Welcome!

Introduction to Computer Architecture

(Computer Organization and Design: ARM Edition)

Instructor:
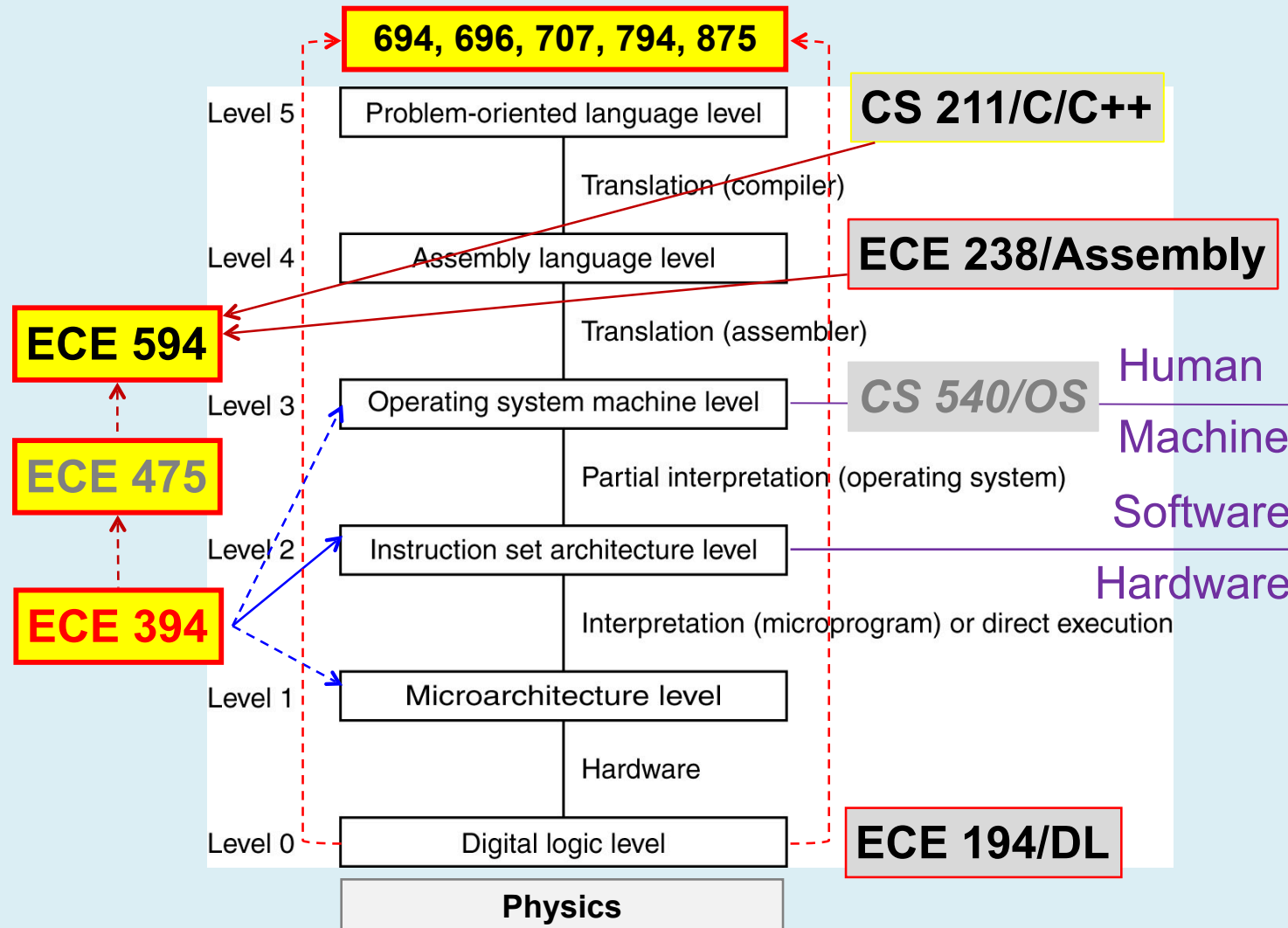
Abu Asaduzzaman (Zaman)

+1-316-978-5261

Abu.Asaduzzaman@wichita.edu

ARM - Advanced RISC Machines
RISC - Reduced Instruction Set Computing (a computer architecture)

Computer Systems: A Multilevel Approach

(From Handout 2)

694, 696, 707, 794, 875

Level 5	Problem-oriented language level	**CS 211/C/C++**
	Translation (compiler)	
Level 4	Assembly language level	**ECE 238/Assembly**
	Translation (assembler)	
ECE 594		
Level 3	Operating system machine level	*CS 540/OS* Human
		Machine
ECE 475	Partial interpretation (operating system)	
Level 2	Instruction set architecture level	Software
		Hardware
ECE 394	Interpretation (microprogram) or direct execution	
Level 1	Microarchitecture level	
	Hardware	
Level 0	Digital logic level	**ECE 194/DL**
	Physics	

2

2024 Engineering Salary Statistics

"Engineers Get Top Pay"

Motivation?

❏ **College of Engineering, Michigan Tech**
➢ https://www.mtu.edu/engineering/outreach/welcome/salary/

CoE WSU

Salaries by Engineering In...

Industry	Mean Entry-Level Salary (Payscale)	Mean Annual Salary (BLS)	Top 10 Percent (BLS)
Computer Engineering, IT Engineer (Computer Hardware Engineers)	$76,707	$147,770	$212,770
Computer Engineering, IT Engineer (Software Developers)	$70,115	$138,110	$208,620
Electrical Engineering	$72,904	$117,680	$172,050
Aerospace Engineering	$76,293	$134,330	$188,910
Biomedical Engineering	$66,917	$106,700	$154,350
Mechanical Engineering ME Salaries Details	$69,148	$105,220	$157,470

Figures from payscale.com, accessed May 2024.

Figures from U.S. Bureau of Labor Statistics (BLS), dated May 2023.

Who/What will determine your salary?

➢ You!
  ✓ Your degree
  ✓ Your knowledge

We can help you!

3

Intro to Computer Architecture

Lecture 2

Reading: See Reading Assignments

Tests (HW, Quiz, Exam): HW-1 (Week 2), HW-2 (Week 3), Quiz-1 (Week 4), …

- **Review: Introduction, Syllabus, zyBooks; Tests, …**
- **Computer Architecture: A Quick Introduction**
  - **How does a (simple) computer work?**
- **Introduction to Computers (from zyBooks)**
  - **Eight great ideas in computer architecture**
  - **Technologies for building processors and memory**
  - **The switch from uniprocessor to multiprocessor**

Intro to Computer Architecture

Blackboard (Bb)

- **Content > Information, Course Materials, Tests, etc.**
  - ➤ **Information > Syllabus, K-Probe, Evaluations, etc.**
  - ➤ **Course Materials > Lecture Notes, Reading Materials, Video Clips, etc.**
  - ➤ **Tests > Homework, Quiz, and Exam**
- **Announcements > Important messages, etc.**
- **Gradebook > Individual scores, etc.**

ECE-394-14691-202510   ⚙ Course Settings

Intro Computer Architecture tr 09:30:00 (ECE-394-14691-Fall 2024)

Content   Calendar   Announcements   Discussions   Gradebook   Messages   Analytics   Groups   ↻ Student Preview

WSU | CAPPLab
capplab@wichita.edu

ECE-394 | DRZ

Intro to Computer Architecture

From Syllabus

ECE 394, Introduction to Computer Architecture, Fall, 2024
(Computer Organization and Design: The Hardware Software Interface)

- Instructor: Abu Asaduzzaman (DRZ)
- Department: Electrical and Computer Engineering (ECE)
- Office Location: 303 Wallace Hall (303-WH) building
- Telephone: +1-316-978-5261
- Email: abu.asaduzzaman@wichita.edu
- Preferred Method of Contact: In person during office hours or e-mail
- Classroom, Day/Time: 202-EB, Tuesday & Thursday 9:30-10:45 AM
- Student/Office Hours: Tuesday 11:00-12:30 & Wednesday 10:00-11:30 AM
- Prerequisites: ECE 194 and CS 211
- Teaching Assistant (TA): Grading – Md "Raihan" Uddin
- TA Contacts: Grading – mxuddin11@shockers.wichita.edu

*** Important ***
Please read the syllabus!

Grading Assignments/Components	Values (%)
Readings (as assigned on zyBooks.com)	10%
Homework (five of six, take home via Blackboard)	15%
Quiz (two of three, 30-minute during class-time)	10%
Exam-1 (~ Week 5, 65-minute during class-time)	20%
Exam-2 (~ Week 10, 65-minute during class-time)	20%
Exam-3 (cumulative, 65-minute during class-time)	25%

Intro to Computer Architecture

From Syllabus

Required Books

Required Texts/Readings Textbook

Please talk to the instructor before buying books for this course.

