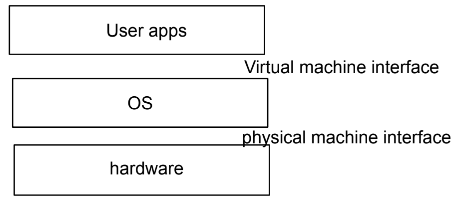
Last Class: Introduction to Operating Systems



- An operating system is the interface between the user and the architecture.
  - History lesson in change.
  - OS reacts to changes in hardware, and can motivate changes.

Course Staff Office Hours

- Instructor: Prashant Shenoy
  - TuTh 9:45 to 10:45, CS building, room 336 or by appt

- TA: Brendan Murphy
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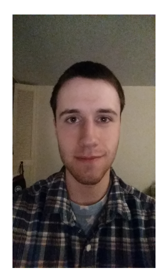


Today: OS and Computer Architecture

- Basic OS Functionality
- Basic Architecture reminder
- What the OS can do is dictated in part by the architecture.
- Architectural support can greatly simplify or complicate the OS.

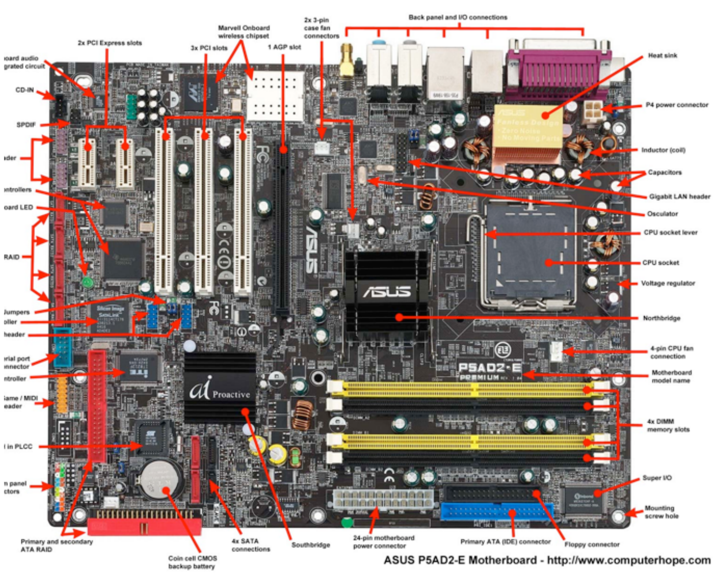
Modern Operating System Functionality

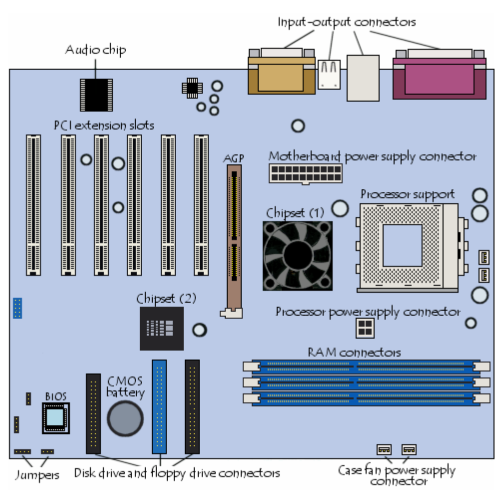
- **Process and Thread Management**
- **Concurrency:** Doing many things simultaneously (I/0, processing, multiple programs, etc.)
  - Several users work at the same time as if each has a private machine
  - Threads (unit of OS control) - one thread on the CPU at a time, but many threads active concurrently
- **I/O devices:** let the CPU work while a slow I/O device is working
- **Memory management**: OS coordinates allocation of memory and moving data between disk and main memory.
- **Files:** OS coordinates how disk space is used for files, in order to find files and to store multiple files
- **Distributed systems & networks:** allow a group of machines to work together on distributed hardware

Summary of Operating System Principles

- **OS as juggler:** providing the illusion of a dedicated machine with infinite memory and CPU.
- **OS as government:** protecting users from each other, allocating resources efficiently and fairly, and providing secure and safe communication.
- **OS as complex system:** keeping OS design and implementation as simple as possible is the key to getting the OS to work.
- **OS as history teacher:** learning from past to predict the future, i.e., OS design tradeoffs change with technology.

