Department of Physics,
Computer Science & Engineering

CPSC 410 – Operating Systems I

Computer System Overview

Keith Perkins

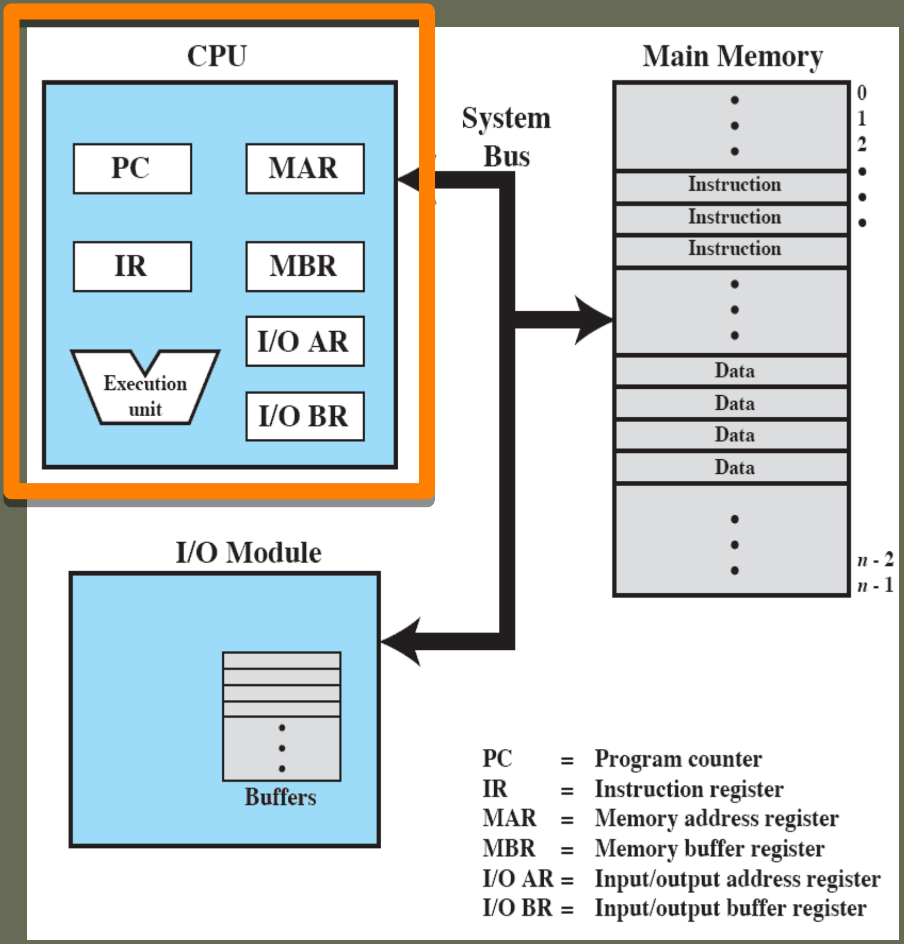
Original slides by Dr. Roberto A. Flores
Additional content from https://onlinecourses.nptel.ac.in/noc17_cs29/preview

