CS 333
Introduction to Operating Systems

Class 2 – OS-Related Hardware & Software
The Process Concept

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Administrivia …

- **CS333 lecture videos are available from**
  - www.media.pdx.edu
  - Click on the link for
    - Walpole: CS333-2 - Introduction to Operating Systems
  - Submit password cs333s07wa
  - Click on the lecture date desired
  - Requires windows media player to be installed

Lecture 2 overview

OS-Related Hardware & Software

Complications in real systems

Brief introduction to

- *memory protection and relocation*
- *virtual memory & MMUs*
- *I/O & Interrupts*

The "process" abstraction

Process scheduling

Process states

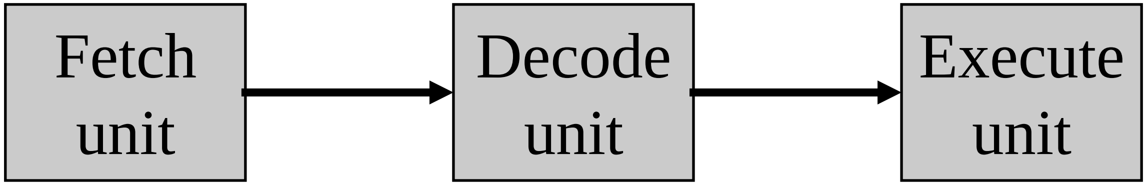
Process hierarchies

Process system calls in Unix

Why its not quite that simple ...

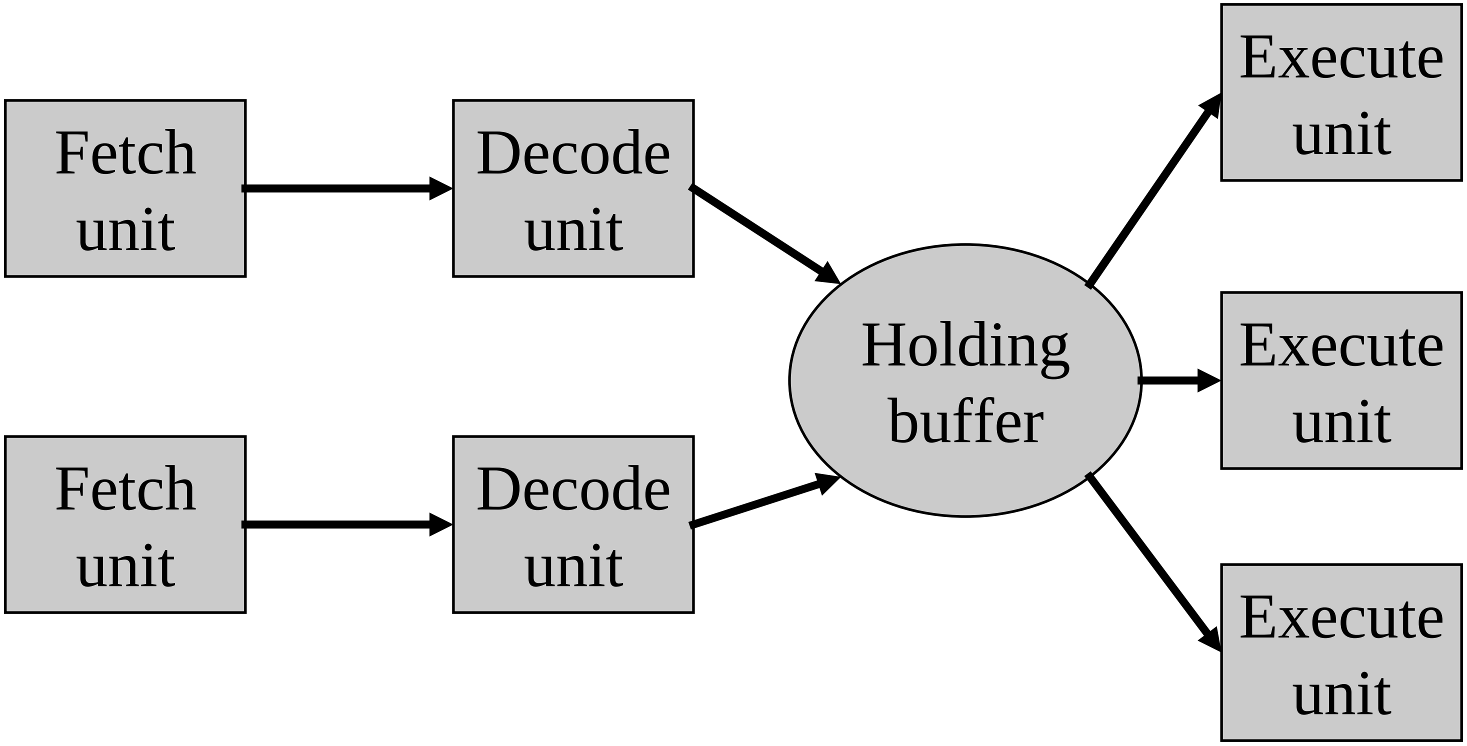
- **The basic model introduced in lecture 1still applies, but the following issues tend to complicate implementation in real systems:**
  - Pipelined CPUs
  - Superscalar CPUs
  - Multi-level memory hierarchies
  - Virtual memory
  - Complexity of devices and buses

Pipelined CPUs



Execution of current instruction performed in parallel with decode of next instruction and fetch of the one after that

Superscalar CPUs



What does this mean for the OS?

- **Pipelined CPUs**
  - more complexity in taking a snapshot of the state of a running application
  - more expensive to suspend and resume applications
- **Superscalar CPUs**
  - even more complexity in capturing state of a running application
  - even more expensive to suspend and resume applications
  - support from hardware is useful ie. precise interrupts

- **More details, but fundamentally the same task**
- **The BLITZ CPU is not pipelined or superscalar**

The memory hierarchy

- **2GHz processor → 0.5 ns clock cycle**
- **Data/instruction cache access time → 0.5ns – 10 ns**
  - This is where the CPU looks first!
  - Memory this fast is *very* expensive !
  - Size ~64 kB- 1MB (too small for whole program)
- **Main memory access time → 60 ns**
  - Slow, but cheap
  - Size 512 MB – 1GB+
- **Magnetic disk →**
  10 ms, 160 Gbytes

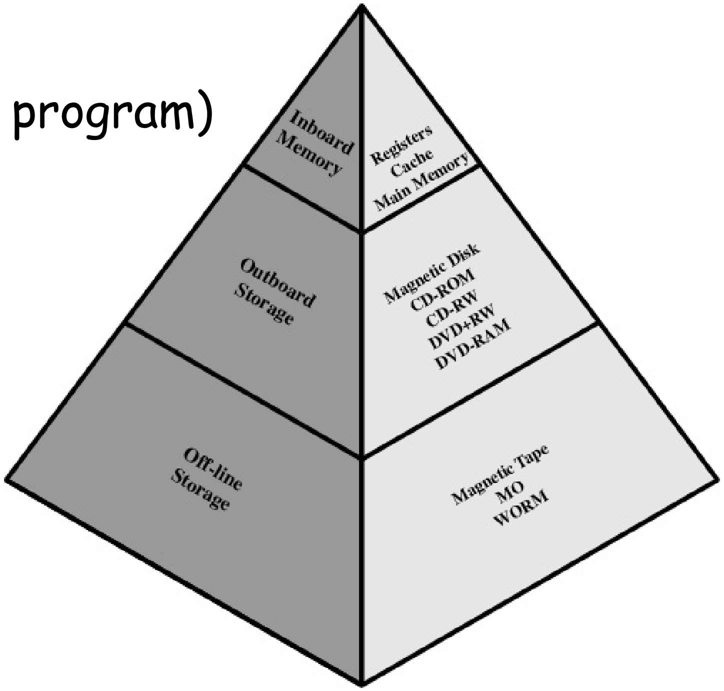


Figure 1.14 The Memory Hierarchy

Terminology review - metric units

Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta
10^{-18}	0.000000000000000001	atto	10^{18}	1,000,000,000,000,000,000	Exa
10^{-21}	0.000000000000000000001	zepto	10^{21}	1,000,000,000,000,000,000,000	Zetta
10^{-24}	0.000000000000000000000001	yocto	10^{24}	1,000,000,000,000,000,000,000,000	Yotta

The metric prefixes

Who manages the memory hierarchy?