Textbook: zyBooks: ECE 394: Introduction to Computer Architecture ["Computer Organization and Design: The Hardware / Software Interface, ARM Edition," by David A. Patterson and John L. Hennessy, Morgan Kaufmann, 2017 edition.]

Students will access zyBooks directly. Instructions for students:

1) Sign in or create an account at learn.zybooks.com
2) Enter zyBook code: WICHITAECE394AsaduzzamanFall2024
3) Subscribe

Other Readings/Materials

Book: "Structured Computer Organization," Andrew S. Tanenbaum and Todd Austin, Pearson, sixth edition, 2016.
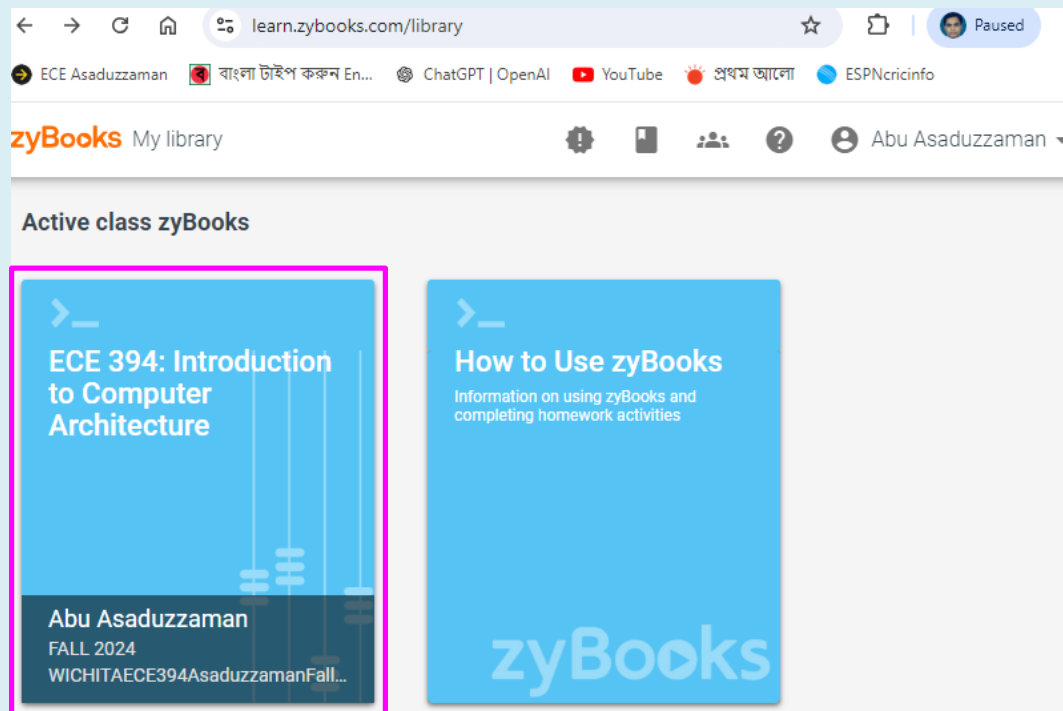
Intro to Computer Architecture

Syllabus

■ **Syllabus on Blackboard**

➢ **Course Content > Information > ECE394fall24_Syllabus_**

■ **Textbook on learn.zybooks.com**

Intro to Computer Architecture

From Syllabus

Brief List of Topics to Cover

Chapter 1: Introduction
- Eight great ideas in computer architecture
- Technologies for building processors and memory
- Performance
- From uniprocessors to multiprocessors

Handout: Multilevel Computers
- Evolution of multilevel machines
- Milestones in computer architecture
- The Computer Zoo

Chapter 3: The Processor
- Building a datapath
- Parallelism: Pipelining
- Data hazards, Control hazards

Chapter 4: Memory Hierarchy
- Memory, Caches
- Virtual memory

Chapter 5: Parallel Processors
- Parallel processing
- SISD, MIMD, SIMD, SPMD, and vector
- Hardware multithreading
- Multicore and other shared memory multiprocessors

Tentative Schedule

Week Tue	Note	Important topics/readings, assignments, due dates, and reminders are listed here so that you can organize your time and academic work.
1 08/20		ECE 394: Intro to Computer Architecture, Syllabus; K-probe; zyBook 1.1 (Intro to Computers); Homework, Quiz, and Exam;
2 08/27	HW-1	HW-1 Discussion; zyBook 1.2-1.5 (eight ideas, processors); HW-1 (due on Blackboard); zyBook 1.6 (performance);
3 09/03	HW-2	9/02 (Labor Day) No Class/Lab; HW-2 (Bb); zyBook 1.7-1.9 (... uni- and multiprocessors, Core i7);
4 09/10	Quiz-1	Quiz-1 Discussion; Handout: Multilevel Computers; Quiz-1 (class test, 30-min / 30-pts, closed book);
5 09/17	Exam-1	Exam-1 Discussion; Handout: Computer Generations; Exam-1 (class test, 65-min / 65-pts, closed book);
6 09/24	Update	zyBook: 3.1 (The Processor: Introduction); zyBook: 3.2-3.3 (The Processor: Datapath, Pipelining);
7 10/01	HW-3	zyBook 3.4-3.5 (Data hazards: Forwarding versus stalling); HW-3 (Bb); zyBook 3.6 (Data hazards and Control hazards);
8 10/08	Mid-Pt HW-4	zyBook 3.7 (Parallelism via instructions); HW-4 (Bb); zyBook 3.8 (Going faster: ILP and matrix multiply);
9 10/15	Fal-Brk Quiz-2	10/12 (Sat) to 10/15 (Tue) (Fall Break) No Class; Quiz-2 (class test, 30-min / 30-pts, closed book);
10 10/22	Exam-2	Exam-2 Discussion; zyBook 4.1 (Memory Hierarchy: Introduction); Exam-2 (class test, 65-min / 65-pts, closed book);
11 10/29	Update	zyBook 4.2-4.3 (Memory Hierarchy: Caches); zyBook 4.4-4.5 (Memory Hierarchy: Virtual memory);
12 11/05	HW-5	zyBook 5.1 (Parallel Processors: Introduction); HW-5 (Bb); zyBook 5.2 (Difficulty of Parallel Processing);
13 11/12	HW-6	zyBook 5.3 (SISD, MIMD, SIMD, SPMD, and vector); HW-6 (Bb); zyBook 5.4 (Hardware multithreading);
14 11/19	Quiz-3	zyBook 5.5-5.6 (Multicore processors, graphics processing units); Quiz-3 (class test, 30-min / 30-pts, closed book);
15 11/26	Thx-Brk	Future of Computers (selected materials); 11/27 (Wed) to 12/01 (Sun) (Thanksgiving Break) No Class;
16 12/03	Exam-3	Exam-3 Discussion; Exam-3 (class test, 65-min / 65-pts, closed book);
Finals		None!

