# Ch 4: Operating-System Design

Bill Cheng

*http://merlot.usc.edu/cs402-s16*







## OS Design

- We will now look at how OSes are constructed
  - what goes into an OS
  - how they interact with each other
  - how is the software structured
  - how performance concerns are factoered in
- We will introduce new components in this chapter
  - scheduling (Ch 5)
  - file systems (Ch 6)
  - virtual memory (Ch 7)
- We will start with a simple hardware configuration
  - what OS is needed to support this
- Applications views the OS as the "computer"
  - the OS needs to provide a *consistent* and *usable interface*
    - while being *secure* and *efficient*
  - that's a pretty tall order!







## OS Design

- Our goal is to *build a general-purpose OS*
  - can run a variety of applications
    - some are interactive
    - many use network communication
    - all read/write to a file system
  - it's like most general-purpose OSes
    - Linux
    - Solaris
    - FreeBSD
    - Mac OS X
    - Chromium OS (has a Linux kernel)
    - Windows (the only one that's not directly based on Unix)
  - all these OSes are quite similar, functionally! they all provide:
    - processes
    - threads
    - file systems
    - network protocols with similar APIs
    - user interface with display, mouse, keyboard
    - access control based on file ownership and that file owers can control







## OS Design Issues

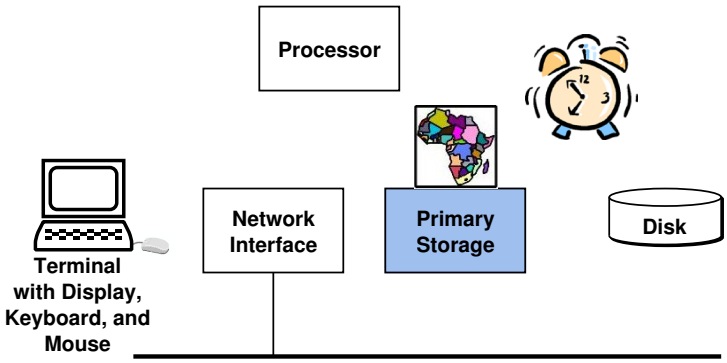
- Performance
  - efficiency of application
- Modularity
  - tradeoffs between modularity and performance
- Device independence
  - for new devices, don't need to write a new OS
- Security/Isolation
  - isolate OS from application







## Simple Configuration



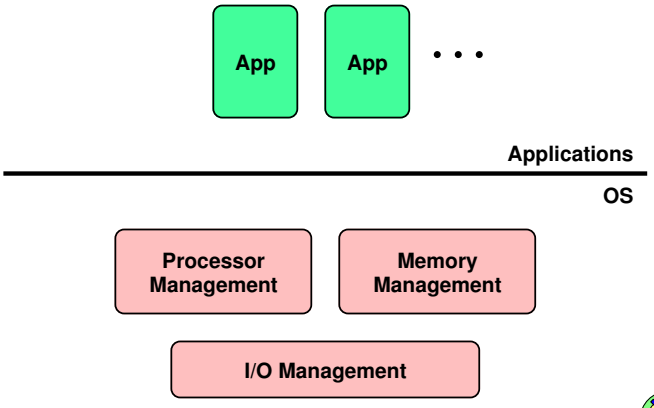

- Early 1980s OS, so we can focus on the basic OS issues
  - no support for bit-mapped displays and mice
  - generally *less efficient* design







## OS Components




# A Simple System: To Be Discussed

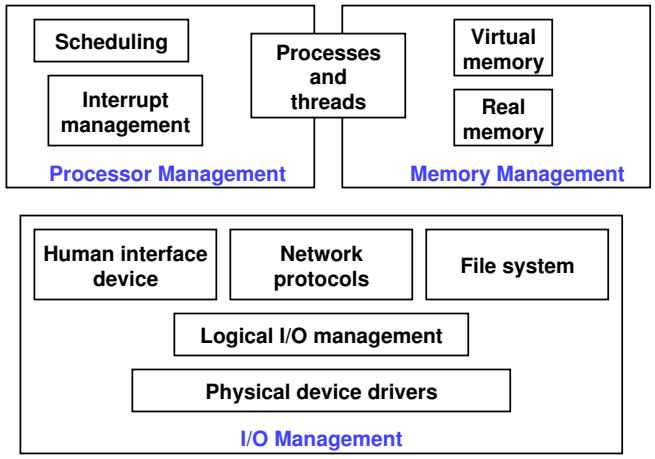
- What is the functionality of the components?
- What are the key data structures?
- What mechanisms are there to support the applications?
- How is the system broken up into modules?
- To what extent is the system extensible?
- What parts run in the OS kernel in privileged mode? What parts run as library code in user applications? What parts run as separate applications?
- In which execution contexts do the various activities take place?
  - e.g., thread context vs. interrupt context