- **Movement of data from main memory to cache is under hardware control**
  - cache *lines* loaded on demand automatically
  - Placement and replacement policy fixed by hardware
- **Movement of data from cache to main memory can be affected by OS**
  - instructions for "flushing" the cache
  - can be used to maintain consistency of main memory
- **Movement of data among lower levels of the memory hierarchy is under direct control of the OS**
  - virtual memory page faults
  - file system calls

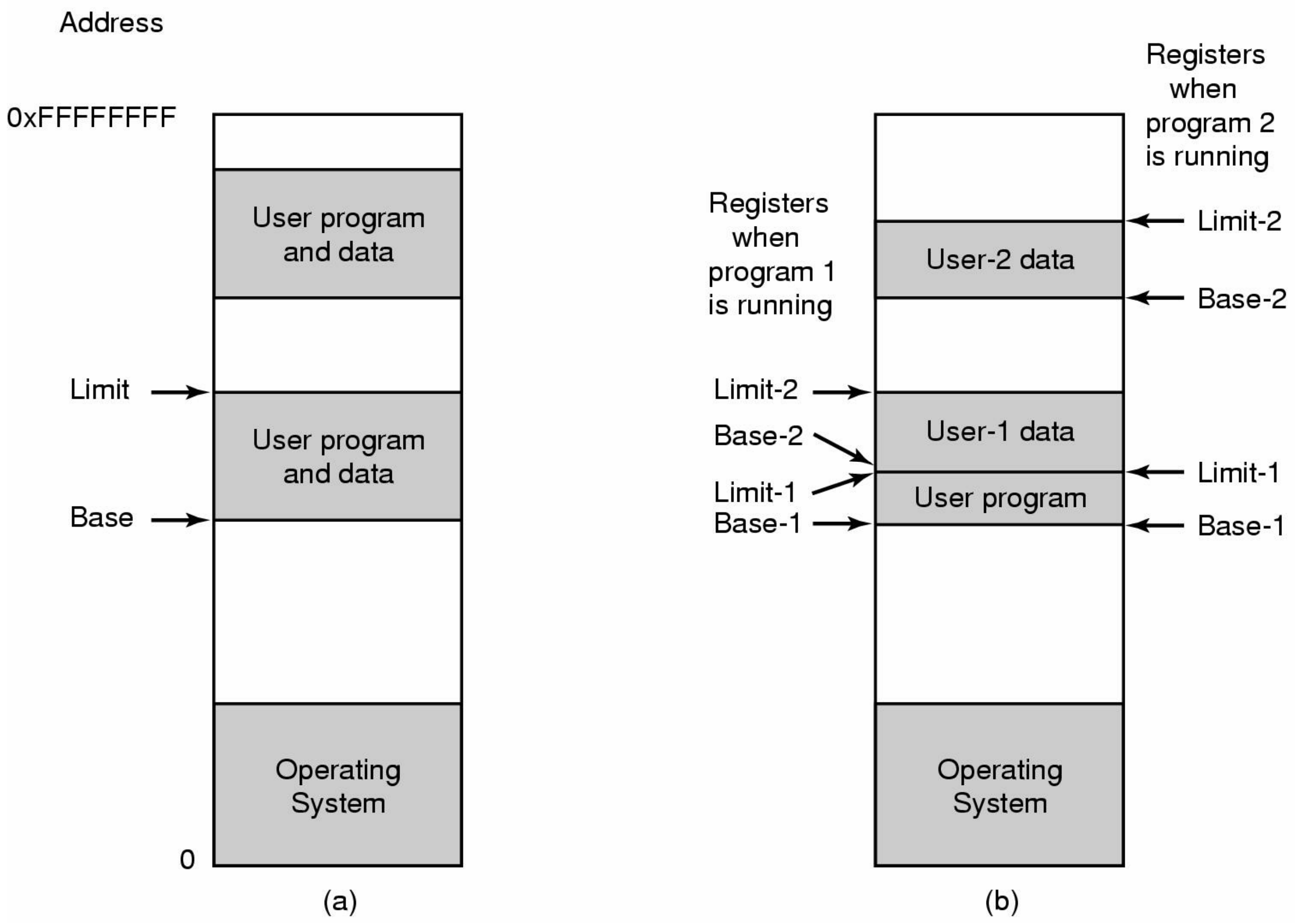
OS implications of a memory hierarchy?

- How do you keep the contents of memory consistent across layers of the hierarchy?
- How do you allocate space at layers of the memory hierarchy "fairly" across different applications?
- How do you hide the latency of the slower subsystems?
  - Main memory… yikes!
  - Disk
- How do you protect one application's area of memory from other applications?
- How do you *relocate* an application in memory?
  - *How does the programmer know where the program will ultimately reside in memory?*

Memory protection and relocation ...

- **Memory protection – the basic ideas**
  - virtual vs physical addresses
    - **address range in each application starts at 0**
  - “base register” used to convert each virtual address to a physical address before main memory is accessed
  - address is compared to a “limit register” to keep memory references within bounds
- **Relocation**
  - by changing the base register value
- **Paged virtual memory**
  - same basic concept, but more powerful (and complex)