Note: A date in Column 1 indicates the Tuesday of that week. Here, 12/03 is Tueday of Week 16.

Homework Preparation / Submission

Homework Preparation and Submission

- **How to prepare/submit homework?**
  - Must have: <u>Course #</u>; <u>Semester</u>; and <u>HW #</u>
  - Must have: <u>Name</u> & <u>WSU ID</u>
  - Must submit: Everything in <u>one single PDF file</u> <u>via Blackboard</u>
  - …
  - Collaborate, do not cheat!!!

Homework Preparation / Submission

Homework Preparation and Submission

■ **How to prepare/submit homework?**
  ➢ **Must have: <u>Course #</u>; <u>Semester</u>; and <u>HW #</u>**
  ➢ **Must have: <u>Name</u> & <u>WSU ID</u>**
  ➢ **Must submit: Everything in <u>one single PDF file</u> <u>via Blackboard</u>**
  ➢ **…**
  ➢ **Collaborate, do not cheat!!!**
  ➢ **No e-mail submission!**
  ➢ **Late submission: Penalty 10% per day for five days!!**

■ **Homework**
  ➢ **(Blackboard) Discussion on Tuesday, Submission on Thursday**

If you have grading questions on paper-based tests, please bring the papers as they were returned.
     If you make any changes, it will be considered as cheating; you will get a zero on that test, and it may be sent to the related department for further disciplinary actions.

■ **Reading Assignments (see Blackboard)**

Reading Assignments

Week	Note	Important reading assignments
1		zyBook Ch. 1.1: Introduction (Introduction to Computers) Ch. 1.2 – Ch. 1.4: Ch. 1.5: Technologies for building processors and memory
2	HW-1	zyBook Ch. 1.6: Performance Ch. 1.7 – Ch. 1.8: Ch. 1.9: Intel Core i7

Introduction to Computer Architecture

Do you have any questions?

1:31 PM

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Intro to Computer Architecture

Lecture 2

Reading: See Reading Assignments

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  - ➢ **The switch from uniprocessor to multiprocessor**

Let's talk about <u>ECE 394</u>

Introduction to Computer Architecture

Digital Design (ECE 194), Programming (CS 211) … (pre-requisite)

■ **Why do we care?**

➢ **Computers are everywhere; we cannot live without computers. Need BETTER Computer Architecture!!!**

■ **Why ECE 394?**

➢ **ECE 394 introduces computer architecture.**

➢ **We learn *what* make a computer and how computers execute programs! (How does it sound? Simple?)**

➢ **Here, things will be complicated. How?**

➢ **Processors, Memory Hierarchy, Parallel Processors, …**

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Intro to Computer Architecture

World/Life before 'computers'

- **History of transportation [1]**
  - ➤ **Road: the 4th or 5th millennium BC**
  - ➤ **Rail: ~ 500 years back, cast iron plates in 1760s, …**
  - ➤ **Modern locomotive: in 1820s**
  - ➤ **The history of transport is largely one of technological innovation.**
- **History of airplane or aeroplane [2]**
  - ➤ **Around 400 BC, …**
  - ➤ **The Wright brothers, in 1903 CE, …**
  - ➤ **On Jan. 1, 1914, the world's first scheduled passenger airline service took off, operating between St. Petersburg and Tampa, Fla.**
- **History of (computer) modern computer [3]**
  - ➤ **Around (1801, 1822 CE,) 1945 CE, …**
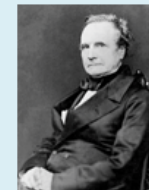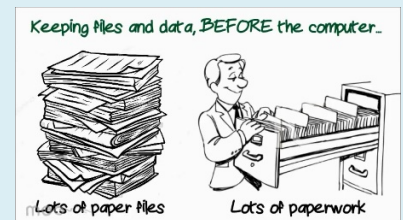
Charles Babbage | Alan Turing | John von Neumann
1791-1871 | 1912-1954 | 1903-1957

[1] "History of transport - Wikipedia," https://en.wikipedia.org/wiki/History_of_transport
[2] "Airplane – Wikipedia," https://en.wikipedia.org/wiki/Airplane
[3] "History of Computers: A Brief Timeline," https://www.livescience.com/20718-computer-history.html
https://www.space.com/16657-worlds-first-commercial-airline-the-greatest-moments-in-flight.html

Motivation!

Intro to Computer Architecture

Computers → HPC Systems [1]

- **History of (computer) modern computer**
  - ➢ Around (1801, 1822 CE,) 1945 CE, …

- **History of HPC Systems**
  - ➢ In 1985, U.S. National Science Foundation (NSF), …
  - ➢ (i) the San Diego Supercomputer Center (SDSC) at the University of California San Diego,
  - ➢ (ii) the Pittsburgh Supercomputer Center (PSC) at the University of Pittsburgh,
  - ➢ (iii) the Nat'l Center for Supercomputing Apps (NCSA) at the University of Illinois Champagne-Urbana,
  - ➢ (iv) the Cornell Theory Center (CTC) at Cornell University, and
  - ➢ (v) the John von Neumann Center (JNC) at Princeton University.

Student life is easy.
Buzzle.com

[1] "High Performance Computing," https://confluence.xsede.org/pages/viewpage.action?pageId=1677620

Intro to Computer Architecture

Computer Systems: 1975–2009

My First Computer, IBM PC, Windows 3.x/95, 1995/1997

The first computer, 1937

Single-core

Dual-core, Multicore started after 2004
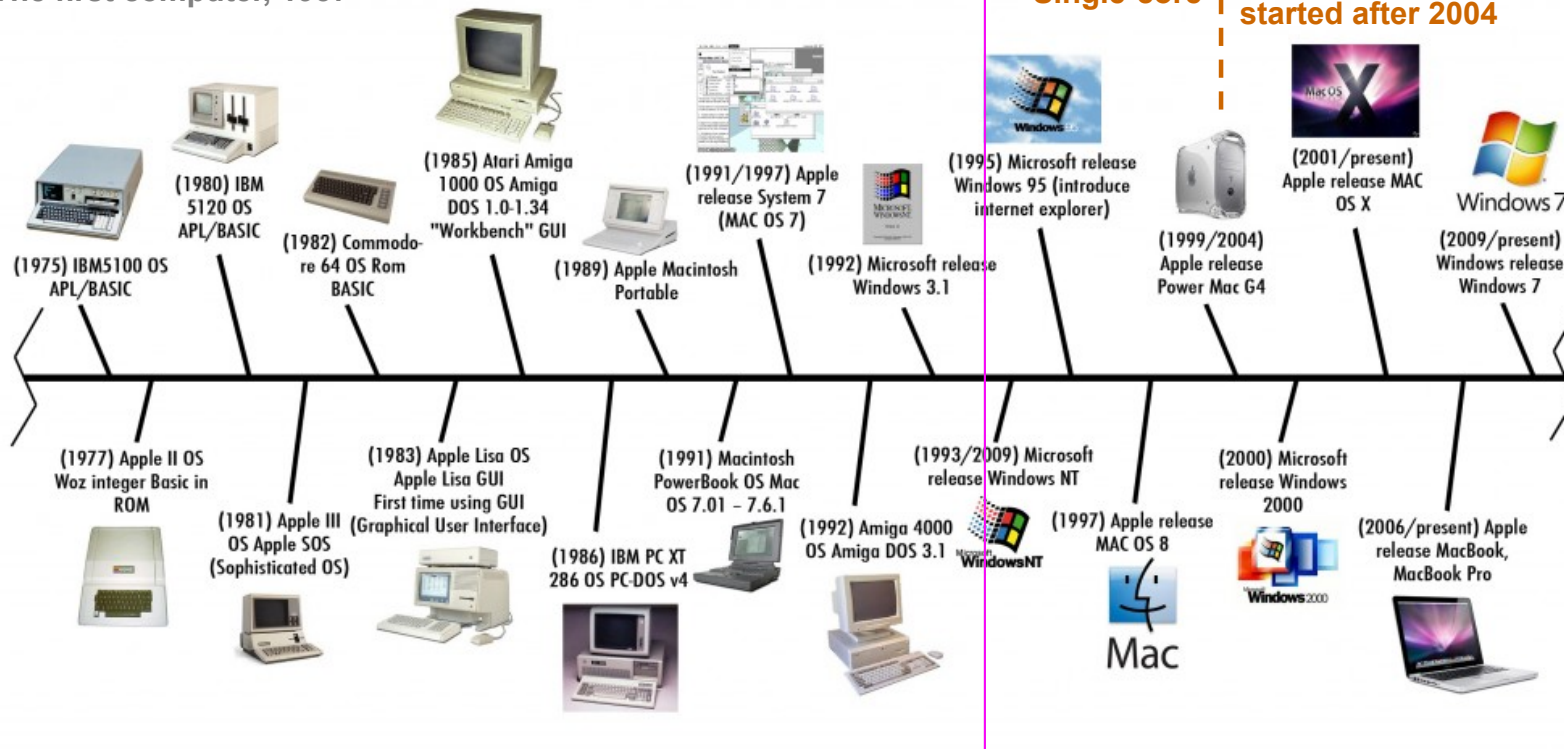
Hybrid High Performance Computing (HPC) Systems, since 1985

