EECS 678: Introduction to Operating Systems

Instructor: Heechul Yun

About Me

- Heechul Yun, Assistant Prof., Dept. of EECS
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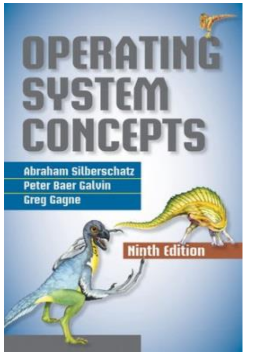
  - Email: heechul.yun@ku.edu
- Research Areas
  - Operating systems and architecture support for embedded/real-time systems
    - To improve time predictability, energy efficiency, and throughput
    - Multicore, memory systems
- Previously
  - Systems software engineer, Samsung Electronics, Nvidia
    - mainly worked on Linux kernel
- More Information
  - http://ittc.ku.edu/~heechul

About This Class



- Textbook: Operating System Concepts
- Objectives: Learn OS basics and practical system programming skills
  - Understand *how it works!*
- Audience: Senior and Junior undergraduate (grad students)
- Course website: http://ittc.ku.edu/~heechul/courses/eecs678/

About This Class

- Course structure
  - Lecture
    - Office hour: MF 11:00 – 11:50 @ 3040 Eaton
    - Discuss OS concepts and the design of major OS components
  - Lab
    - Hands-on system programming experiences.
    - Each lab includes lab discussion and an assignment
    - TA will help you better understand the concepts learned during the lecture.
  - Programming projects
    - Design and implement some parts of OS (e.g., shell, scheduler)
    - 3 projects are expected, each will be given 2~3 weeks to finish
    - To do in groups of two persons. Solo project needs permission

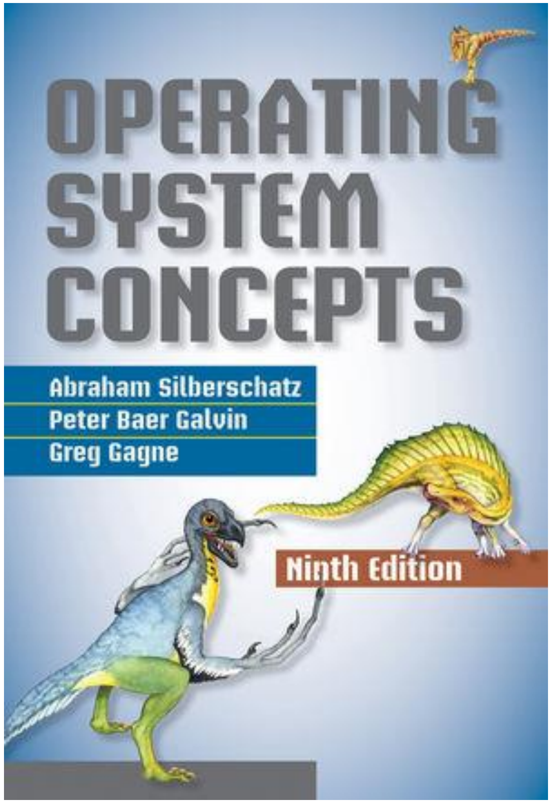
About This Class

- Grading
  - Exam: 50% (mid:20%, final:30%)
  - Quiz: 5%
  - Lab: 15%
  - Programming projects: 30%

About This Class

- Late submissions
  - 20% off / day

- Cheating
  - You can discuss about code and help find bugs of your peers. However, copying another’s code or writing code for someone else is cheating and, if identified, **the involved students will be notified to the department chair**


OPERATING
SYSTEM
CONCEPTS
Abraham Silberschatz
Peter Baer Galvin
Greg Gagne
Ninth Edition

Operating Systems Are Everywhere

- Computers
- Smart phones
- Cars
- Airplanes
- …
- Almost everything





What is an Operating System?

Windows 10

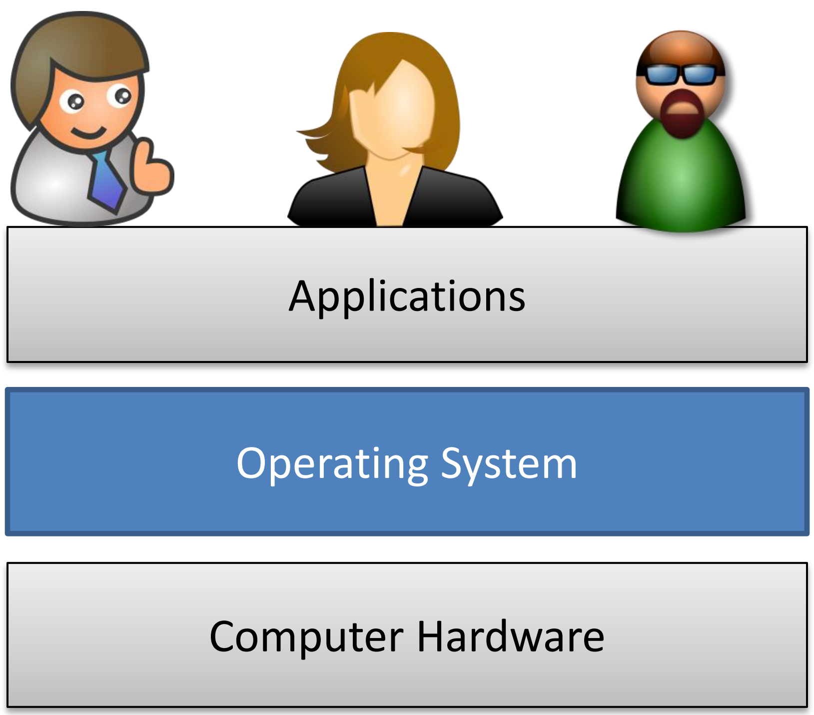
ubuntu

android

QNX SOFTWARE SYSTEMS

What is an Operating System?

- A program that acts as an intermediary **between users** and the computer **hardware**

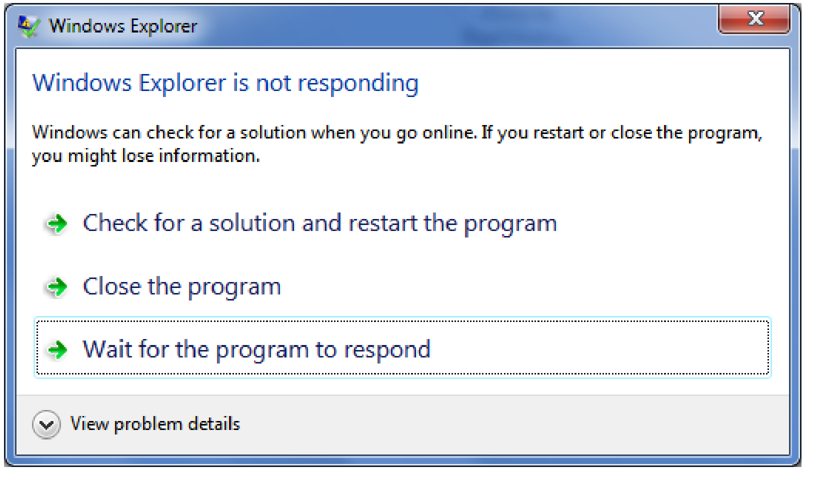


What is an Operating System?