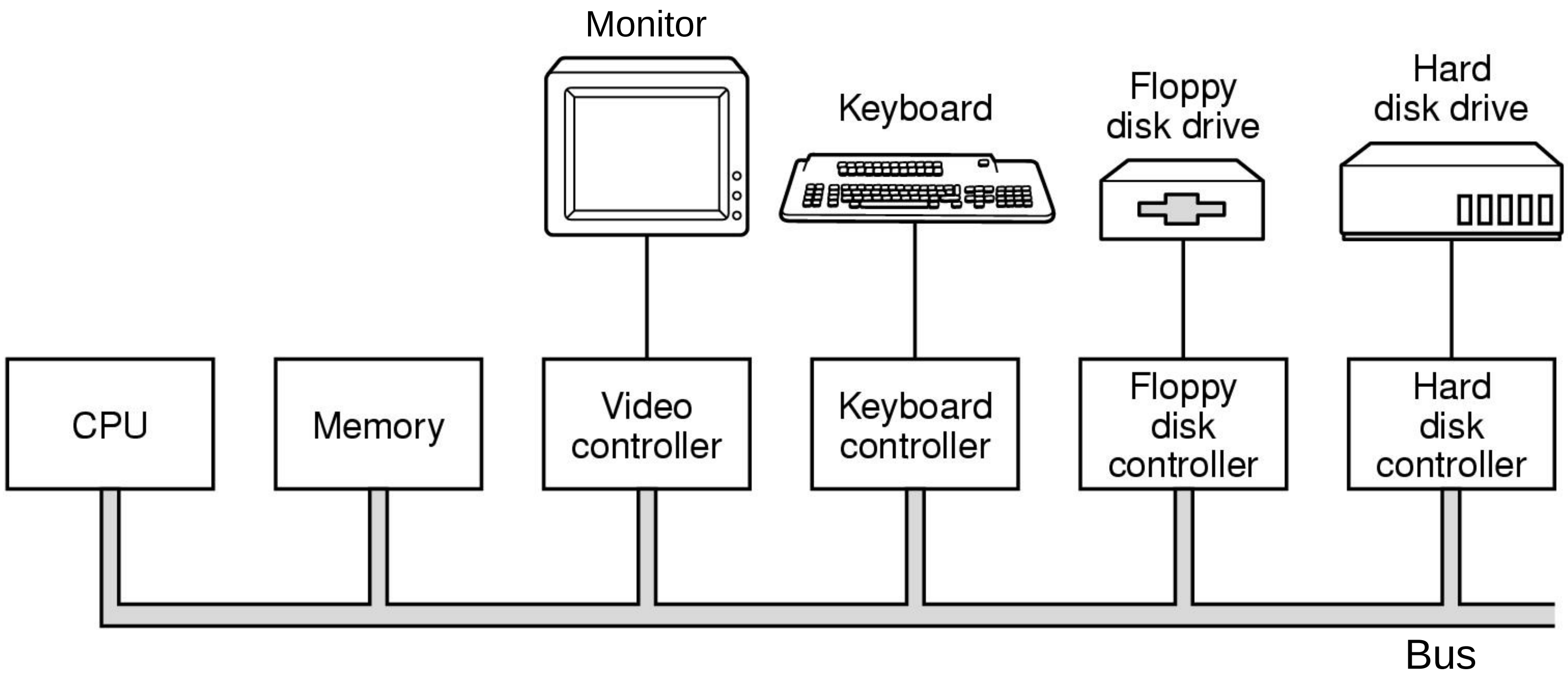
Base & Limit Registers (single & multiple)



Virtual memory and MMUs

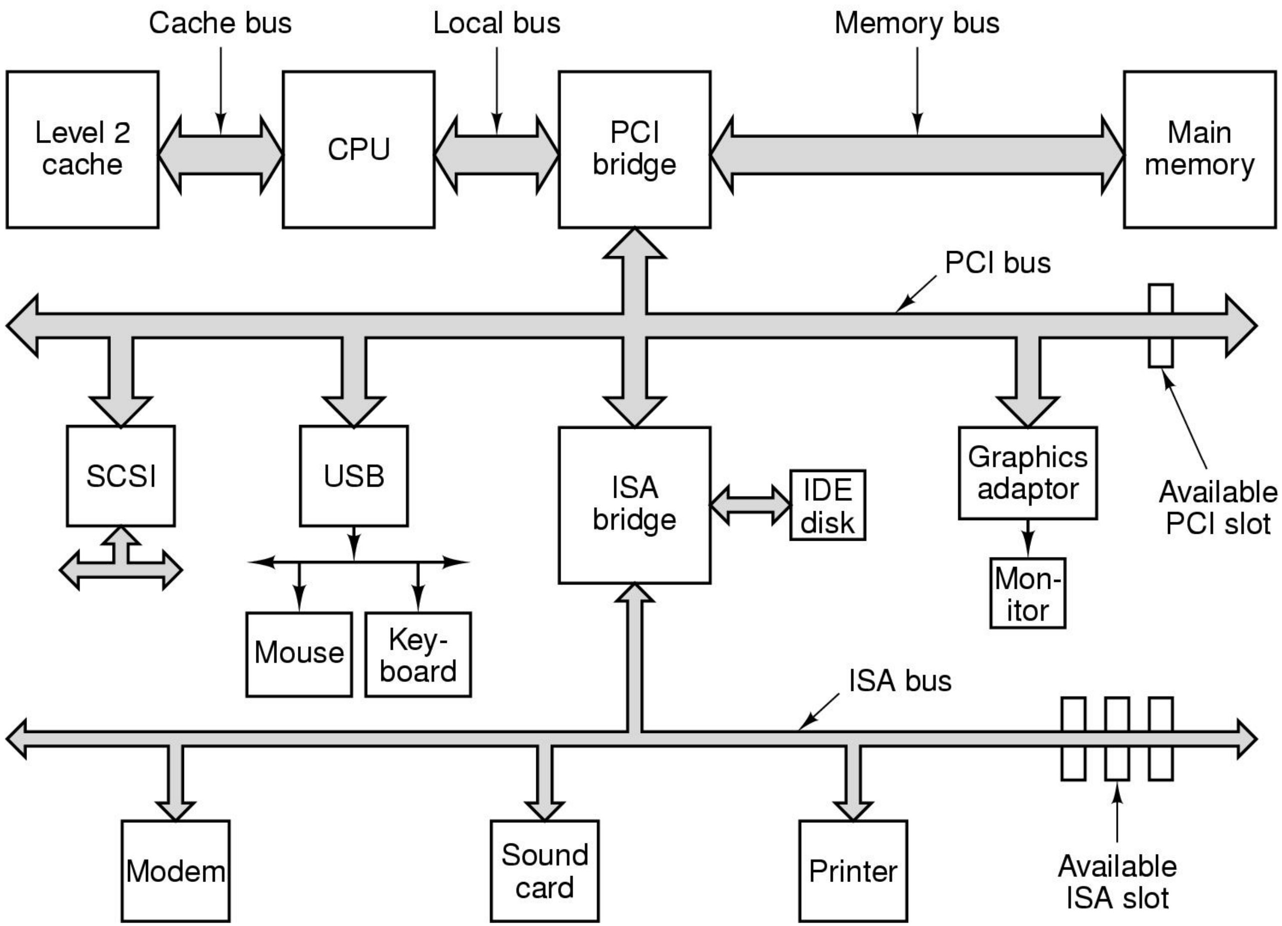
- **Memory management unit (MMU)**
  - hardware provided equivalent of multiple base registers
  - at the granularity of “pages” of memory, say 2kB, i.e., lots of them!
  - supports relocation at page granularity by replacing high order address bits
  - applications need not occupy contiguous physical memory
- **Memory protection**
  - limit registers don’t work in this context
  - per-page and per-application protection registers
- **Relocation and protection occur at CPU speeds!**

What about I/O devices?



A simplified view of a computer system

Structure of a large Pentium system



How do programs interact with devices?