Quantum Computing, since before 1980

(1980) IBM 5120 OS APL/BASIC

(1985) Atari Amiga 1000 OS Amiga DOS 1.0-1.34 "Workbench" GUI

(1991/1997) Apple release System 7 (MAC OS 7)

(1995) Microsoft release Windows 95 (introduce internet explorer)

(2001/present) Apple release MAC OS X

(1982) Commodore 64 OS Rom BASIC

(1989) Apple Macintosh Portable

(1992) Microsoft release Windows 3.1

(1999/2004) Apple release Power Mac G4

(2009/present) Windows release Windows 7

(1975) IBM5100 OS APL/BASIC

(1977) Apple II OS Woz integer Basic in ROM

(1983) Apple Lisa OS Apple Lisa GUI First time using GUI (Graphical User Interface)

(1991) Macintosh PowerBook OS Mac OS 7.01 – 7.6.1

(1993/2009) Microsoft release Windows NT

(2000) Microsoft release Windows 2000

(1981) Apple III OS Apple SOS (Sophisticated OS)

(1986) IBM PC XT 286 OS PC-DOS v4

(1992) Amiga 4000 OS Amiga DOS 3.1

(1997) Apple release MAC OS 8

(2006/present) Apple release MacBook, MacBook Pro

"Invention/evolution of the relay computer," https://prezi.com/d_-cpssu6zyx/inventionevolution-of-the-relay-computer/

Dr. Zaman; WSU-5261

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capplab@wichita.edu

Computer architecture!

Computer Architecture

Computer Architecture (Digital Computer Organization): The conceptual design and fundamental operational structure of a computer system.
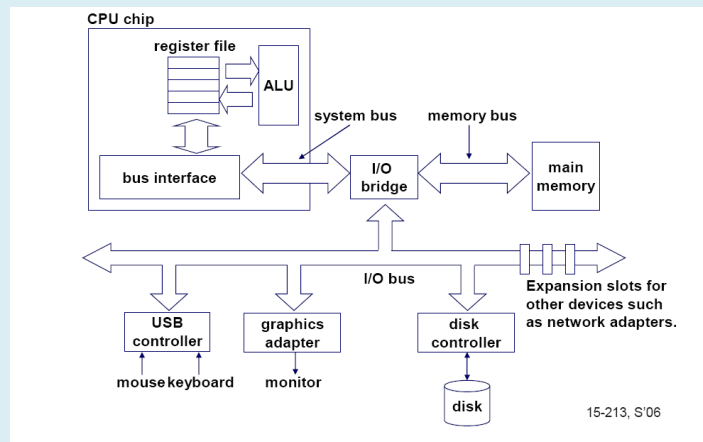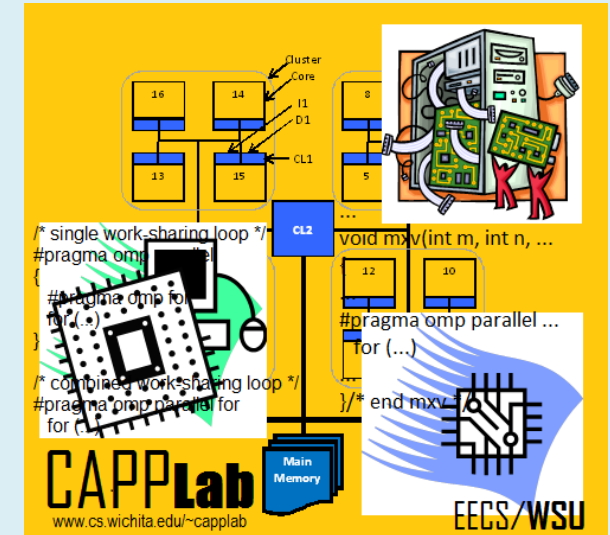

Computer architecture is a set of rules and methods that describe the functionality, organization, and implementation of computer systems. Computer organization helps optimize performance-based products.

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Intro to Computer Architecture

Computer Architecture

Computer Architecture (Digital Computer Organization): The conceptual design and fundamental operational structure of a computer system.
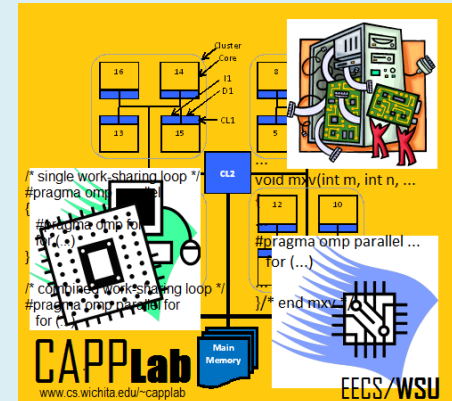
1959 C.E. →   IBM Machine Organization department used "architecture"
1964 C.E. →   IBM System/360 used "architecture"

❑ Harvard architecture, Von Neumann architecture
❑ Single-core architecture →   **Multi-core architecture**
❑ Chaos computer
❑ Quantum computer
❑ … …

Intro to Computer Architecture

Computer Architecture (+)
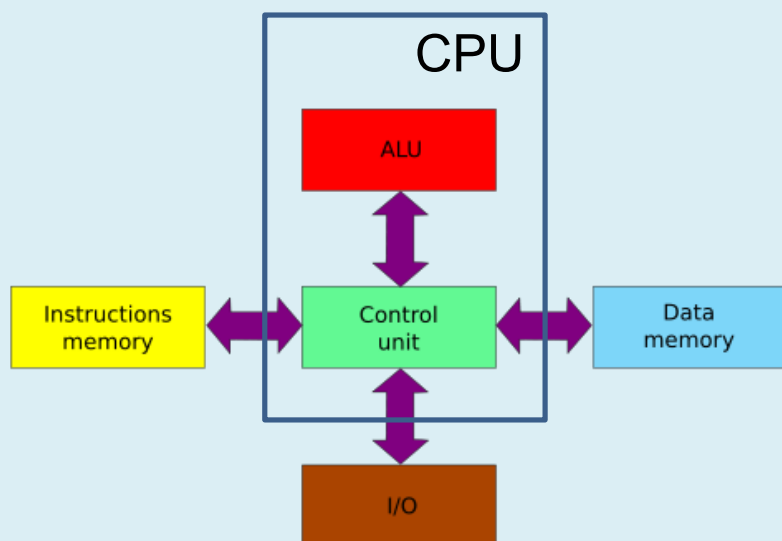
Pure Harvard Arch