- An easy to use virtual machine – **User's view**
  - Hide complex details for you.
    - What CPU am I using? Intel or AMD?
    - How much memory do I have?
    - Where and how to store my data on the disk?
  - Provide APIs and services
    - read(…), write(..)
    - Virtual memory, filesystems, …

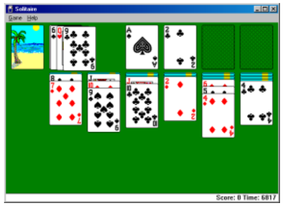
What is an Operating System?

- A resource manager – **System's view**
  - Make everybody get a fair share of resources
    - Time and space multiplexing hardware resources
  - Monitor/prevent error or improper use



What is an Operating System?

- Is an internet browser part of an OS?
  - Everything that shipped by the OS vendor?
  - What about 'solitaire'?



- The program that always runs
  - Typically in kernel mode (we will learn it later)

Why Needed?

- Programmability
  - You don’t need to know hardware details to do stuffs
- Portability
  - You can run the same program on different hardware configurations
- Safety
  - The OS protects your program from faults in other programs
- Efficiency
  - Multiple programs/users can share the same hardware efficiently

What to Study?

- Not “how to use”
  - I’m sure you know better than me about how to use the iOS in your iPhone.
- But “how it works!”
  - We will study the underlying concepts, standard OS components and their designs

OS Design Issues

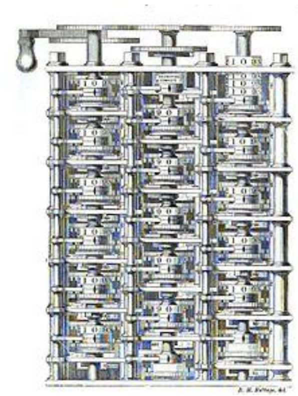
- Structure
  - How to organize the OS?
- Communication
  - How to exchange data among different programs?
- Performance
  - How to maximize/guarantee performance and fairness?
- Naming
  - How to name/access resources ?
- Protection
  - How to protect with each other?
- Security
  - How to prevent unauthorized access?
- Reliability
  - How to prevent system crash?

Why Study?

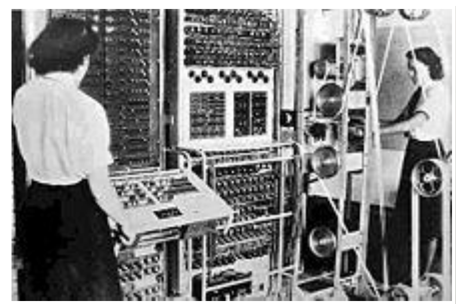
- I’m a user
  - Have you ever wondered how it works?
  - You can better tune the OS to improve performance (or save energy)
- I’m a system programmer
  - You can write more efficient programs by knowing how the OS works.
- I’m a hacker
  - You need to know the enemy (the OS) to beat it

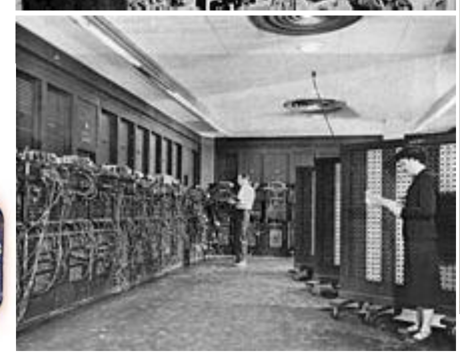
Brief History of Computers

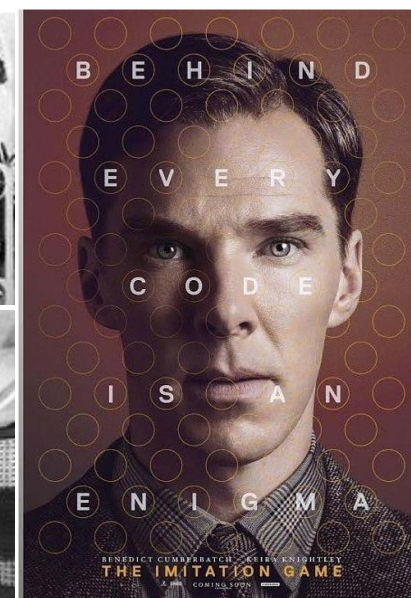
- Early computing machines
  - Babbage's analytical engine
  - First programmer: Ada Lovelace

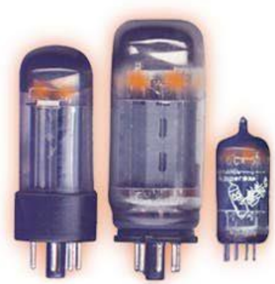


- Vacuum tube machines
  - 1940s ~ 1950s
  - Used to break code in WWII
  - No OS, No PL









Brief History of Computers

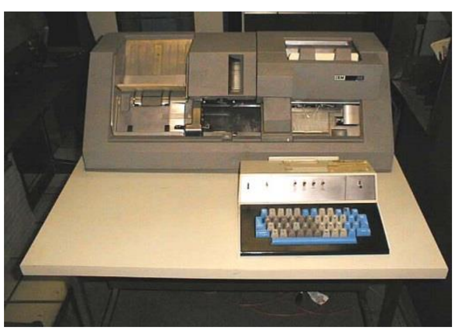
- Vacuum tubes → Transistors → IC → VLSI
  - Smaller, faster, and more reliable
  - Enable smaller computers
- 1960s Mainframes
- 1970s Minicomputers
- 1980s Microprocessor, Apple, IBM PC
- 1990s PC, Internet
- 2000s Cloud computing
- 2010s Mobile, Internet-of-things (IoT)



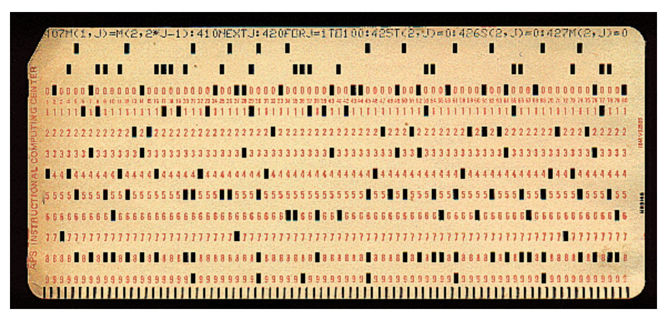



Evolution of Operating Systems

- Batch systems
  - Each user submits her job on punch cards
  - Collect a batch of jobs, read the batch before start processing
  - The ‘OS’ processes each job at a time
  - Problems
    - No interactivity
    - CPU is underutilize to wait I/O operations



