i206: Lecture 18: Memory Management; Operating Systems

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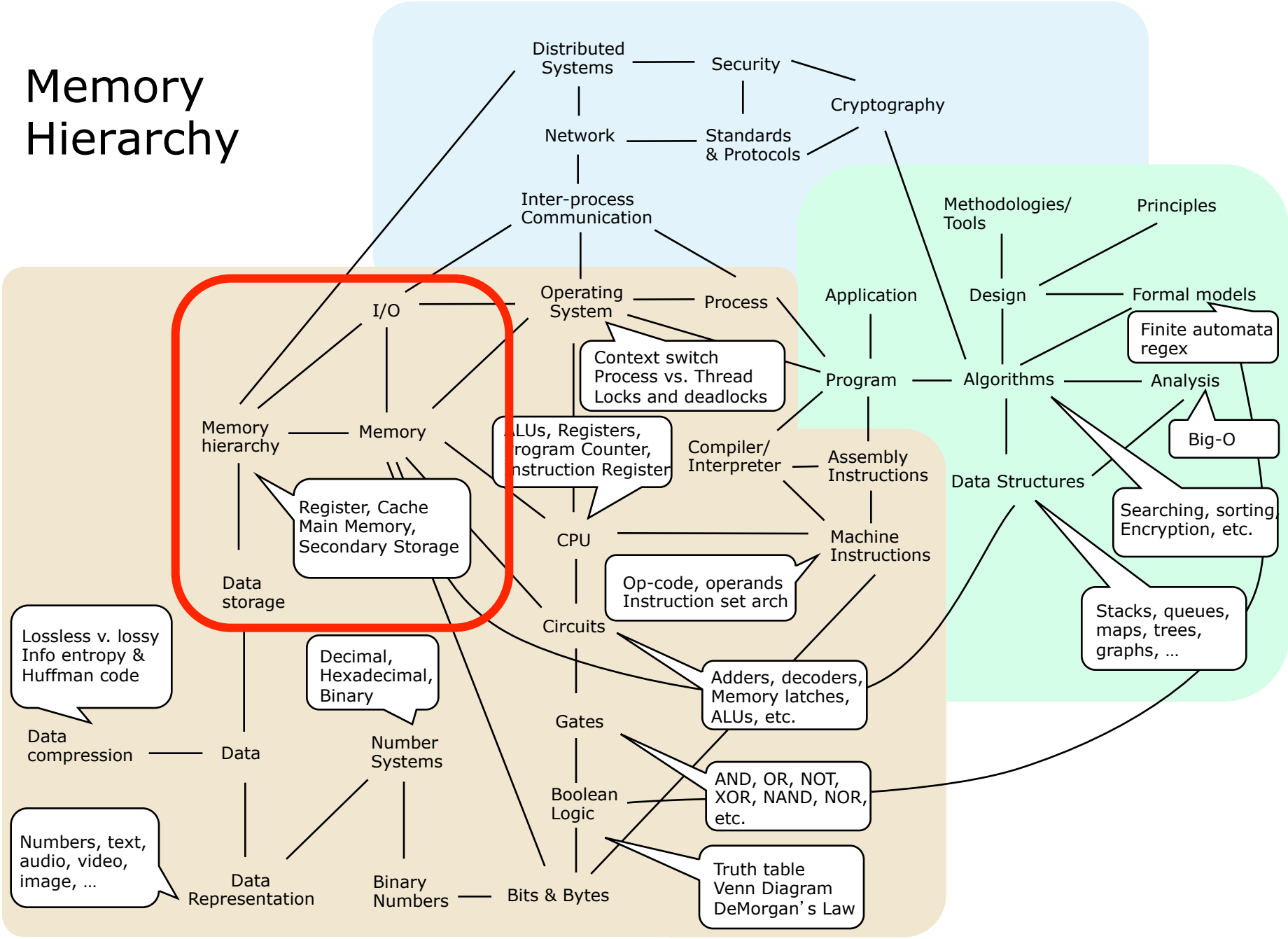
Some slides courtesy Marti Hearst, John Chuang and others

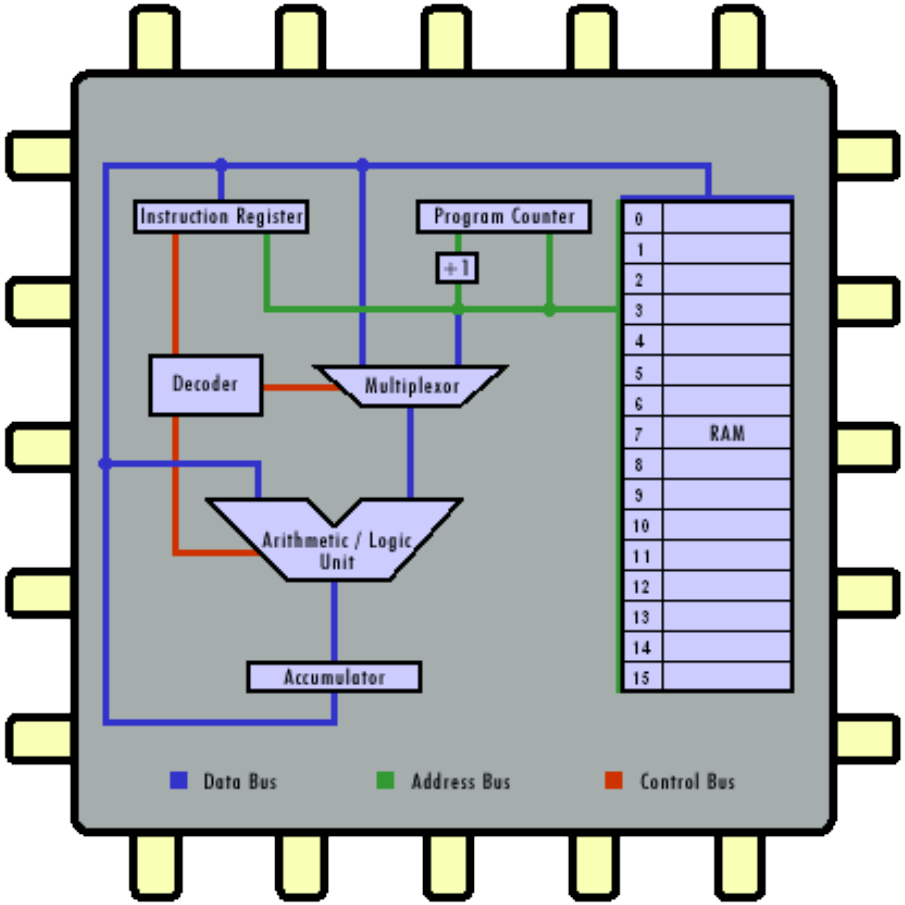
Summary of Key Concepts

- Data Storage:
  - Bit storage using transistors
  - Memory hierarchy
  - Locality of reference and caching
- Operating System:
  - Process management
  - Context switch
  - Threads vs. processes
  - Synchronization and locks