# OS Components

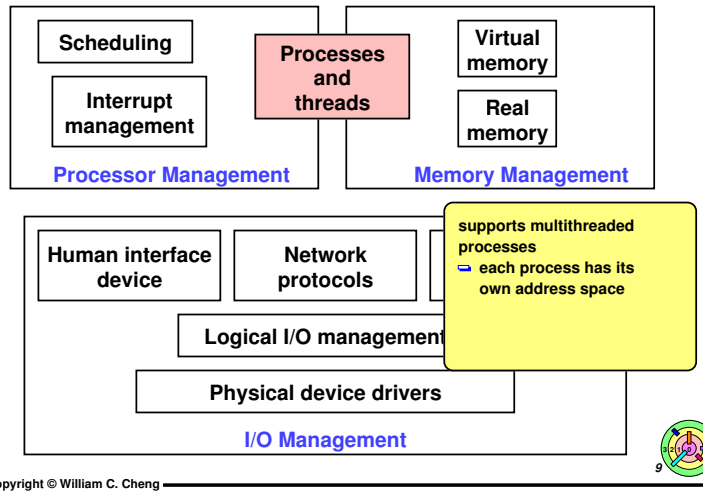









# OS Components



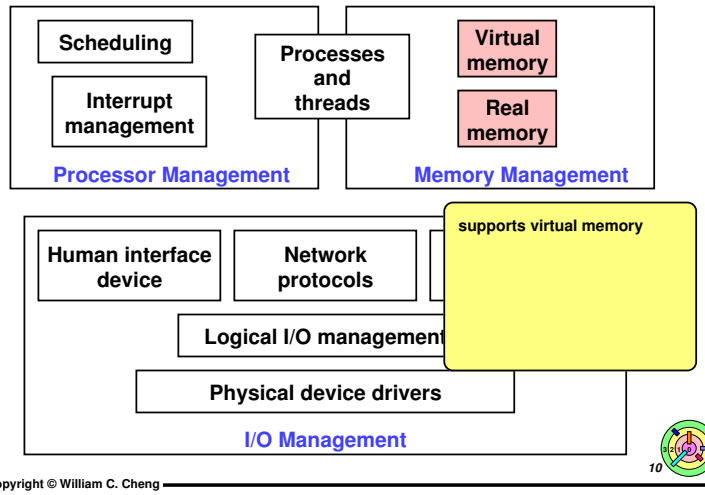









# OS Components



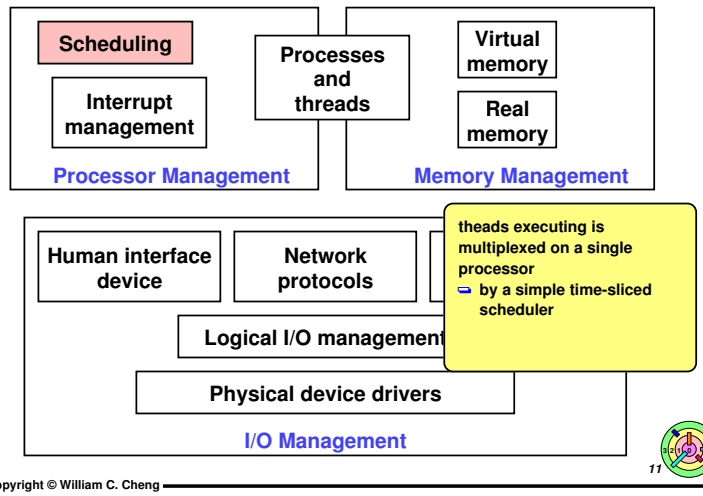









# OS Components



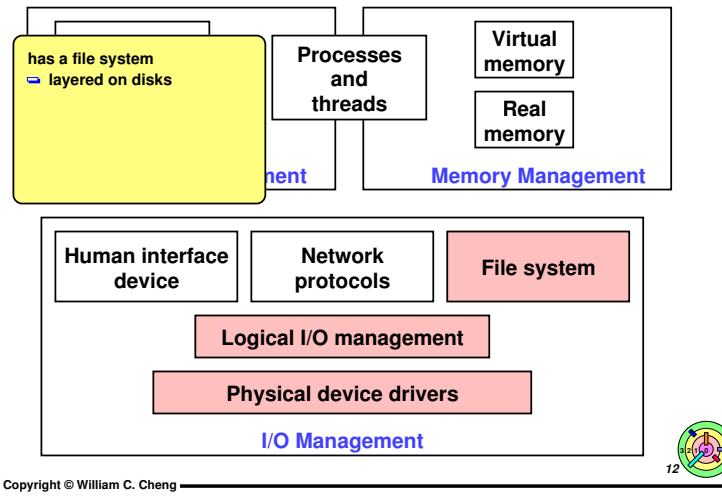




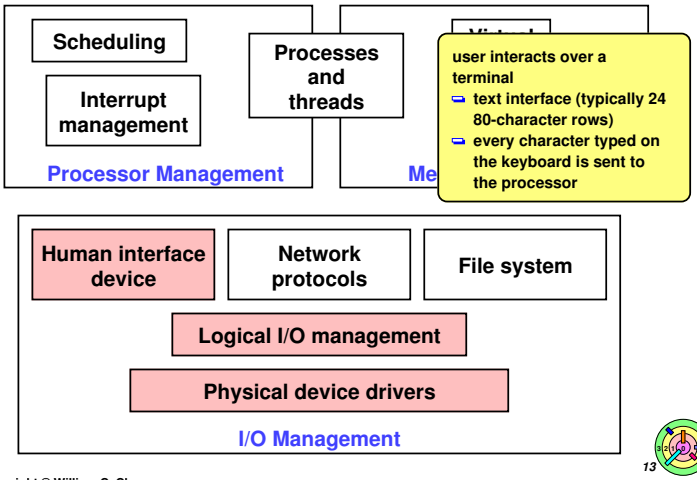





# OS Components



## OS Components

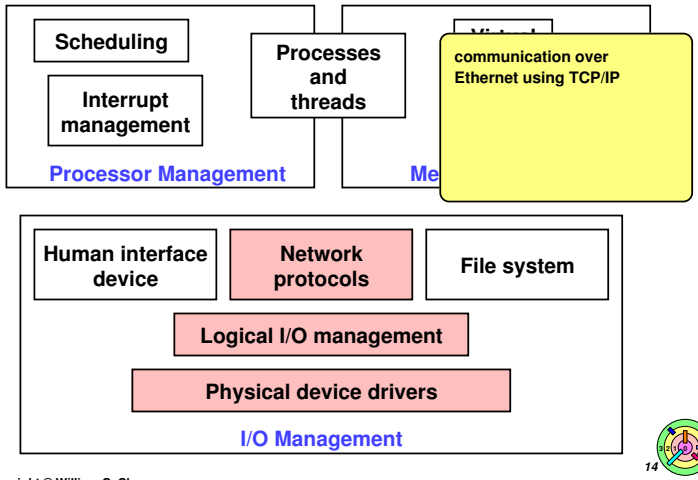









## OS Components










## Some Important OS Concepts

- From an application program's point of view, our system has:
  - processes with threads
  - a file system
  - terminals (with keyboards)
  - a network connection
- Need more details on these... Need to look at:
  - how can they be provided
  - how applications use them
  - how this affects the design of the OS







## Processes And File Systems

- The purpose of a *process*
  - holds an *address space*
  - holds a group of *threads* that execute within that address space
  - holds a collection of references to *open files* and other *"execution context"*
- *Address space:*