IBM 029 card punch



http://www.catb.org/esr/writings/taouu/html/ch02s01.html

Evolution of Operating Systems

- Multiprogramming
  - Multiple runnable jobs at a time
  - I/O and compute can overlap
  - OS goal: maximize system throughput
  - IBM OS/360

Evolution of Operating Systems

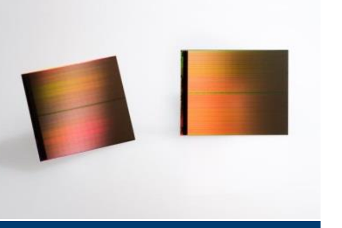
- Timesharing
  - Multiple interactive users sharing a machine
  - Each user accesses the machine via a terminal
  - Provide each user an illusion of using the entire machine
  - OS goal: optimize response time
  - UNIX

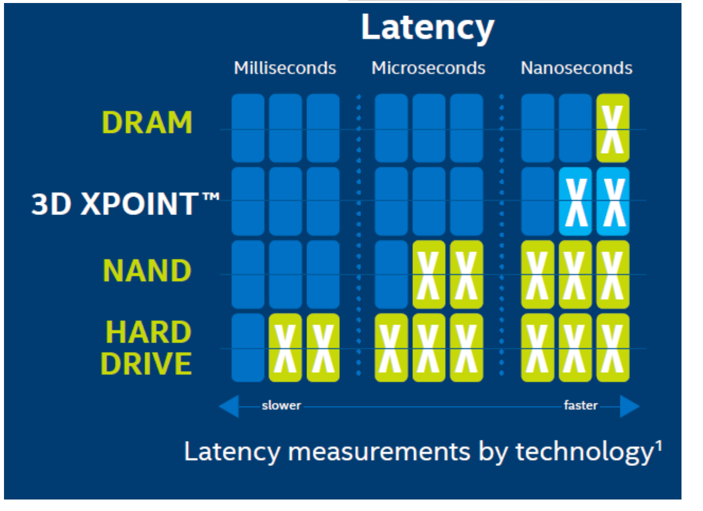
Evolution of Operating Systems

- Parallel computing
  - Use multiple CPUs/cores to speed up performance
  - OS goal: fast synchronization, max utilization
- Distributed computing
  - Physically separate networked computers
- Virtualization
  - Multiple OSes on a single machine

Challenges for Future OS

- New kinds of hardware are keep coming
  - Heterogeneous multicore processors (e.g., ARM big.LITTLE)
  - Storage Class Memory (SCM): non-volatile DRAM-like memories





- New computing paradigms
  - Cloud computing
  - Internet-of-Things (IoT)

Summary

- In this class, you will learn
  - Major OS components
  - Their structure, interface, mechanisms, policies, and algorithms
- This class will (hopefully) help you
  - Understand the foundation of computing systems
  - Understand various engineering trade-offs in designing complex systems you would build in future

Computer Architecture and OS

Recap

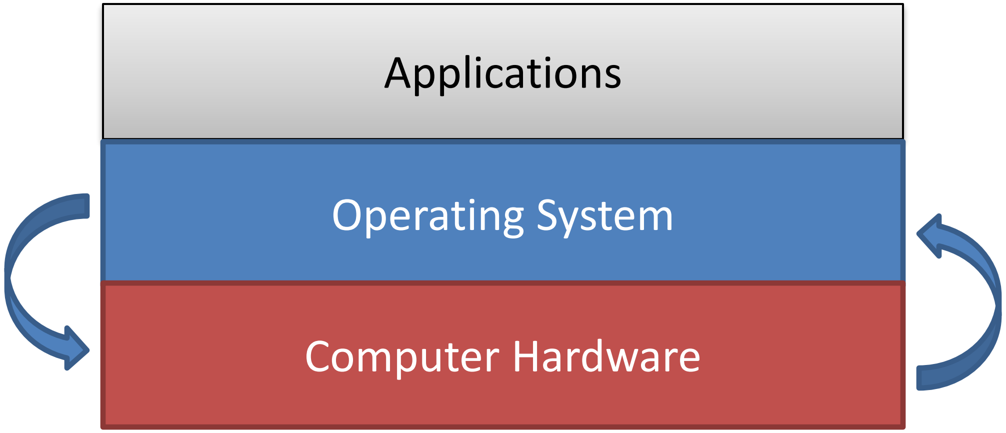
- What is an OS?
  - An intermediary between users and hardware
  - A program that is always running
  - A resource manager
    - Manage resources efficiently and fairly
  - A easy to use virtual machine
    - providing APIs and services

Agenda

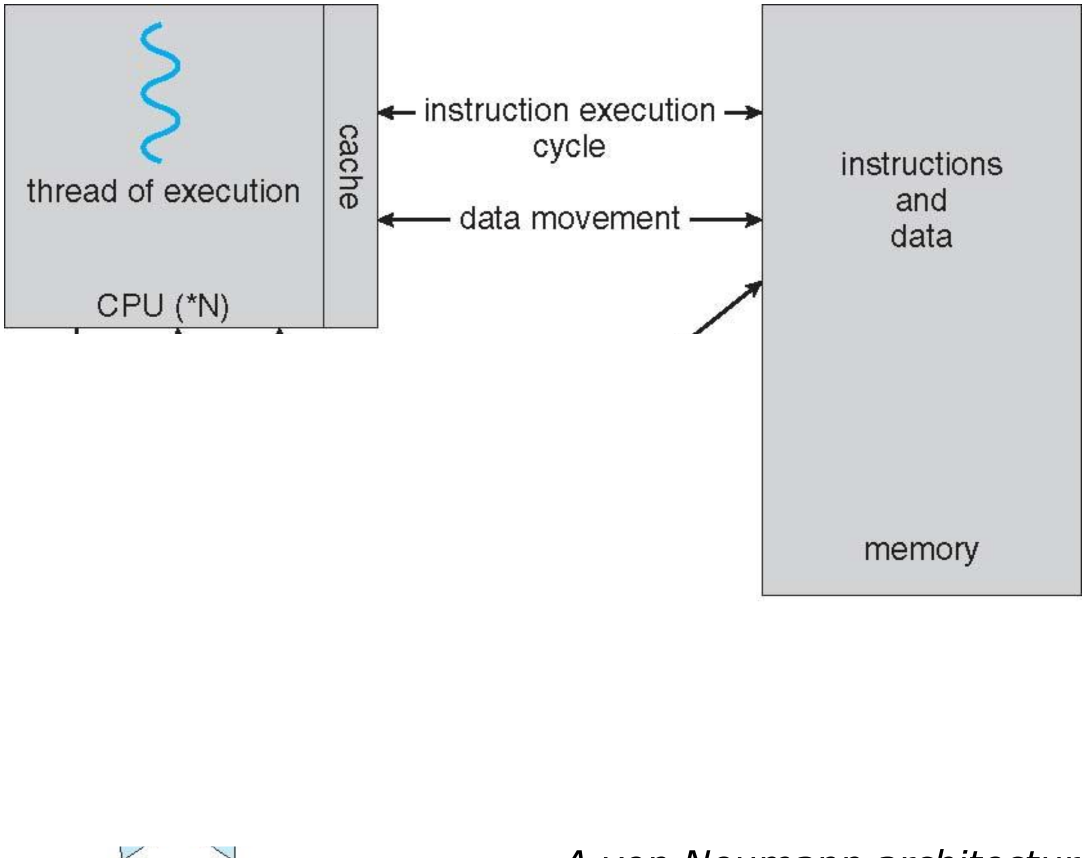
- Computer architecture and OS
  - CPU, memory, disk
  - Architecture trends and their impact to OS
  - Architectural support for OS