Memory Hierarchy

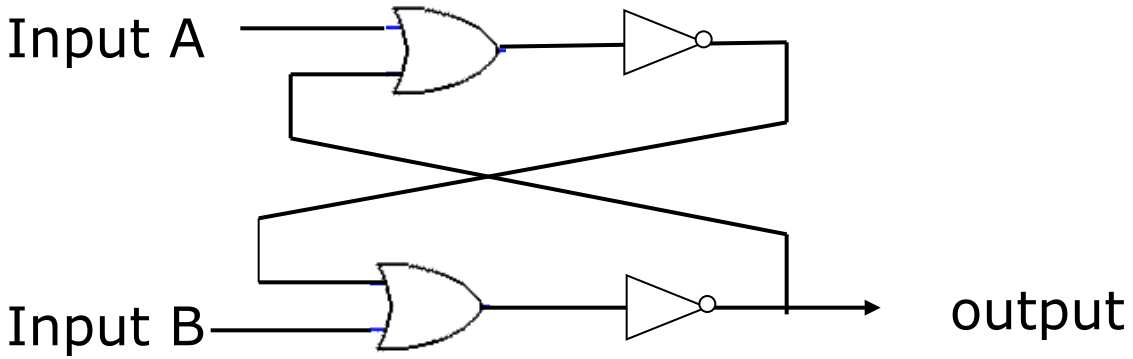


2	010 0 001111	STORE 15	Store the value of the Accumulator in memory location 15



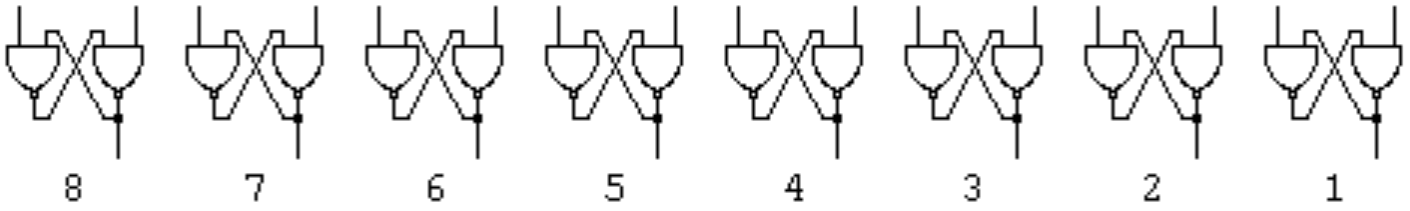
Images from http://courses.cs.vt.edu/~csonline/MachineArchitecture/Lessons/

Storing 1 Bit of Data



Adapted from Brookshear Fig 1.5

- **Flip-flop** (also called a latch) is a circuit built from gates that can store one bit of data
  - Setting input A to 1 sets output to 1
  - Setting input B to 1 sets output to 0
  - While both input lines are 0, the most recently stored value is preserved



The Memory Hierarchy

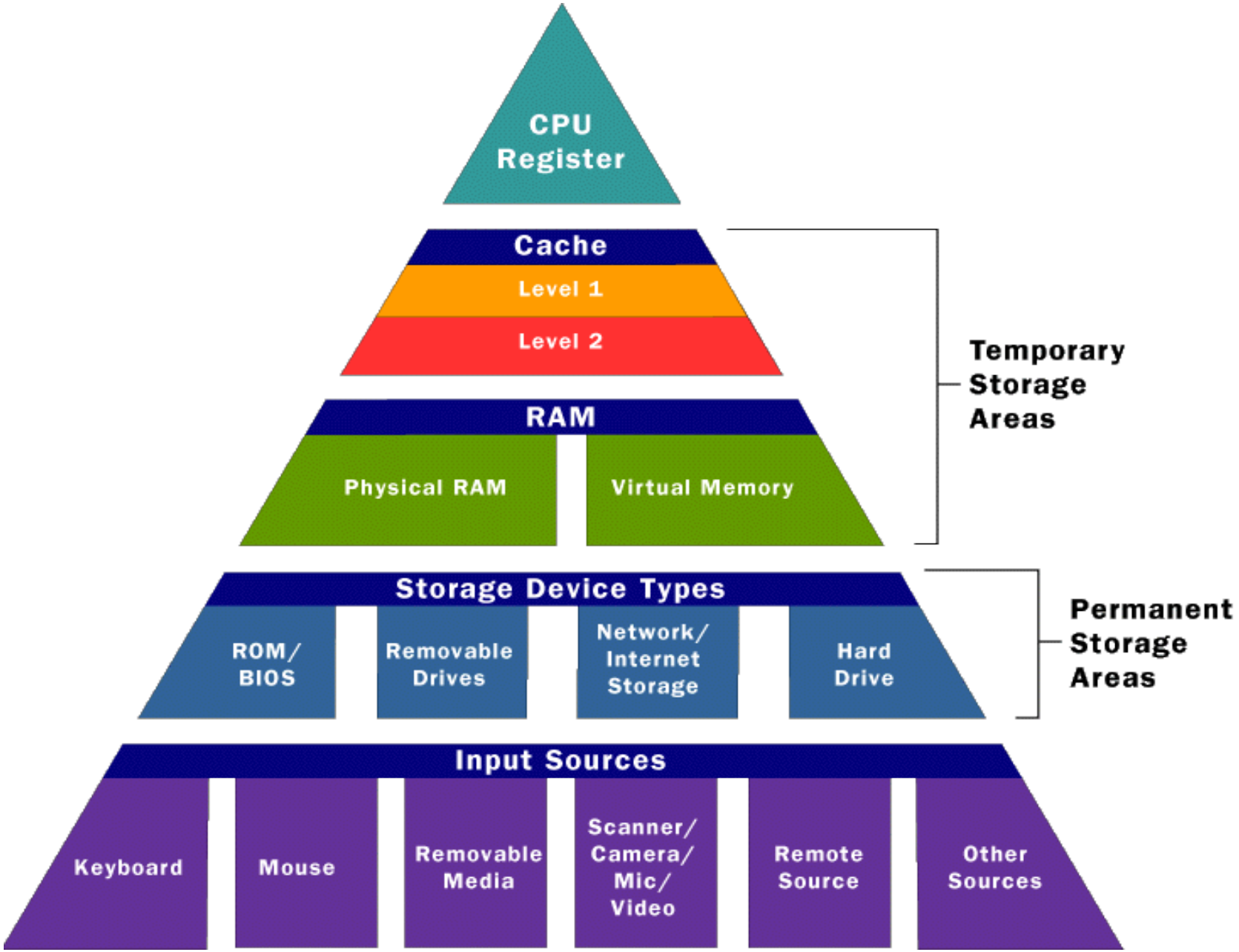
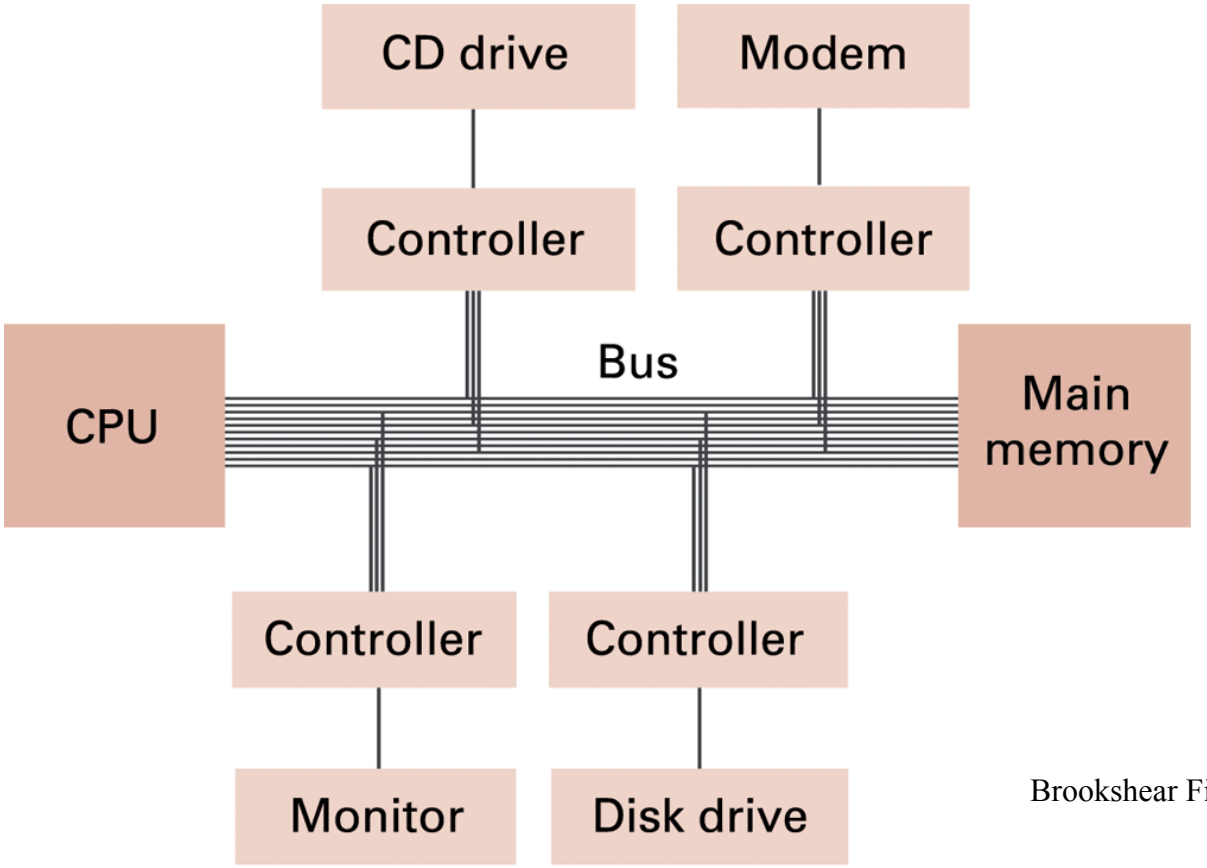


Image from http://www.howstuffworks.com/computer-memory1.htm

Data Storage

- Where and how do we store data?