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

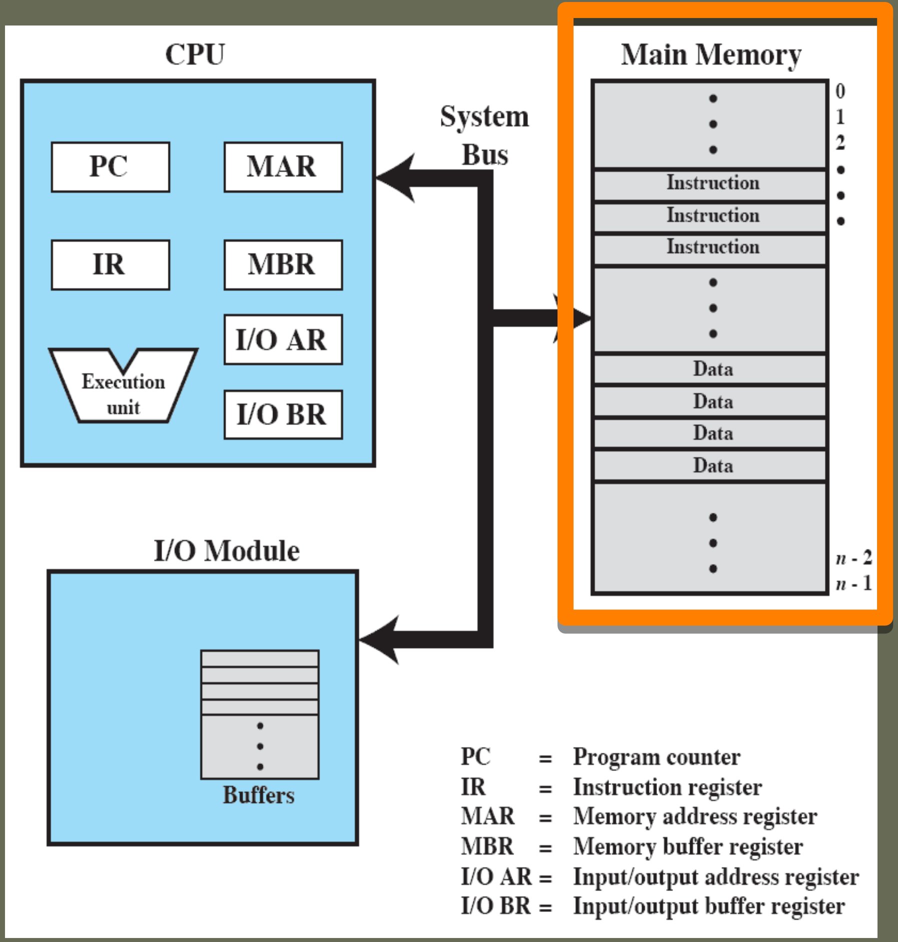
Basic Elements

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



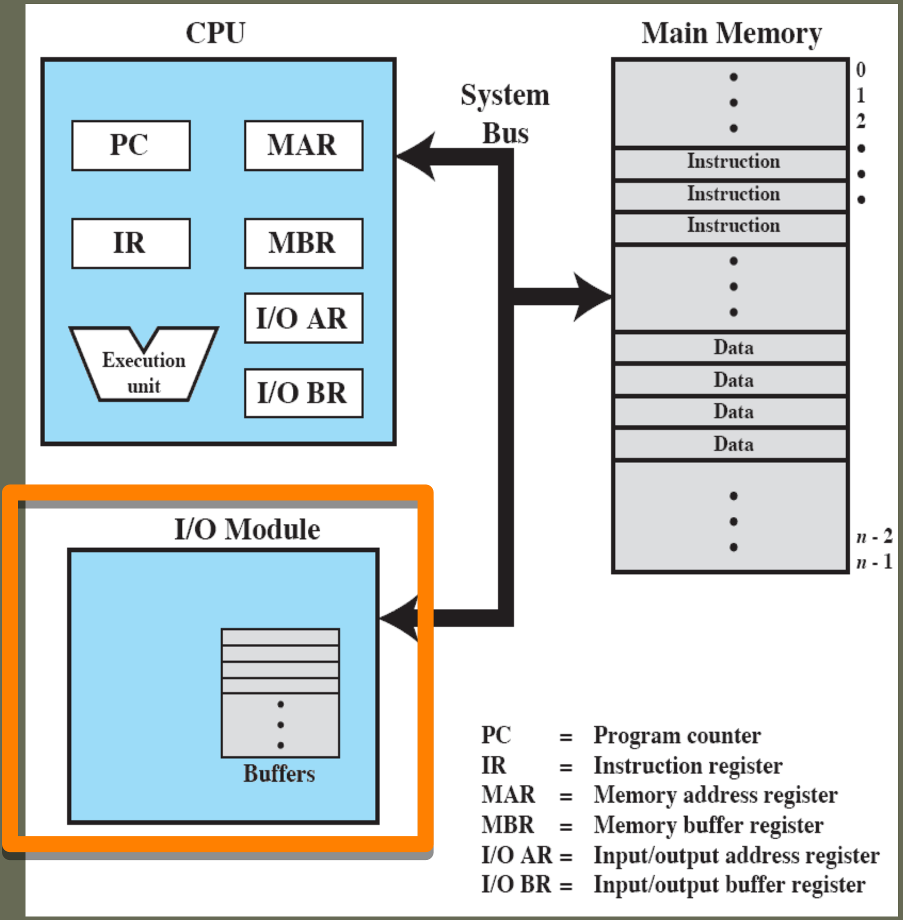
Basic Elements

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



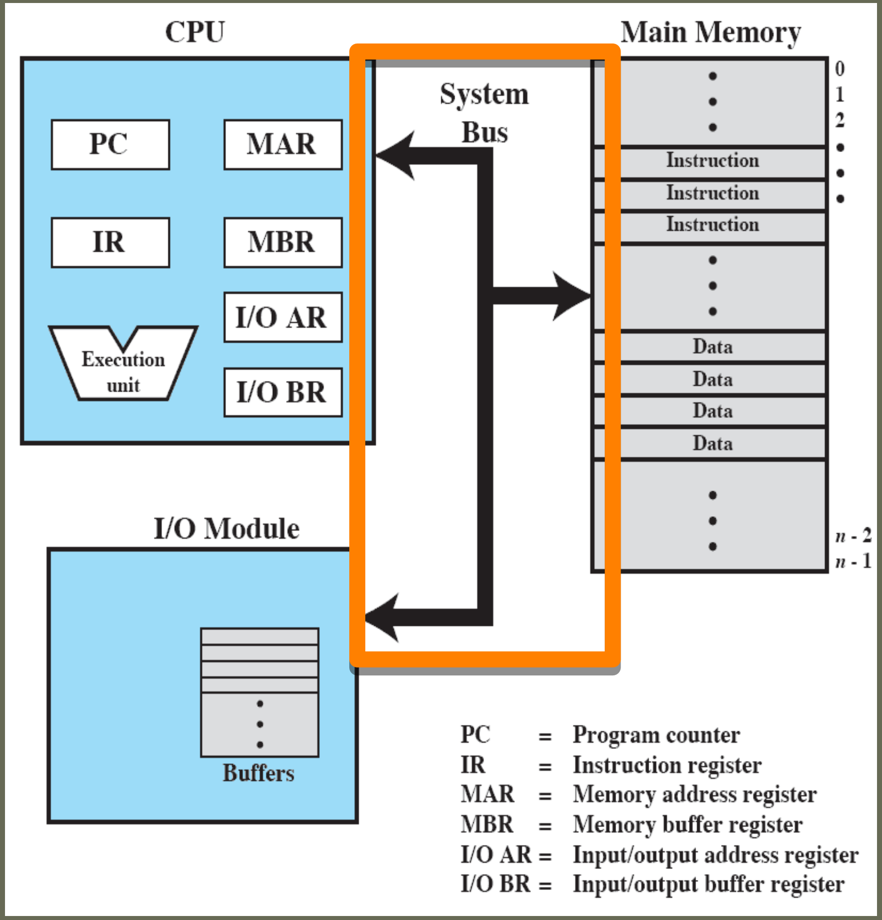
Basic Elements

- 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



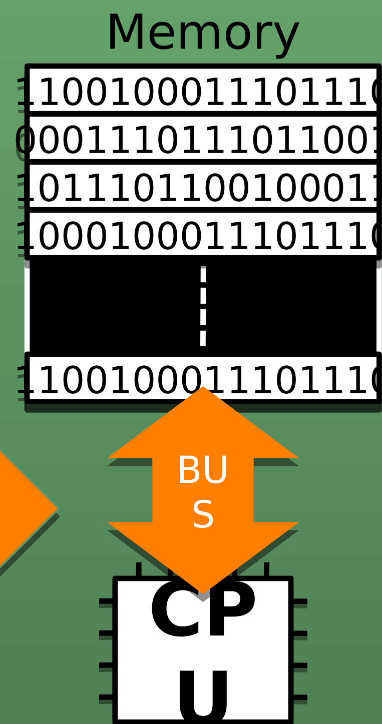
Basic Elements

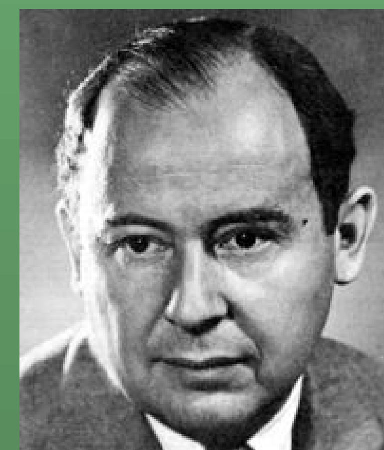
- System bus
  - Means of communication among processors, memory & I/O modules
  - Its speed limits computer performance
    - Known as the….



Basic Elements

- System bus





<u>von Neumman Bottleneck</u>

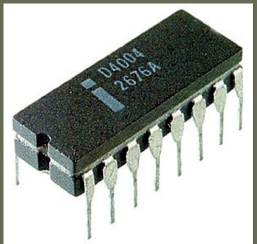
- Data & Code must pass through the bus (the bottleneck)
- Physical & Intellectual barrier*

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

Microprocessors

- General Purpose
  - It brought about PC & handheld computing
  - 1 processor or more (cores) on a single chip