Computer Architecture and OS

- OS talks to hardware
  - OS needs to know the hardware features
  - OS drives new hardware features



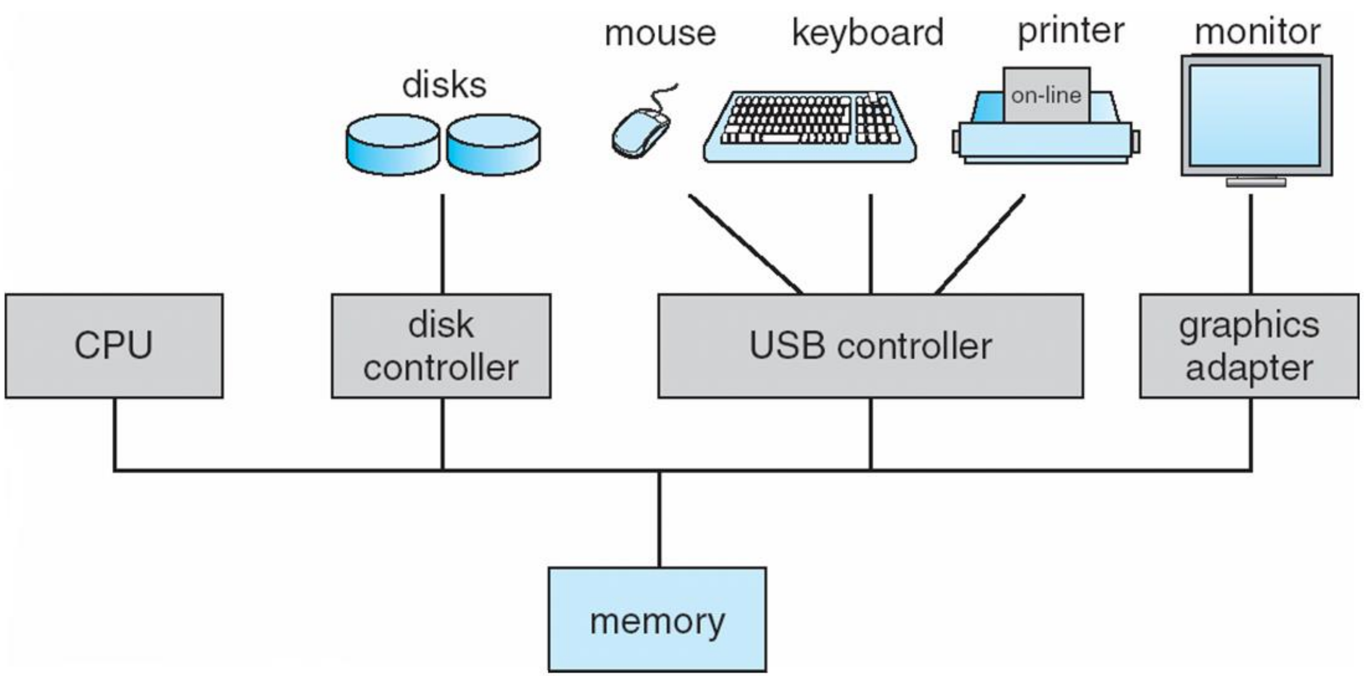
Simplified Computer Architecture



A von Neumann architecture

A Computer System

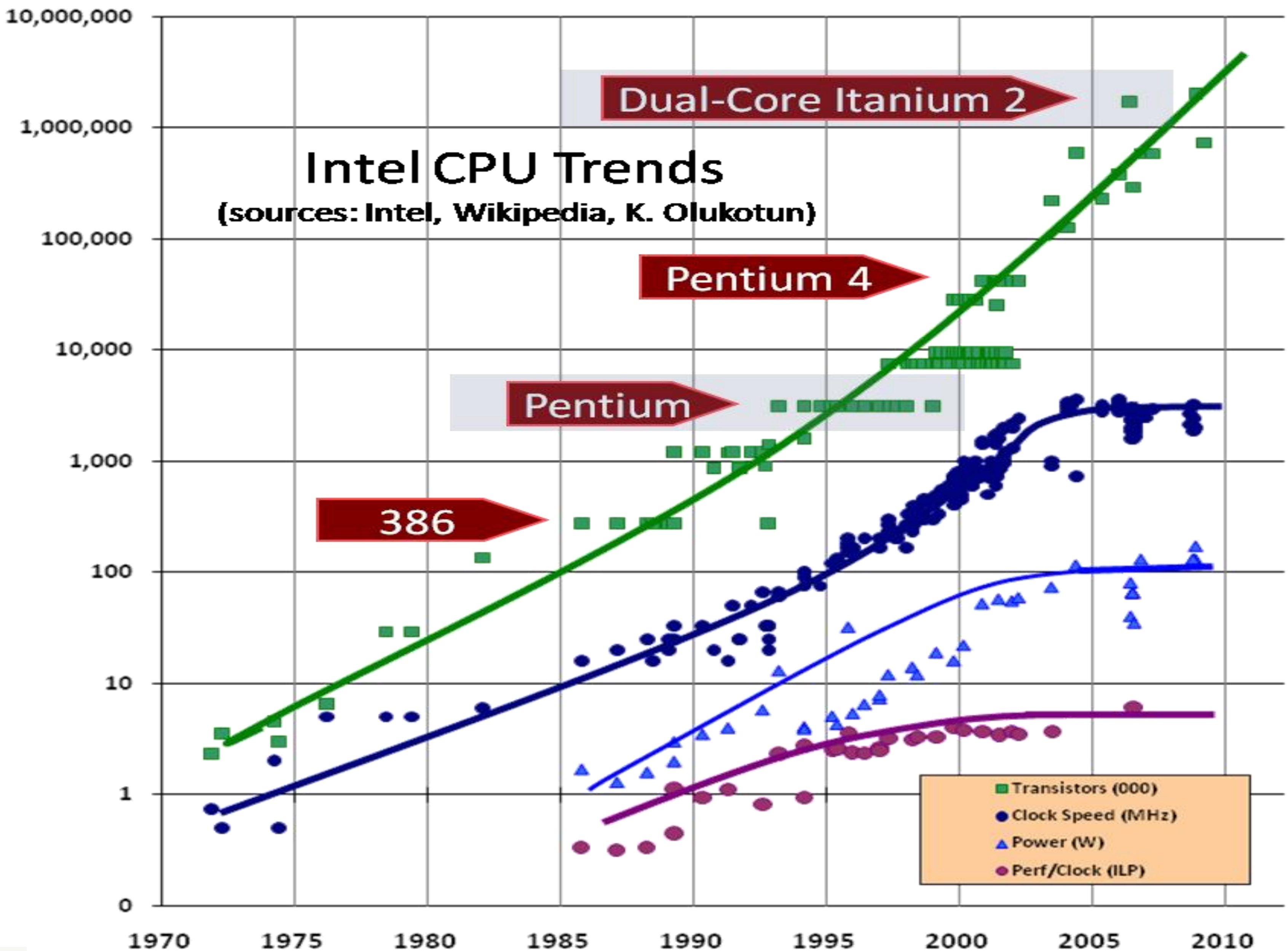
– **Essentials: CPU, Memory, Disk**
– Others: graphic, USB, keyboard, mouse, …