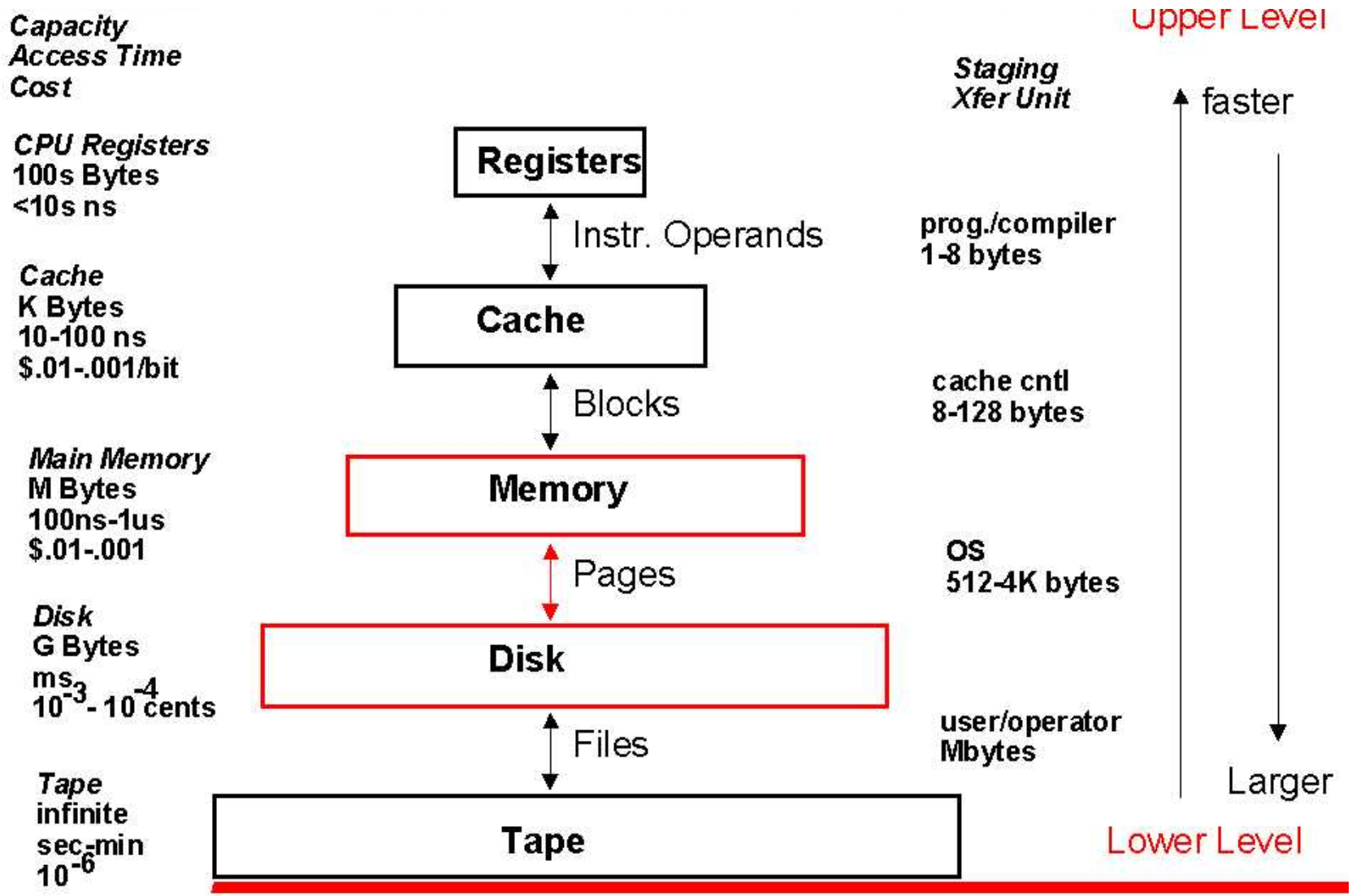
Brookshear Fig 2.13

Data Storage

- In general, we want data to be located in close proximity of their use (the CPU in this case)
- Why do we want to store data at so many different locations within a computer?
- Considerations of
  - Storage capacity
  - Access latency
  - Cost
  - Patterns of data access
  - …

Levels of a Memory Hierarchy

(circa 2000)



http://www.ece.arizona.edu/~ece369/lec10S01/sld047.htm

Caching

- Caches store items that have been used recently for faster access
- Based on the notion of locality
  - Something used recently is more likely to be used again soon than other items.
- Can be done using
  - Registers
  - Caches
  - RAM
  - Hard Disk, etc