  - set of addresses that threads of the process can usefully reference
  - more precisely, it's the content of these addressable locations
    - text, data, bss, dynamic, stack regions and what's in them







## Processes And File Systems

- Design issue:
  - how should the OS *initialize* these address space regions?
- Simple approach: copy their contents from the file system to the process address space (as part of the *exec* operation)
  - quite wasteful (both in space and time) for the text region since it's read-only data
    - should *share* the text region
  - what about data regions? they can potentially be written into
    - can also *share* a portion of a data region if that portion is never modified







## Remember This?

- *Virtual Memory*

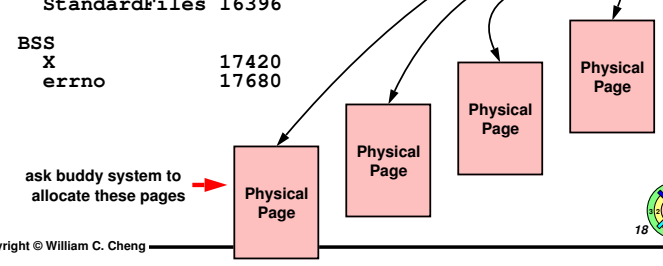
```
Text
  main          4096
  subr          4132
  printf        4156
  write        16156
  startup      16172

Data
  aX           16384
  printfargs   16388
  StandardFiles 16396

BSS
  X            17420
  errno        17680
```