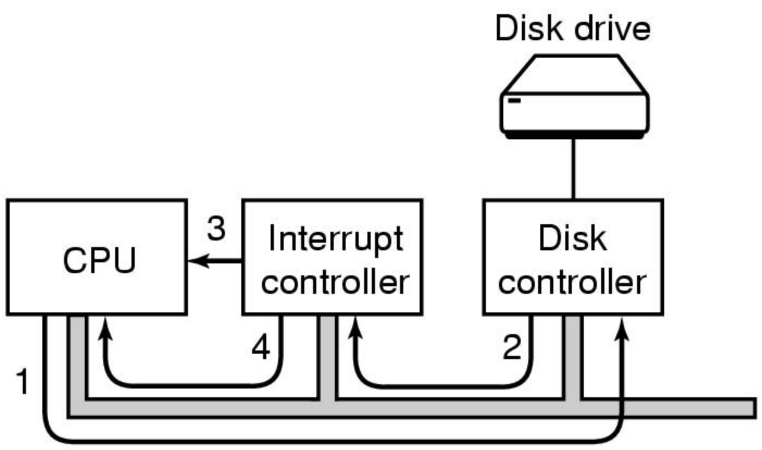
- **Why protect access to devices by accessing them indirectly via the OS?**

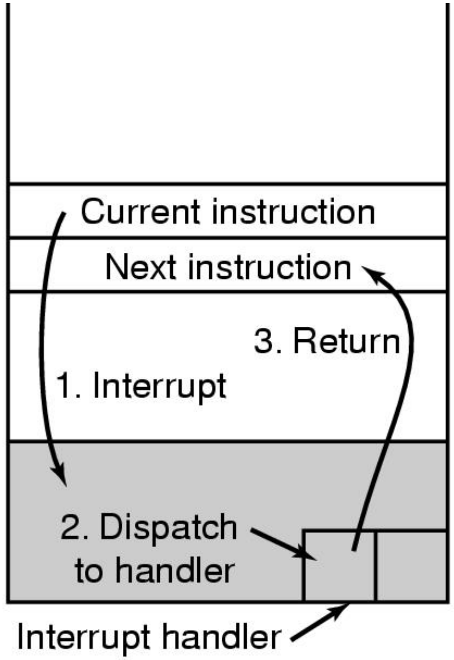
- **Devices vs device controllers vs device drivers**
  - device drivers are part of the OS (ie. Software)
  - programs call the OS which calls the device driver

- **Device drivers interact with device controllers**
  - either using special IO instructions
  - or by reading/writing controller registers that appear as memory locations
  - Device controllers are hardware
  - They communicate with device drivers via interrupts

How do devices interact with programs?

- **Interrupts**





Different types of interrupts

- **Timer interrupts**
  - Allows OS to keep control after calling app' code
  - One way to keep track of time
- **I/O interrupts**
  - Keyboard, mouse, disks, network, etc…
- **Hardware failures**
- **Program generated (traps & faults)**
  - Programming errors: seg. faults, divide by zero, etc.
  - System calls like read(), write(), gettimeofday()

System calls

- *System calls* are the mechanism by which programs communicate with the O.S.
- Implemented via a TRAP instruction
- Example UNIX system calls:

```
open(), read(), write(), close()
kill(), signal()
fork(), wait(), exec(), getpid()
link(), unlink(), mount(), chdir()
setuid(), getuid(), chown()
```

The inner workings of a system call

User-level code

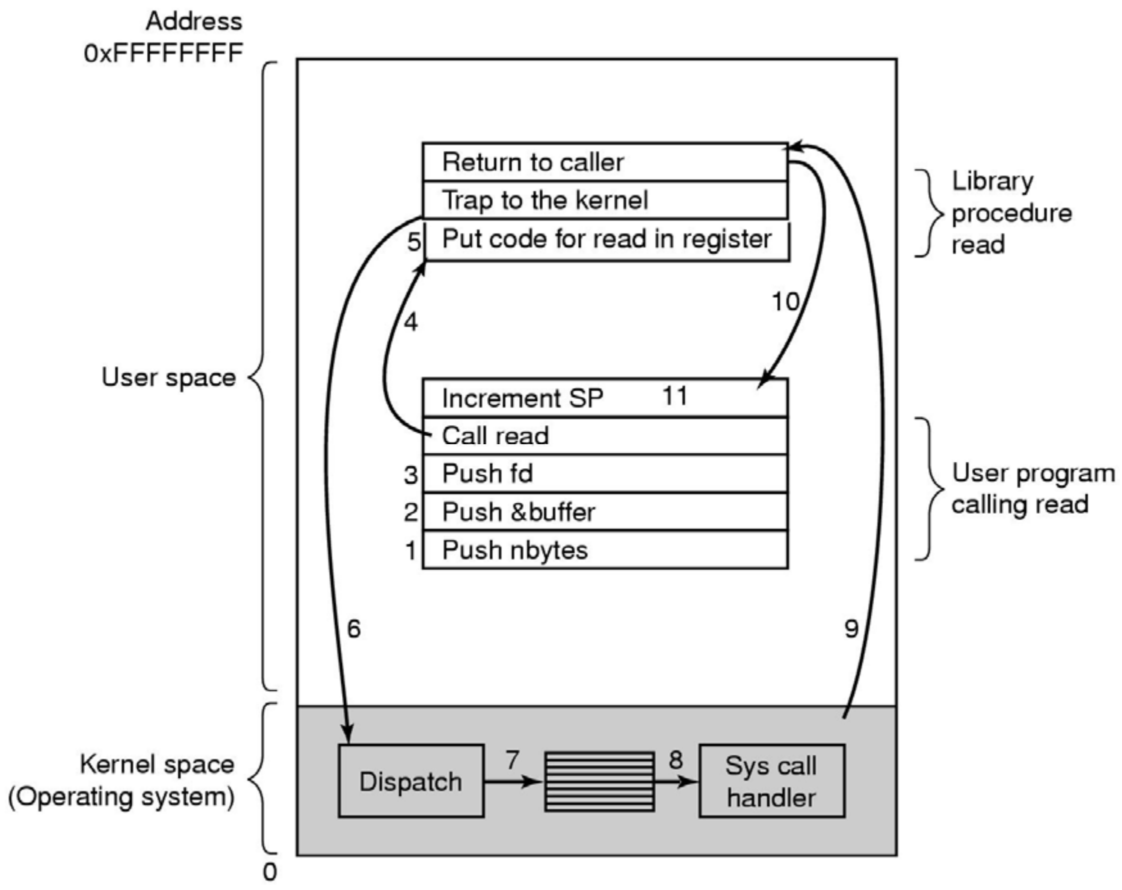
```
Process usercode
  {
   ...
   read (file, buffer, n);
   ...
  }
```