Intel 4004, wikipedia.org

- 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

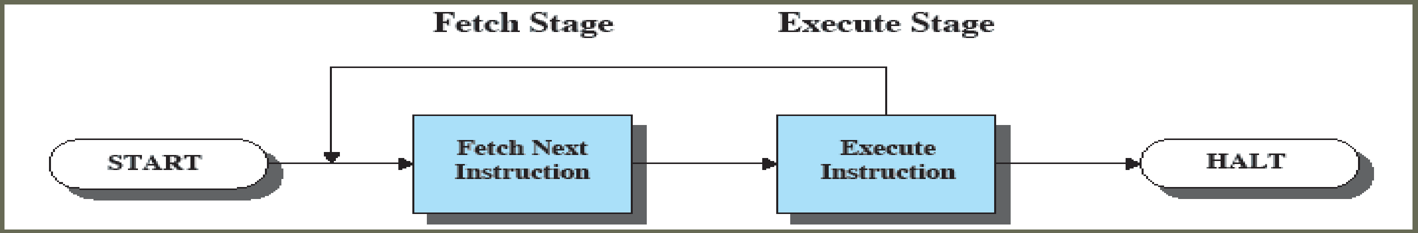
Exynos5octa, samsung.com

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

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

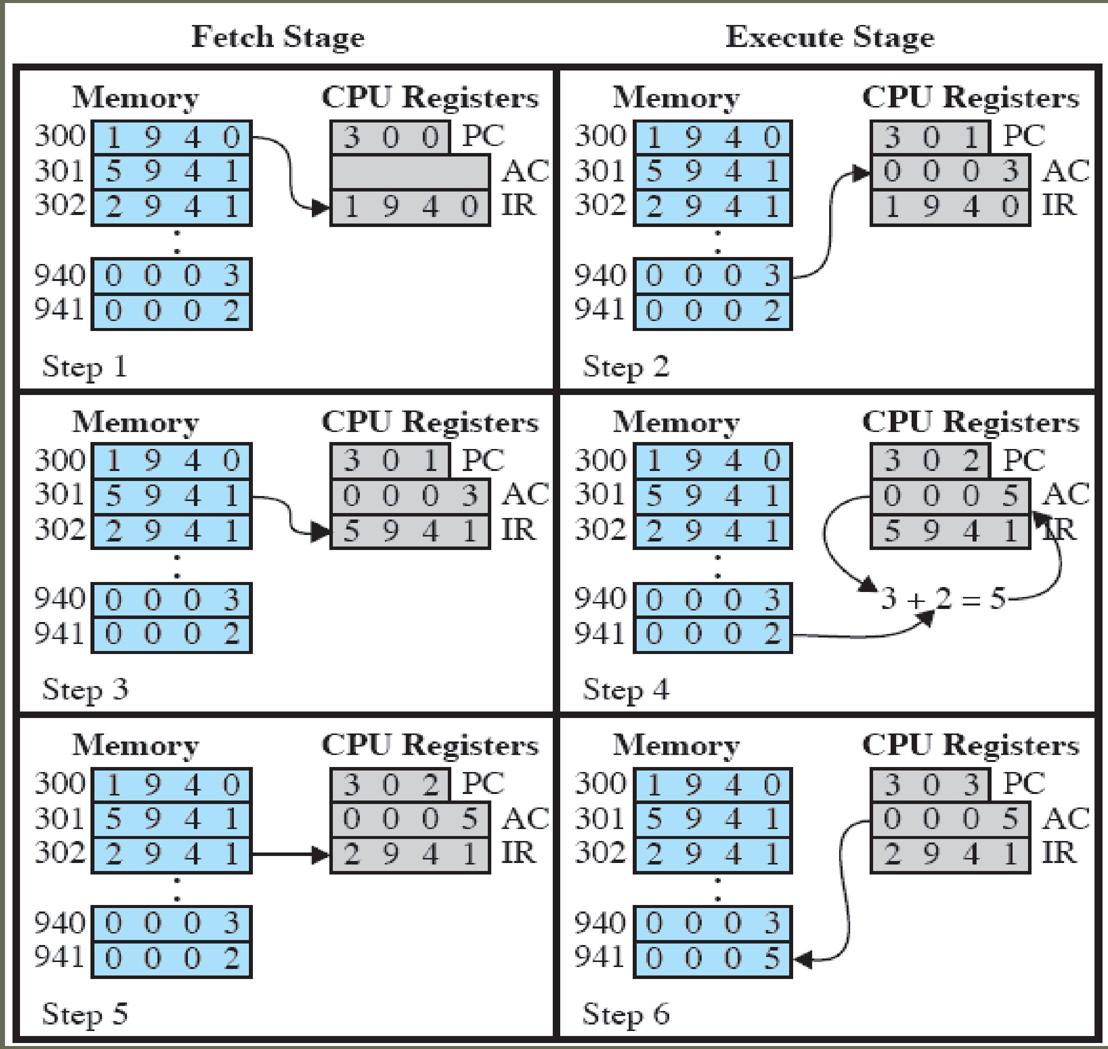


program counter (PC) has address of next instruction
processor fetches instruction from memory
instruction stored in instruction register (IR)
program counter increments address
processor executes instruction; repeat until forever

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

Instructions

- Example



Topics

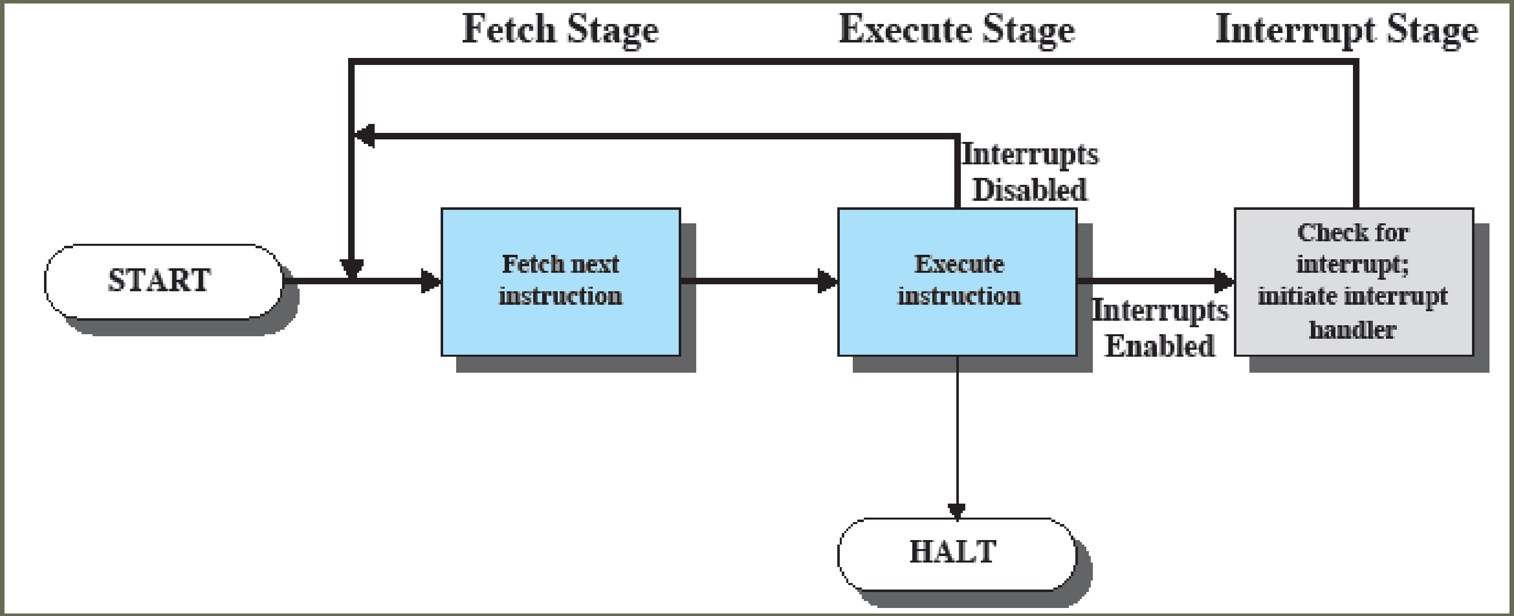
- Basic Elements
  - Processor, main memory, I/O modules, system bus
- Microprocessors
  - General purpose, graphics, digital signal, system on chip
- Instructions
  - Execution, fetch & execute (F&E), instruction register
- Interrupts
  - Types, flow of control, F&E&I, multiple interrupts
- Memory
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