Page Table

| Start | Access | Physical Addr |
|---|---|---|
| 0 | - | - |
| 4096 | R | |
| 8192 | R | |
| 12288 | R | |
| 16384 | R/W | |



# Processes Can Share Memory Pages

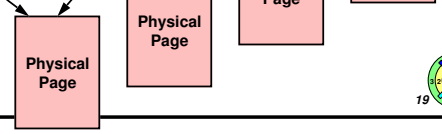
- Inside `fork()`, can simply copy parent's page table to child

Child Page Table

| Start | Access | Physical Addr |
|---|---|---|
| 0 | - | - |
| 4096 | R | |
| 8192 | R | |
| 12288 | R | |
| 16384 | R/W | |

Parent Page Table

| Start | Access | Physical Addr |
|---|---|---|
| 0 | - | - |
| 4096 | R | |
| 8192 | R | |
| 12288 | R | |
| 16384 | R/W | |







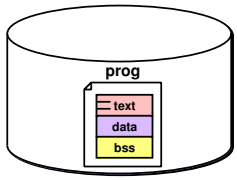



# exec()

- Inside `exec()`, need to wipe out the address space (and page table) and create a new address space (and page table)

Child Page Table

| Start | Access | Physical Addr |
|---|---|---|
| 0 | - | - |
| 4096 | - | - |
| 8192 | - | - |
| 12288 | - | - |
| 16384 | - | - |










# Memory Map

- For the text region, why bother copying the executable file into the address space in the first place?
  - can just *map* the *file* into the *address space* (Ch 7)
    - *mapping* is an important concept in the OS
    - *mapping* let the OS *tie* the regions of the address space to the file system
    - address space and files are divided into pieces, called *pages*
    - if several processes are executing the same program, then at most one copy of that program's text page is in memory at once
  - *text regions* of all processes running this program are setup, using hardware address translation facilities, to share these pages
    - this type of mapping is known as *shared mapping*







# Memory Map

- The kernel uses a *memory map* to keep track of the mapping from *virtual pages* to *file pages*

Child Page Table

| Start | Access | Physical Addr |
|---|---|---|
| 0 | - | - |
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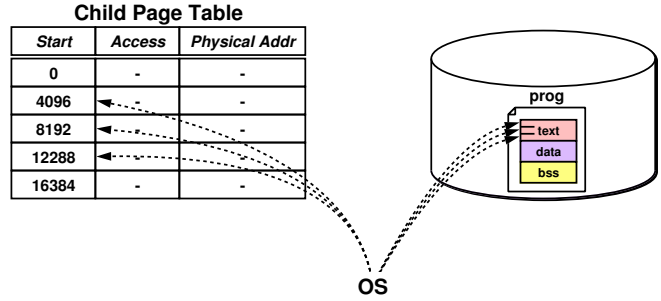
| 8192 | - | - |
| 12288 | - | - |
| 16384 | - | - |




  - the kernel also uses *memory map* to keep track of the mapping from *virtual pages* to *physical pages*







# Processes Can Share Memory Pages

Child Page Table

| Start | Access | Physical Addr |
|---|---|---|
| 0 | - | - |
| 4096 | R | |
| 8192 | R | |
| 12288 | R | |
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Parent Page Table

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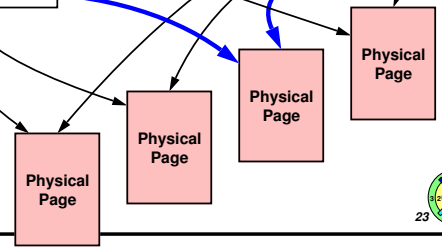



- can we really share *data segment* pages?







# Processes And File Systems

- *Data regions* of all processes running this program *initially* refer to pages of memory containing a copy of the *initial* data region
  - this type of mapping is known as *private mapping*
    - when does each process really need a private copy of such a page?
    - when data is *modified* by a process, it gets a *new* and *private* copy of the initial page

## Copy-On-Write

- *Copy-on-write (COW):*
  - a process gets a *private* copy of the page after a thread in the process performs a *write* for the *first time*
    - the basic idea is that only those pages of memory that are modified are copied
- The dynamic/heap and stack regions use a special form of private mapping
  - their pages are initialized, with zeros; *copy-on-write*
    - these are known as *anonymous pages*
    - managed by *anonymous objects* in `weenix`






## Shared Files

- If a bunch of processes *share* a *file*
  - we can also *map* the file into the *address space* of each process
  - in this case, the mapping is *shared*
  - when one process modifies a page, no private copy is made
    - instead, the original page itself is modified
    - everyone gets the changes
    - and changes are written back to the file
      - more on issues in Ch 6