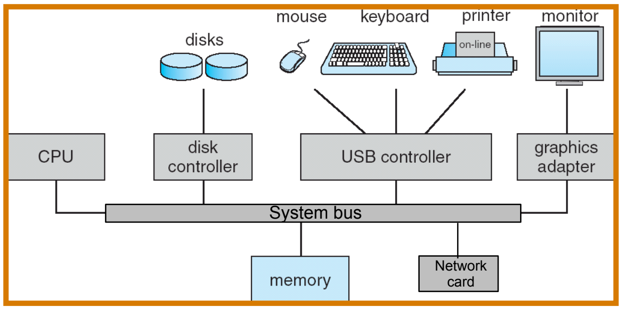
Computer Architecture Basics





- Picture of a motherboard/logicboard

Generic Computer Architecture



- **CPU:** the processor that performs the actual computation
  - Multiple "cores" common in today's processors
- **I/O devices:** terminal, disks, video board, printer, etc.
  - Network card is a key component, but also an I/O device
- **Memory:** RAM containing data and programs used by the CPU
- **System bus:** communication medium between CPU, memory, and peripherals

Architectural Features Motivated by OS Services

OS Service	Hardware Support
Protection	Kernel/user mode, protected instructions, base/limit registers
Interrupts	Interrupt vectors
System calls	Trap instructions and trap vectors
I/O	Interrupts and memory mapping
Scheduling, error recovery, accounting	Timer
Synchronization	Atomic instructions
Virtual memory	Translation look-aside buffers

Protection

- CPU supports a set of assembly instructions
  - MOV [address], ax
  - ADD ax, bx

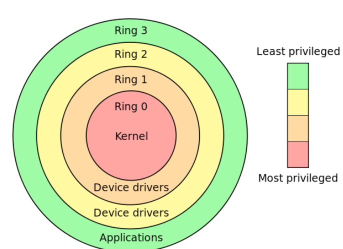
  - MOV CRn (move control register)
  - IN, INS (input string)
  - HLT (halt)
  - LTR (load task register)
  - INT n (software interrupt)

  - Some instructions are sensitive or privileged

Protection

Kernel mode vs. User mode: To protect the system from aberrant users and processors, some instructions are restricted to use only by the OS. Users may not

- address I/O directly
- use instructions that manipulate the state of memory (page table pointers, TLB load, etc.)
- set the mode bits that determine user or kernel mode
- disable and enable interrupts
- halt the machine



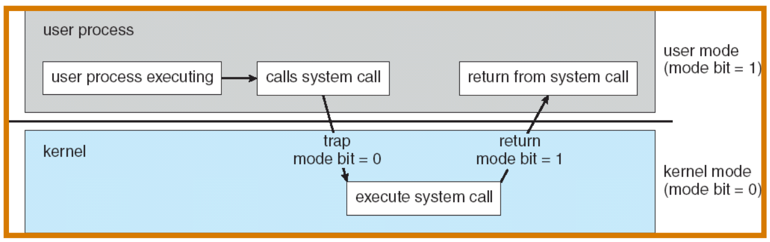
but in kernel mode, the OS can do all these things.

The hardware must support at least kernel and user mode.

- A status bit in a protected processor register indicates the mode.
- Protected instructions can only be executed in kernel mode.

Crossing Protection Boundaries

- **System call:** OS procedure that executes privileged instructions (e.g., I/O) ; also API exported by the kernel
  - Causes a trap, which vectors (jumps) to the trap handler in the OS kernel.
  - The trap handler uses the parameter to the system call to jump to the appropriate handler (I/O, Terminal, etc.).
  - The handler saves caller's state (PC, mode bit) so it can restore control to the user process.
  - The architecture must permit the OS to verify the caller's parameters.
  - The architecture must also provide a way to return to user mode when finished.



