



**Department of Physics,
Computer Science & Engineering**

CPSC 410 – Operating Systems I

Computer System Overview

Keith Perkins

Original slides by Dr. Roberto A. Flores

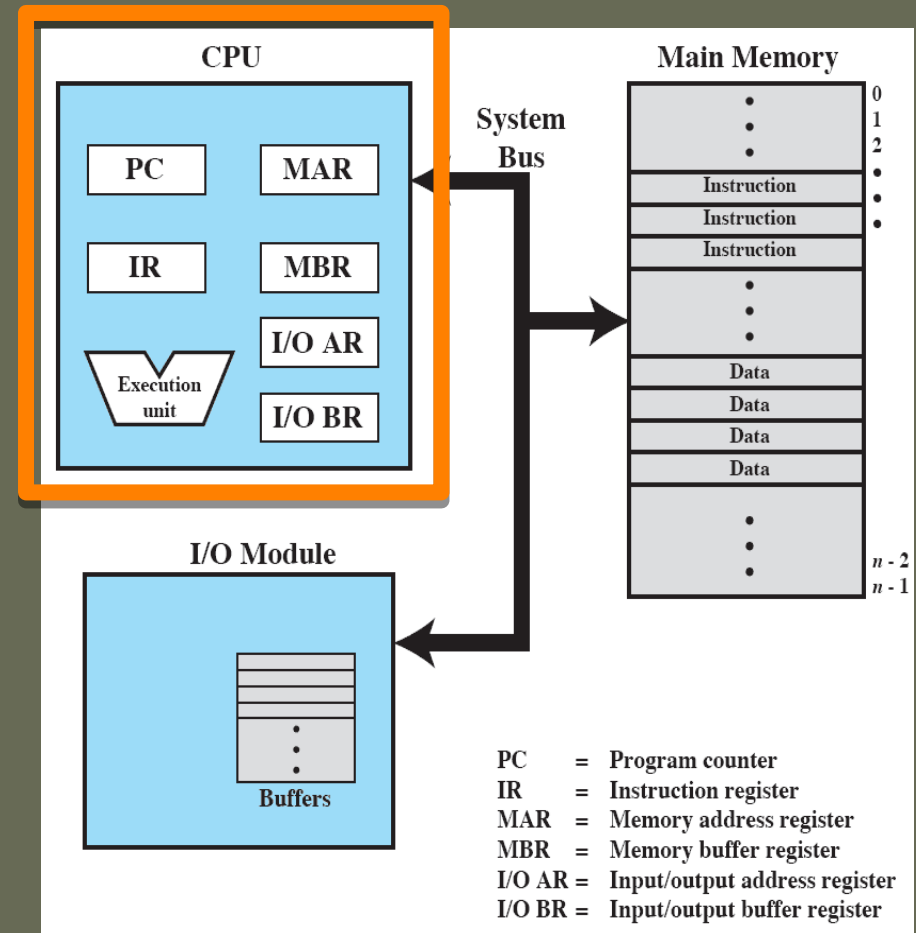
Additional content from https://onlinecourses.nptel.ac.in/noc17_cs29/preview

Topics

- **Basic Elements**
 - Processor, main memory, I/O modules, system bus
- **Microprocessors**
 - General purpose, graphics, digital signal, system on chip
- **Instructions**
 - Execution, fetch & execute (F&E), instruction register
- **Interrupts**
 - Types, flow of control, F&E&I, multiple interrupts
- **Memory**
 - Hierarchy, principle of locality, cache
- **I/O Techniques**
 - Programmed, interrupt-driven, direct memory access
- **Symmetric multi-processors**
 - Advantages, organization, multi-core

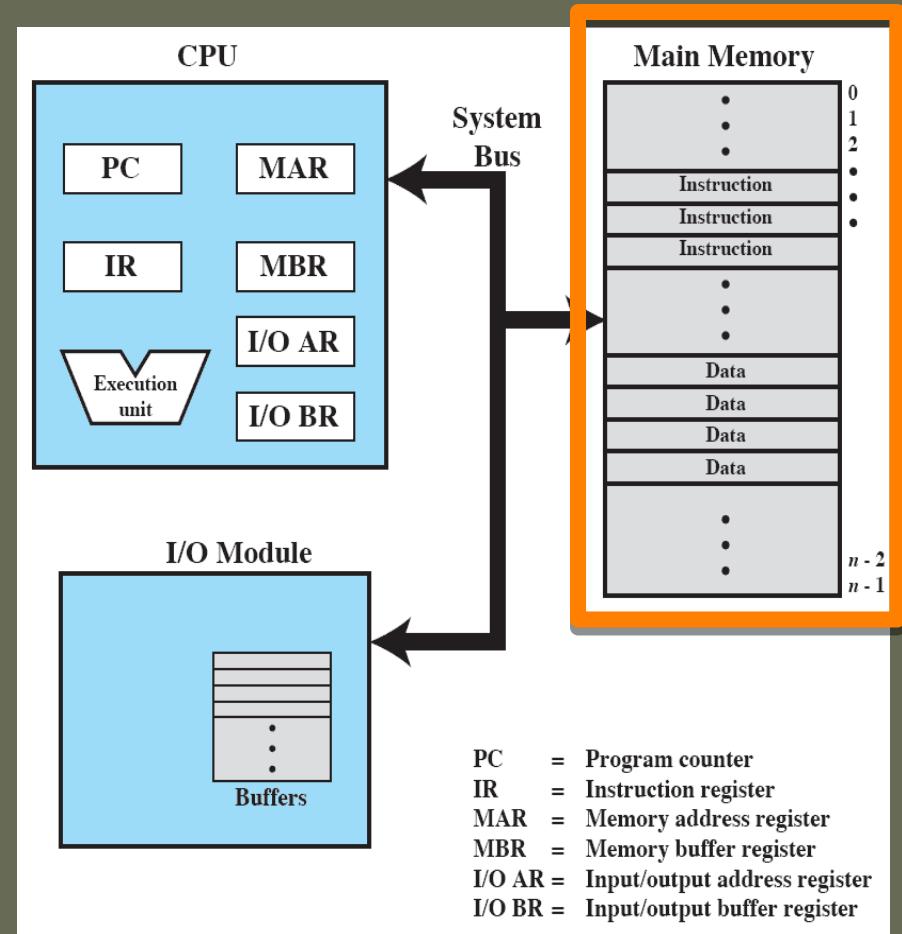
Basic Elements

- Processor
 - aka CPU
 - Central Processing Unit
 - Controls execution of instructions
 - Performs data processing