Library code

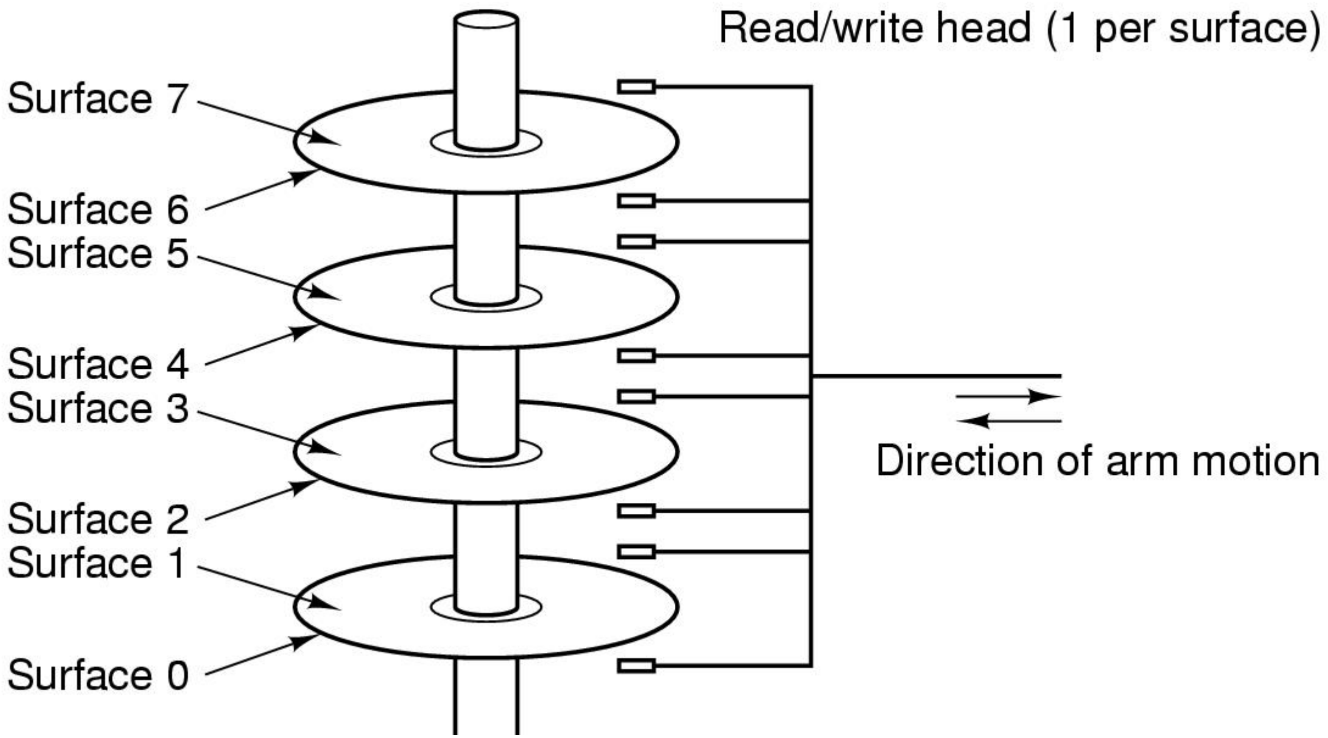
```
Procedure read(file, buff, n)
  {
   ...
   read(file, buff, n)
   ...
  }

_read:
  LOAD r1, @SP+2
  LOAD r2, @SP+4
  LOAD r3, @SP+6
  TRAP Read_Call
```

Steps in making a read() system call



What about disks and file storage?

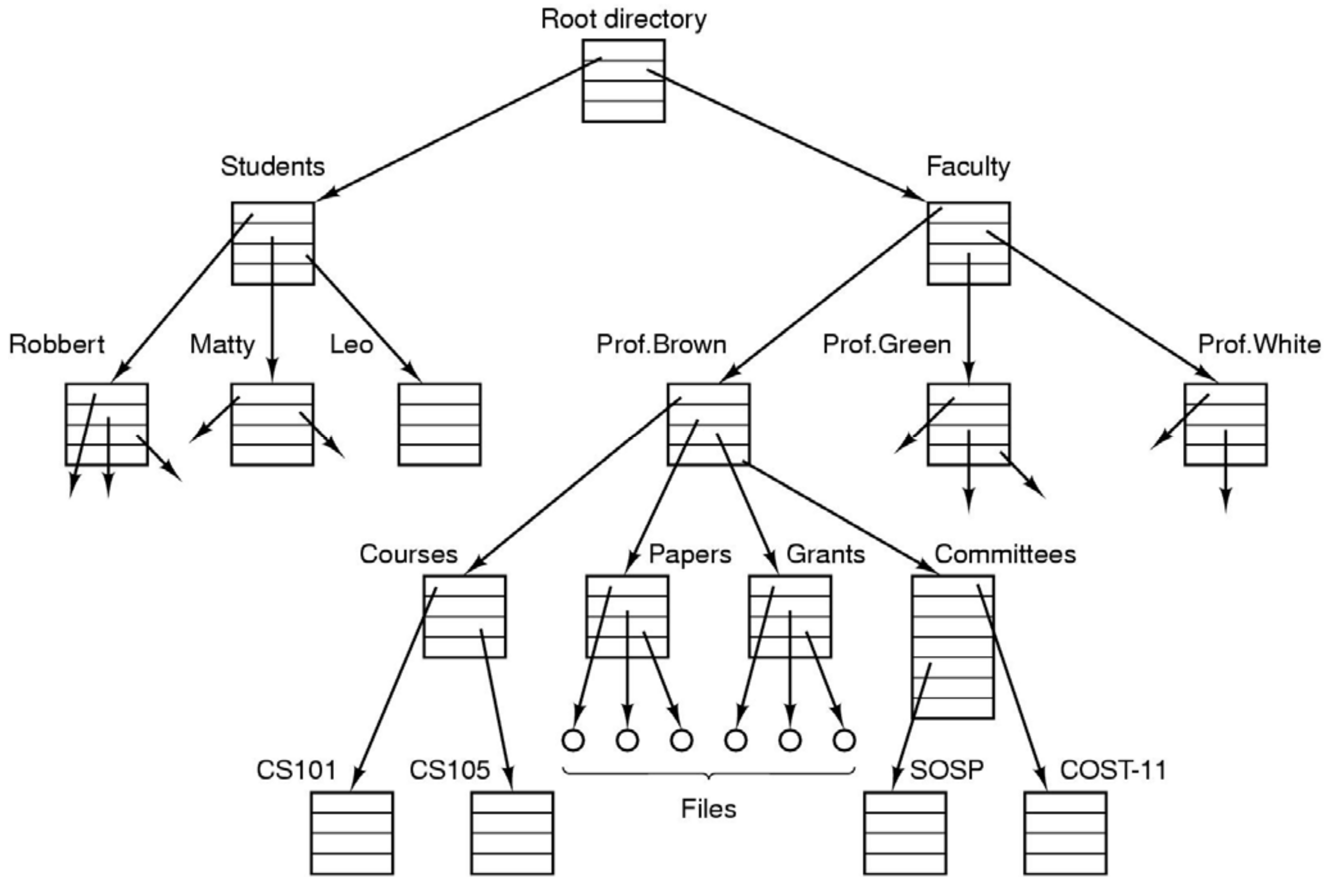


Structure of a disk drive

Disks and file storage

- **Manipulating the disk device is complicated**
  - hide some of the complexity behind disk controller, disk device driver
- **Disk blocks are not a very user-friendly abstraction for storage**
  - contiguous allocation may be difficult for large data items
  - how do you manage administrative information?
- **One application should not (automatically) be able to access another application's storage**
  - OS needs to provide a "file system"

File systems



File system - an abstraction above disk blocks

What about networks?

- **Network interfaces are just another kind of shared device/resource**
- **Need to hide complexity**
  - send and receive primitives, packets, interrupts etc
  - protocol layers
- **Need to protect the device**
  - access via the OS
- **Need to allocate resources fairly**
  - packet scheduling

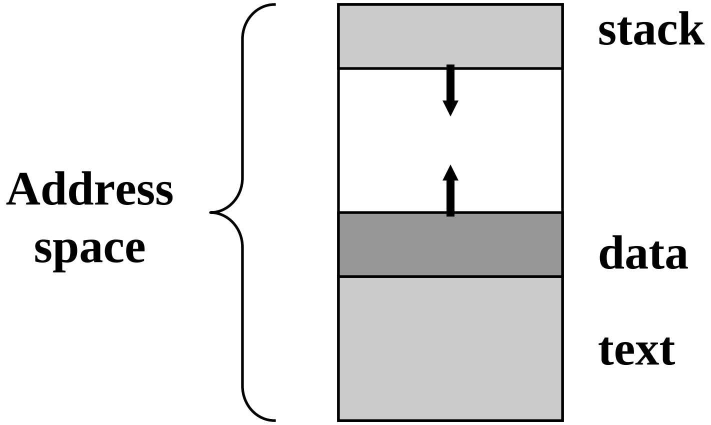
The Process Concept

The Process Concept

- **Process – a program in execution**
  - Program
    - **description of how to perform an activity**
    - **instructions and static data values**
  - Process
    - **a snapshot of a program in execution**
    - **memory (program instructions, static and dynamic data values)**
    - **CPU state (registers, PC, SP, etc)**
    - **operating system state (open files, accounting statistics etc)**