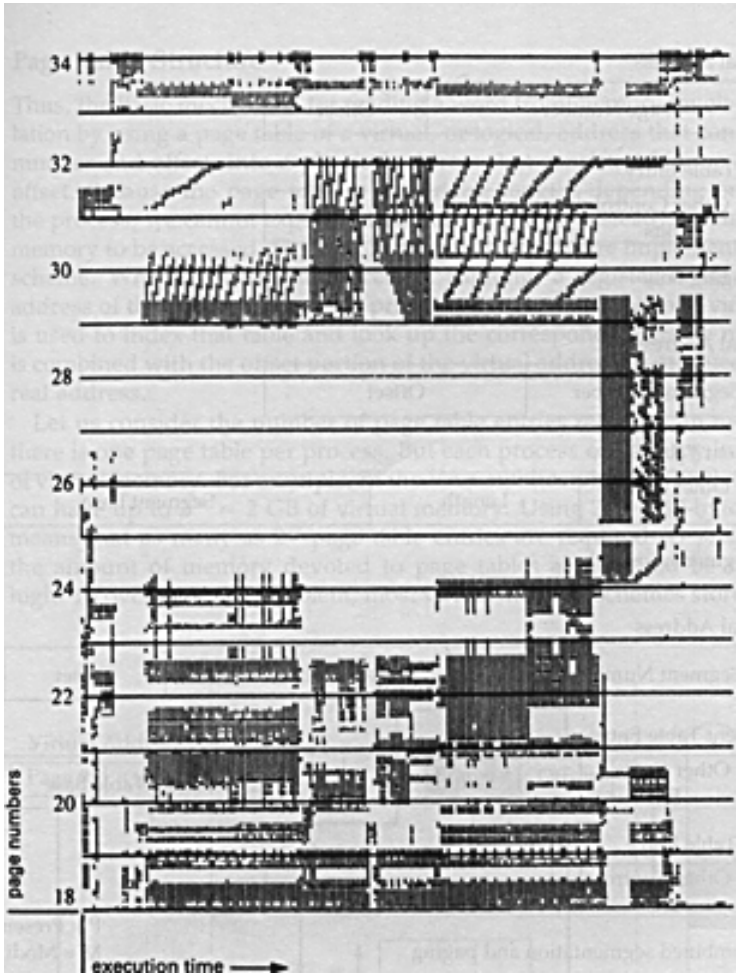
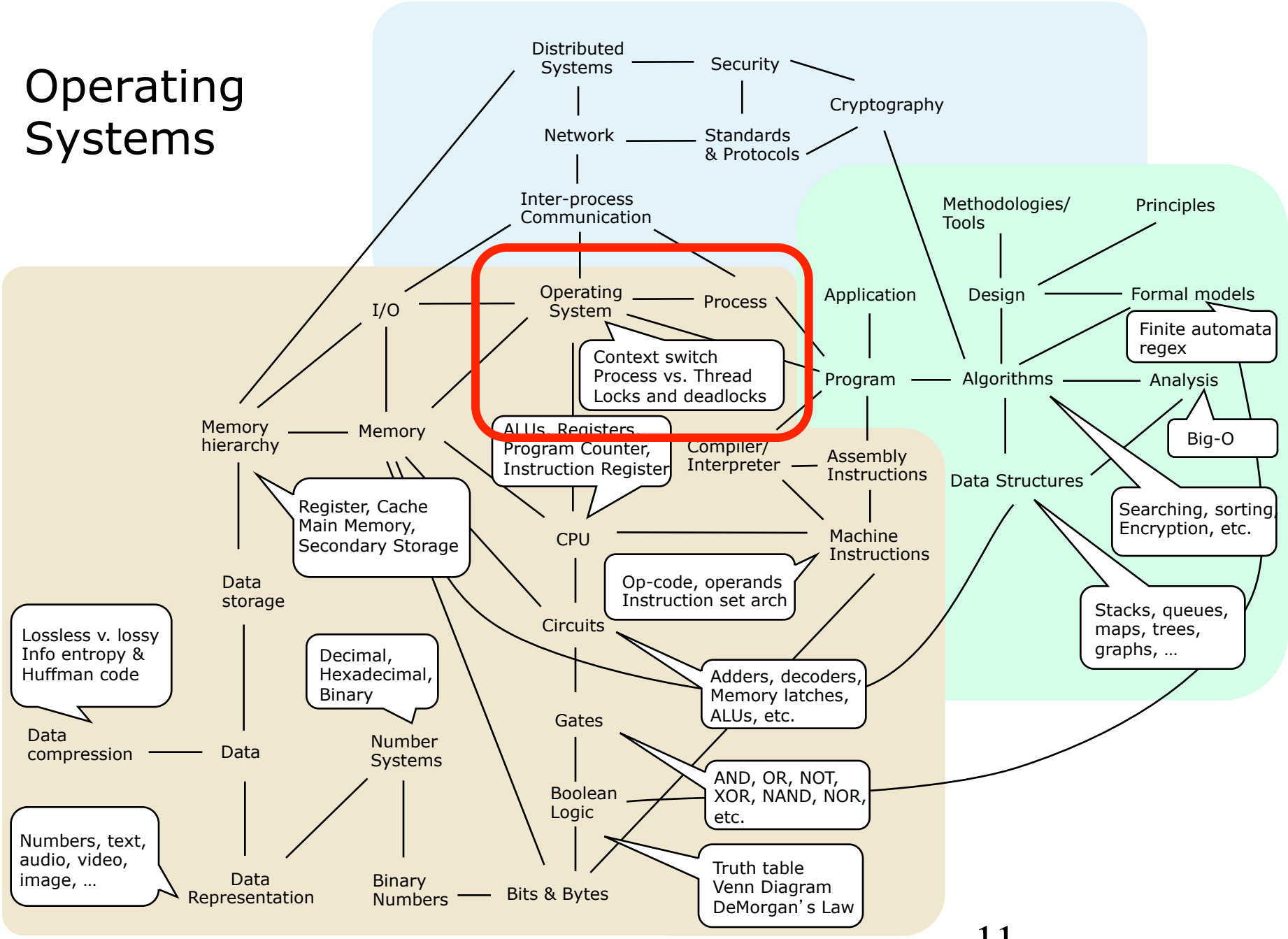


Image from http://cne.gmu.edu/modules/vm/orange/realprog.html

Operating Systems

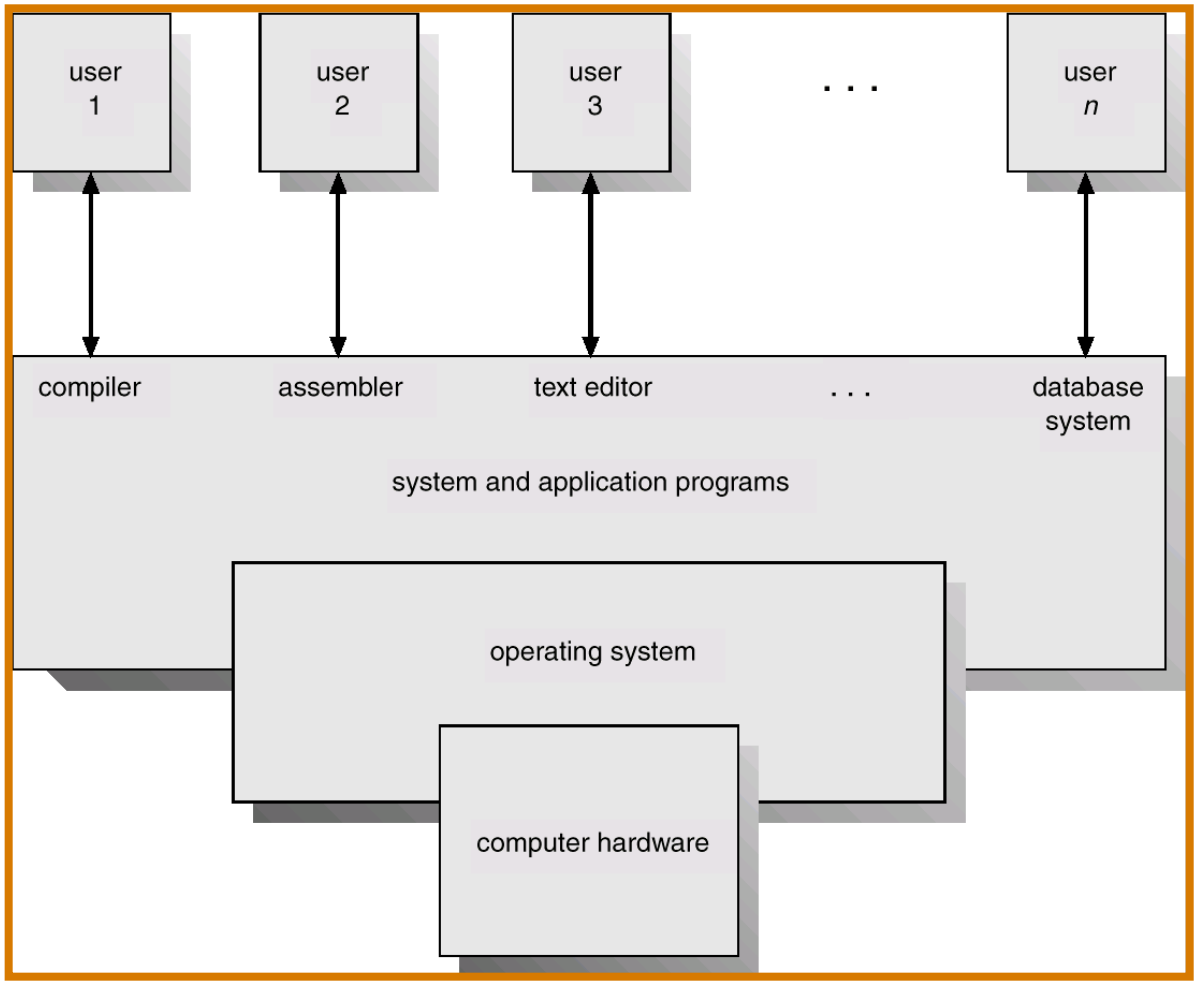


What is an Operating System?