Central Processing Unit (CPU)

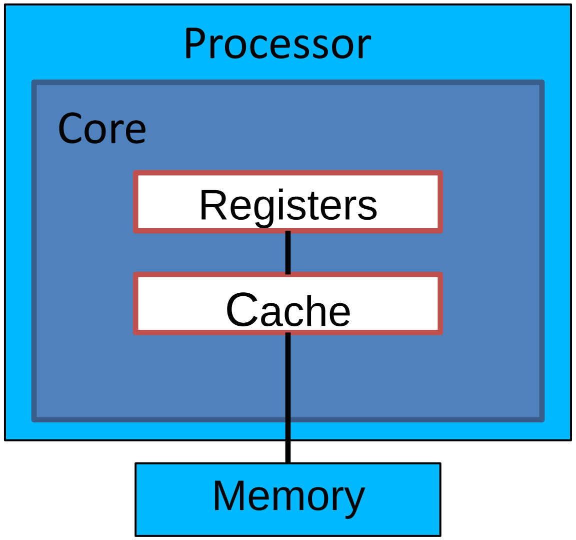
- The brain of a computer
  - Fetch instruction from memory
  - Decode and execute
  - Store results on memory/registers

- Moore's law
  - Transistors double every 1~2yr
  - 5.56 billion in a 18-core Intel Xeon Haswell-E5



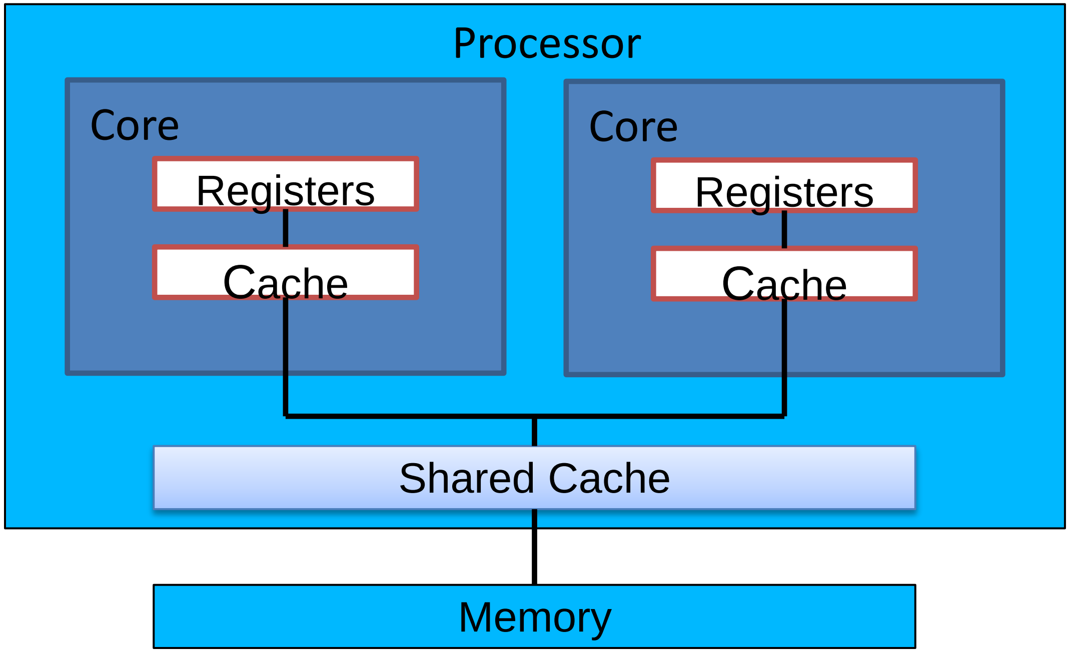
H Sutter, “The Free Lunch Is Over”, Dr. Dobb's Journal, 2009

Single-core CPU



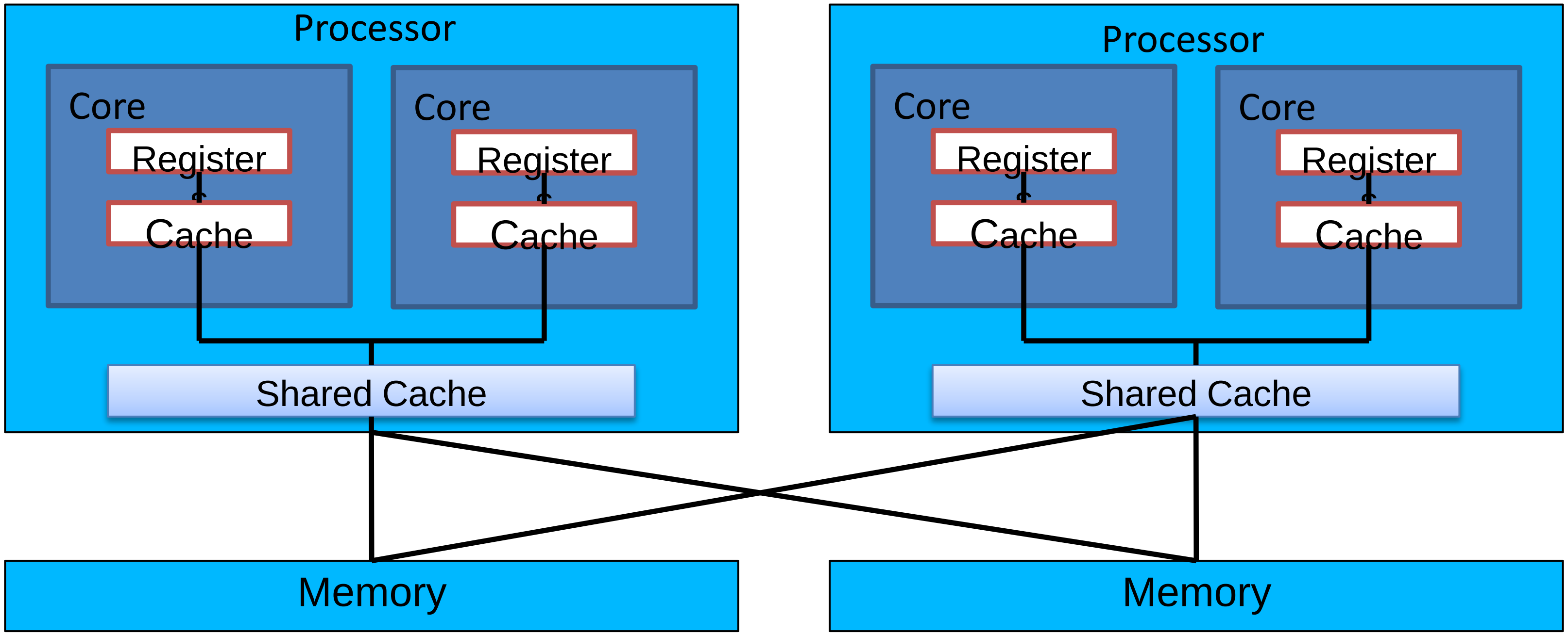
- Time sharing
  - When to schedule which task?