Interrupts

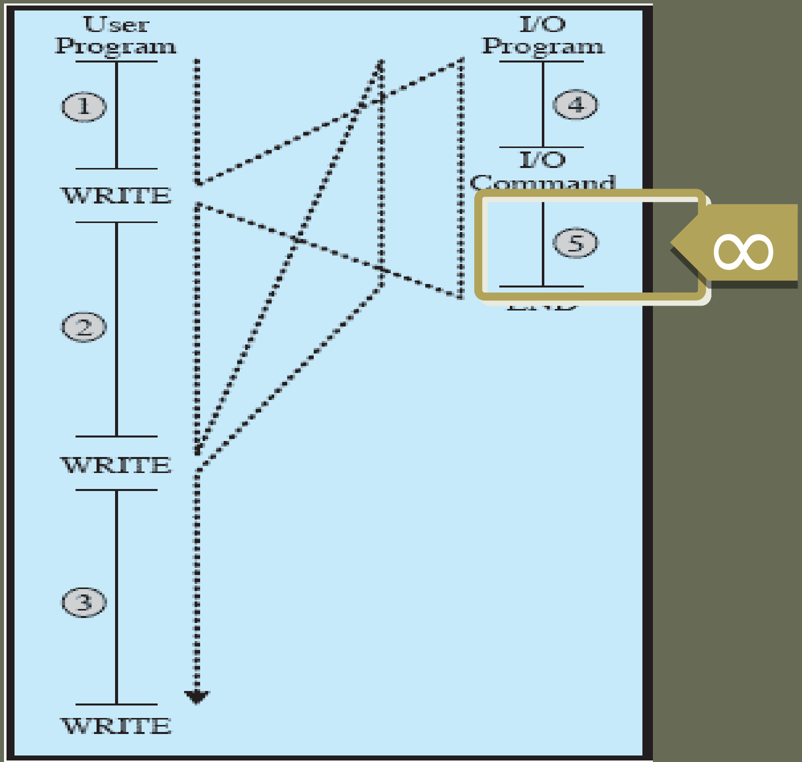
- Interrupts normal sequencing of the processor
- Provided to improve processor utilization
  - I/O devices are slower than CPU
  - Without interrupts, CPU must pause to wait for I/O device (wastes its time)
- Interrupts ensure timely process switches
- Interrupts provide safe user access to potentially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

Interrupts- where in instruction cycle

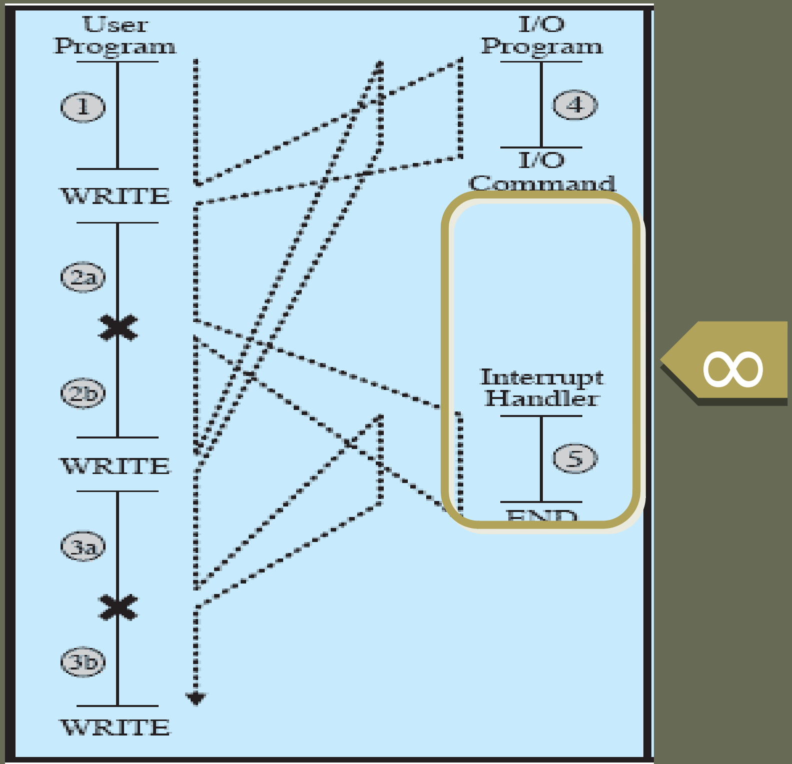
- Fetch & Execute & Interrupt
  - Same as before, plus an Interrupt Stage



Interrupts-Why



(a) No interrupts



(b) Interrupts; short I/O wait

- 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

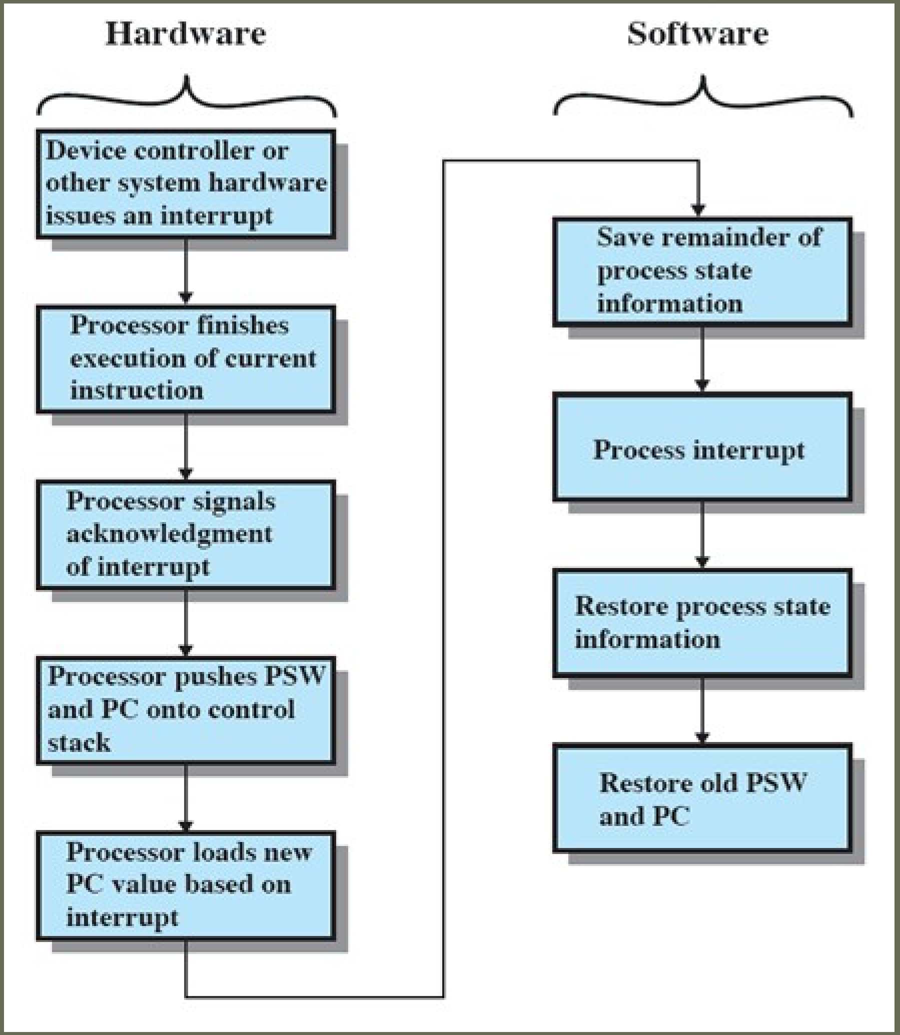
Example - why we need interrupts (or why polling is often bad)