Separate storage for instructions and data
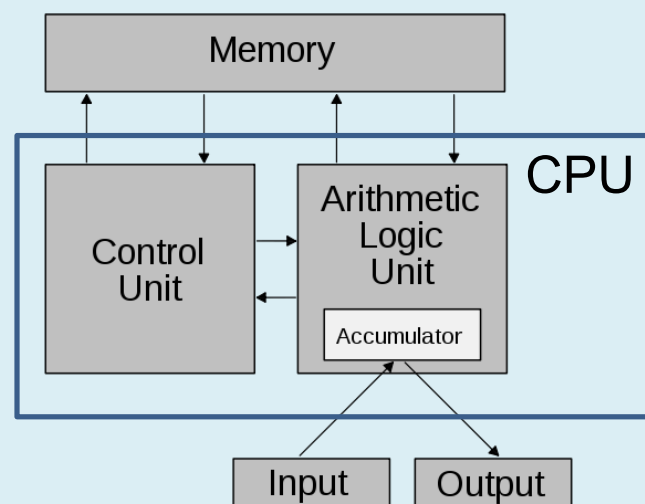
Von Neumann Arch

Instructions and data in a single memory

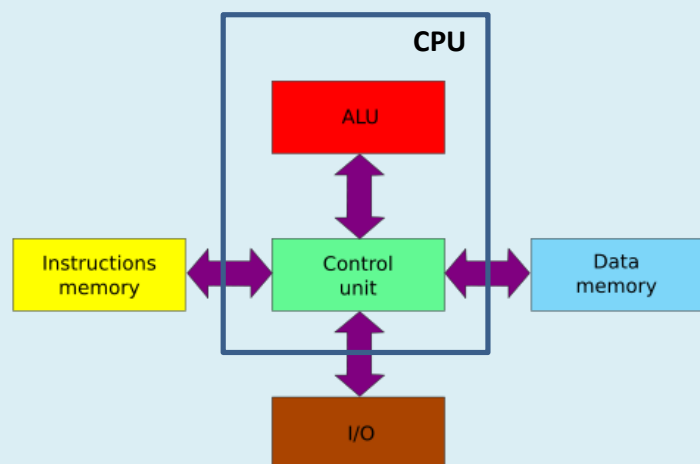# Intro to Computer Architecture

Computer Architecture (+)
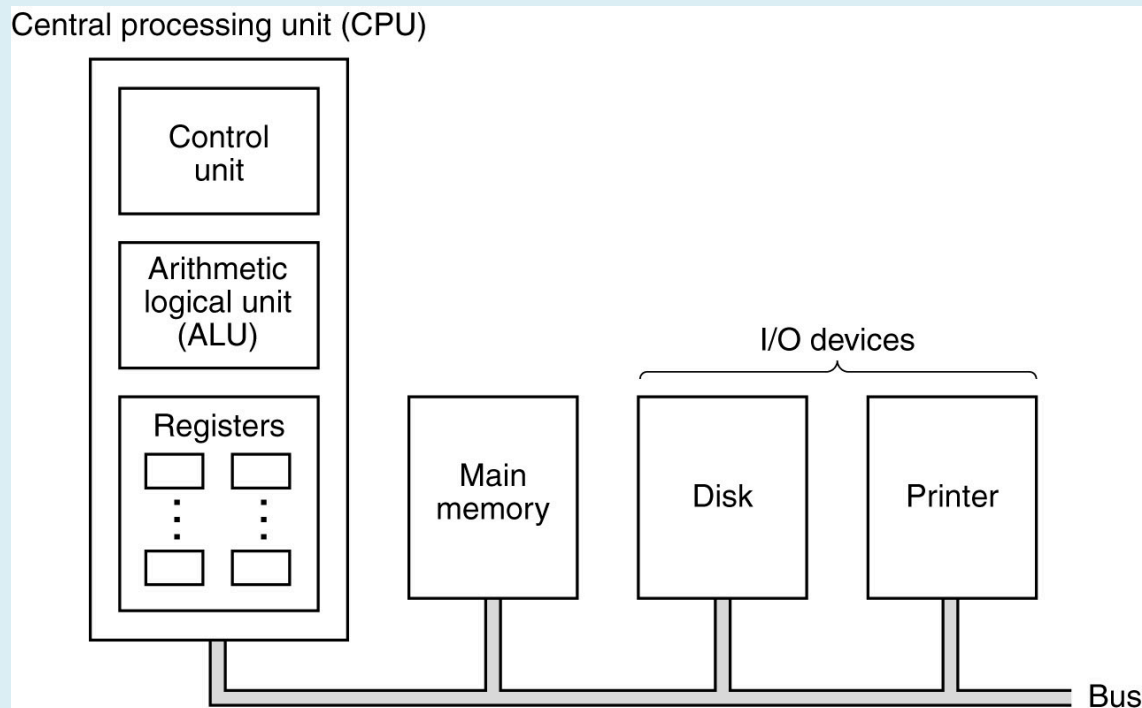
The organization of a simple computer with one CPU and two I/O devices

Programmed Data Processor (PDP)
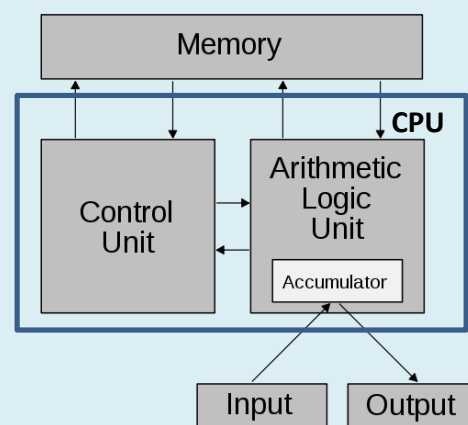Digital Equipment Corporation (DEC)

Intro to Computer Architecture

Key components of a <u>simple</u> computer system
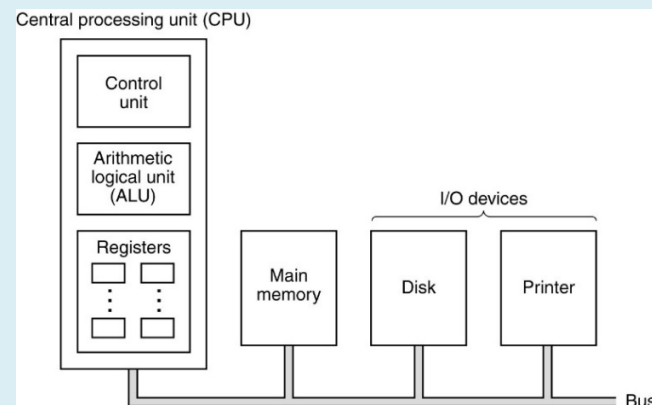
- **CPU (CU, ALU, Registers)**
- **Memory (Main/Primary Memory, split or unified)**
- **Bus (collection of wires)**
- **Input / Output (I/O, Monitor, Printer)**
- **Storage (Secondary Memory)**

