

See self-exercise in Teams

https://www.tutorialspoint.com/compile_c_online.php

Colorado State University

wait/waitpid

- Wait/waitpid ( ) allows caller to suspend execution until child's status is available
- Process status availability
  - Generally after termination
  - Or if process is stopped
- pid_t waitpid(pid_t pid, int *status, int options);
- The value of pid can be:
  - 0 wait for any child process with same *process group ID* (perhaps inherited)
  - > 0 wait for child whose process group ID is equal to the value of pid
  - -1 wait for any child process *(equi to wait ( ))*
- Status: where status info needs to be saved

Linux: fork ( )

- Search for man fork( )
- http://man7.org/linux/man-pages/man2/fork.2.html

NAME fork - create a child process

SYNOPSIS #include <unistd.h>

pid_t fork(void);

DESCRIPTION fork() creates a new process by duplicating the calling process. The new process is referred to as the child process. …

The child process and the parent process run in separate memory spaces…

The child process is an exact duplicate of the parent process except for the following points: ….

RETURN VALUE On success, the PID of the child process is returned in the parent, and 0 is returned in the child. On failure, -1 is returned in the parent, no child process is created, and errno is set appropriately.

EXAMPLE See pipe(2) and wait(2).

…

errno is a global variable in errno.h

Process Group ID

- Process group is a collection of related processes
- Each process has a process group ID
- Process group leader?
  - Process with pid==pgid
- A process group has an associated controlling terminal, usually the user's keyboard
  - Control-C: sends interrupt signal (SIGINT) to all processes in the process group
  - Control-Z: sends the suspend signal (SIGSTOP) to all processes in the process group

Applies to foreground processes: those interacting
With the terminal

Process Groups

A child Inherits parent's process group ID. Parent or child can change group ID of child by using setpgid.

By default, a Process Group comprises:

- Parent (and further ancestors)
- Siblings
- Children (and further descendants)

A process can only send signals to members of its process group

- Signals are a limited form of inter-process communication used in Unix.
- Signals can be sent using system call
  - int kill(pid_t pid, int sig);

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 **`kill( )`** 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

```
kill(child_pid,SIGKILL);
```

Colorado State University

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 (it is still running, reclaimed by init)

Zombie: a process that has completed execution (via the exit system call) but still has an entry in the process table

Colorado State University

Multi-process Program Ex – Chrome Browser

- Early web browsers ran as single process
  - If one web site causes trouble, entire browser can hang or crash
- Google Chrome Browser is multiprocess with 3 different types of processes:
  - **Browser** process manages user interface, disk and network I/O
  - **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    - Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  - **Plug-in** process for each type of plug-in

Each tab represents a separate process

Multitasking

Cooperating Processes

- ***Independent*** process cannot affect or be affected by the execution of another process
- ***Cooperating*** process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience

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**

Producer-Consumer Problem

- Common paradigm for cooperating processes, *producer* process produces information that is consumed by a *consumer* process
  - **unbounded-buffer** places no practical limit on the size of the buffer
  - **bounded-buffer** assumes that there is a fixed buffer size

Why do we need a buffer (shared memory region)?
- The producer and the consumer process operate at their own speeds. Items wait in the buffer when consumer is slow.

Where does the bounded buffer "start
- It is circular

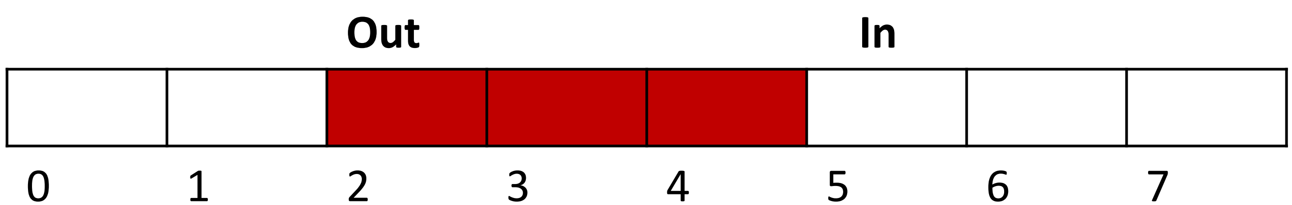
Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 8
typedef struct {
    . . .
} item;