Basic Elements

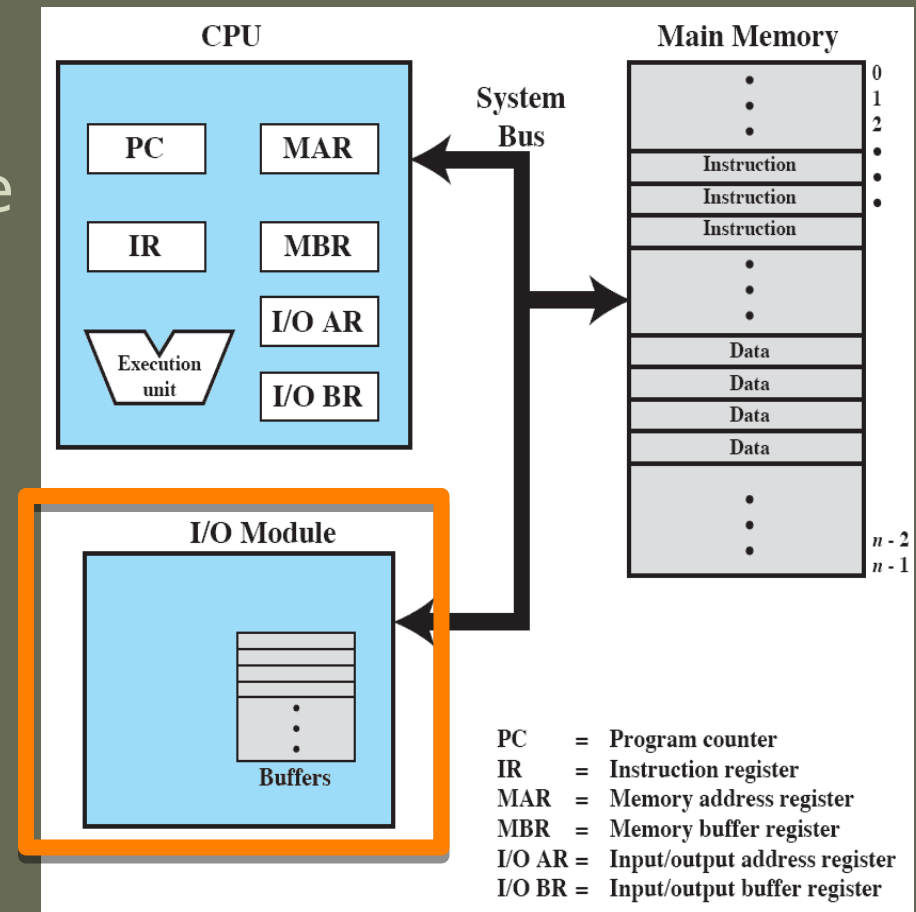
- Memory
 - aka primary/main memory, RAM
 - Random Access Memory
 - Stores instructions & data
 - Volatile
 - Contents are lost when the computer is shut down



Basic Elements

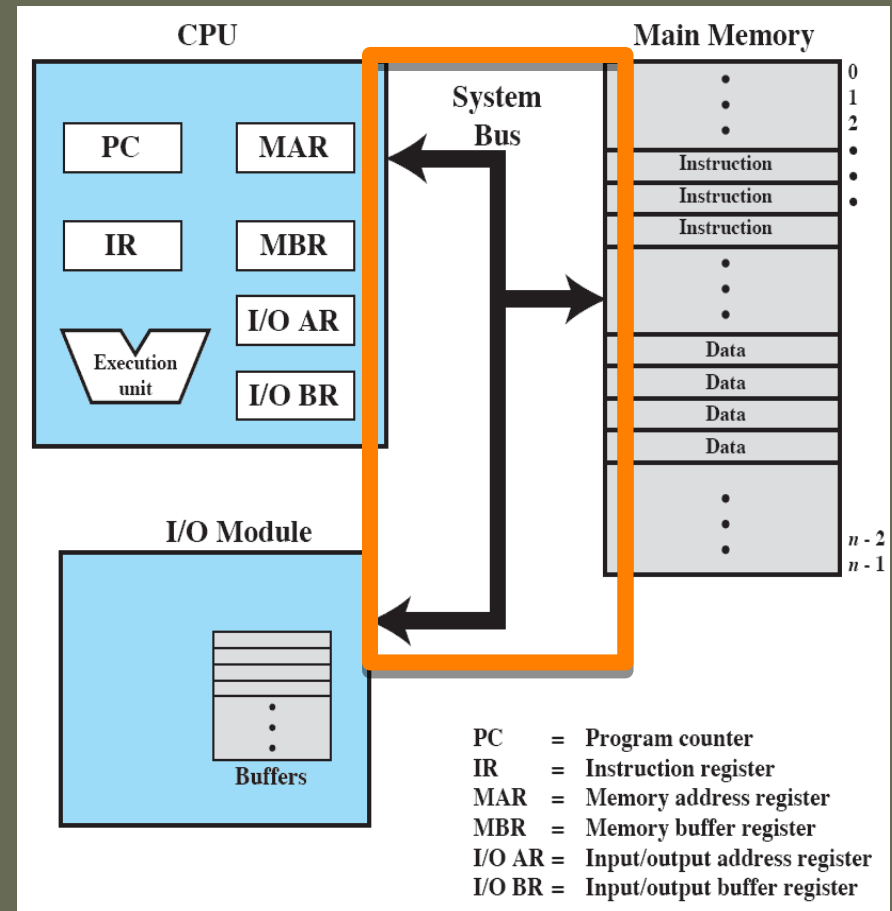
- I/O Modules

- aka device drivers
- Move data between the computer and external devices:
 - storage (e.g. hard drive)
 - communications equipment
 - terminals
- Have buffers to push/pull data