- A software program that acts as an intermediary between a user of a computer and the computer hardware

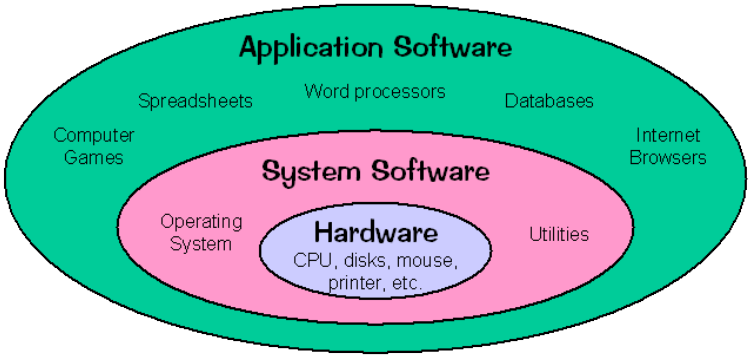
- Operating system functions:
  - Oversee operation of computer
  - Store and retrieve files
  - Schedule programs for execution
  - Execute programs

Abstract View of System Components



Source: Silberschatz, Galvin, Gagne

Operating Systems



- Main Roles:
  - Allow user applications to run on a given machine's hardware
  - Act as a "traffic cop" for allocating resources.
- Resources
  - CPU, I/O devices, Memory, Files, Allocation
- Processes
  - Scheduling
  - Synchronization
- Memory Management
- File Management

Image from http://courses.cs.vt.edu/~csonline/OS/Lessons/Introduction/index.html

Process Management

- A **process** is a *program in execution*
  - A process needs certain resources, including CPU time, memory, files, and I/O devices, to accomplish its task

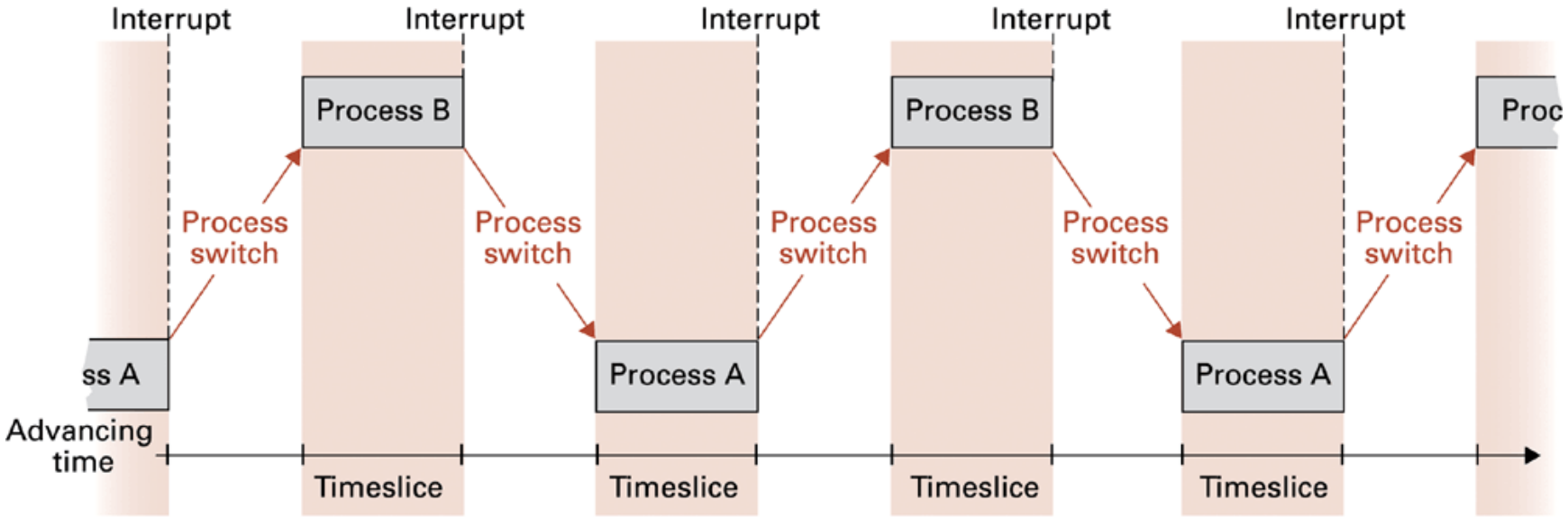
- The operating system is responsible for the following activities in connection with process management
  - Process creation and deletion
  - Process suspension and resumption
  - Provision of mechanisms for:
    - process synchronization
    - process communication

Programs vs. Processes

- Program
  - The code, both in human and machine-readable form
- Process
  - A running program is a process.
  - It is allocated a number of resources:
    - Registers in the CPU
    - Some part of the CPU's RAM
    - I/O devices (the monitor, files in the file system)
- Several copies of the same program can be running as different processes.
  - But data values, current Program Counter location, etc., will differ among the different processes.
- One program may spawn several processes

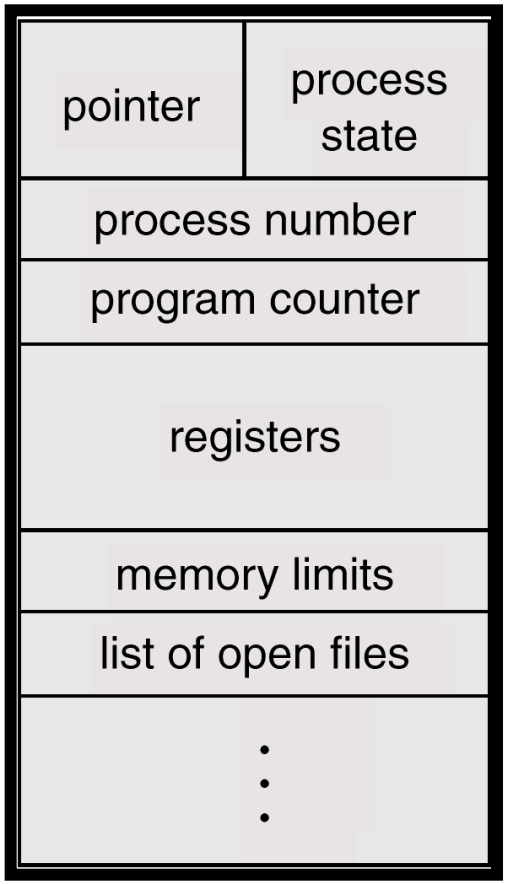
Resource Sharing

- Many processes share hardware resources
  - CPU, I/O (mouse, keyboard, monitor, disk, …)
- Processes must take turns
  - Context switch (aka process switch)
- Operating system serves as coordinator/ scheduler



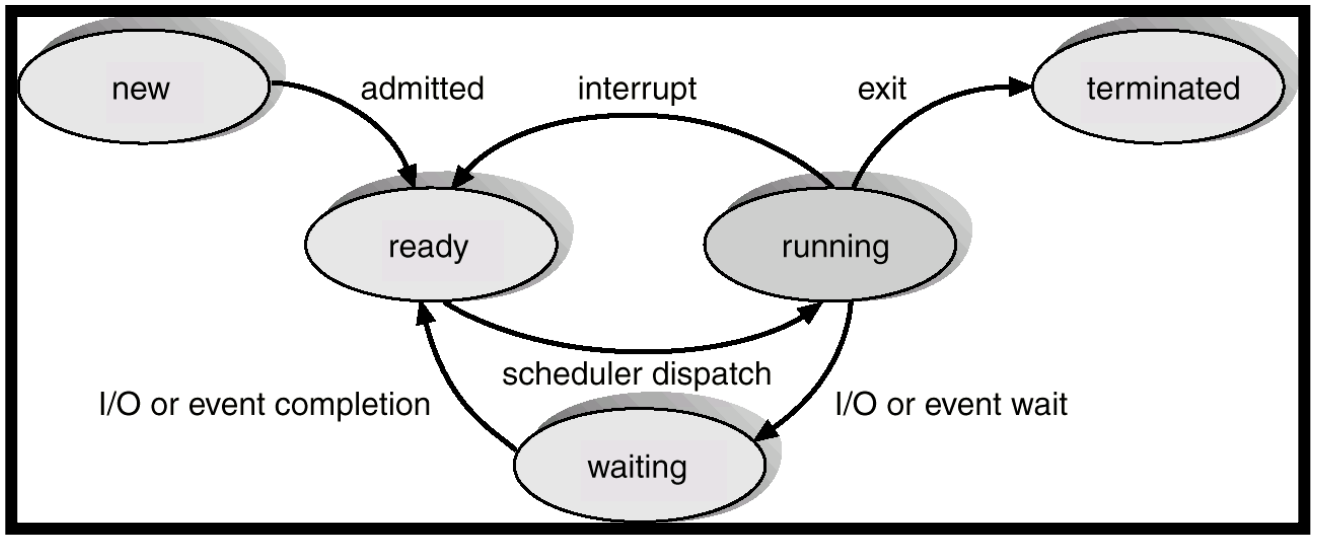
Context Switch

- 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
- Process control block (PCB, on right) contains information associated with each process
- Context-switch time is overhead; the system does no useful work while switching
  - A system is said to be "thrashing" when it spends more time performing context switches than useful work