Example System calls

Process management

Call	Description
pid = fork( )	Create a child process identical to the parent
pid = waitpid(pid, &statloc, options)	Wait for a child to terminate
s = execve(name, argv, environp)	Replace a process' core image
exit(status)	Terminate process execution and return status

File management

Call	Description
fd = open(file, how, ...)	Open a file for reading, writing or both
s = close(fd)	Close an open file
n = read(fd, buffer, nbytes)	Read data from a file into a buffer
n = write(fd, buffer, nbytes)	Write data from a buffer into a file
position = lseek(fd, offset, whence)	Move the file pointer
s = stat(name, &buf)	Get a file's status information

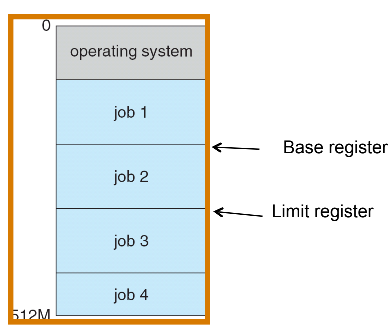
Windows System Calls

UNIX	Win32	Description
fork	CreateProcess	Create a new process
waitpid	WaitForSingleObject	Can wait for a process to exit
execve	(none)	CreateProcess = fork + execve
exit	ExitProcess	Terminate execution
open	CreateFile	Create a file or open an existing file
close	CloseHandle	Close a file
read	ReadFile	Read data from a file
write	WriteFile	Write data to a file
lseek	SetFilePointer	Move the file pointer
stat	GetFileAttributesEx	Get various file attributes
mkdir	CreateDirectory	Create a new directory
rmdir	RemoveDirectory	Remove an empty directory
link	(none)	Win32 does not support links
unlink	DeleteFile	Destroy an existing file
mount	(none)	Win32 does not support mount
umount	(none)	Win32 does not support mount
chdir	SetCurrentDirectory	Change the current working directory
chmod	(none)	Win32 does not support security (although NT does)
kill	(none)	Win32 does not support signals
time	GetLocalTime	Get the current time

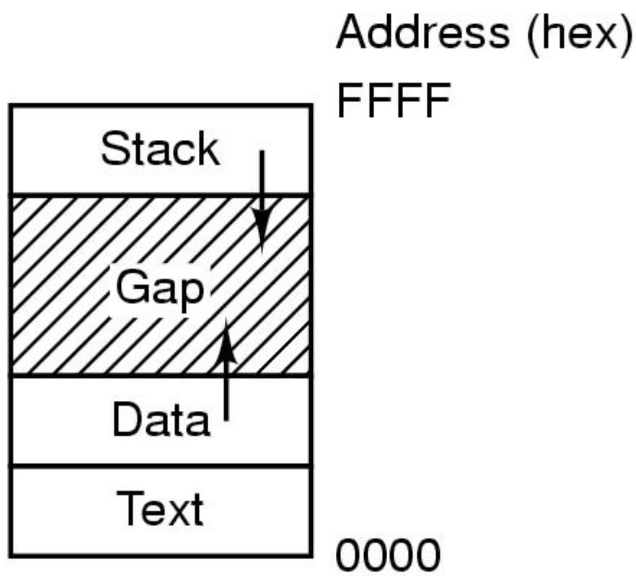
Some Win32 API calls

Memory Protection

- Architecture must provide support so that the OS can
  - protect user programs from each other, and
  - protect the OS from user programs.
- The simplest technique is to use base and limit registers.
- Base and limit registers are loaded by the OS before starting a program.
- The CPU checks each user reference (instruction and data addresses), ensuring it falls between the base and limit register values