- CPU clock 2.5 Ghz or
  4x10**-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

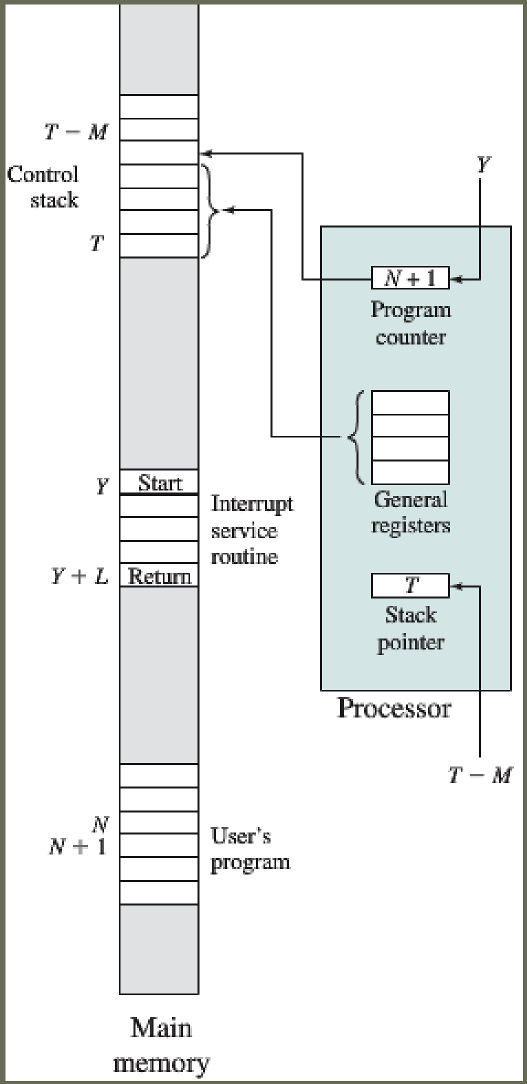
- **<u>Don’t want CPU to wait on HD</u>**

Simple Interrupt Processing



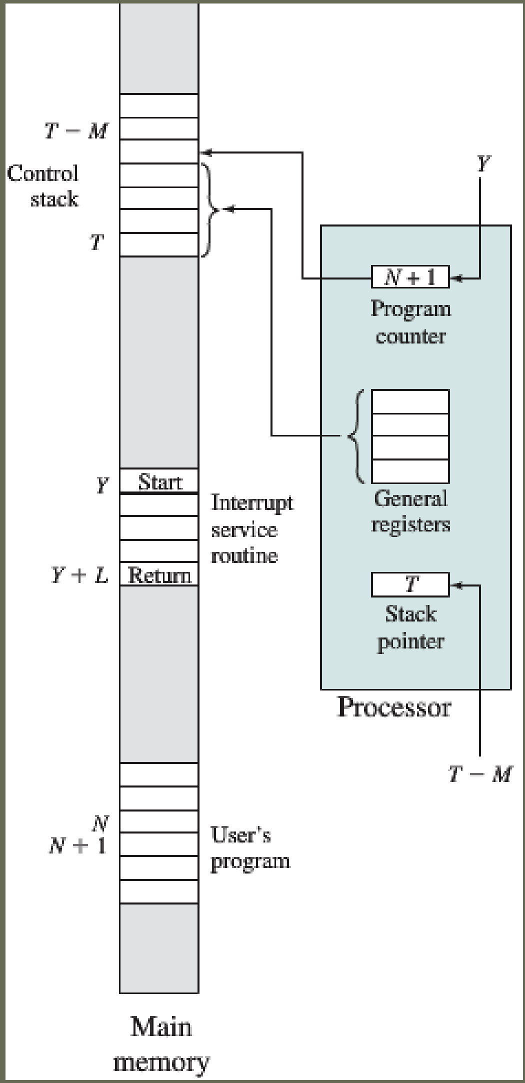
Interrupts

- 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

- 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

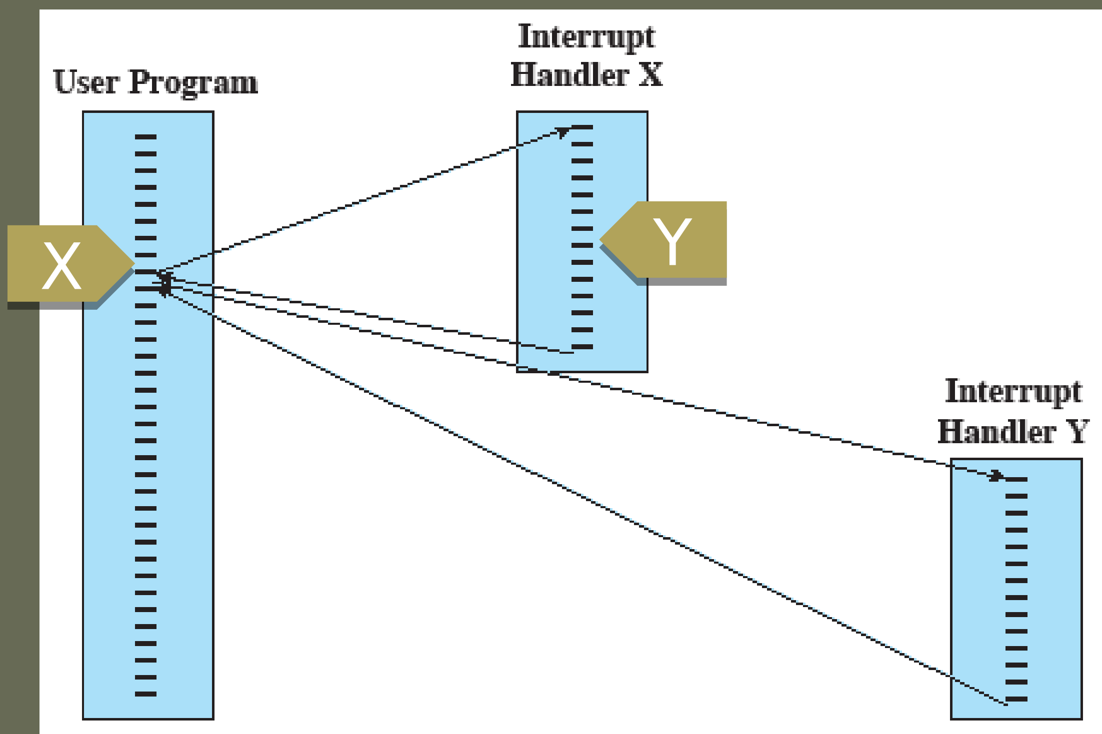


Interrupts

- 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)