Source: Silberschatz, Galvin, Gagne

Process State

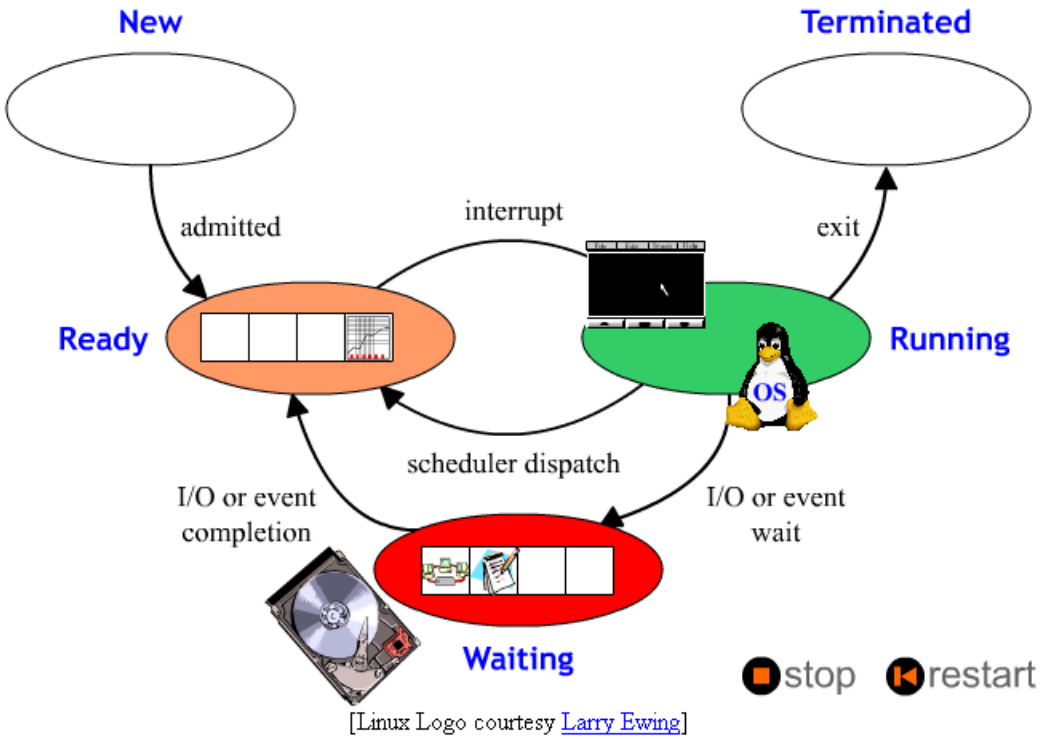


Source: Silberschatz, Galvin, Gagne

- 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 CPU.
  - **terminated**: The process has finished execution.

Scheduling

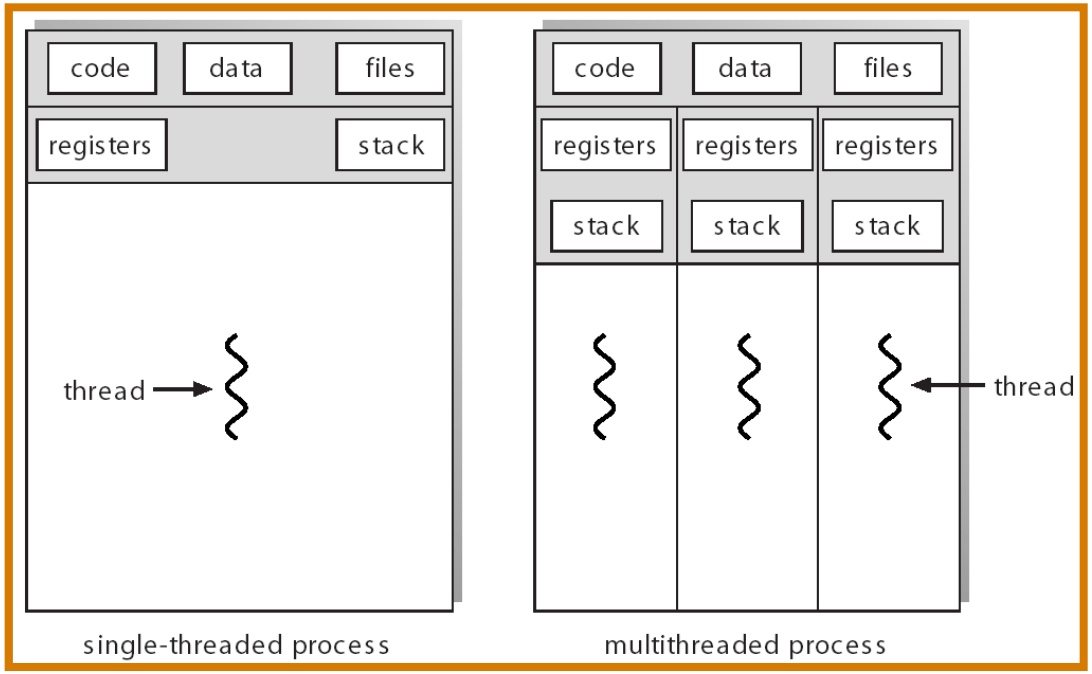
- An animation



http://courses.cs.vt.edu/~csonline/OS/Lessons/Processes/index.html

Threads

- A *thread* (or *lightweight process*) is a basic unit of CPU utilization
- Each thread has its own
  - program counter
  - stack
  - register set
- The threads share
  - text section (program)
  - data section (global variables)



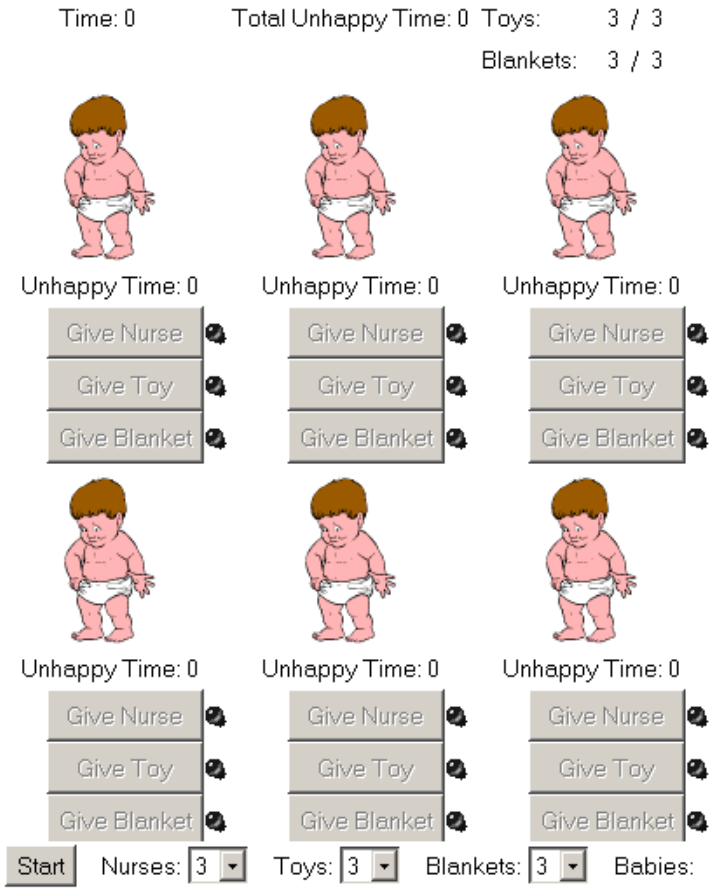
Source: Silberschatz, Galvin, Gagne

Threads versus Multiple Processes

- Threads are cheaper to create than processes (~10-20x)
- Switching to a different thread in same process is much cheaper than switching to a different process (~5-50x); less context switching required
- Threads within same process can share data and other resources more conveniently and efficiently than with Inter-Process Communication (see next lecture)
- Threads within a process are not protected from one another