Process address space

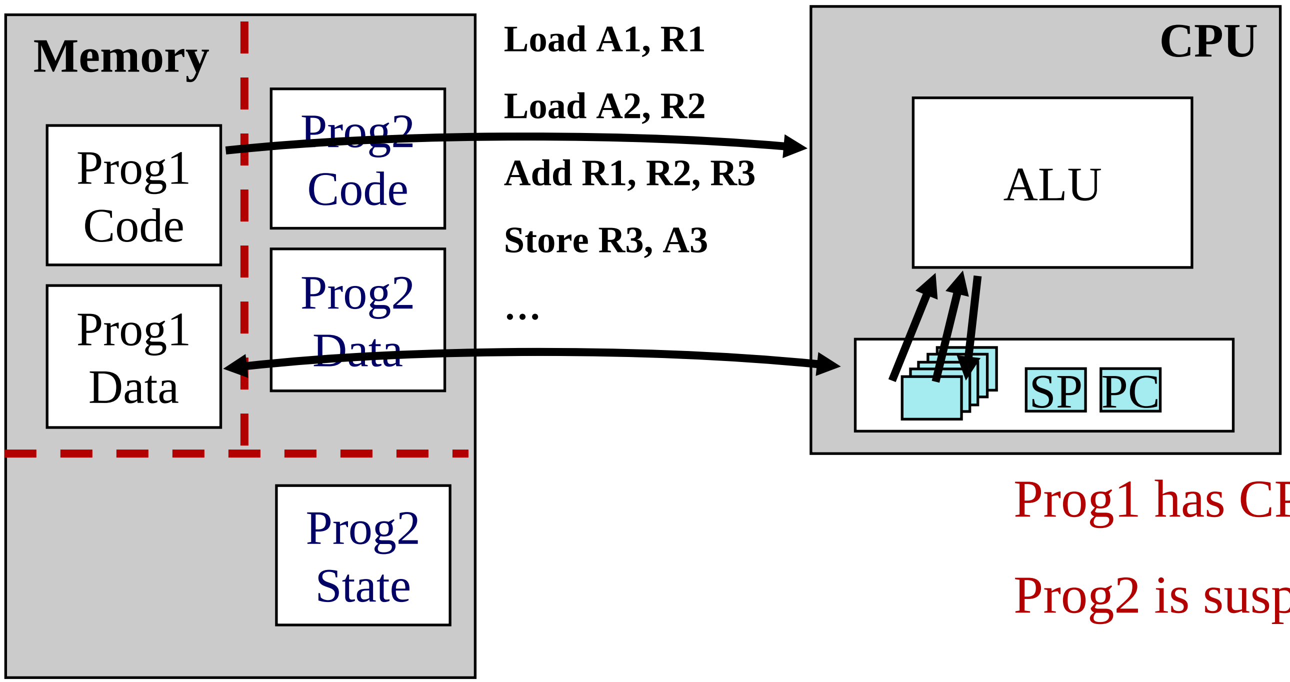
- **Each process runs in its own virtual memory *address space* that consists of:**
  - *Stack space* – used for function and system calls
  - *Data space* – variables (both static and dynamic allocation)
  - *Text* – the program code (usually read only)



- **Invoking the same program multiple times results in the creation of multiple distinct address spaces**

Switching among multiple processes

- Program instructions operate on operands in memory and (temporarily) in registers

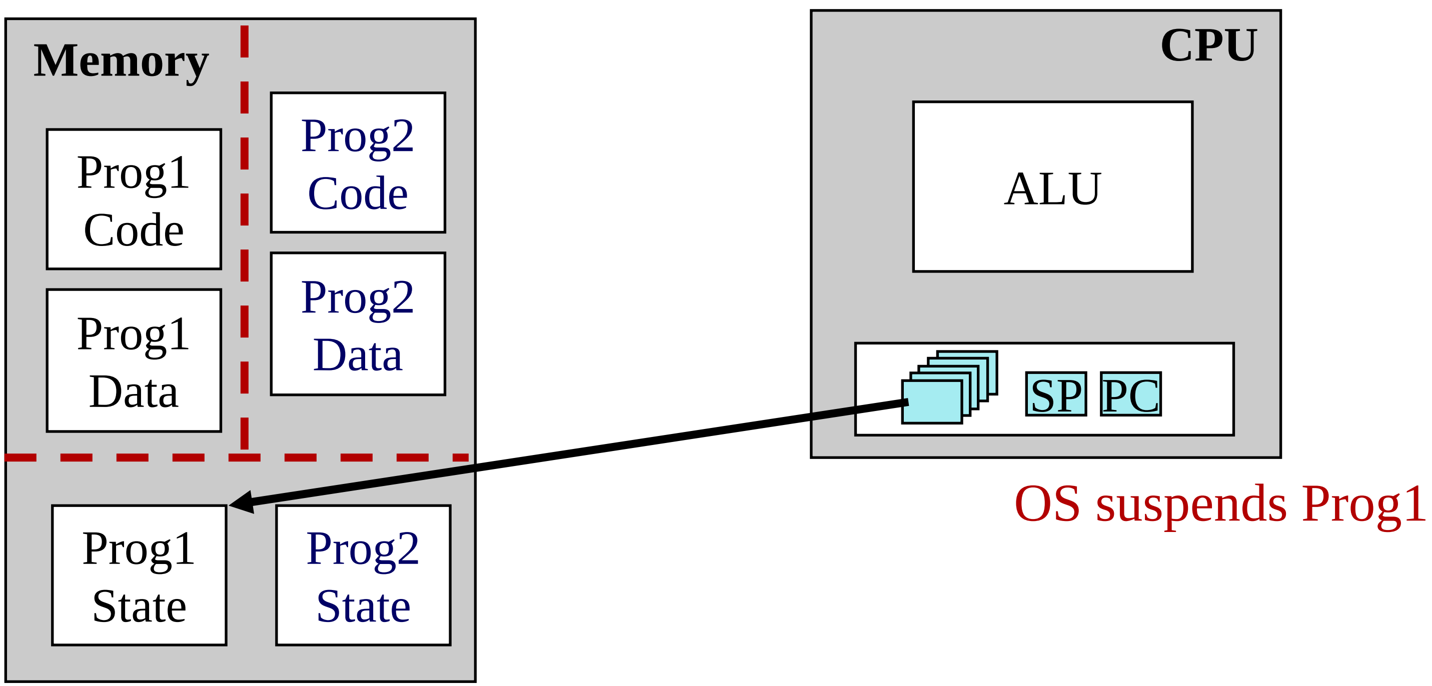


Prog1 has CPU

Prog2 is suspended

Switching among multiple processes

- Saving all the information about a process allows a process to be *temporarily suspended* and later *resumed* from the same point