## Block I/O vs. Sequential I/O

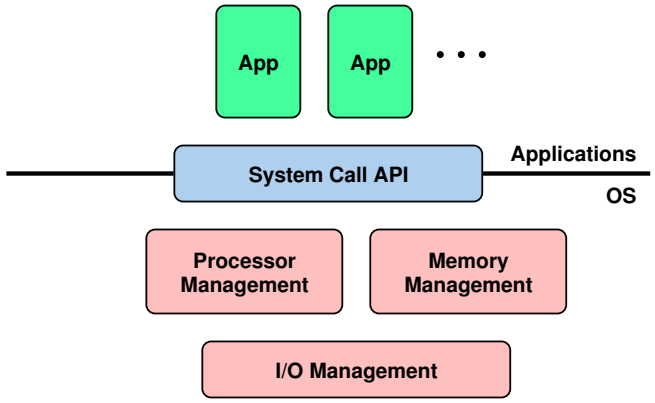
- Mapping files into address space is one way to perform I/O on files
  - block/page is the basic unit
  - this is referred to as *block I/O*
- Some devices cannot be mapped into the address space
  - e.g., receiving characters typed into the keyboard, sending a message via a network connection
  - need a more traditional approach using explicit system calls such as `read()` and `write()`
  - this is referred to as *sequential I/O*
- It also makes sense to be able to read a file like reading from the keyboard
  - similarly, a program that produces lines of text as output should be able to use the same code to write output to a file or write it out to a network connection
  - makes life easier! (and make code more robust)






## System Call API

- Backwards compatibility is an important issue
  - try not to change it much (to make the developers happy)



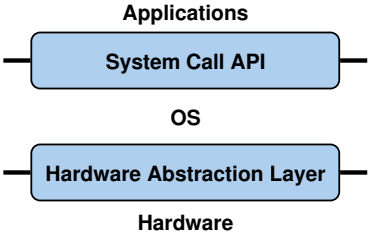






## Portability

- It is desirable to have a portable operating system
  - portable across various hardware platforms
- For a monolithic OS, it is achieved through the use of a *Hardware Abstraction Layer (HAL)*
  - a *portable interface* to *machine configuration* and *processor-specific operations* within the kernel









## Hardware Abstraction Layer (HAL)

- Portability across machine configuration
  - e.g., different manufacturers for x86 machines will require different code to configure interrupts, hardware timers, etc.
- Portability across processor families
  - e.g., may need additional code for context switching, system calls, interrupting handler, virtual memmory management, etc.
- With a well-defined Hardware Abstraction Layer, most of the OS is *machine* and *processor independent*
  - porting an OS to a new computer is done by
    - writing new HAL routines
    - relink with the kernel

# 4.1 A Simple System (Monolithic Kernel)

- *A Framework for Devices*
- Low-level Kernel (will come back to talk about this after Ch 7)
- Processes & Threads
- Storage Management (will come back to talk about this after Ch 5)







## Computer Terminal

- VT100







## A "tty"







## Devices

- Challenges in supporting devices
  - device independence
  - device discovery
- Device naming
  - two choices
    - independent name space (i.e., named independently from other things in the system)
    - devices are named as files







## A Framework for Devices

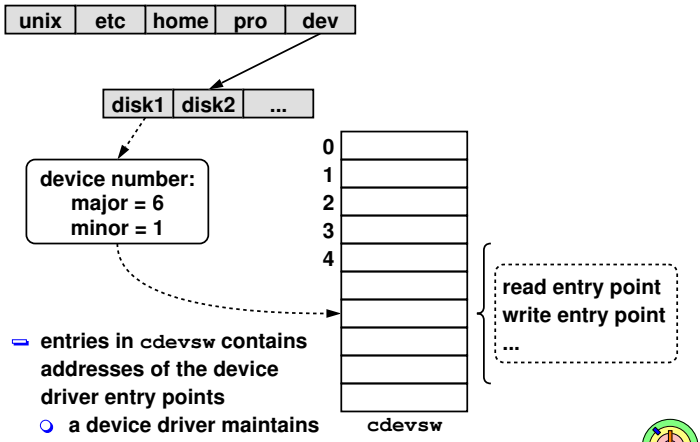
- Device driver:
  - every device is identified by a device "number", which is actually a pair of numbers
    - a *major device number* - identifies the device driver
    - a *minor device number* - device index for all devices managed by the same device driver
- Special entries were created in the file system to refer to devices
  - usually in the `/dev` directory
    - e.g., `/dev/disk1`, `/dev/disk2` each marked as a *special file*
      - a *special file* does not contain data
      - it refers to devices by their major and minor device numbers
      - if you do "`ls -l`", you can see the device numbers
- Data structure in the early Unix systems
  - statically allocated array in the kernel called `cdevsw` (character device switch)