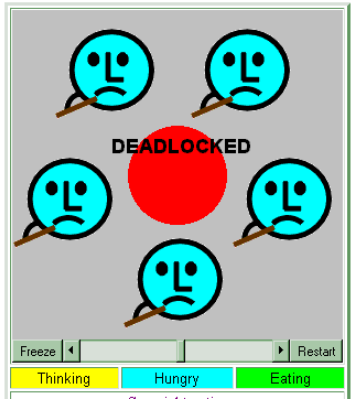
Resource Allocation

- Allocation of files, printers, main memory, and other shared resources.



http://courses.cs.vt.edu/~csonline/OS/Lessons/Resources/index.html

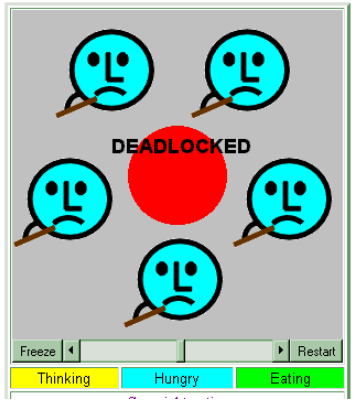
Deadlock



- Like Gridlock: everyone is stuck waiting for other people to get out of the way
  - The 3 conditions for deadlock (necessary but not sufficient) from Brookshear
    - There is competition for nonshareable resources
    - The resources are requested on a partial basis
      - (having received some resource, a process will ask for another later)
    - Once a resource is allocated, it cannot be "forcibly" retrieved
  - Another way to say these:
    - Mutex (mutual exclusion)
    - Hold-and-wait
    - No preemption

Image from http://courses.cs.vt.edu/~csonline/OS/Lessons/Deadlock/index.html

Deadlock

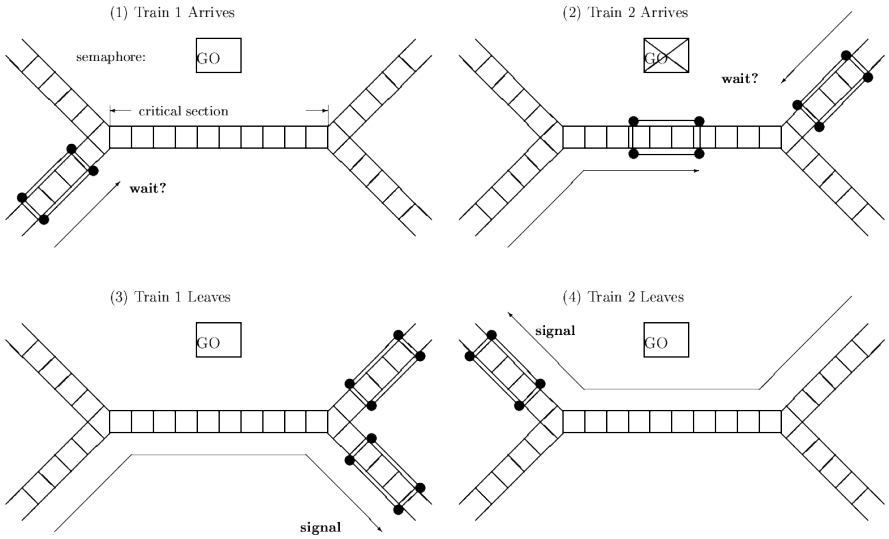


- Example:
  - Two processes running; both require the printer and the CD drive
  - Process A has the CD drive, but is waiting for the printer; process B has the printer but is waiting for the CD drive.
  - Have to "break the deadlock" via preemption
  - Instead: don't allow it to happen in the first place
    - Don't ever allow all three conditions to hold
    - e.g., make processes "spool" their print jobs

Image from http://courses.cs.vt.edu/~csonline/OS/Lessons/Deadlock/index.html

Synchronization

- Use locks to coordinate actions of competing processes
- Also known as mutual exclusion (mutex)
- Simplest form of lock is a semaphore
  - Process must acquire semaphore before entering critical section; release semaphore upon exit



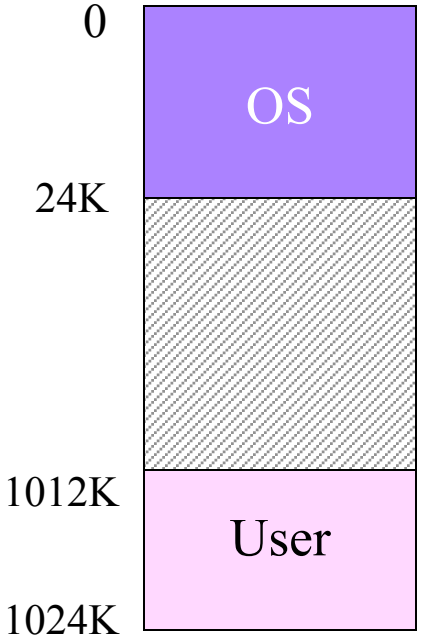

```
initialize_lock()
        ...
acquire_lock()
try:
            change_shared_data()
finally:
            release_lock()
```

Memory Management: User vs. System Address Spaces

- The OS allocates memory for all the user processes running on the machine.
  - Each user process runs in its own address space.
- User processes have to handle their own memory management.
  - The C language makes the user do this explicitly
  - Python does it for you
    - Every time you do declare a new object, you get a new object
    - If you stop using the object, you don't say "remove"
    - Cleanup is done for you by the python interpreter

Address Space

- The range of bytes in memory that are assigned to a process.
- Often will locate the OS address space in low memory addresses, and user programs in high memory addresses.
- Example:
  - OS needs 24 Kbytes
  - User needs 12 Kbytes