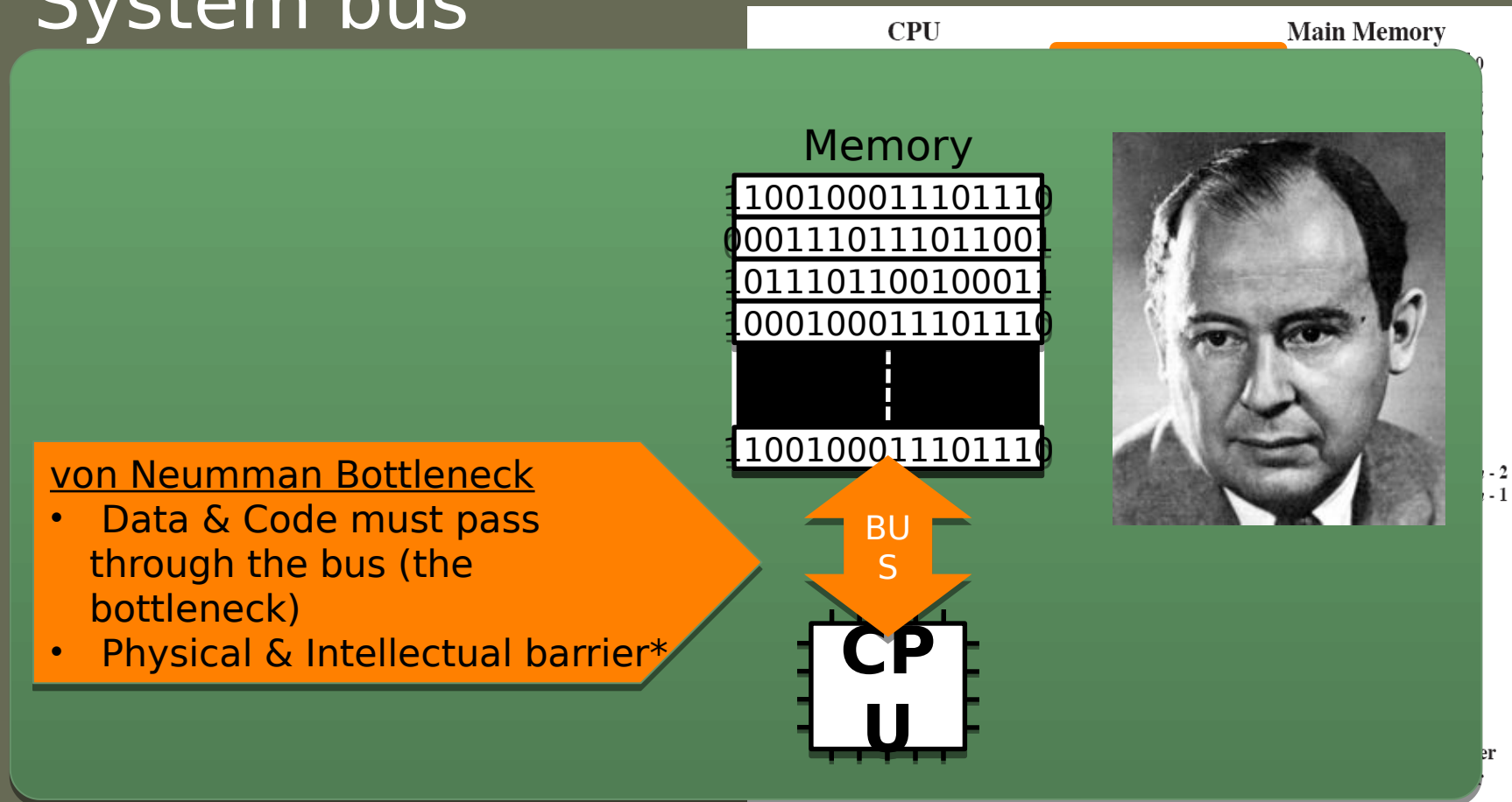
Basic Elements

- System bus
 - Means of communication among processors, memory & I/O modules
 - Its speed limits computer performance
 - Known as the....



Basic Elements

- System bus



Topics

- Basic Elements

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- Microprocessors

- General purpose, graphics, digital signal, system on chip

- Instructions

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- Interrupts

- Types, flow of control, F&E&I, multiple interrupts

- Memory

- Hierarchy, principle of locality, cache

- I/O Techniques

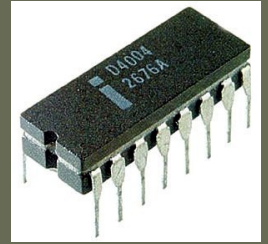
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Microprocessors

- **General Purpose**
 - It brought about PC & handheld computing
 - 1 processor or more (cores) on a single chip
- **Graphical Processing Units (GPU)**
 - Efficient computation on arrays of data, e.g., math & physics simulations (for games), large spreadsheets
- **Digital Signal Processors (DSP)**
 - Streaming audio or video signals; en/decoding (codecs)
- **System on a Chip (SoC)**
 - Embedded systems (handheld)
 - CPU, GPU, DSP, memory in one chip



Intel 4004, wikipedia.org



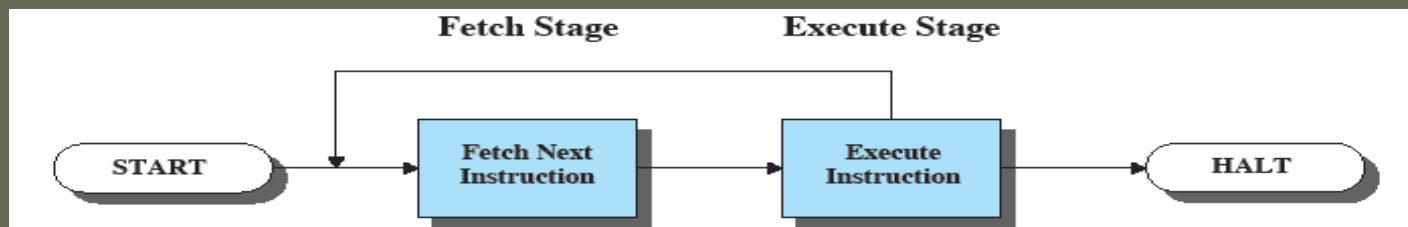
Exynos5octa, samsung.com

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Instructions

- A program is a set of instructions stored in memory
- CPU instruction cycle (fetch & execute)
 - *program counter (PC) has address of next instruction*
 - **processor reads (fetches) an instruction from memory**
 - *instruction stored in instruction register (IR)*
 - *program counter increments address*
 - **processor executes instruction**; repeat until done

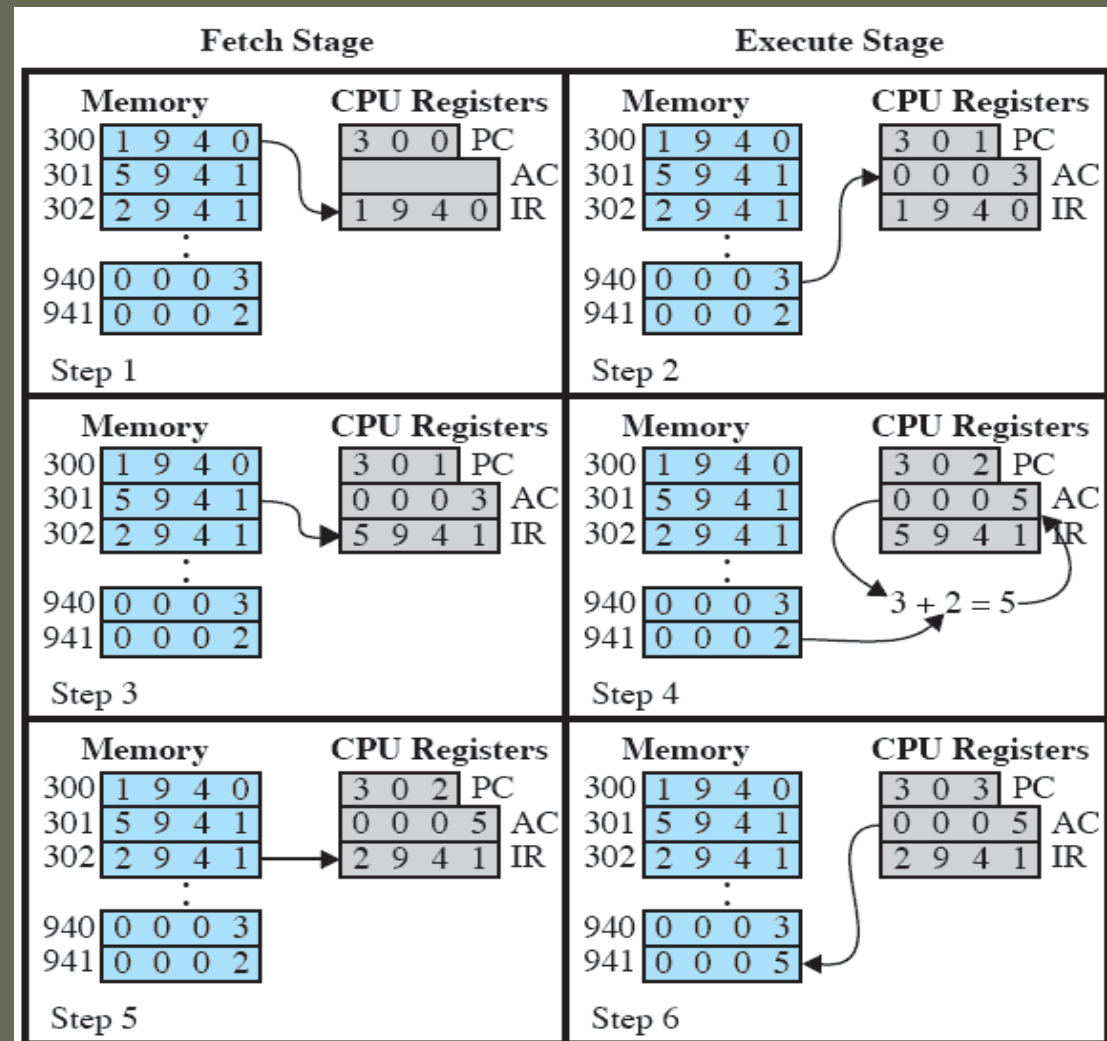


program counter (PC) has address of next instruction
 processor fetches instruction from memory
 instruction stored in instruction register (IR)
 program counter increments address
 processor executes instruction; repeat until forever