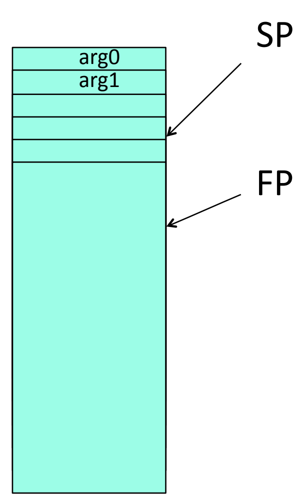
Process Layout in Memory



- Processes have three segments: text, data, stack

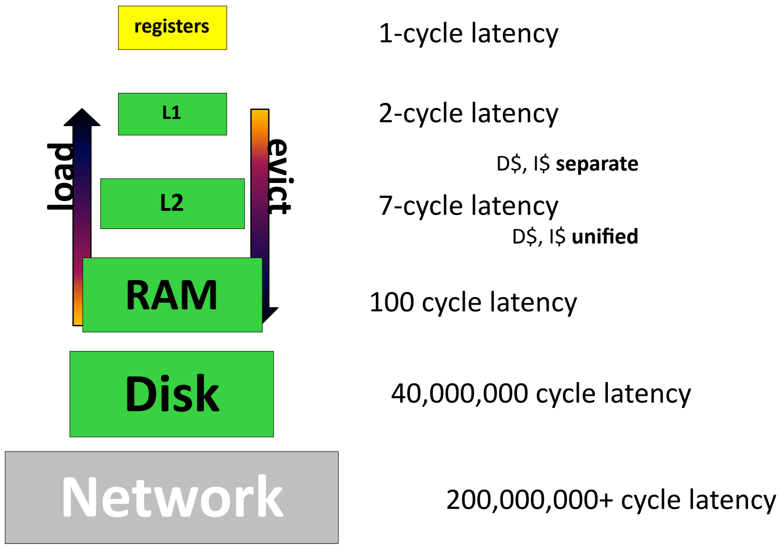
Registers

- Register = dedicated name for one word of memory managed by CPU
  - General-purpose: “AX”, “BX”, “CX” on x86
  - Special-purpose:
    - “SP” = stack pointer
    - “FP” = frame pointer
    - “PC” = program counter
- Change processes: save current registers & load saved registers = context switch



Memory Hierarchy

- Higher = small, fast, more $, lower latency
- Lower = large, slow, less $, higher latency



Caches

- Access to main memory: "expensive"
  - ~ 100 cycles (slow, but relatively cheap ($))
- Caches: small, fast, expensive memory
  - Hold recently-accessed data (D$) or instructions (I$)
  - Different sizes & locations
    - Level 1 (L1) – on-chip, smallish
    - Level 2 (L2) – on or next to chip, larger
    - Level 3 (L3) – pretty large, on bus
  - Manages lines of memory (32-128 bytes)

- Caches are managed by hardware (no explicit OS management)

Traps

- **Traps:** special conditions detected by the architecture
  - Examples: page fault, write to a read-only page, overflow, systems call

0: 0x00080000
1: 0x00100000
2: 0x00100480
3: 0x00123010

- On detecting a trap, the hardware
  - Saves the state of the process (PC, stack, etc.)
  - Transfers control to appropriate trap handler (OS routine)
    - The CPU indexes the memory-mapped trap vector with the trap number,
    - then jumps to the address given in the vector, and
    - starts to execute at that address.
    - On completion, the OS resumes execution of the process

Traps

Trap Vector:

0: 0x00080000	Illegal address
1: 0x00100000	Memory violation
2: 0x00100480	Illegal instruction
3: 0x00123010	System call

- Modern OS use Virtual Memory traps for many functions: debugging, distributed VM, garbage collection, copy-on-write, etc.
- Traps are a performance optimization. A less efficient solution is to insert extra instructions into the code everywhere a special condition could arise.