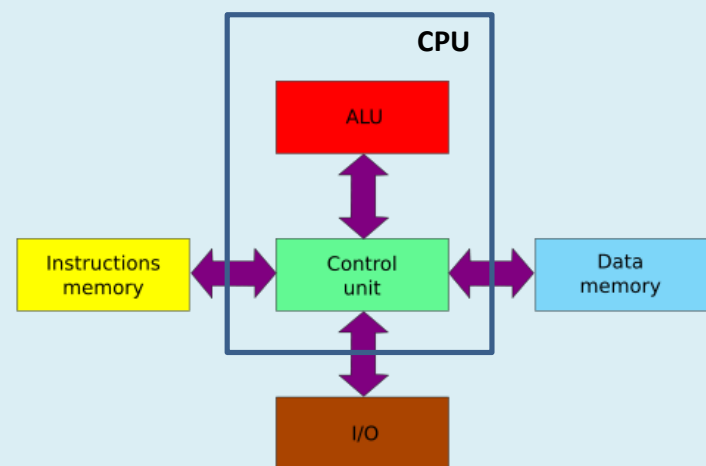**Pure Harvard Arch**   **Von Neumann Arch**   **PDP-8**
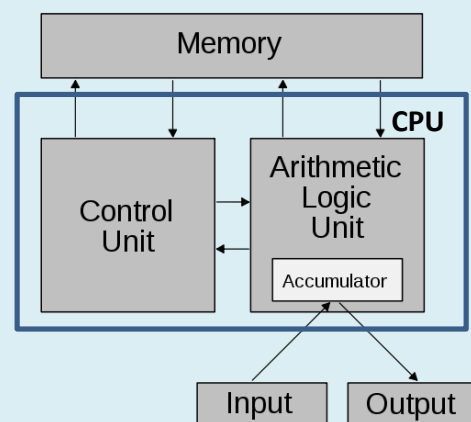
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Intro to Computer Architecture

Key components of a <u>simple</u> computer system

- CPU (CU, ALU, Registers)
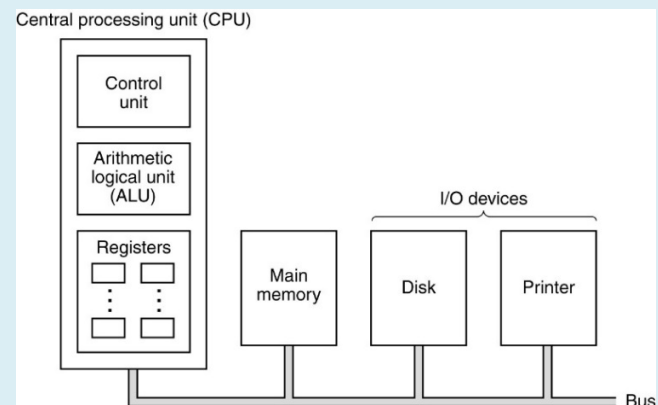- Memory (Main/Primary Memory, split or unified)
- Bus (collection of wires)

What/how does 'it' do/work?

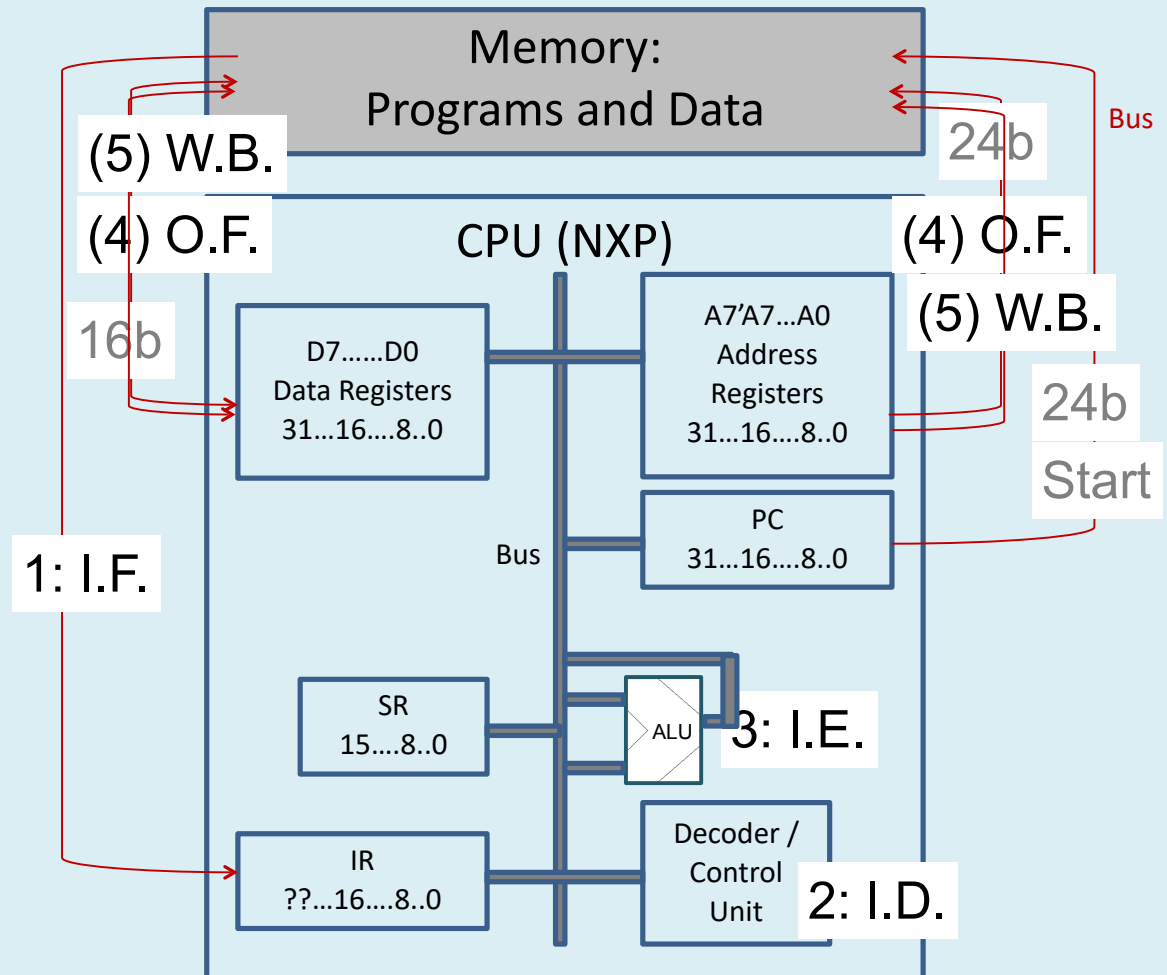**Pure Harvard Arch**   **Von Neumann Arch**   **PDP-8**

Intro to Computer Architecture

Computer System:

➢ **Programs**

➢ **Execution**

Major Steps to Execute an Instruction (A program is a set of wisely selected instructions.)

Memory: Programs and Data

Bus

(5) W.B.

(4) O.F.

CPU (NXP)

(4) O.F.

(5) W.B.

24b

16b

D7......D0 Data Registers 31...16....8..0

A7'A7...A0 Address Registers 31...16....8..0

24b

Start

PC 31...16....8..0

Bus

1: I.F.

SR 15....8..0

ALU

3: I.E.