## Finding Devices




- entries in `cdevsw` contains addresses of the device driver entry points
  - a device driver maintains its own data structure

## Device Drivers in Early Unix Systems

- The kernel was statically configured to contain device-specific information such as:
  - interrupt-vector locations
  - locations of device-control registeres on whatever bus the device was attached to
- Static approach was simple, but cannot be easily extended
  - a kernel must be custom configured for each installation







## Device Probing

- First step to improve the old way
  - allow the devices to to be found and automatically configured when the system booted
  - (still require that a kernel contain all necessary device drivers)
- Each device driver includes a ***probe routine***
  - invoked at boot time
  - probe the relevant buses for devices and configure them
    - including identifying and recording interrupt-vector and device-control-register locations
- This allowed one kernel image to be built that could be useful for a number of similar but not identical installations
  - boot time is kind of long
  - impractical as the number of supported devices gets big







## Device Probing

- What's the right thing to do?
  - Step 1: discover the device without the benefit of having the relevant device driver in the kernel
  - Step 2: find the needed device drivers and dynamically link them into the kernel
  - but how do you achieve this?
- Solution: use meta-drivers
  - a meta-drive handles a particular kind of bus
  - e.g., USB (Universal Serial Bus)
    - a USB meta-driver is installed into the kernel
    - any device that goes onto a USB (Universal Serial Bus) must know how to interact with the USB meta-driver via the ***USB protocol***
    - once a connected device is identified, system software would select the appropriate device driver and load into the kernel
    - what about applications? how can they reference dynamically discovered devices?







## Discovering Devices

- So, you plug in a new device to your computer on a particular bus
  - OS would notice
  - find a device driver
    - what kind of device is it?
    - where is the driver?
  - assign a name, but how is it chosen?
  - multiple similar devices, but how does application choose?
- In some Linux systems, entries are added into `/dev` as the kernel discovers them
  - lookup the names from a database of names known as `devfs`
    - downside of this approach is that device naming conventions not universally accepted
    - what's an application to do?
  - some current Linux systems use `udev`
    - user-level application assigns names based on rules provided by an administrator







## Discovering Devices

- What about the case where different devices acted similarly?
  - e.g., touchpad on a laptop and USB mouse
  - how should the choice be presented to applications?
- Windows has the notion of ***interface classes***
  - a device can register itself as members of one or more such classes
  - an application can ***enumerate*** all currently connected members of such a class and choose among them (or use them all)







# 4.1 A Simple System (Monolithic Kernel)

- A Framework for Devices
- Low-level Kernel (will come back to talk about this after Ch 7)
- ***Processes & Threads***
- Storage Management (will come back to talk about this after Ch 5)

## Processes and Threads

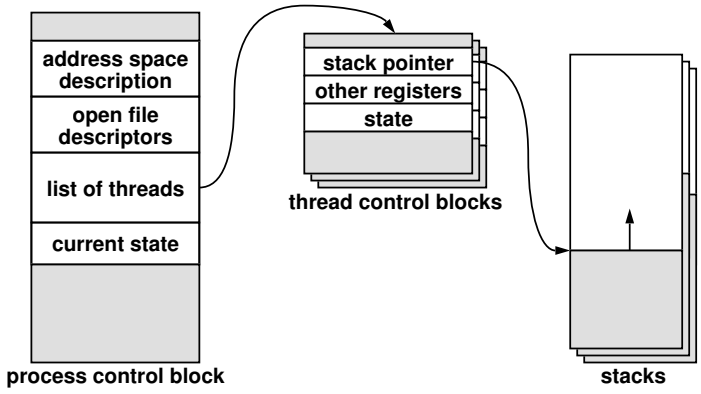
- A process is:
  - a holder for an *address space*
  - a collection of other information shared by a set of *threads*
  - a collection of references to *open files* and other "execution context"
- As discussed in Ch 1, processes related APIs include
  - `fork()`, `exec()`, `wait()`, `exit()`







## Processes and Threads




- Note: all these are relevant to your Kernel Assignment 1
  - although we are only doing *one thread per process*