Switching among multiple processes

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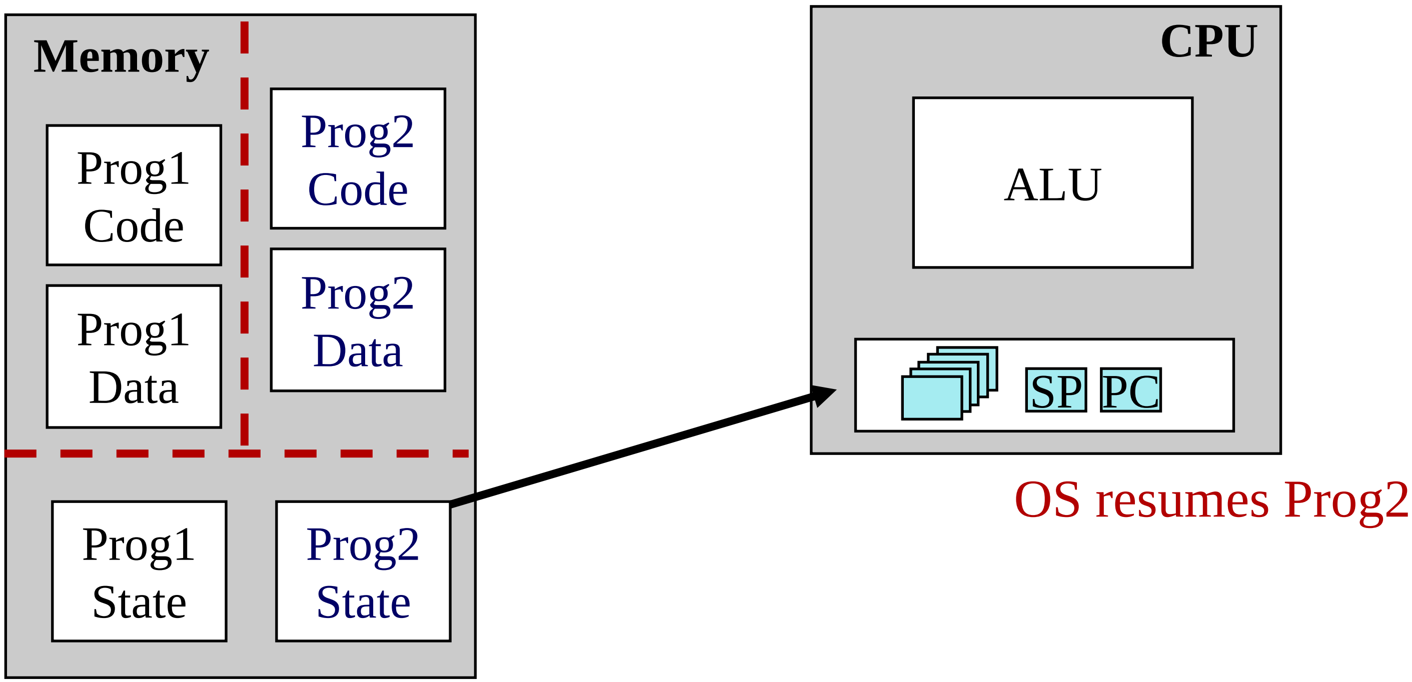

Switching among multiple processes

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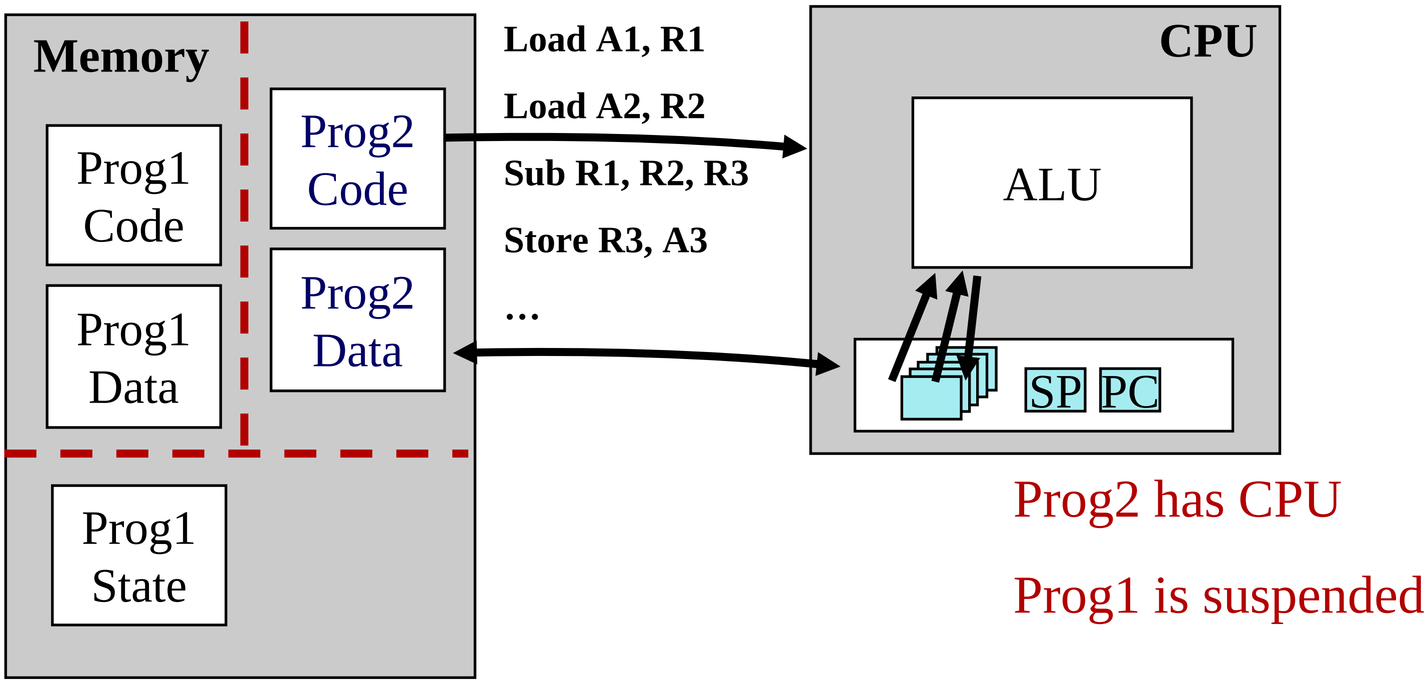
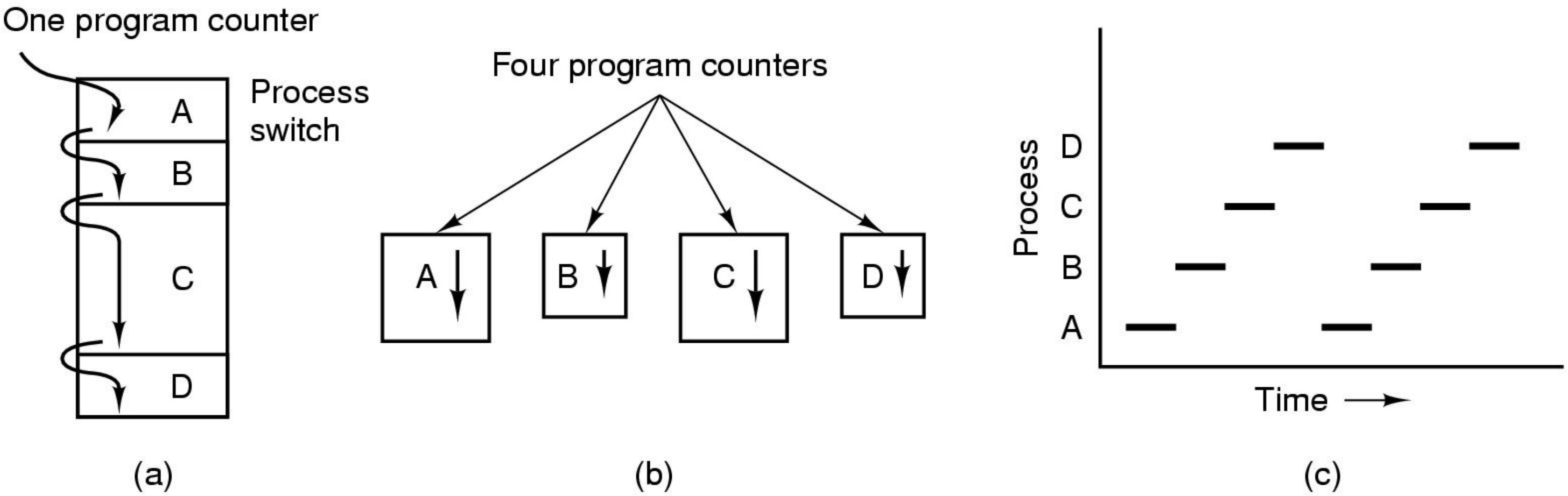
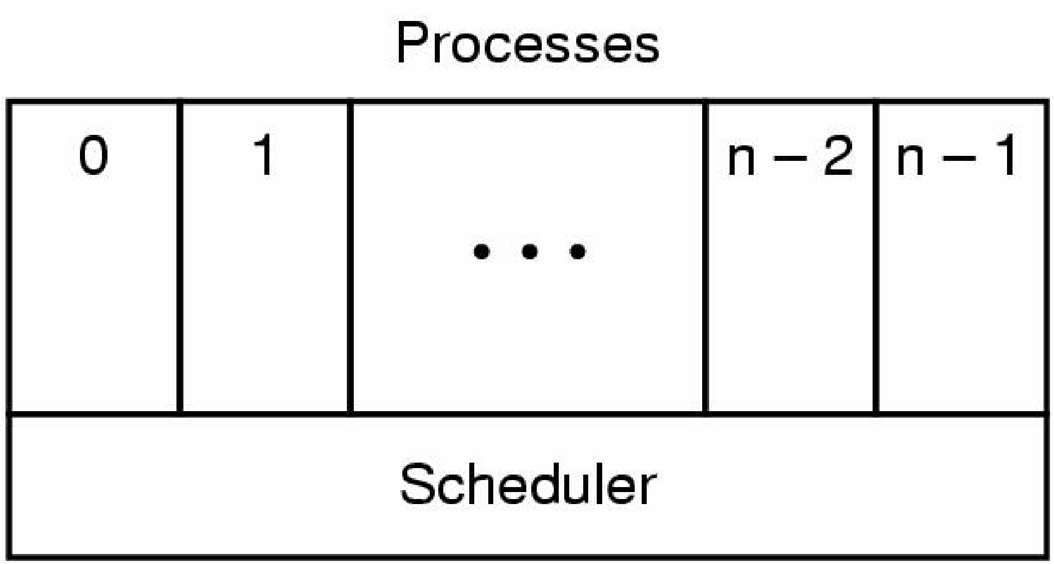