1 load AC from memory
 2 store store AC to memory
 5 add to AC from memory

Instructions

• Example



Topics

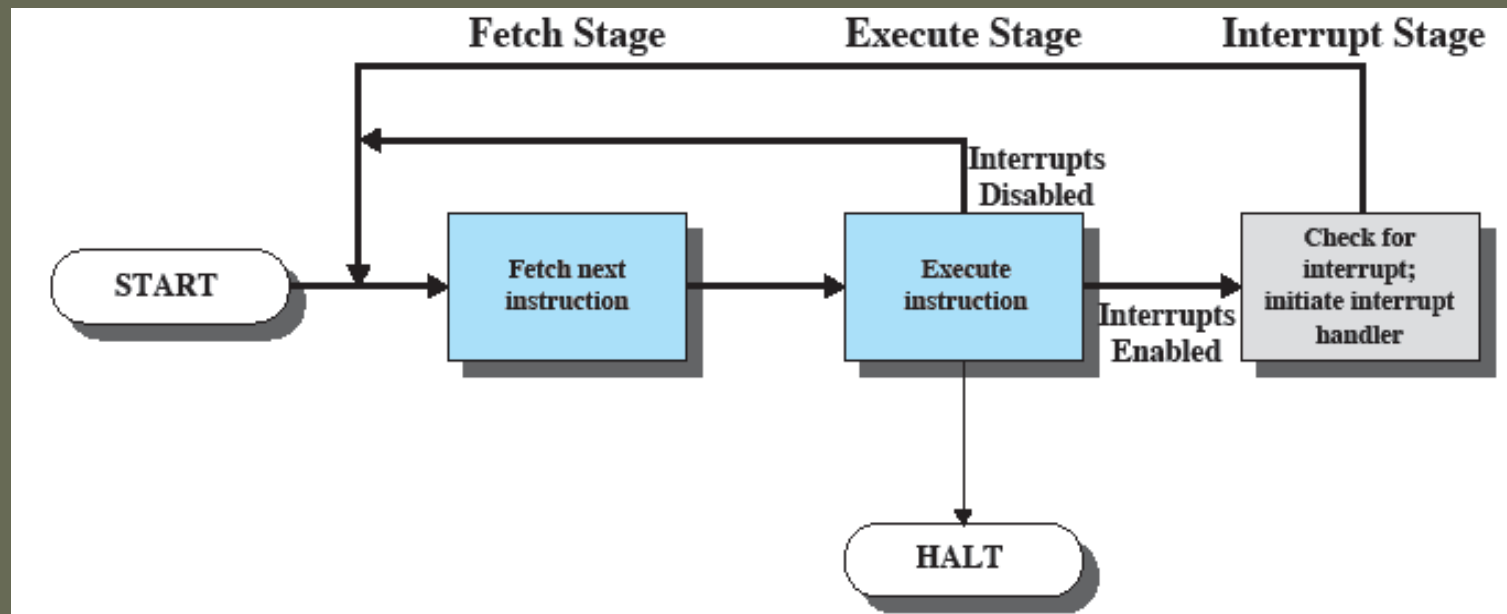
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Interrupts

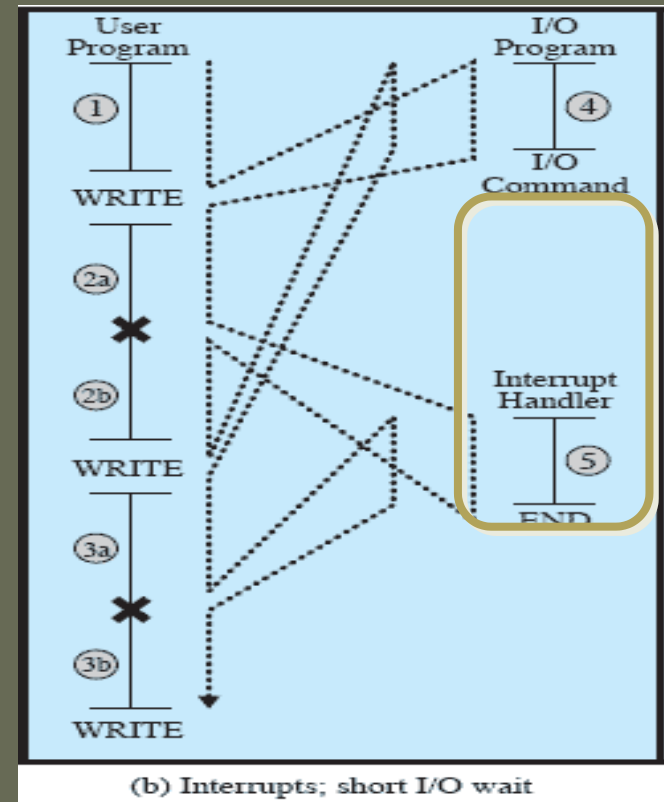
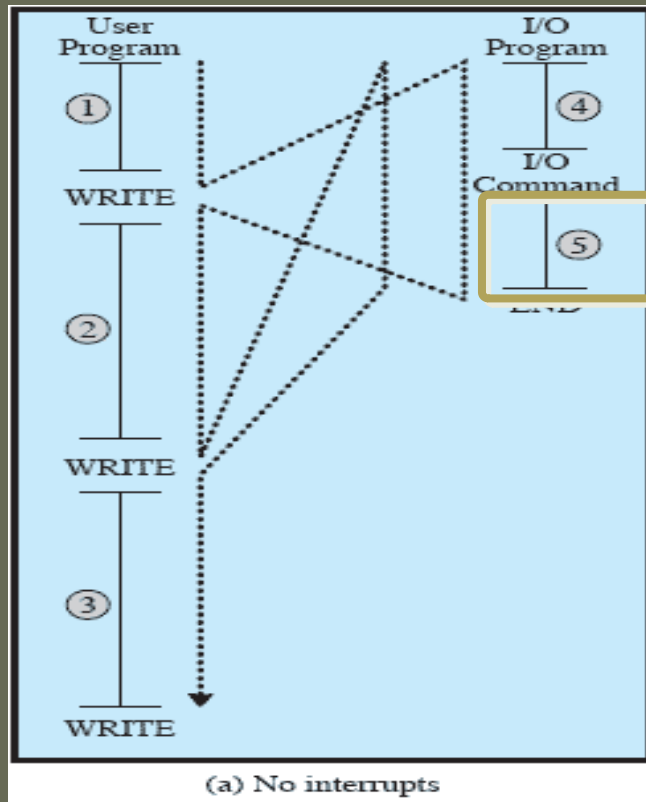
- Interrupts normal sequencing of the processor
- Provided to improve processor utilization
 - I/O devices are slower than CPU
 - Without interrupts, CPU must pause to wait for I/O device (wastes its time)
- Interrupts ensure timely process switches
- Interrupts provide safe user access to potentially dangerous instructions (like file read/write)