Multicore CPU



- Parallel processing
  - Which tasks to which cores?
    - May have performance implication due to cache contention → contention-aware scheduling

Multiprocessors



- Non-uniform memory access (NUMA) architecture
  - Memory access cost varies significantly: local vs. remote
  - Which tasks to which processors?

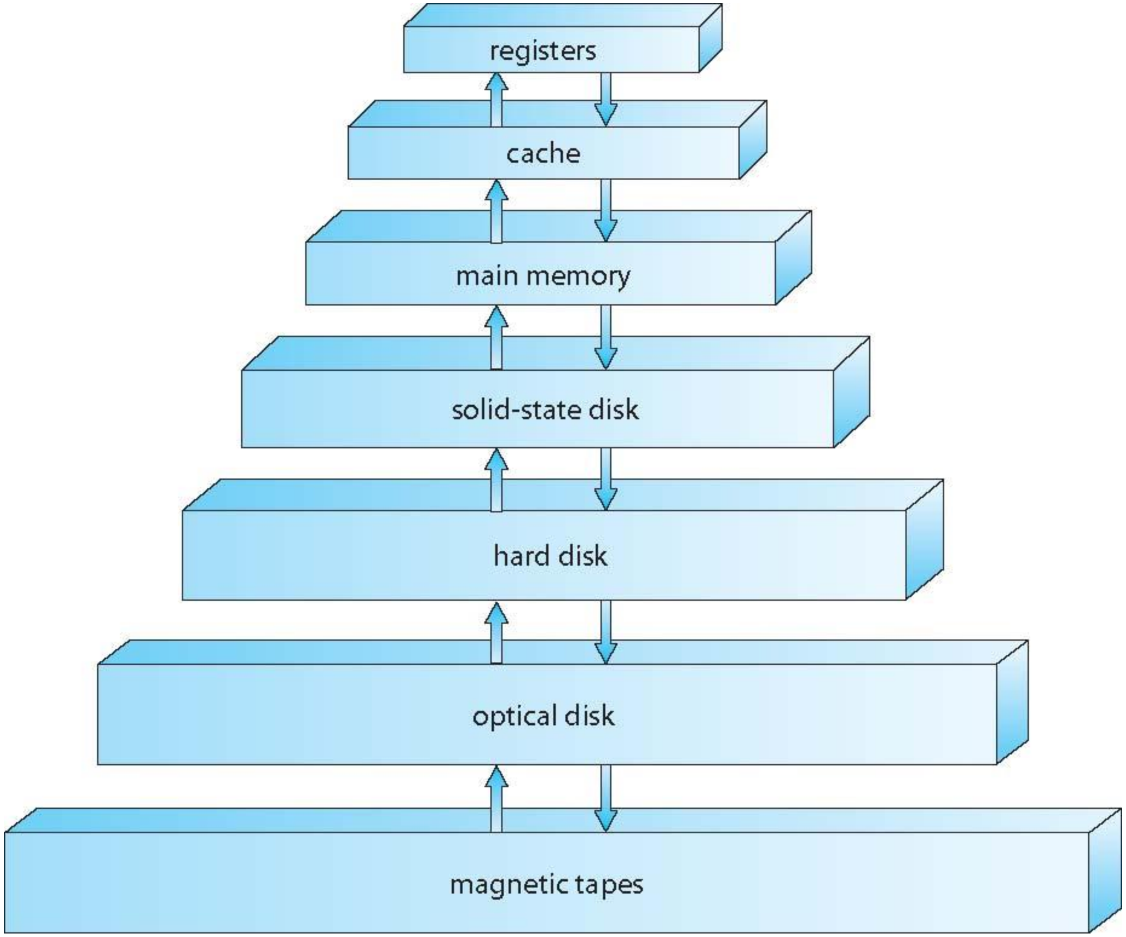
Memory Hierarchy

- Main memory
  - DRAM
  - Fast, volatile, expensive
  - CPU has direct access
- Disk
  - Hard disks, solid-state disks
  - Slow, non-volatile, inexpensive
  - CPU doesn't have direct access.

Memory Hierarchy

Fast,
Expensive

Slow,
Inexpensive



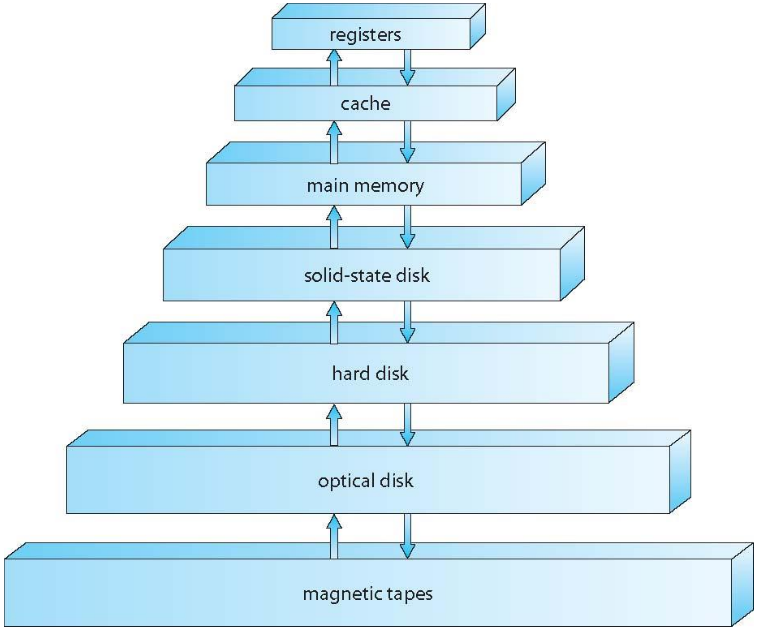
Storage Performance

- Performance of various levels of storage depends on
  - distance from the CPU, size, and process technology used
- Movement between levels of storage hierarchy can be explicit or implicit