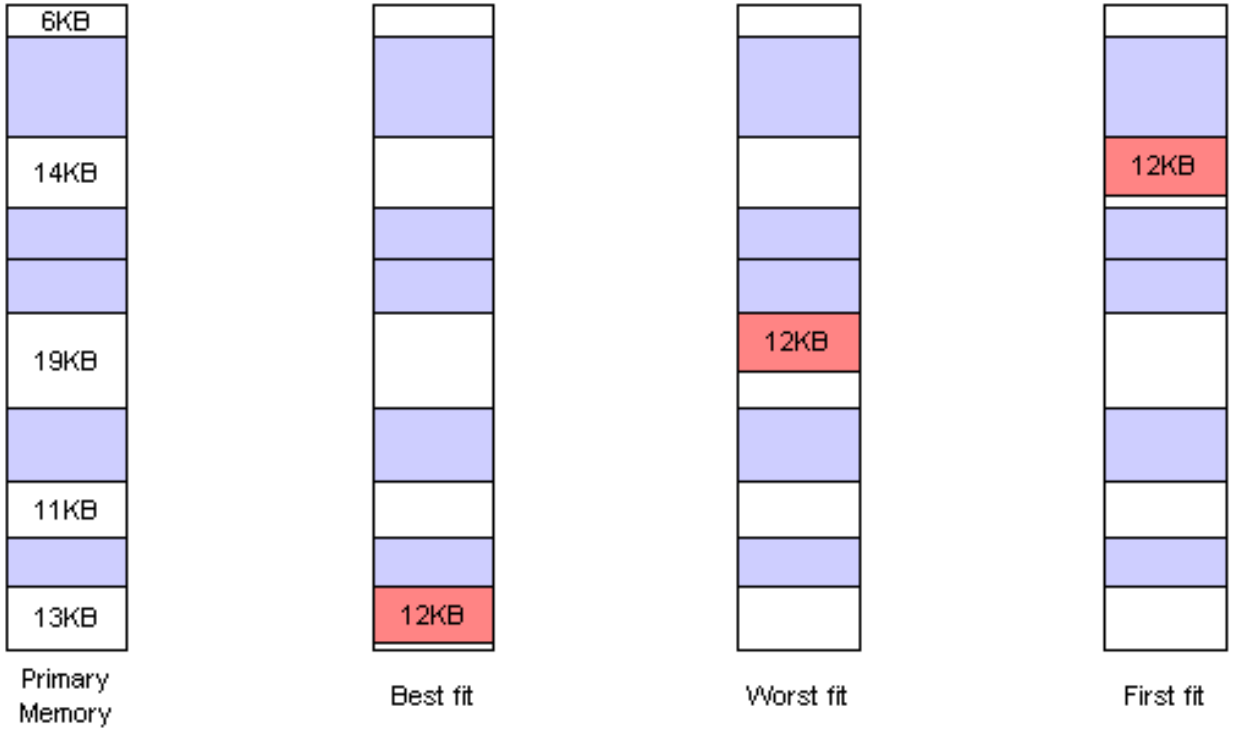
Address Space

- The address space can begin anywhere in memory.
- Example:
  - Say your program requires 2K for instructions and 30K for data.
  - If stored starting at position 0, then the address space ranges from 0 to 32K-1
  - If stored starting at position 12K, then the address space ranges from 12K to 44K-1.
  - That means the first instruction starts at location 12K. (This is where the Program Counter starts.)
- How does the Program Counter know what to do?
  - The OS automatically adds 12K to every address in the program.

Memory Allocation Policies

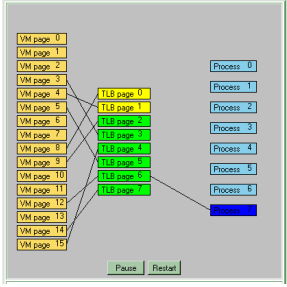
- The OS tries to accommodate as many user processes as possible.
- Problem: where to put which process in memory?
- Strategies:
  - Best fit: smallest possible free block
  - Worst fit: largest possible free block
  - First fit: first free block that fits
- Occasionally “house cleans” (reorganizes everything).

Memory Allocation Policies



http://courses.cs.vt.edu/~csonline/OS/Lessons/MemoryAllocation/index.html

Virtual Memory



- Allows a process to run even if the full amount of needed memory is not currently available.
  - **Pages:**
    - The memory needed by a program is divided up into 4K blocks
    - This allows the process to run in non-continguous blocks of memory
  - **Page table**
    - Shows which pages are in RAM and which on disk.
  - **Page Fault**
    - Happens when the process tries to access a page that is not currently in RAM.

http://courses.cs.vt.edu/~csonline/OS/Lessons/VirtualMemory/index.html

Page Table Maps Pages in Virtual Memory to Main Memory or Disk

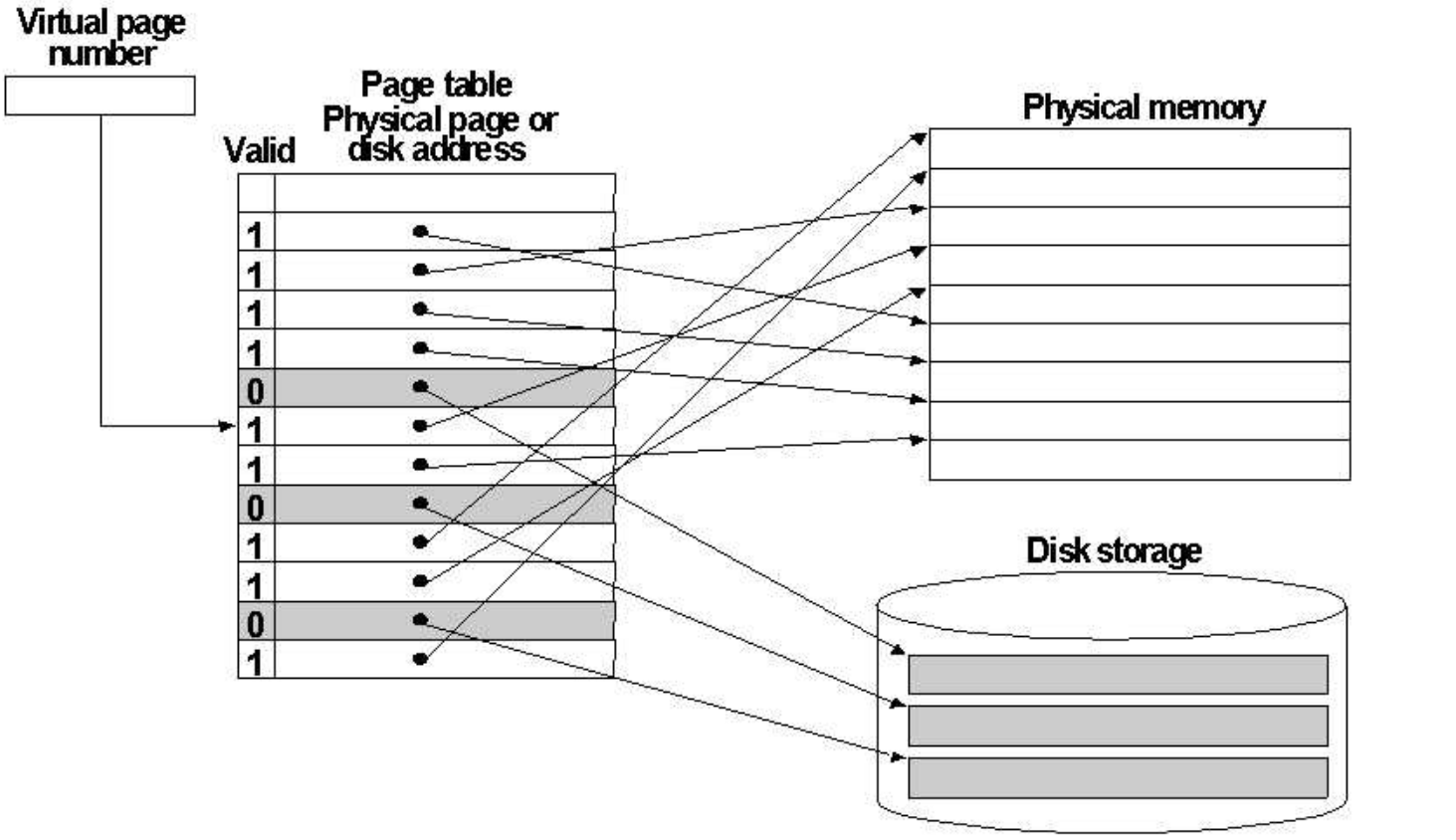
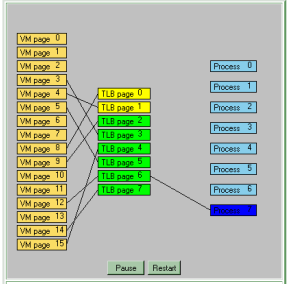


Image from http://www.ece.arizona.edu/~ece369/lec10S01/sld058.htm

Virtual Memory



- Allows a process to run even if the full amount of needed memory is not currently available.
  - **Swapping**
    - Moving a page from memory to disk, and vice versa
    - Can also refer to moving an entire process into or out of RAM memory
    - A page fault has to be handled by the Scheduler – so slow (accessing the disk resource; can cause a context switch)
  - **Thrashing**
    - When there isn't enough room in main memory for all the pages that the process needs at the same time
    - The process spends all its time page faulting, swapping processes into and out of memory, and gets little work done.

VM simulation: http://courses.cs.vt.edu/~csonline/OS/Lessons/VirtualMemory/index.html

Page Replacement Policies

- To decide which page to throw out of RAM
  - Least Recently Used (LRU)
  - Least Frequently Used (LFU) LRU with counts
  - First In First Out (FIFO) Remove oldest
  - Random
  - Many others

Summary of Key Concepts

- Data Storage:
  - Memory hierarchy
  - Locality of reference and caching
- Operating System:
  - Process management
  - Context switch
  - Synchronization and locks
  - Memory Management Policies