Interrupts- where in instruction cycle

- Fetch & Execute & Interrupt
 - Same as before, plus an Interrupt Stage



Interrupts-Why



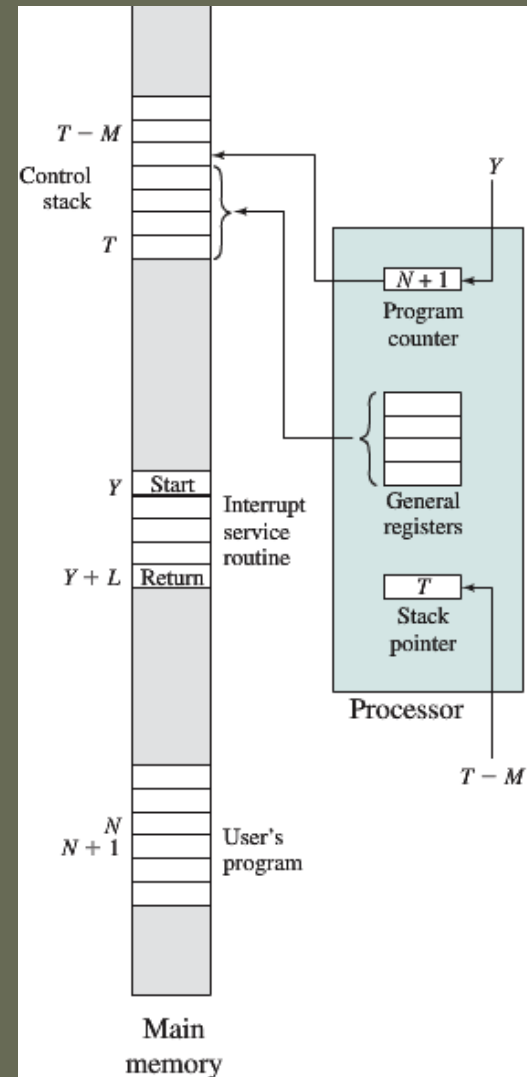
- Polling (left side) CPU periodically checks device to see if it needs attention. Almost always a huge waste of time.
- Instead, start operation, have CPU do other work until notified by interrupt that operation is finished

Example - why we need interrupts (or why polling is often bad)

- CPU clock 2.5 Ghz or 4×10^{-10} seconds per instruction
- Hard Drive 4×10^{-3} seconds per access
- CPU is 10 million times faster than HD
- Or, if 1 CPU instruction took 1 second, 1 HD access would take 16.5 weeks
- **Don't want CPU to wait on HD**

Interrupts

- What happens when CPU is disrupted by an interrupt?
 - Finish executing instruction N
 - { interrupt }
 - store registers, PC (size M) in control stack @ T
 - update stack pointer to $T-M$
 - execute interrupt instruction @ Y until finishing @ $Y+L$
 - load back top of control stack
 - continue executing @ $N+1$

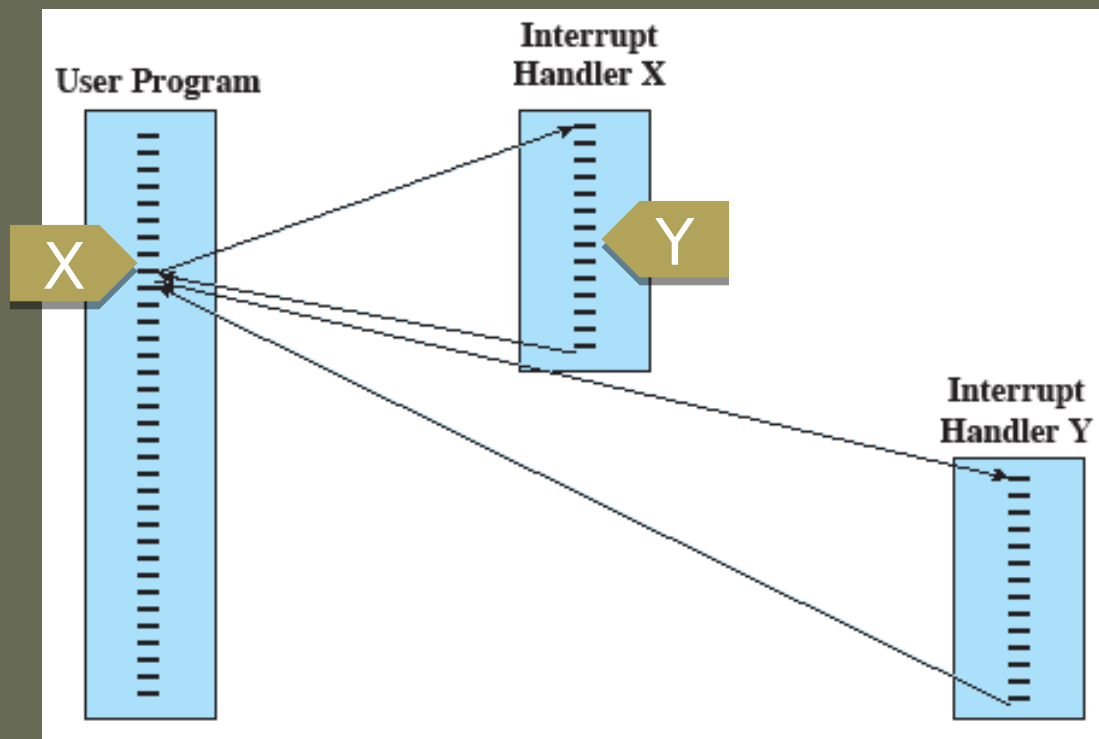


Interrupts

- Multiple overlapping interrupts
 - An interrupt happens when another is being handled
 - 1. **Disable interrupts** (when handling an interrupt)
 - 2nd interrupt waits until 1st interrupt is handled
 - Strictly sequential
 - 2. Use a **priority scheme**
 - Interrupts can interrupt interrupt-handling...
 - ...but only if they have a higher priority; otherwise they wait
 - Hierarchical (by priority)