Level	1	2	3	4	5
Name	registers	cache	main memory	solid state disk	magnetic disk
Typical size	< 1 KB	< 16MB	< 64GB	< 1 TB	< 10 TB
Implementation technology	custom memory with multiple ports CMOS	on-chip or off-chip CMOS SRAM	CMOS SRAM	flash memory	magnetic disk
Access time (ns)	0.25 - 0.5	0.5 - 25	80 - 250	25,000 - 50,000	5,000,000
Bandwidth (MB/sec)	20,000 - 100,000	5,000 - 10,000	1,000 - 5,000	500	20 - 150
Managed by	compiler	hardware	operating system	operating system	operating system
Backed by	cache	main memory	disk	disk	disk or tape

Caching

- A very important principle applied in all layers of hardware, OS, and software
  - Put frequently accessed data in a small amount of faster memory
  - Fast, most of the time (hit)
  - Copy from slower memory to the cache (miss)



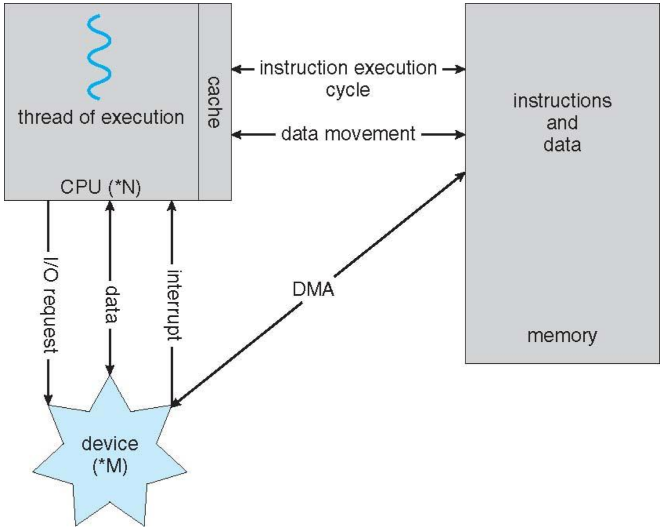
Architectural Support for OS

- Interrupts and exceptions
- Protected modes (kernel/user modes)
- Memory protection and virtual memory
- Synchronization instructions

Interrupt

- What is an interrupt?
  - A signal to the processor telling "do something now!"
- Hardware interrupts
  - Devices (timer, disk, keyboard, …) to CPU
- Software interrupts (exceptions)
  - Divide by zero, special instructions (e.g., int 0x80)

Interrupt Handling



- save CPU states (registers)
- execute the associated interrupt service routine (ISR)
- restore the CPU states
- return to the interrupted program

Timesharing

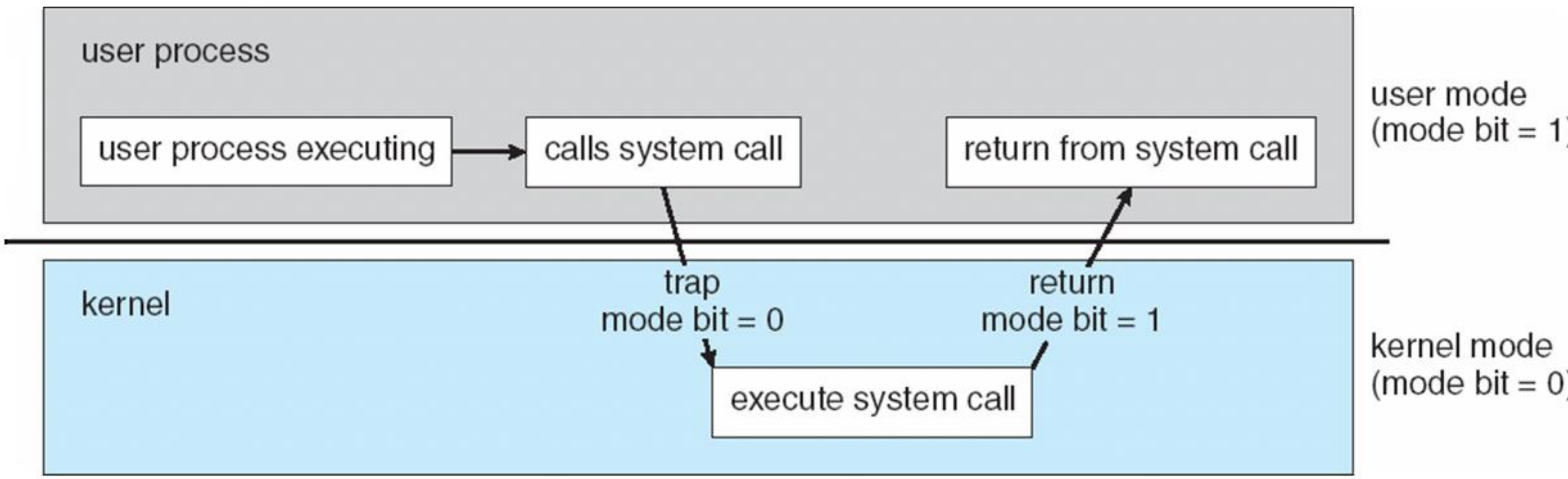
- Multiple tasks share the CPU at the same time
  - But there is only one CPU (assume single-core)
  - Want to schedule different task at a regular interval of 10 ms, for example.

- Timer and OS scheduler tick
  - The OS programs a timer to generate an interrupt at every 10 ms.

Dual (User/Kernel) Mode

- Some operations must be restricted to the OS
  - accessing registers in the disk controller
  - updating memory management unit states
  - …
- User/Kernel mode
  - Hardware support to distinguish app/kernel
  - Privileged instructions are only for kernel mode
  - Applications can enter into kernel mode only via pre-defined **system calls**

User/Kernel Mode Transition



- System calls
  - Programs ask OS services (privileged) via system calls
  - Software interrupt. “int <num>” in Intel x86