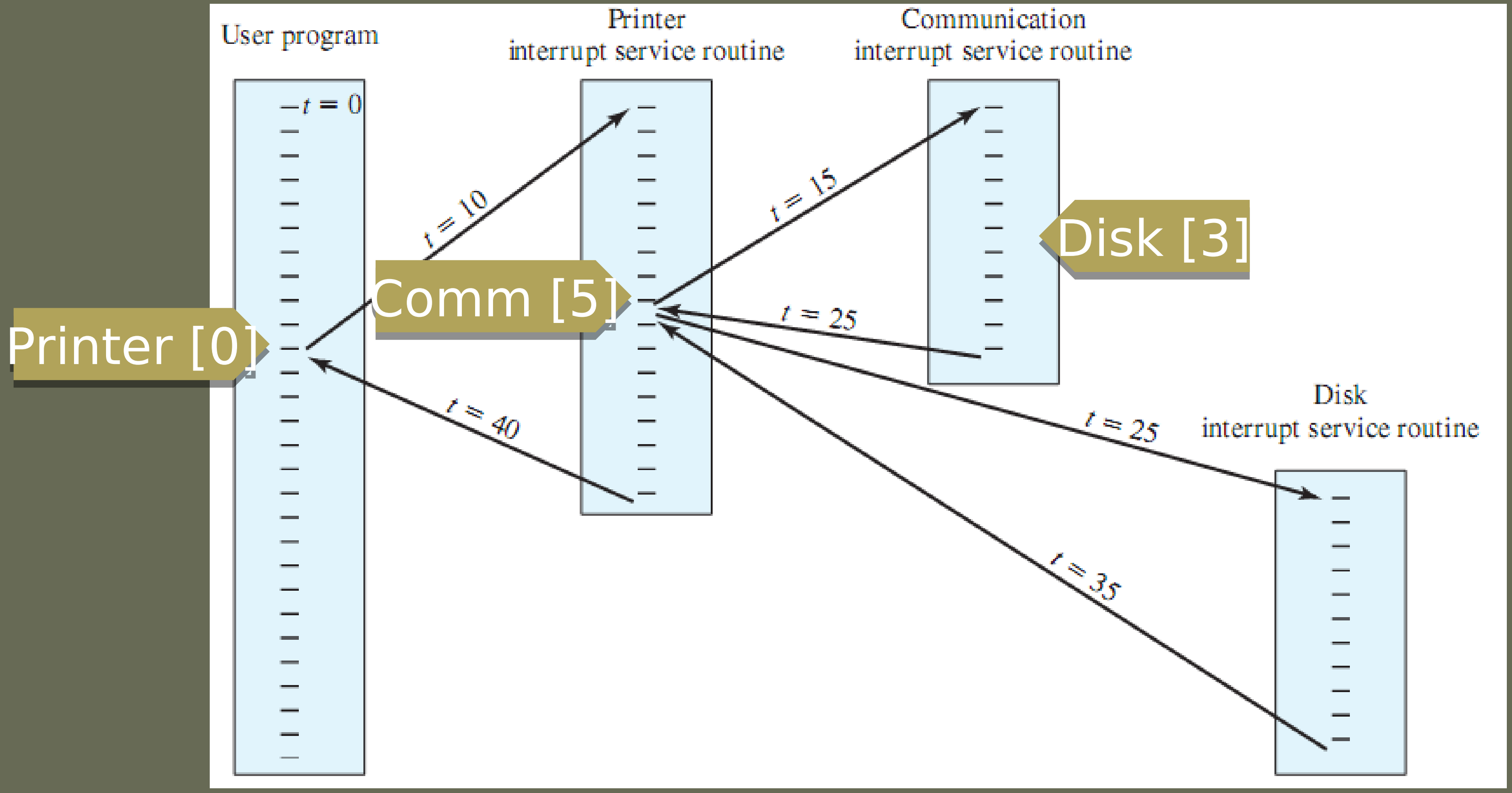
Interrupts

- Multiple overlapping interrupts
  - (approach 1) Interrupts disabled



Interrupts

- Multiple overlapping interrupts
  - (approach 2) Priority Scheme



Topics

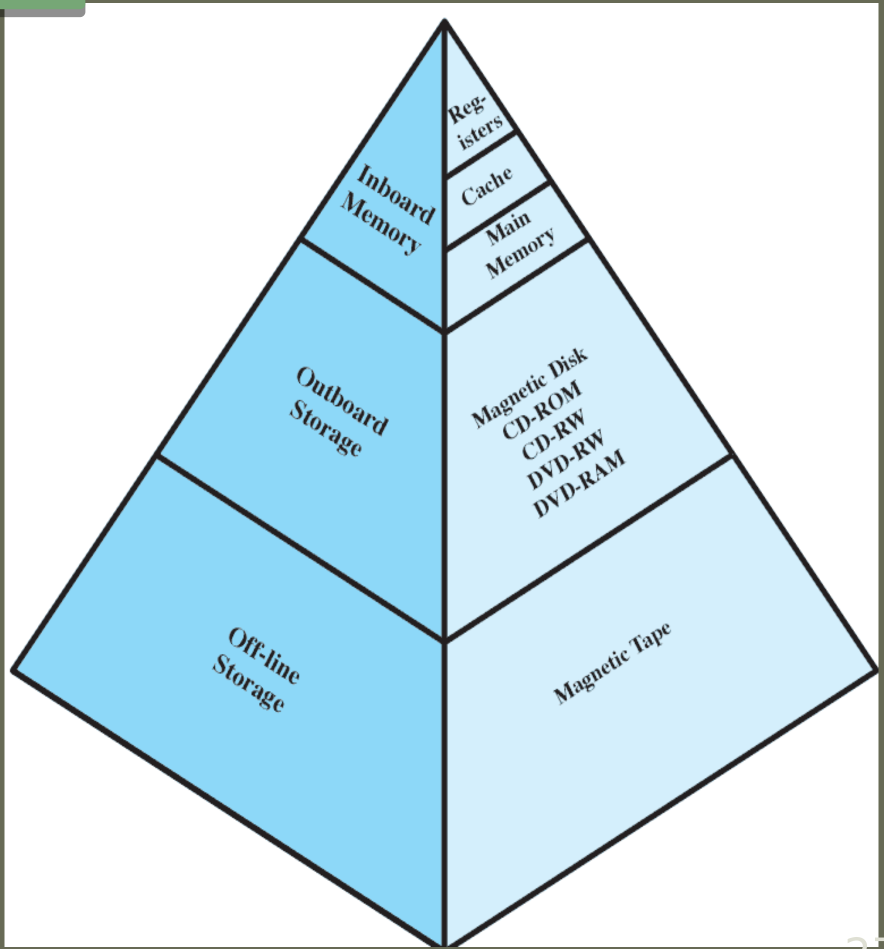
- Basic Elements
  - Processor, main memory, I/O modules, system bus
- Microprocessors
  - General purpose, graphics, digital signal, system on chip
- Instructions
  - Execution, fetch & execute (F&E), instruction register
- Interrupts
  - Types, flow of control, F&E&I, multiple interrupts
- Memory
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

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?