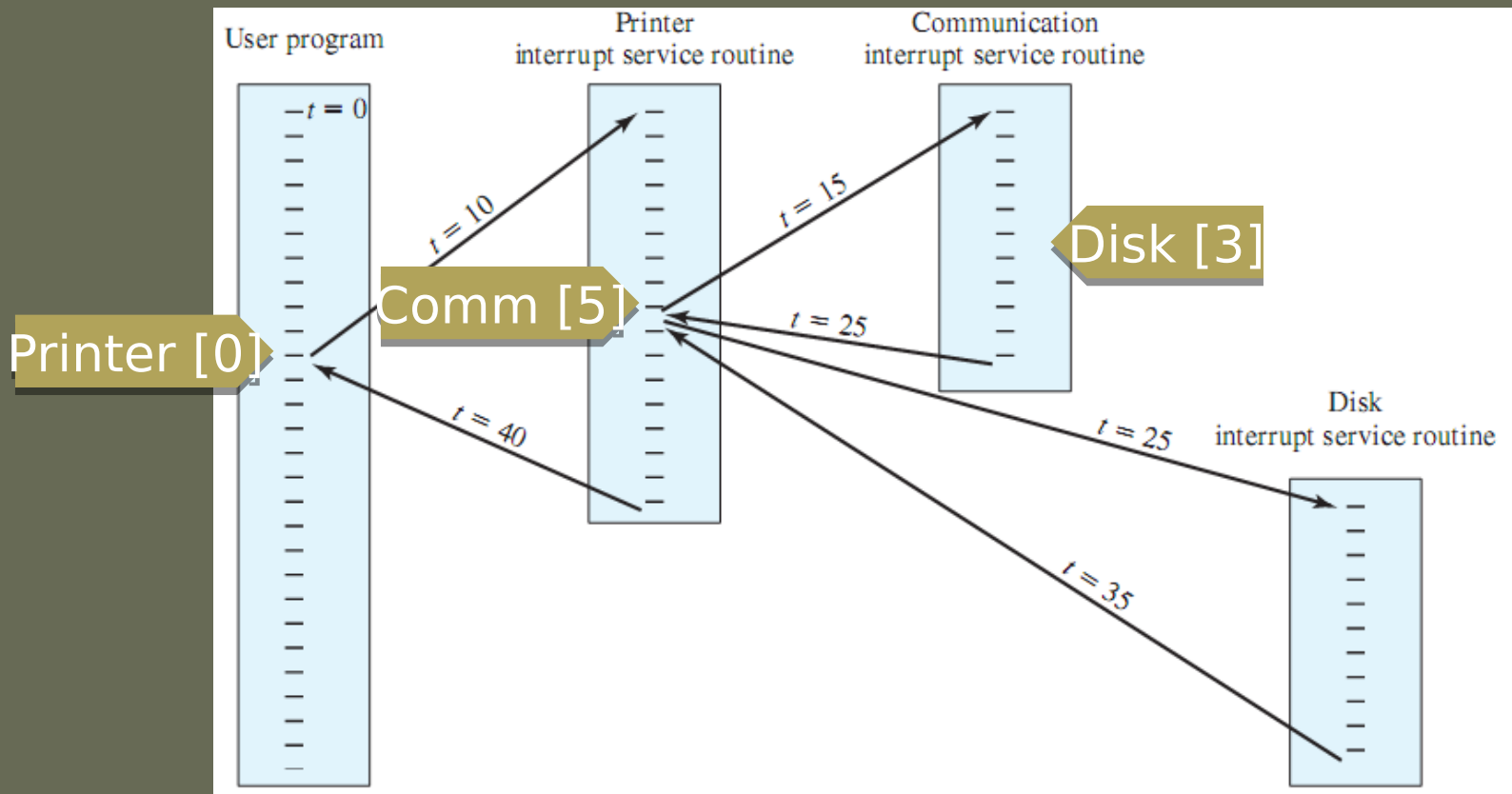
Interrupts

- Multiple overlapping interrupts
 - (approach 1) **Interrupts disabled**



Interrupts

- Multiple overlapping interrupts
 - (approach 2) **Priority Scheme**



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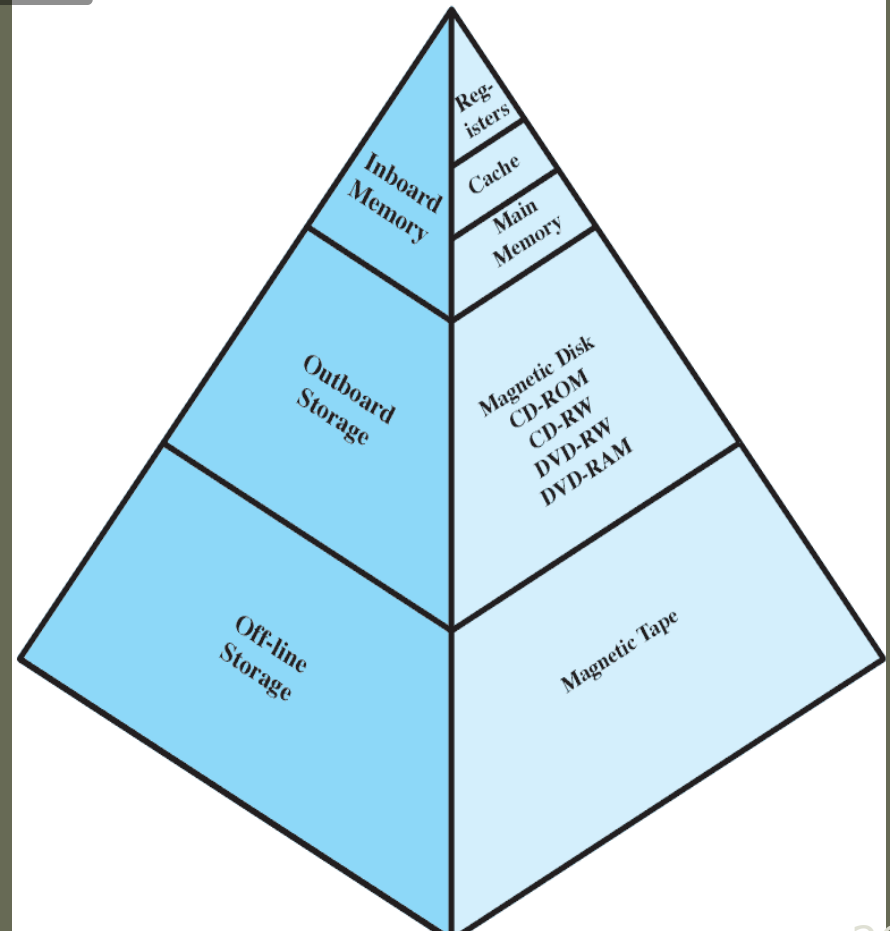
Memory

- Major (conflicting) constraints
 - speed (access time), amount, cost
 - Memory must keep up with CPU (speed)
 - Faster access time = greater cost
 - Memory must satisfy data volumes (amount)
 - Greater capacity = smaller cost = slower access speed

Memory

- Hierarchy going down

- **cost** decreases
- **capacity** increases
- **access time** increases
- **frequency of access by CPU** decreases
- really? how does it happen?



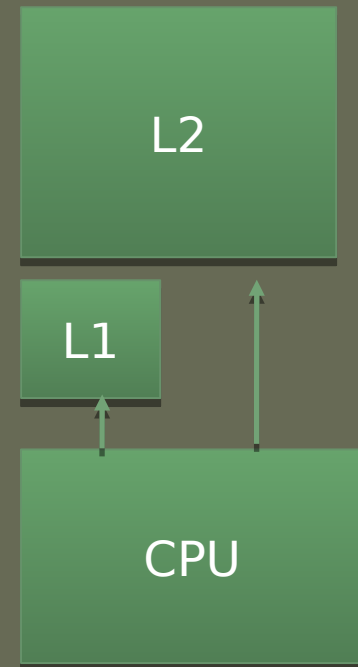
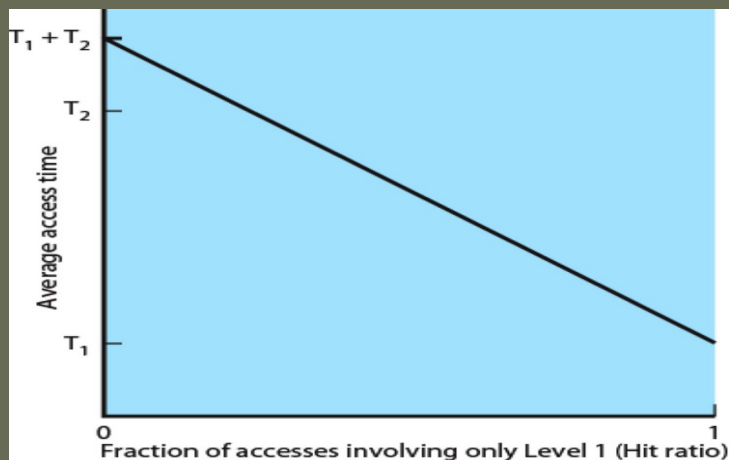
Memory

Principle of Locality

- Memory references (i.e., data) needed by CPU tend to cluster
 - Temporal locality -- near in time, we need the same data soon. For example often go back and execute the same function
 - Spatial locality -- near in space/distance, our next access is often very close to our last. For example an array “a” being read in a loop
- Eventually a set of data is replaced by another, but it's less frequent proportionally to the use within a set, which makes overhead bearable.