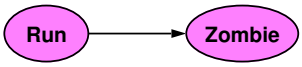






## Process Life Cycle

- Pretty simple
  - a process starts in the *run* state



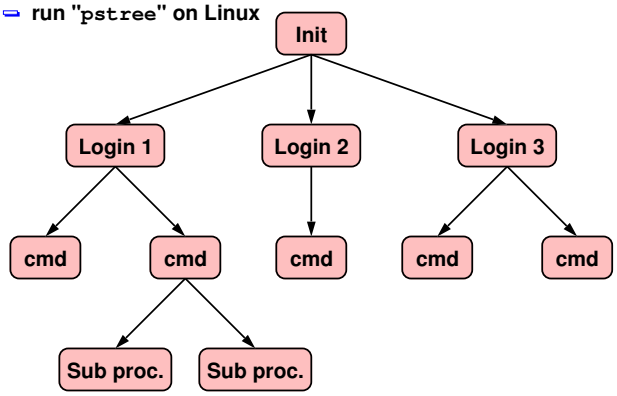







## Process Relationships (1)

- Process hierarchy
  - run "`pstree`" on Linux

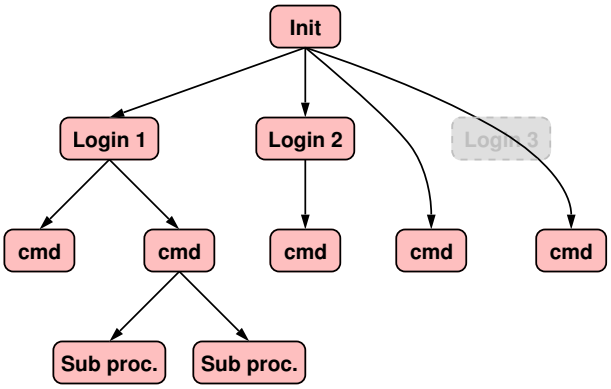









## Process Relationships (2)

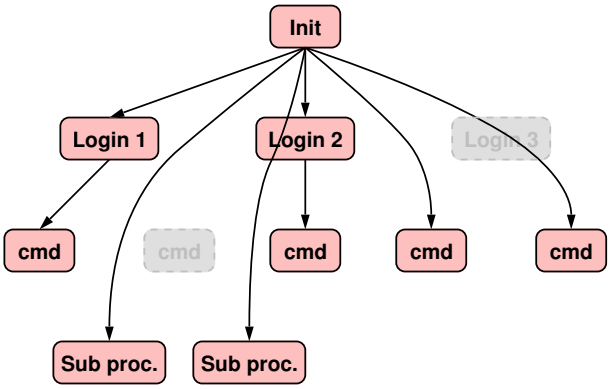




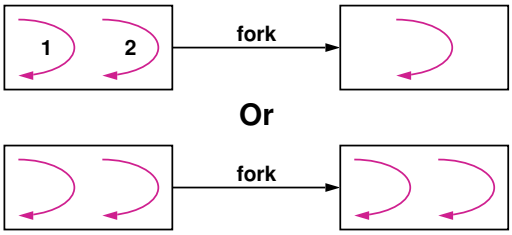





## Process Relationships (3)




## Fork and Threads



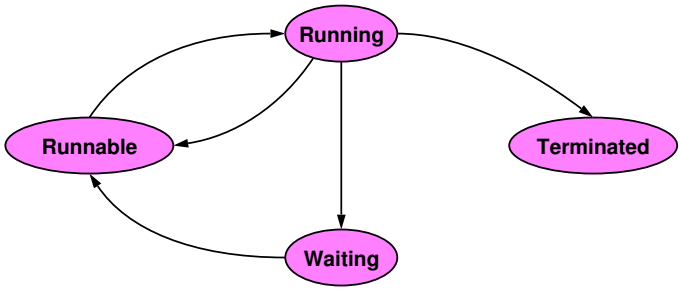

- Solaris uses the 2nd approach
  - expensive to fork a process
- Problem with 1st approach
  - thread 1 called `fork()` and thread 2 has a mutex locked
    - who will unlock the mutex?
  - POSIX solution is to provide a way to unlock all mutex before `fork()`