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

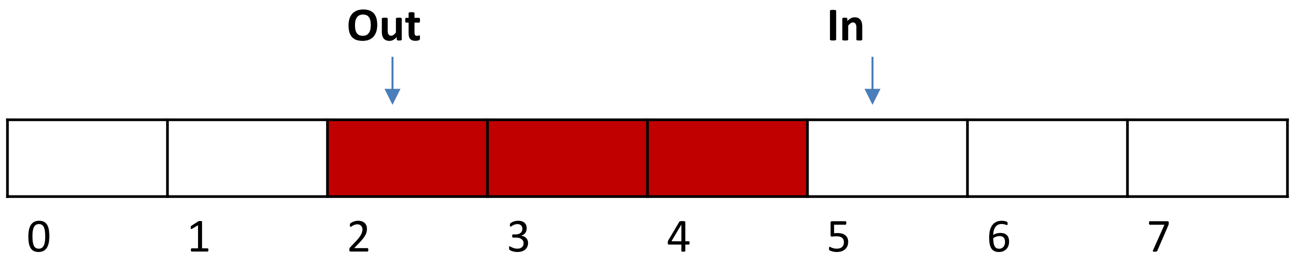
- **in** points to the **next free position** in the buffer
- **out** points to the **first full position** in the buffer.
- Buffer is empty when **in == out**;
- Buffer is full when
  ((in + 1) % BUFFER SIZE) == out.   (Circular buffer)
- This scheme can only use BUFFER_SIZE-1 elements



(2+1)%8 =3 but   (7+1)%8 =0

Bounded-Buffer – Producer

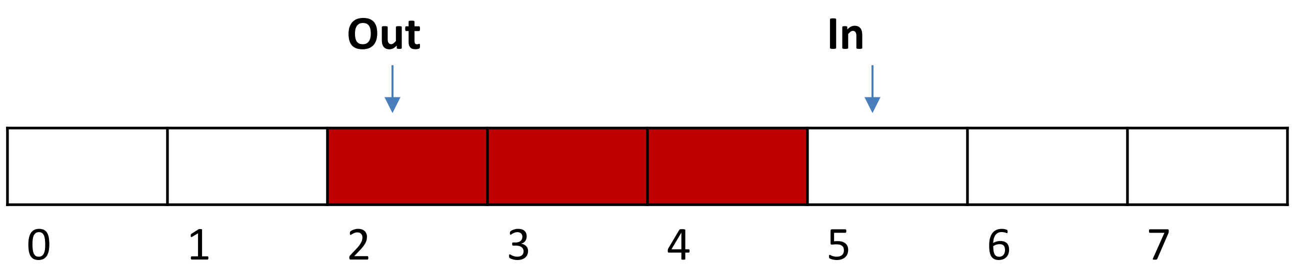
```
item next_produced;
while (true) {
        /* produce an item in next produced */
        while (((in + 1) % BUFFER_SIZE) == out)
                ; /* do nothing */
        buffer[in] = next_produced;
        in = (in + 1) % BUFFER_SIZE;
}
```



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 */
}
```



Colorado State University

Interprocess Communication – Shared Memory

- Each process has its own private address space.
- An area of memory shared among the processes that wish to communicate
- The communication is under the control of the user processes, not the operating system.
- Major issue 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 a later Chapter.
- Example soon.

Only one process may access shared memory at a time

Interprocess Communication – Message Passing

- Mechanism for processes to communicate and to synchronize their actions
- Message system – 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?

Message Passing (Cont.)

- Implementation of communication link
  - Physical:
    - Shared memory
    - Hardware bus
    - Network
  - Logical: Options (details next)
    - Direct (process to process) or indirect (mail box)
    - Synchronous (blocking) or asynchronous (non-blocking)
    - Automatic or explicit buffering