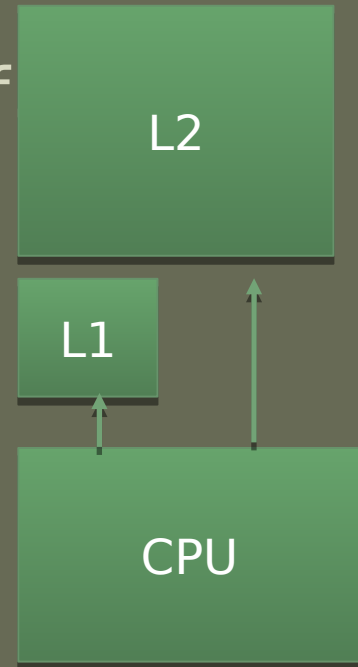
Memory

- Performance Example
 - 2 levels of memory (L1,L2)
 - T1 @ $0.1\mu\text{s}$ (1kb total) faster but scarce
 - T2 @ $1\mu\text{s}$ (100kb total) slower but plenty
 - CPU checks L1 first then L2



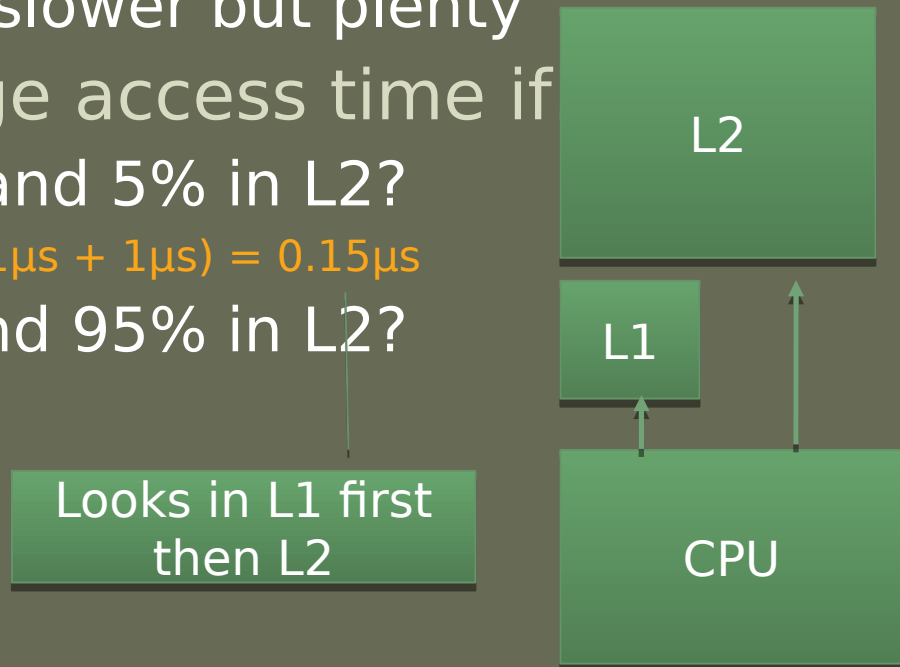
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 - What's the average access time if
 - 95% of data in L1 and 5% in L2?



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 - 95% of data in L1 and 5% in L2?
 - $0.95 * 0.1\mu\text{s} + 0.05 * (0.1\mu\text{s} + 1\mu\text{s}) = 0.15\mu\text{s}$
 - 5% of data in L1 and 95% in L2?



Memory

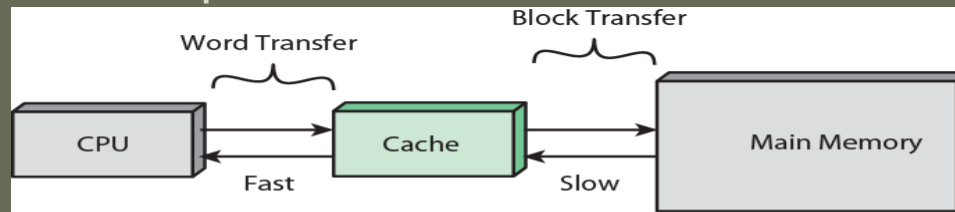
- Performance Example

- 2 levels of memory (L1, L2) What if you have 3 levels?
 - T1 @ $0.1\mu\text{s}$ (1kb) faster but scarce
 - T2 @ $1\mu\text{s}$ (100kb) slower but plenty
- What's the average access time if...
 - 95% of data in L1 and 5% in L2?
 - $0.95 * 0.1\mu\text{s} + 0.05 * (0.1\mu\text{s} + 1\mu\text{s}) = 0.15\mu\text{s}$
 - 5% of data in L1 and 95% in L2?
 - $0.05 * 0.1\mu\text{s} + 0.95 * (0.1\mu\text{s} + 1\mu\text{s}) = 1.05\mu\text{s}$
 - It's to our advantage to have frequently accessed data in faster memory locations

reason why caches exist

Memory

- Cache
 - Exploits the Principle of Locality
 - Controlled by hardware (i.e., it is invisible to OS)
 - How it's used
 - Contains a copy of a portion of main memory
 - CPU checks cache for data
 - **if found**: use data
 - **if not found**: reads block of data from memory (where data is) and copies it into cache



Memory

- Cache

- Exploit

- Control (OS)

- Principle

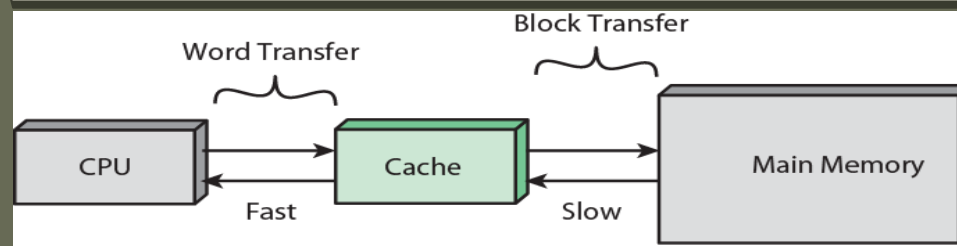
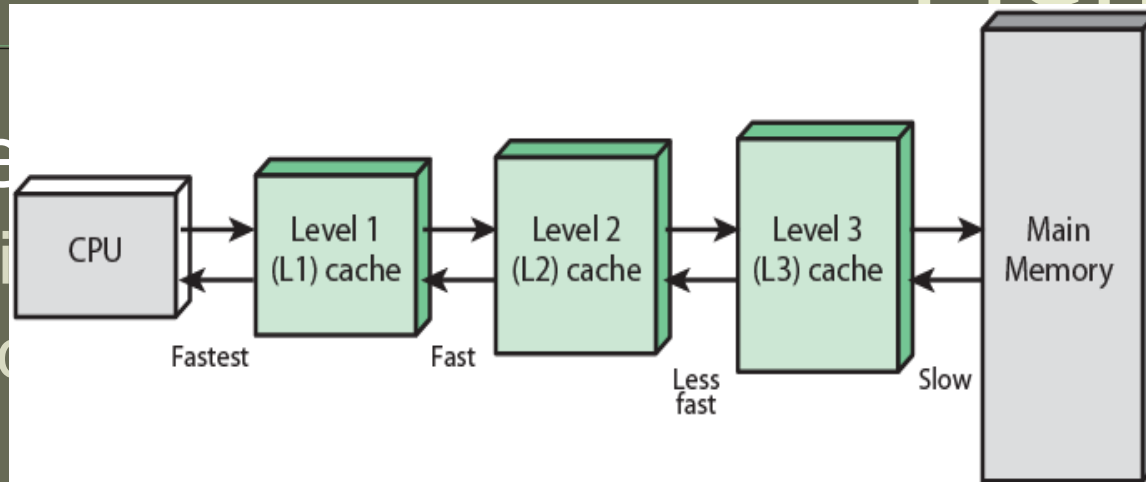
- Contains