IR ??...16....8..0
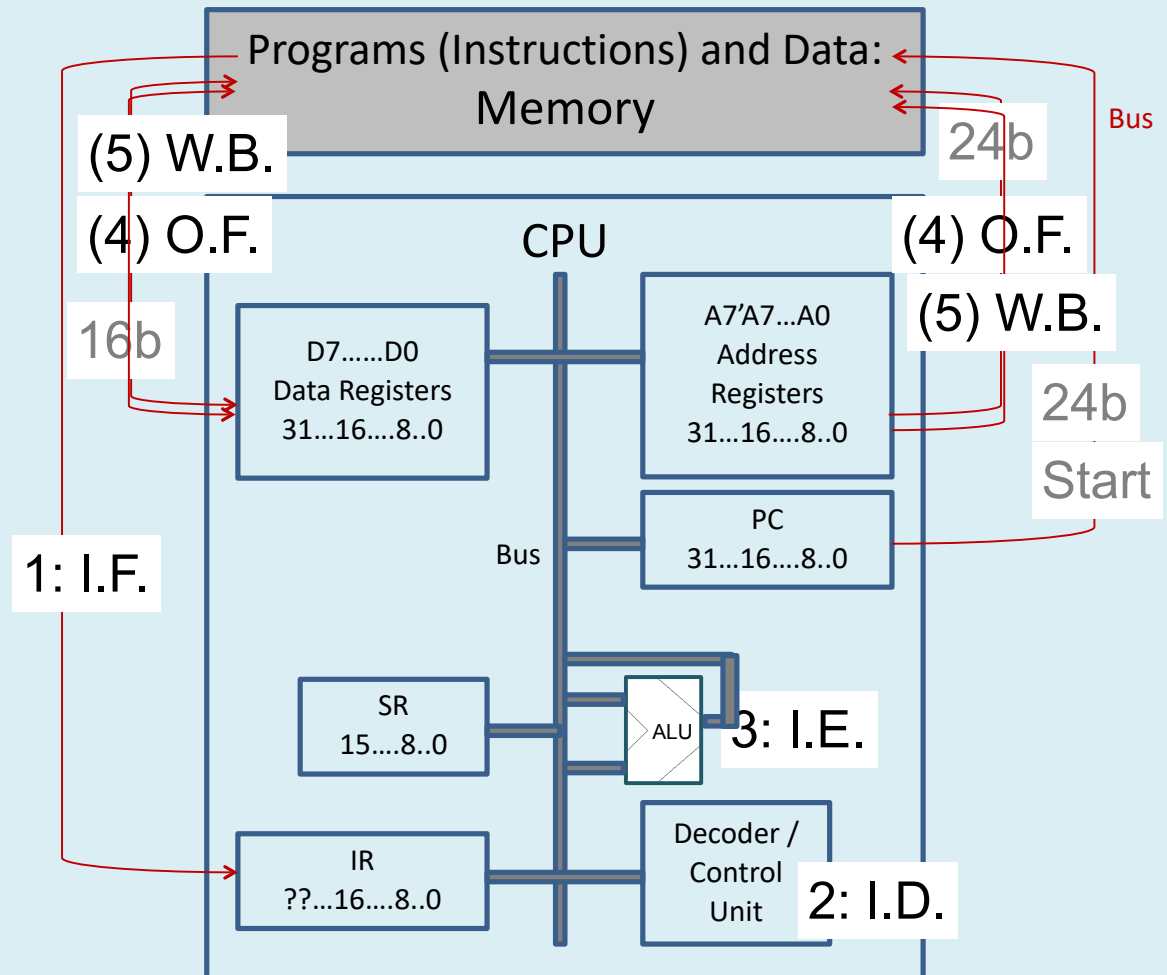
Decoder / Control Unit

2: I.D.

Intro to Computer Architecture

Computer System:
- ➢ **Programs**
- ➢ **Execution**

Major Steps to Execute an Instruction

1. **Instruction Fetch**
2. **Instruction Decode**
3. **Instruction Execution**
4. **Operand Fetch** (optional)
5. **Result Write Back to Main Memory (optional)**

Programs (Instructions) and Data: Memory

CPU

(5) W.B.

(4) O.F.

16b

24b

Bus

(4) O.F.

(5) W.B.

24b

Start

D7......D0
Data Registers
31...16....8..0

A7'A7...A0
Address Registers
31...16....8..0

PC
31...16....8..0

Bus

1: I.F.

SR
15....8..0

ALU

3: I.E.

IR
??...16....8..0

Decoder /
Control
Unit

2: I.D.

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Intro to Computer Architecture

Computer System:

➢ **Programs**

➢ **Execution**

Major Steps to Execute an Instruction

1. **Instruction Fetch**
2. **Instruction Decode**
3. **Instruction Execution**
(4) **MEMory access (optional, not for every operation)**
(5) **Result Write Back to Main Memory (optional)**
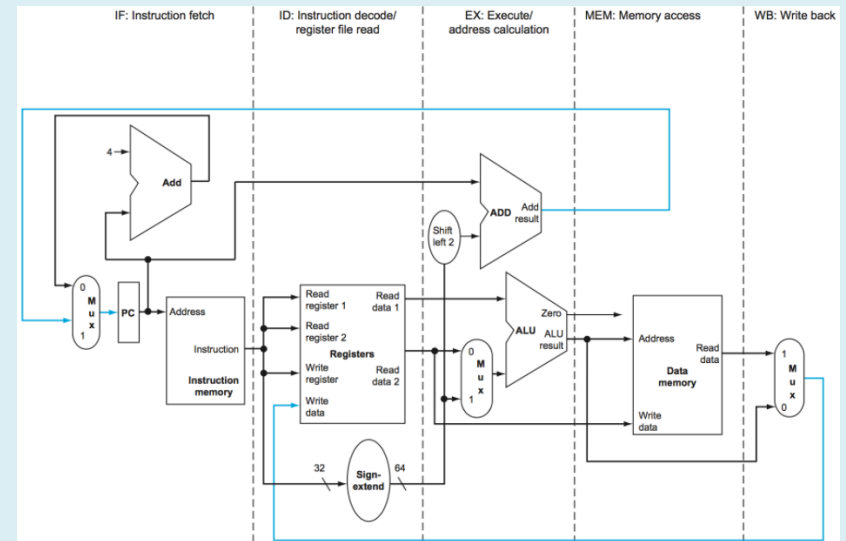
A logical organization of computer components
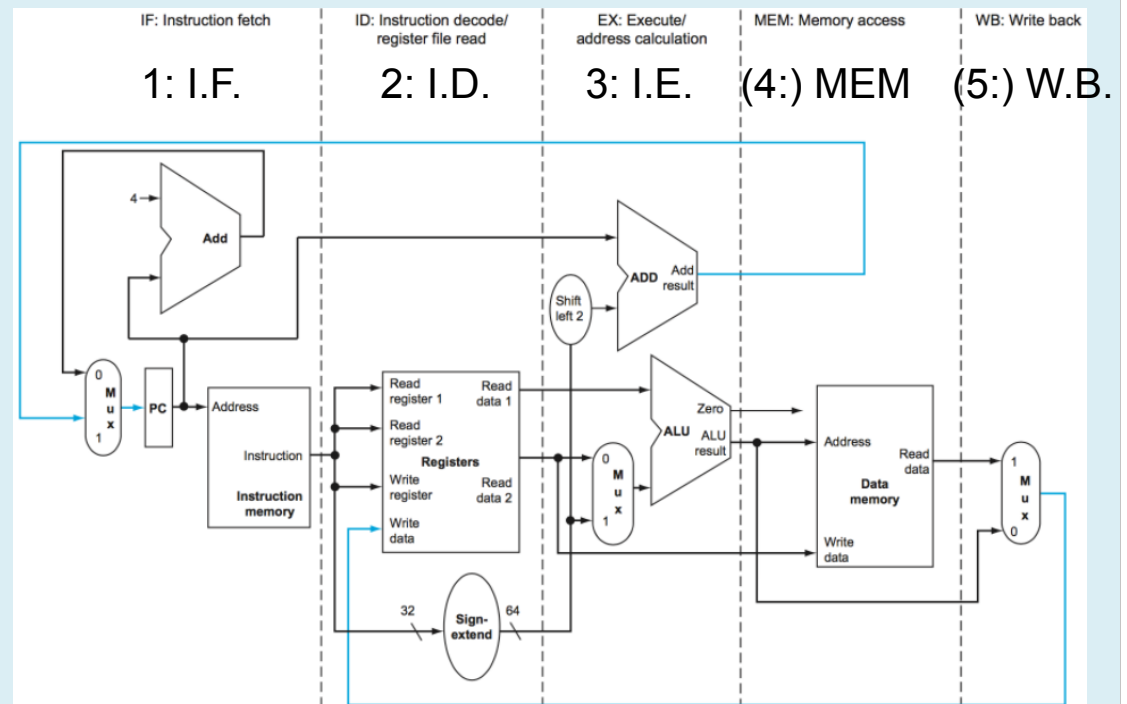
IF: Instruction fetch	ID: Instruction decode/ register file read	EX: Execute/ address calculation	MEM: Memory access	WB: Write back
1: I.F.	2: I.D.	3: I.E.	(4:) MEM	(5:) W.B.