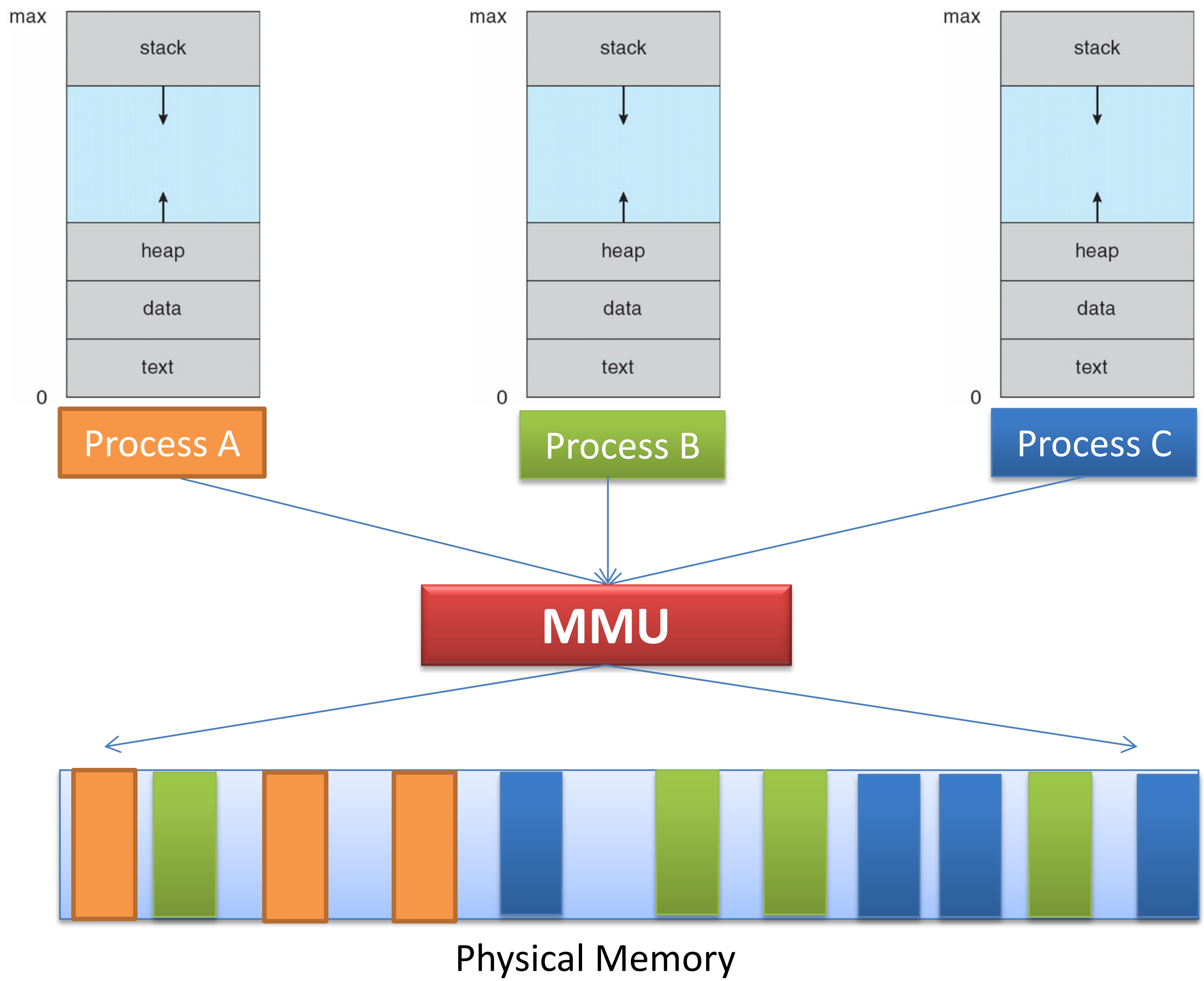
Memory Protection

- How to protect memory among apps/kernel?
  - Applications shouldn’t be allowed to access kernel’s memory
  - An app shouldn’t be able to access another app’s memory

Virtual Memory

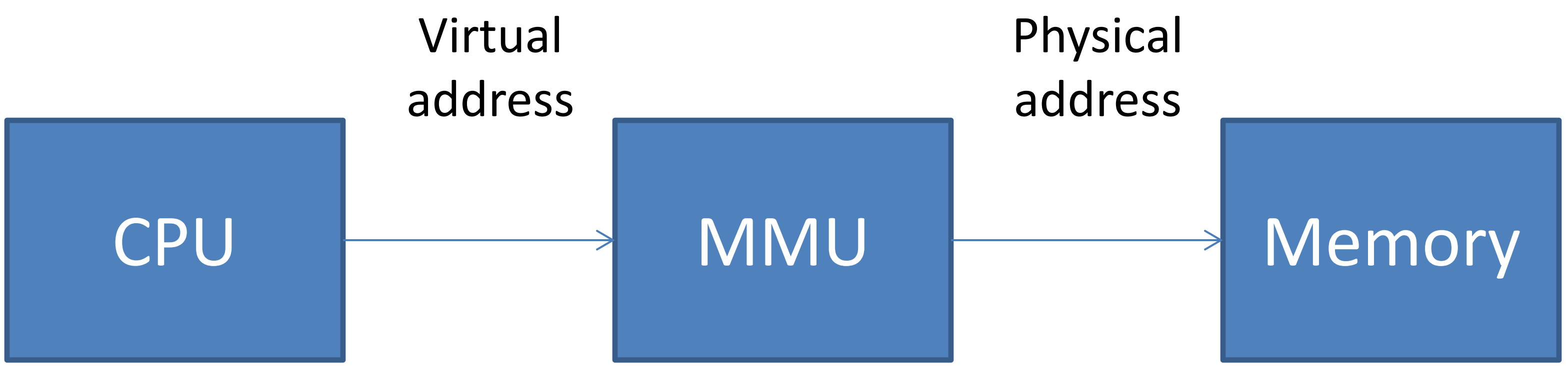
- How to overcome memory space limitation?
  - Multiple apps must share limited memory space
  - But they want to use memory as if each has dedicated and big memory space
  - E.g.,) 1GB physical memory and 10 programs, each of which wants to have a linear 4GB address space

Virtual Memory



MMU

- Hardware unit that translates *virtual address* to *physical address*
  - Defines the boundaries of kernel/apps
  - Enable efficient use of physical memory



Synchronization

- Synchronization problem with threads

```
Deposit(account, amount) {
{
   account->balance += amount;
}
```

Thread 1: *Deposiit(acc, 10)*	**Thread 2: :** *Deposiit(acc, 10)*
LOAD R1, account->balance	
	LOAD R1, account->balance
	ADD R1, amount
	STORE R1, account->balance
ADD R1, amount	
STORE R1, account->balance	

Synchronization Instructions

- Hardware support for synchronization
  - *TestAndSet, CompareAndSwap* instructions
  - Atomic load and store
  - Used to implement **lock** primitives
  - New TSX instruction → hardware transaction

- Another methods to implement locks in single-core systems
  - Disabling interrupts

Summary

- OS needs to understand architecture
  - Hardware (CPU, memory, disk) trends and their implications in OS designs

- Architecture needs to support OS
  - Interrupts and timer
  - User/kernel mode and privileged instructions
  - MMU
  - Synchronization instructions

OS Abstractions

Reality	***Abstraction***
A single computer	Multiple computers
Limited RAM capacity	Infinite capacity
Mechanical disk	File system
Insecure and unreliable networks	Reliable and secure