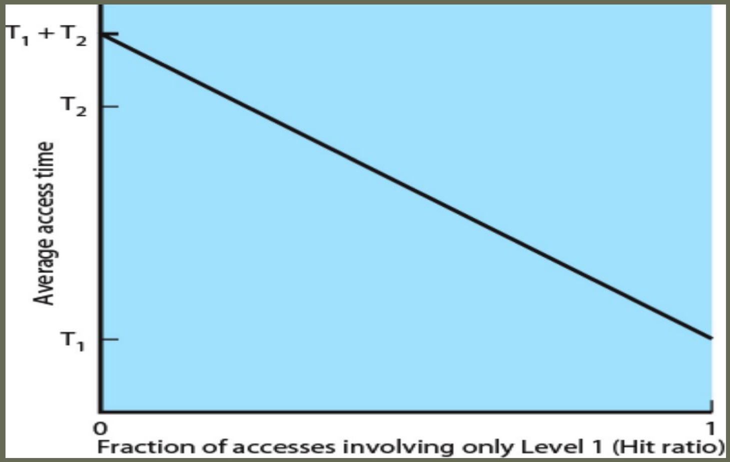


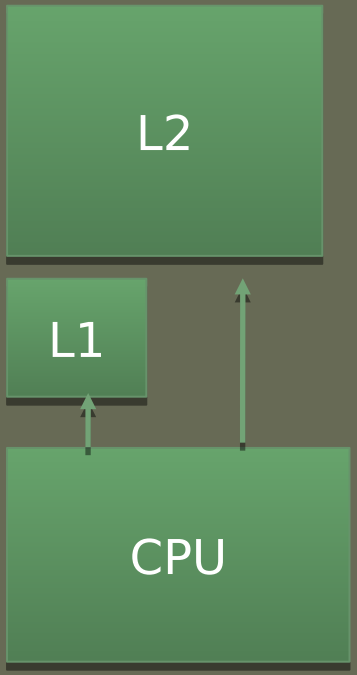
Memory

- Principle of Locality
  - Why does frequency of access by CPU decrease?
    - Memory references (i.e., data) needed by CPU (i.e., the current set of instructions in a program) tend to cluster
      - e.g. 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

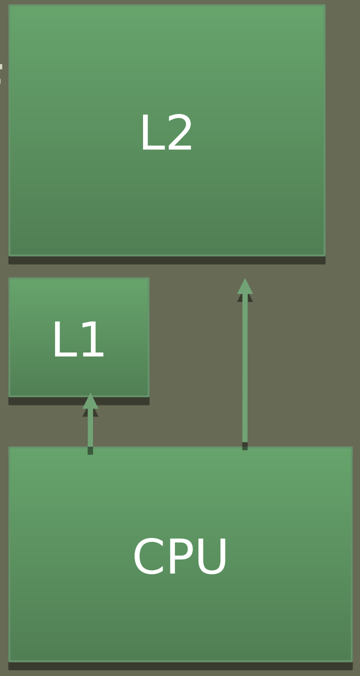
- Performance Example
  - 2 levels of memory (L1,L2)
    - T1 @ 0.1µs (1kb total) faster but scarce
    - T2 @ 1µs (100kb total) slower but plenty
  - CPU checks L1 first then L2





Memory

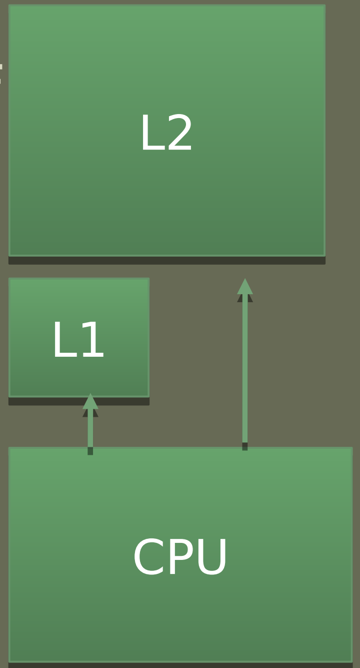
- Performance Example
  - 2 levels of memory (L1,L2)
    - T1 @ 0.1μs (1kb) faster but scarce
    - T2 @ 1μs (100kb) slower but plenty
  - What's the average access time if
    - 95% of data in L1 and 5% in L2?



Memory

- Performance Example
  - 2 levels of memory (L1,L2)
    - T1 @ 0.1µs (1kb)   faster but scarce
    - T2 @ 1µs (100kb)   slower but plenty
  - What's the average access time if
    - 95% of data in L1 and 5% in L2?
      - 0.95 * 0.1µs + 0.05 * (0.1µs + 1µs) = 0.15µs
    - 5% of data in L1 and 95% in L2?

Looks in L1 first then L2



Memory

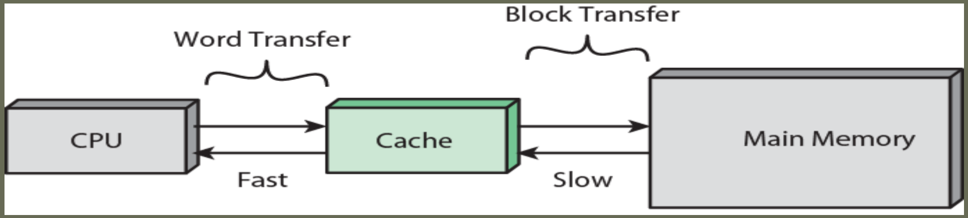
- Performance Example
  - 2 levels of memory (L1,L2)
    - T1 @ 0.1µs (1kb)   faster but scarce
    - T2 @ 1µs (100kb) slower but plenty
  - What's the average access time if...
    - 95% of data in L1 and 5% in L2?
      - $0.95 * 0.1\mu s + 0.05 * (0.1\mu s + 1\mu s) = 0.15\mu s$
    - 5% of data in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

What if you have 3 levels?