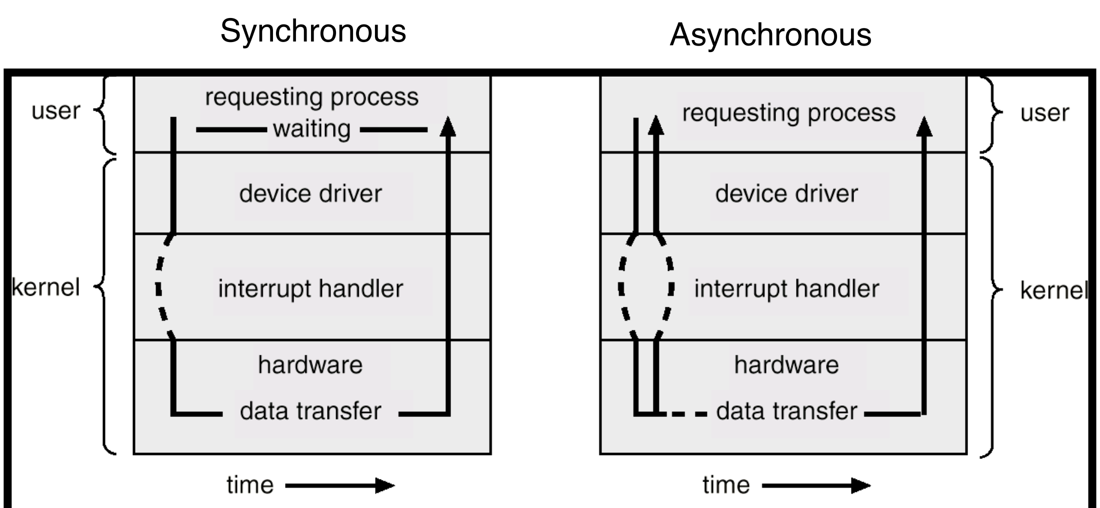
- Recap of System Calls from page 8

I/O Control

- Each I/O device has a little processor inside it that enables it to run autonomously.
- CPU issues commands to I/O devices, and continues
- When the I/0 device completes the command, it issues an interrupt
- CPU stops whatever it was doing and the OS processes the I/O device's interrupt

Three I/O Methods

- Synchronous, asynchronous, memory-mapped



(a) (b)

Memory-Mapped I/O

- Enables direct access to I/O controller (vs. being required to move the I/O code and data into memory)
- PCs (no virtual memory), reserve a part of the memory and put the device manager in that memory (e.g., all the bits for a video frame for a video controller).
- Access to the device then becomes almost as fast and convenient as writing the data directly into memory.

Interrupt based asynchronous I/O

- Device controller has its own small processor which executes asynchronously with the main CPU.
- Device puts an interrupt signal on the bus when it is finished.
- CPU takes an interrupt.
  1. Save critical CPU state (hardware state),
  2. Disable interrupts,
  3. Save state that interrupt handler will modify (software state)
  4. Invoke interrupt handler using the *in-memory Interrupt Vector*
  5. Restore software state
  6. Enable interrupts
  7. Restore hardware state, and continue execution of interrupted process

Timer & Atomic Instructions

Timer

- Time of Day
- Accounting and billing
- CPU protected from being hogged using timer interrupts that occur at say every 100 microsecond.
  - At each timer interrupt, the CPU chooses a new process to execute.

Interrupt Vector:

0: 0x2ff080000	keyboard
1: 0x2ff100000	mouse
2: 0x2ff100480	timer
3: 0x2ff123010	Disk 1

Synchronization

- Interrupts interfere with executing processes.
- OS must be able to synchronize cooperating, concurrent processes.

→ Architecture must provide a guarantee that short sequences of instructions (e.g., read-modify write) execute atomically. Two solutions:

1. Architecture mechanism to disable interrupts before sequence, execute sequence, enable interrupts again.
2. A special instruction that executes atomically (e.g., test&set)

Virtual Memory

- Virtual memory allows users to run programs without loading the entire program in memory at once.
- Instead, pieces of the program are loaded as they are needed.
- The OS must keep track of which pieces are in which parts of physical memory and which pieces are on disk.
- In order for pieces of the program to be located and loaded without causing a major disruption to the program, the hardware provides a translation lookaside buffer to speed the lookup.

Summary

Keep your architecture book on hand.

OS provides an interface to the architecture, but also requires some additional functionality from the architecture.

→ The OS and hardware combine to provide many useful and important features.