## Thread Life Cycle



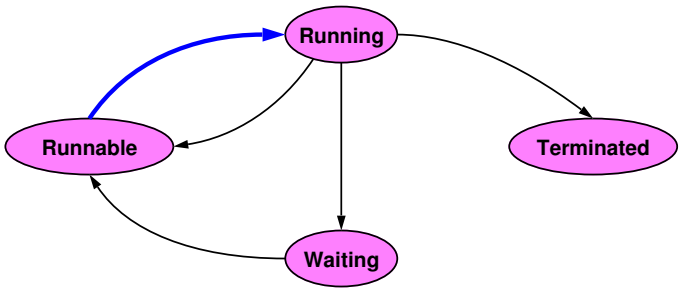

- a thread starts in the *runnable* state







## Thread Life Cycle



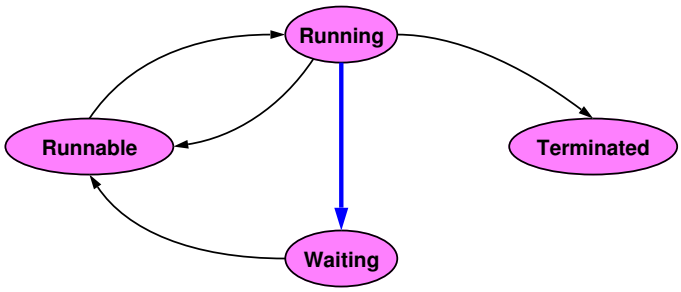

- a thread starts in the *runnable* state
- the *scheduler* switches a thread's state from runnable to running







## Thread Life Cycle



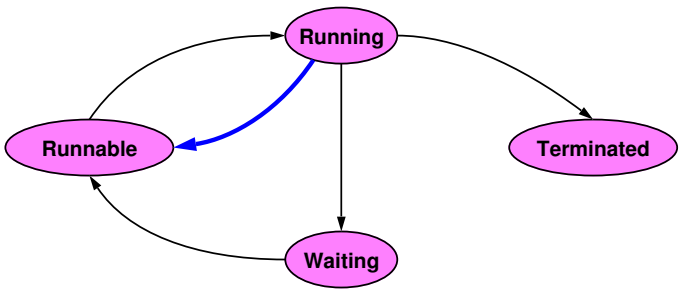

- a thread starts in the *runnable* state
- the *scheduler* switches a thread's state from runnable to running
- a thread goes from running to waiting when a *blocking call* is made







## Thread Life Cycle



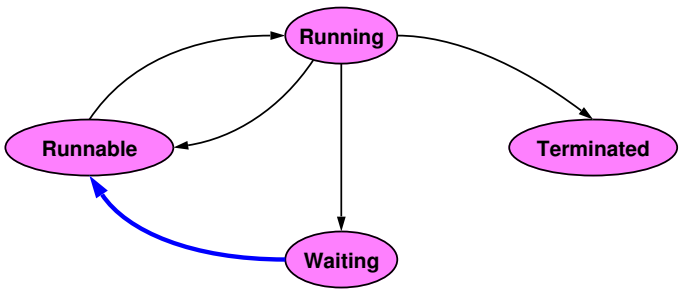

- a thread starts in the *runnable* state
- the *scheduler* switches a thread's state from runnable to running
- a thread goes from running to waiting when a *blocking call* is made
- the *scheduler* switches a thread's state from running to runnable when the thread used up its execution quantum





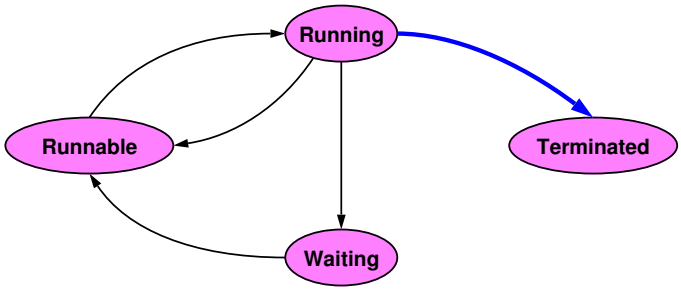


## Thread Life Cycle




- a thread get *unblocked* by the action of another thread or by an interrupt handler

# Thread Life Cycle




- a thread get *unblocked* by the action of another thread or by an interrupt handler
- in order for a thread to enter the terminated state, it has to be in the running state just before that
  - what if `pthread_cancel()` is invoked when the thread is not in the running state?







# Thread Life Cycle

- Does `pthread_exit()` delete the thread (completely) that calls it?
  - no
- What's left in the thread after it calls `pthread_exit()`?
  - its thread control block
    - needs to keep thread ID and return code around
  - its stack
    - how can a thread *delete its own stack*? no way!







# Thread Life Cycle

- Who is deleting the *thread control block* and freeing up the thread's *stack* space?
- If a thread is not detached
  - it can be taken care of in the `pthread_join()` code
    - the thread that calls `pthread_join()` does the clean up
- If a thread is detached (our simple OS does not support this)
  - can do this is one of two ways
    1) use a special *reaper thread*
       - basically doing `pthread_join()`
    2) queue these threads on a list and have other threads free them when it's convenient (e.g., when the scheduler schedule a thread to run)