reason why caches exist

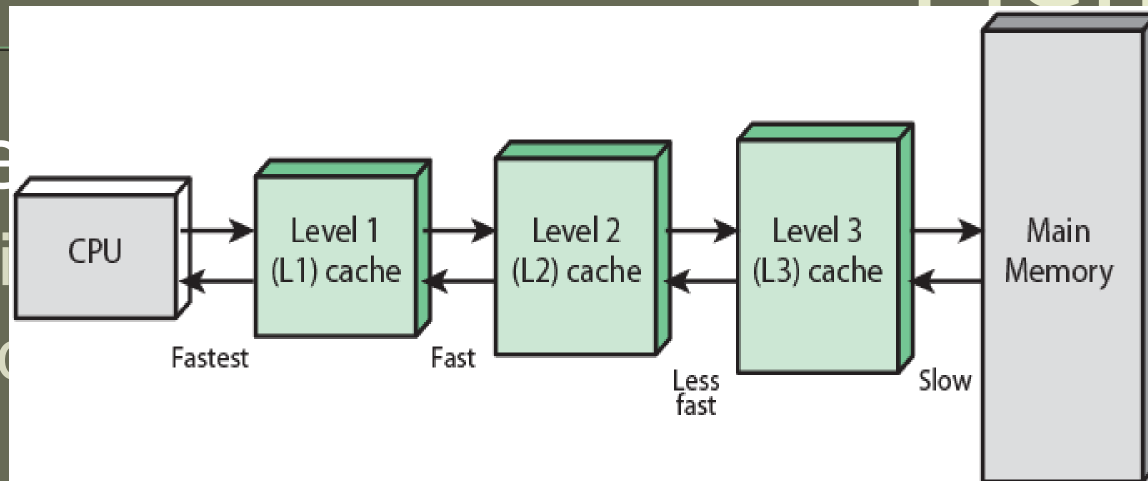
Memory

- Cache
  - Exploits the Principle of Locality
  - Controlled by hardware (i.e., it is invisible to OS)
  - Principles
    - 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

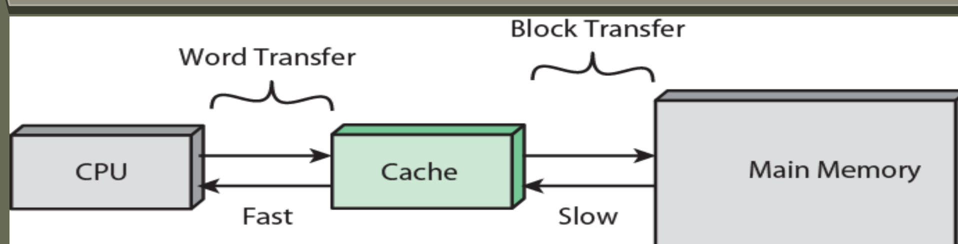


Memory

- Cache
  - Exploi
  - Contro ble to OS)
  - Princip
    - Conta nory
    - CPU ch
      - if found
      - if not fo ry (where data is)



In practice:
several levels are common



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

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 writing, CPU transfers data.*
    - 2. CPU waits until I/O module completes command.
    - *If reading, CPU transfers data*
    - 3. CPU resumes execution
  - 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 writing, CPU transfers data.*
    - 2. CPU resumes execution.
    - 3. I/O module triggers an interrupt when command is done
      - *If reading, CPU transfers data*
    - 4. CPU resumes execution
  - 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)

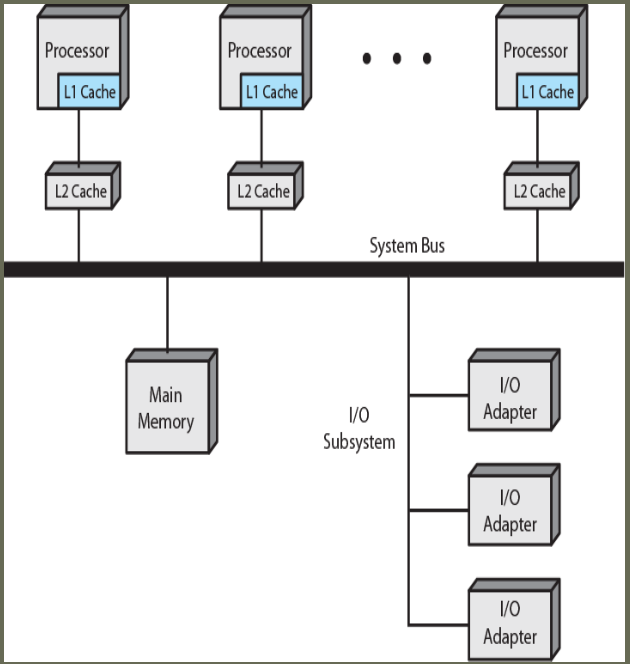
- Performed by a separate module on the system bus (DMA)
- CPU keeps executing while I/O command is completed by DMA module
  - 1. CPU sends I/O command, memory address (where data is read or written), data size and I/O module to DMA
  - 2. CPU resumes execution.
  - 3. I/O module triggers an interrupt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

Chapter 1 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

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)

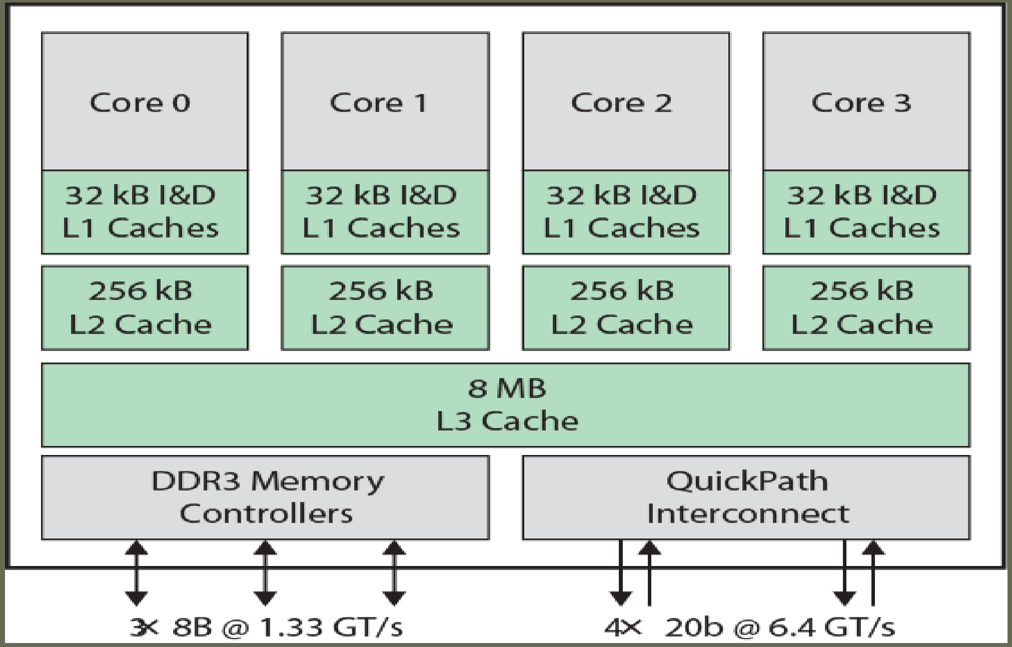


Symmetric Multi-Processors

- 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



Topics

- Basic Elements
  - Processor, main memory, I/O modules, system bus
- Microprocessors
  - General purpose, graphics, digi[illegible]l, system on chip
- Instructions
  - Execution, fetch & execu[illegible], instruction register
- Interrupts
  - Types, flow of con[illegible]&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

Done!