Intro to Computer Architecture

Example → Practice

■ **Which** of the five **steps** are needed?

1) **[Mem-x] = [Mem-y] + [Mem-z]**
2) **[Reg-1] = [Reg-2] – [Reg-3]**
3) **[Reg-4] = [Mem-a] + 1**
4) **[Mem-b] = 7**
5) **Go to [Mem-c]**

1: I. F.
2. I. D.
3. I. E.
(4) MEM
(5) W.B.

Intro to Computer Architecture

Example → Practice

- **Which of the five steps are needed?**

  1) **[Mem-x] = [Mem-y] + [Mem-z]**
     x = y + z;
     (all steps are needed)

  2) **[Reg-1] = [Reg-2] – [Reg-3]**
     (1, 2, and 3 are needed)

  3) **[Reg-4] = [Mem-a] + 1**
     (5 not needed)

  4) **[Mem-b] = 7**

  5) **Go to [Mem-c]**
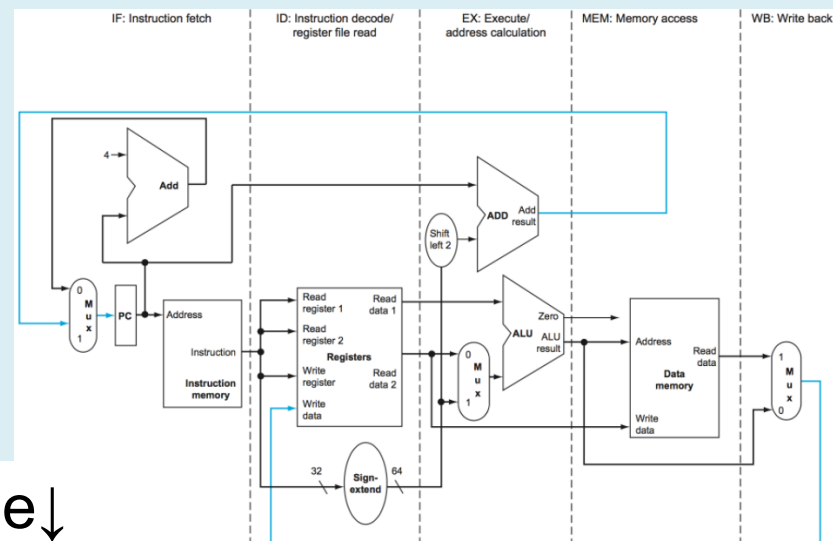
Time↓

t1   1: I.F.

t2   2: I.D.

t3   3: I.E.

t4   (4:) MEM

t5   (5:) W.B.

…

Introduction to Computer Architecture

Do you have any questions?

1:31 PM

Intro to Computer Architecture

Lecture 2

Reading: See Reading Assignments

Tests (HW, Quiz, Exam): HW-1 (Week 2), HW-2 (Week 3), Quiz-1 (Week 4), …

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- **Introduction to Computers (from zyBooks)**
  - ➢ **Eight great ideas in computer architecture**
  - ➢ **Technologies for building processors and memory**
  - ➢ **The switch from uniprocessor to multiprocessor**

Dr. Zaman; WSU-5261

Intro to Computer Architecture

- **ECE394 zyBooks Ch-1: Introduction to Computers**
  - ➢ **1.1 Introduction**
  - ➢ **1.2 Eight great ideas about computer architecture**
  - ➢ **1.3 Below your program**
  - ➢ **1.4 Under the covers**
  - ➢ **1.5 Technologies for processors and memory**
  - ➢ **1.6 Performance**
  - ➢ **1.7 The power wall**
  - ➢ **1.8 The switch from uniprocessor to multiprocessor**
  - ➢ **1.9 The Intel Core i7**

ECE 394
Introduction to Computer Architecture

Tentative Schedule

Week Tue	Note	Important topics/readings, assignments, due dates, and reminders are listed here so that you can organize your time and academic work.
1 08/20		ECE 394: Intro to Computer Architecture, Syllabus; K-probe; zyBook 1.1 (Intro to Computers); Homework, Quiz, and Exam;
2 08/27	HW-1	HW-1 Discussion; zyBook 1.2-1.5 (eight ideas, processors); HW-1 (due on Blackboard); zyBook 1.6 (performance);
3 09/03	HW-2	9/02 (Labor Day) No Class/Lab; HW-2 (Bb); zyBook 1.7-1.9 (... uni- and multiprocessors, Core i7);
4 09/10	Quiz-1	Quiz-1 Discussion; Handout: Multilevel Computers; Quiz-1 (class test, 30-min / 30-pts, closed book);
5 09/17	Exam-1	Exam-1 Discussion; Handout: Computer Generations; Exam-1 (class test, 65-min / 65-pts, closed book);
6 09/24	Update	zyBook: 3.1 (The Processor: Introduction); zyBook: 3.2-3.3 (The Processor: Datapath, Pipelining);
7 10/01	HW-3	zyBook 3.4-3.5 (Data hazards: Forwarding versus stalling); HW-3 (Bb); zyBook 3.6 (Data hazards and Control hazards);
8 10/08	Mid-Pt HW-4	zyBook 3.7 (Parallelism via instructions); HW-4 (Bb); zyBook 3.8 (Going faster: ILP and matrix multiply);
9 10/15	Fal-Brk Quiz-2	10/12 (Sat) to 10/15 (Tue) (Fall Break) No Class; Quiz-2 (class test, 30-min / 30-pts, closed book);
10 10/22	Exam-2	Exam-2 Discussion; zyBook 4.1 (Memory Hierarchy: Introduction); Exam-2 (class test, 65-min / 65-pts, closed book);
11 10/29	Update	zyBook 4.2-4.3 (Memory Hierarchy: Caches); zyBook 4.4-4.5 (Memory Hierarchy: Virtual memory);
12 11/05	HW-5	zyBook 5.1 (Parallel Processors: Introduction); HW-5 (Bb); zyBook 5.2 (Difficulty of Parallel Processing);
13 11/12	HW-6	zyBook 5.3 (SISD, MIMD, SIMD, SPMD, and vector); HW-6 (Bb); zyBook 5.4 (Hardware multithreading);
14 11/19	Quiz-3	zyBook 5.5-5.6 (Multicore processors, graphics processing units); Quiz-3 (class test, 30-min / 30-pts, closed book);
15 11/26	Thx-Brk	Future of Computers (selected materials); 11/27 (Wed) to 12/01 (Sun) (Thanksgiving Break) No Class;
16 12/03	Exam-3	Exam-3 Discussion; Exam-3 (class test, 65-min / 65-pts, closed book);
Finals		None!

Note: A date in Column 1 indicates the Tuesday of that week. Here, 12/03 is Tuesday of Week 16.