In practice:

- CPU caches several levels are common

- if found

- if not found (data is)



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I/O Techniques

- * When the processor encounters an instruction relating to I/O, it executes that instruction by issuing a command to the appropriate I/O module

Three techniques are possible for I/O operations:

Programmed
I/O

Interrupt-
Driven I/O

Direct
Memory
Access
(DMA)

I/O Techniques

What does the CPU do during an I/O (read/write) instruction?

- 1) Programmed I/O

- CPU waits for completion of command and periodically checks the status of the I/O module until it determines the instruction is complete

- 1. CPU sends I/O command to I/O module. If write data is placed in buffer for IO device.
- 2. CPU waits until I/O module completes command.
- 3. CPU resumes execution. If read it gets data from buffer.
- Extreme Inefficiency!

Remember the 1 sec verses
16 weeks example?

I/O Techniques

What does the CPU do during an I/O (read/write) instruction?

- **2) Interrupt-driven I/O**

- CPU keeps executing while I/O command is completed
 - 1. CPU sends I/O command to I/O module. If write data is placed in buffer for IO device.
 - 2. CPU resumes execution.
 - 3. I/O module triggers an interrupt when command is done.
 - 4. CPU resumes execution. If read it gets data from buffer.
- No wait, but CPU still heavily involved in data transfer

I/O Techniques

- 2) Interrupt-driven I/O Drawbacks
 - Transfer rate is limited by the speed with which the processor can service a device
 - The processor is tied up in managing an I/O transfer since a number of instructions must be executed for each I/O transfer

I/O Techniques

What does the CPU do during an I/O (read/write) instruction?

3) Direct Memory Address (DMA)

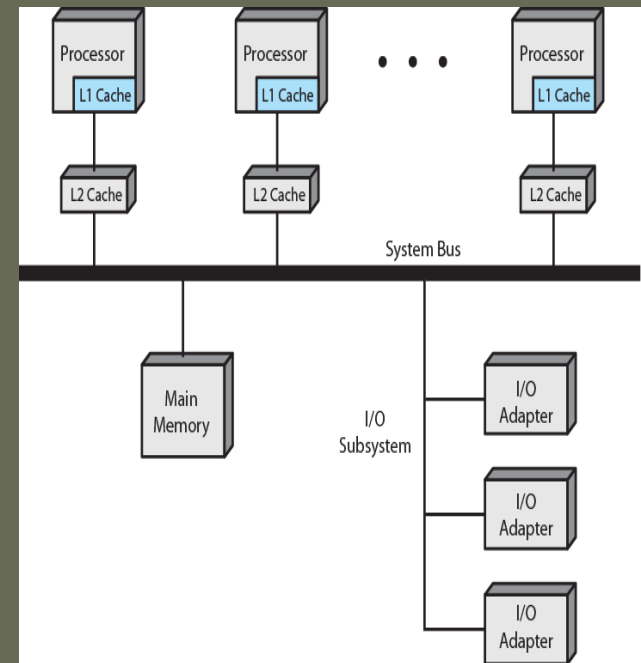
- Performed by a separate module on the system bus (DMA)
- CPU keeps executing while I/O command is completed by DMA module
 - 1. CPU sends I/O command, memory address (where data is read or written), data size and I/O module to DMA
 - 2. CPU resumes execution.
 - 3. I/O module triggers an interrupt when command is done (including data transfer)
 - 4. CPU resumes execution
- No wait & CPU doesn't transfer data (may have bus contention though)

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Symmetric Multi-Processors

- A stand-alone computer system with:
 - 2+ similar processors:
 - capable of performing the same functions
 - which (physically):
 - are interconnected by a bus
 - share memory & I/O devices
 - are controlled by an OS that
 - provides interaction between processors and their programs (at the job, task, file, and data levels)



Symmetric Multi-Processors

- Advantages
 - Performance
 - can yield greater performance (if OS can handle work in parallel)
 - Availability
 - failure of one processor does not halt the machine
 - Scaling
 - additional processors result in a range of products of different price and performance

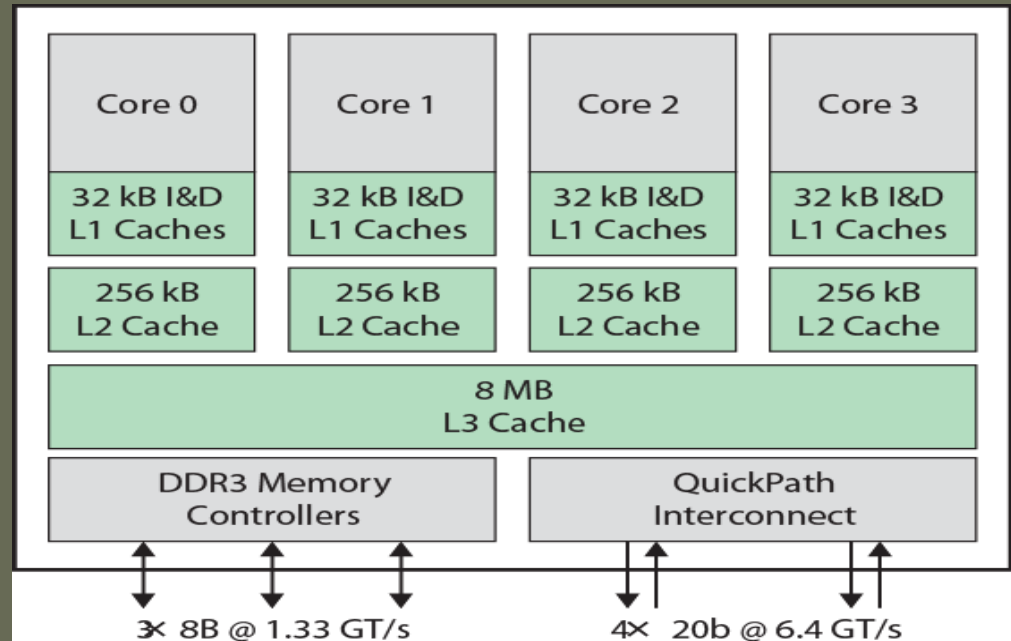
Symmetric Multi-Processors

- Multi-Core

- 2+ processors (cores) in 1 micro-chip
 - each core has all components of an independent processor (including 2 or 3 cache levels)

- Intel Core i7

- 4-8 cores
- 8 Mb L3 cache



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Done!