Why use the process abstraction?



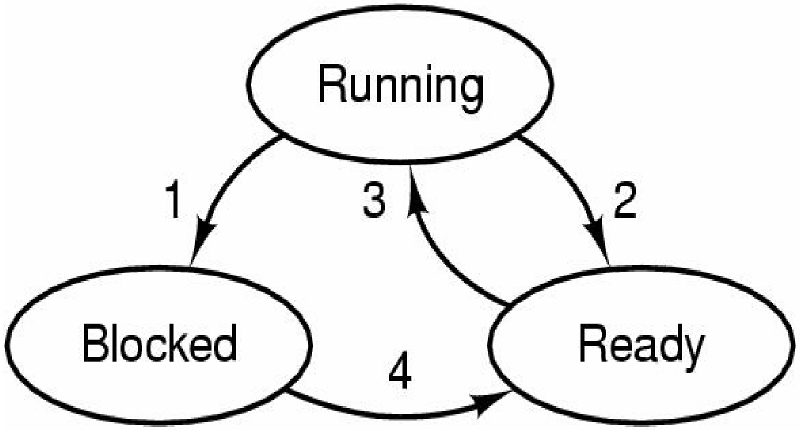
- **Multiprogramming of four programs in the same address space**
- **Conceptual model of 4 independent, sequential processes**
- **Only one program active at any instant**

The role of the scheduler



- **Lowest layer of process-structured OS**
  - handles interrupts & scheduling of processes
- **Above that layer are sequential processes**

Process states



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- **Possible process states**
  - running
  - blocked
  - ready

Implementation of process switching

1. Hardware stacks program counter, etc.
2. Hardware loads new program counter from interrupt vector.
3. Assembly language procedure saves registers.
4. Assembly language procedure sets up new stack.
5. C interrupt service runs (typically reads and buffers input).
6. Scheduler decides which process is to run next.
7. C procedure returns to the assembly code.
8. Assembly language procedure starts up new current process.

- **Skeleton of what the lowest levels of the OS do when an interrupt occurs**

How do processes get created?

Principal events that cause process creation

- System initialization
- Initiation of a batch job
- User request to create a new process
- Execution of a process creation system call from another process

Process hierarchies

- **Parent creates a child process,**
  - special system calls for communicating with and waiting for child processes
  - each process is assigned a unique identifying number or process ID (PID)
- **Child processes can create their own child processes**
  - Forms a hierarchy
  - UNIX calls this a "process group"
  - Windows has no concept of process hierarchy
    - **all processes are created equal**

How do processes terminate?

Conditions which terminate processes

- Normal exit (voluntary)
- Error exit (voluntary)
- Fatal error (involuntary)
- Killed by another process (involuntary)

Process creation in UNIX

- **All processes have a unique process id**
  - *getpid(), getppid()* system calls allow processes to get their information
- **Process creation**
  - *fork()* system call creates a copy of a process and returns in both processes, but with a different return value
  - *exec()* replaces an address space with a new program
- **Process termination, signaling**
  - *signal(), kill()* system calls allow a process to be terminated or have specific signals sent to it

Example: process creation in UNIX

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
  // child…
  …
  exec();
  }
else {
  // parent
  wait();
  }
…
```

Process creation in UNIX example

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
  // child…
  …
  exec();
  }
else {
  // parent
  wait();
  }
…
```

csh (pid = 24)

```
…

pid = fork()
if (pid == 0) {
  // child…
  …
  exec();
  }
else {
  // parent
  wait();
  }
…
```

Process creation in UNIX example

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  // child…
  …
  exec();
  }
else {
  // parent
  wait();
  }
…
```

ls (pid = 24)

```
//ls program

main(){

  //look up dir

  …

}
```

What other process state does the OS manage?

Process management	Memory management	File management
Registers	Pointer to text segment	Root directory
Program counter	Pointer to data segment	Working directory
Program status word	Pointer to stack segment	File descriptors
Stack pointer		User ID
Process state		Group ID
Priority		
Scheduling parameters		
Process ID		
Parent process		
Process group		
Signals		
Time when process started		
CPU time used		
Children's CPU time		
Time of next alarm		

Example fields of a process table entry

What about the OS?

- Is the OS a process?
- It is a program in execution, after all …
- Does it need a process control block?
- Who manages its state when its not running?

What to do before next class

- Reading for next week's class - pages 100-110
- Finish project 1 – Introduction to BLITZ