Computer Architecture I

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L'Université canadienne
Canada's university

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Topics of discussion

- **<u>Computer Engineering</u>**
- Course Organization
- Brief History of Computers

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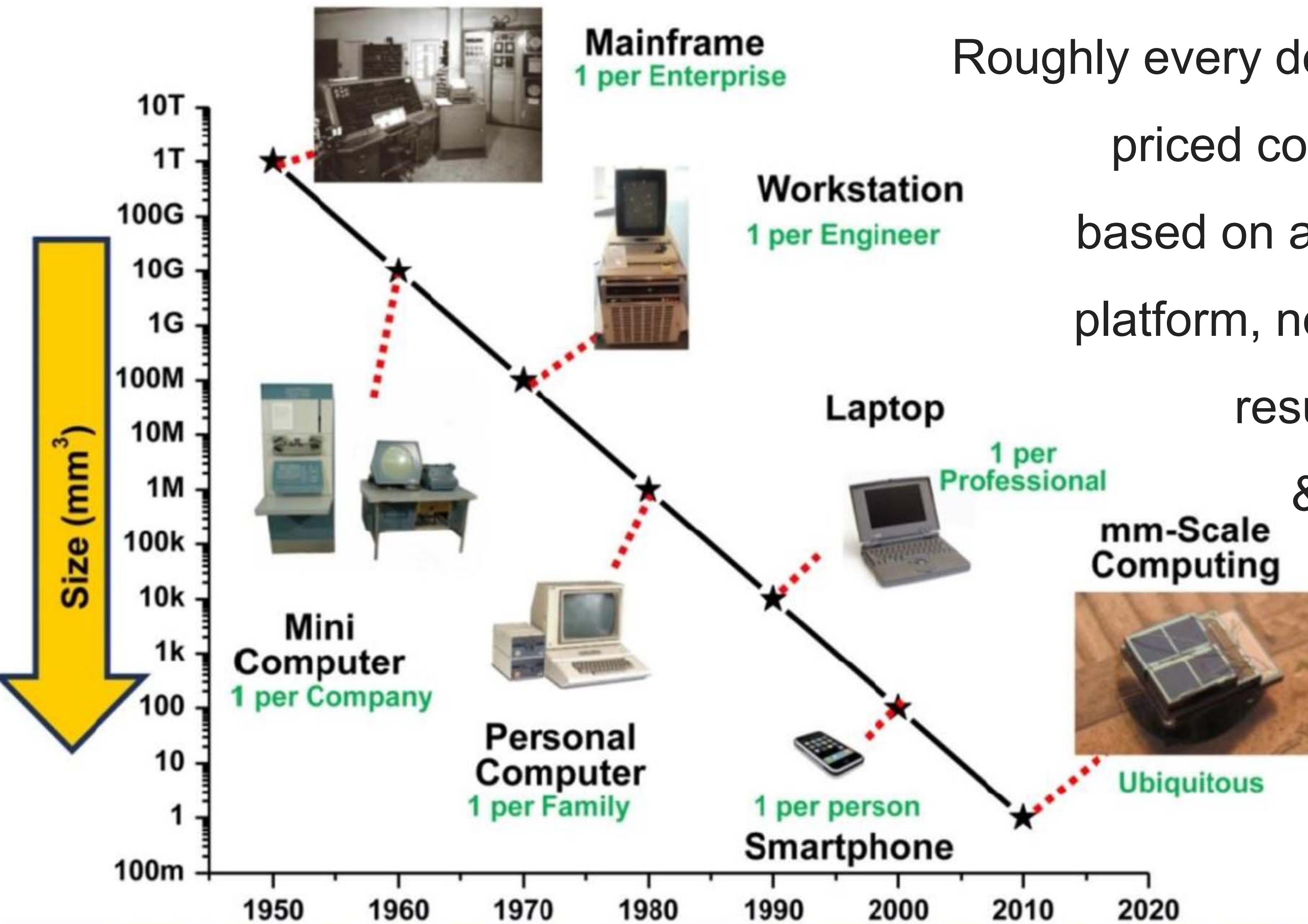
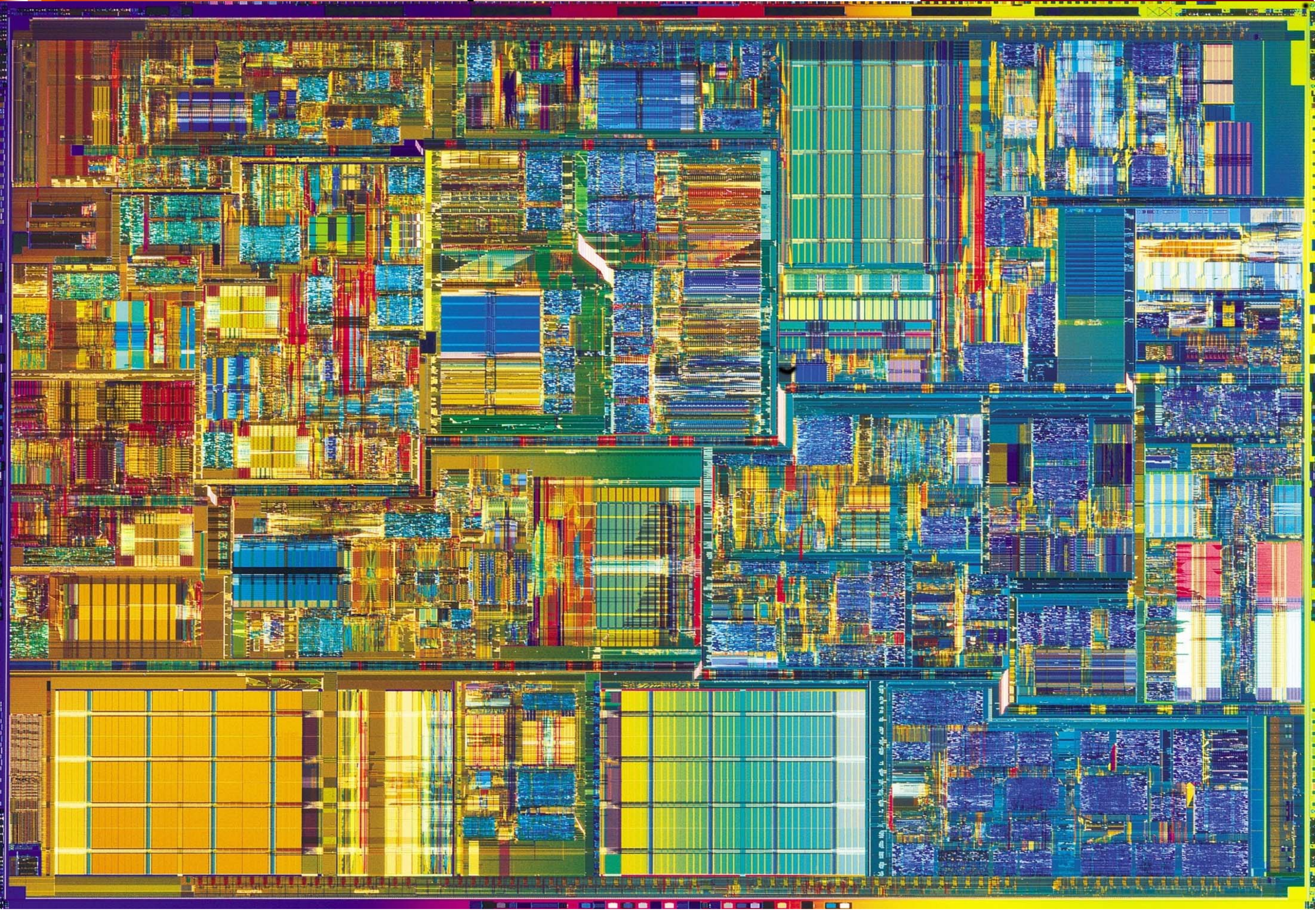
Bell's law of computer classes



Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, & interface, resulting in new usage & the establishment of a new industry.

After "Rebooting the IT Revolution," 2015 (figure courtesy of D. Sylvester)

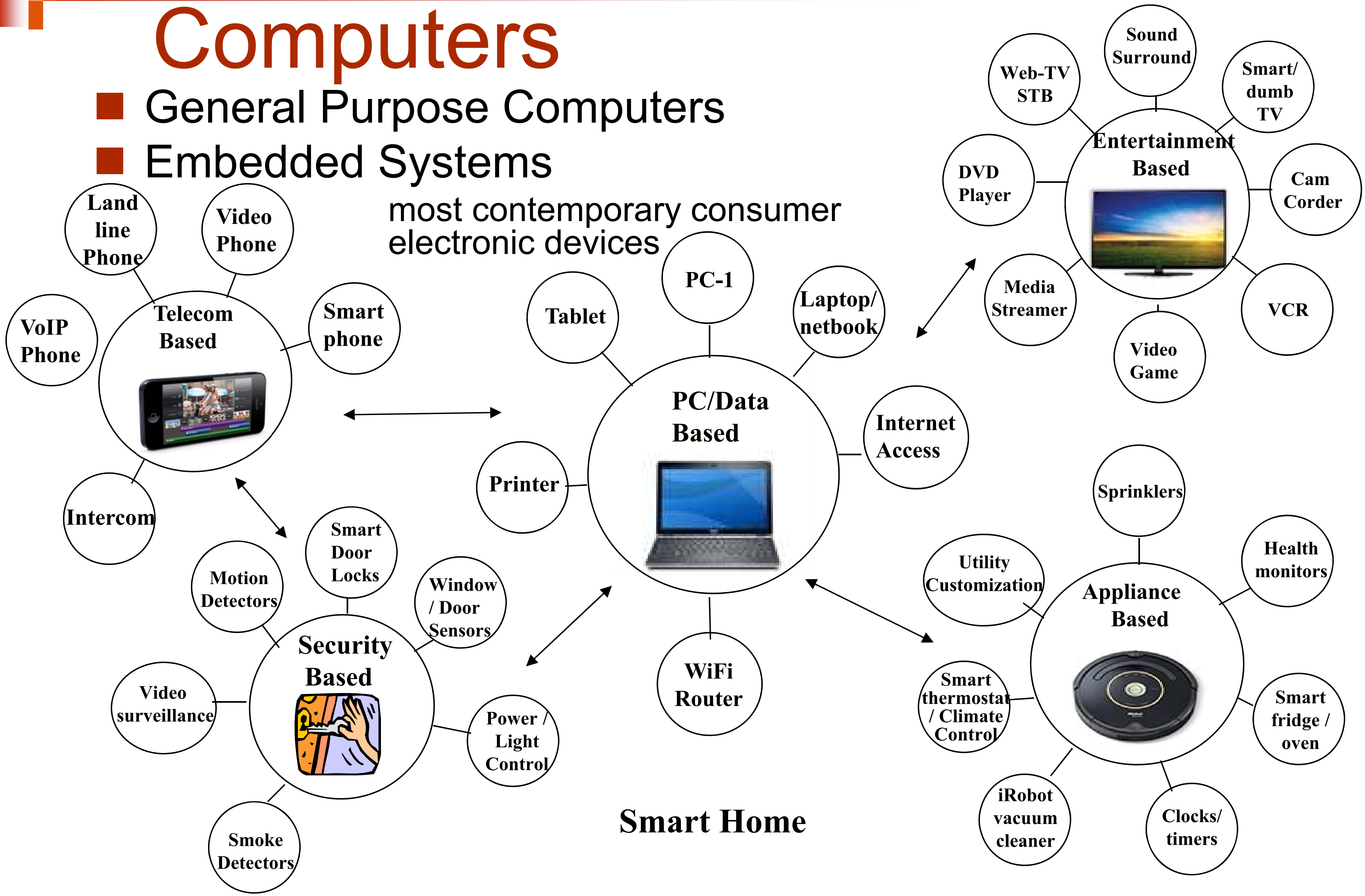
Microprocessor



Computers

- General Purpose Computers
- Embedded Systems

most contemporary consumer electronic devices



*Updated after **Alberto Sangiovanni-Vincentelli**, University of California at Berkeley*

What do Computer Engineers do?

- Few Computer Engineers make a living designing computers from basic components.
- Even fewer Computer Engineers are involved in designing the integrated circuits that form the building blocks of computers.
- The majority of Computer Engineers configure and / or program existing **computer subsystems** in order to build more efficient products.
- Computer Engineers are expected to provide computer expertise (both software and hardware) to customers, to other engineers, and to organizations.

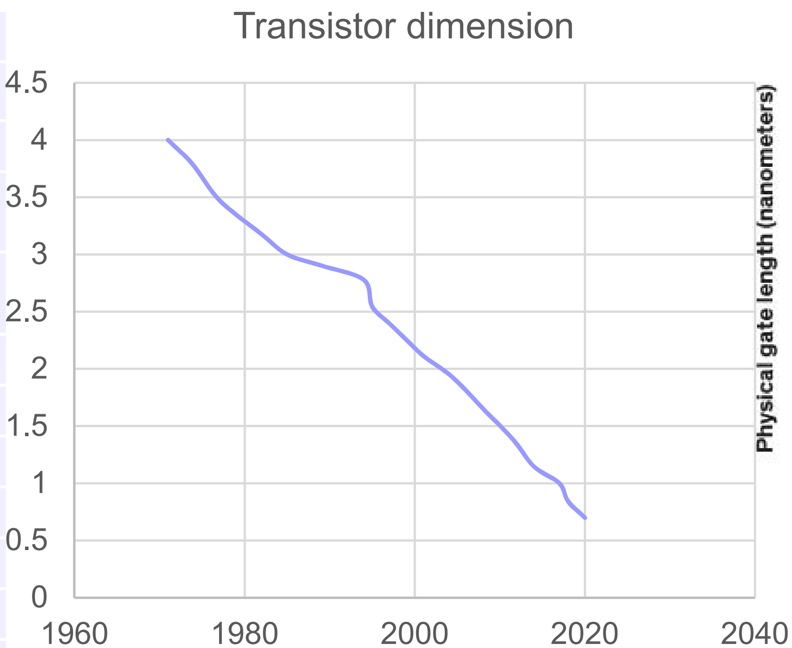
After Dr. Bruce F. Cockburn, Director of Computer Engineering, University of Alberta

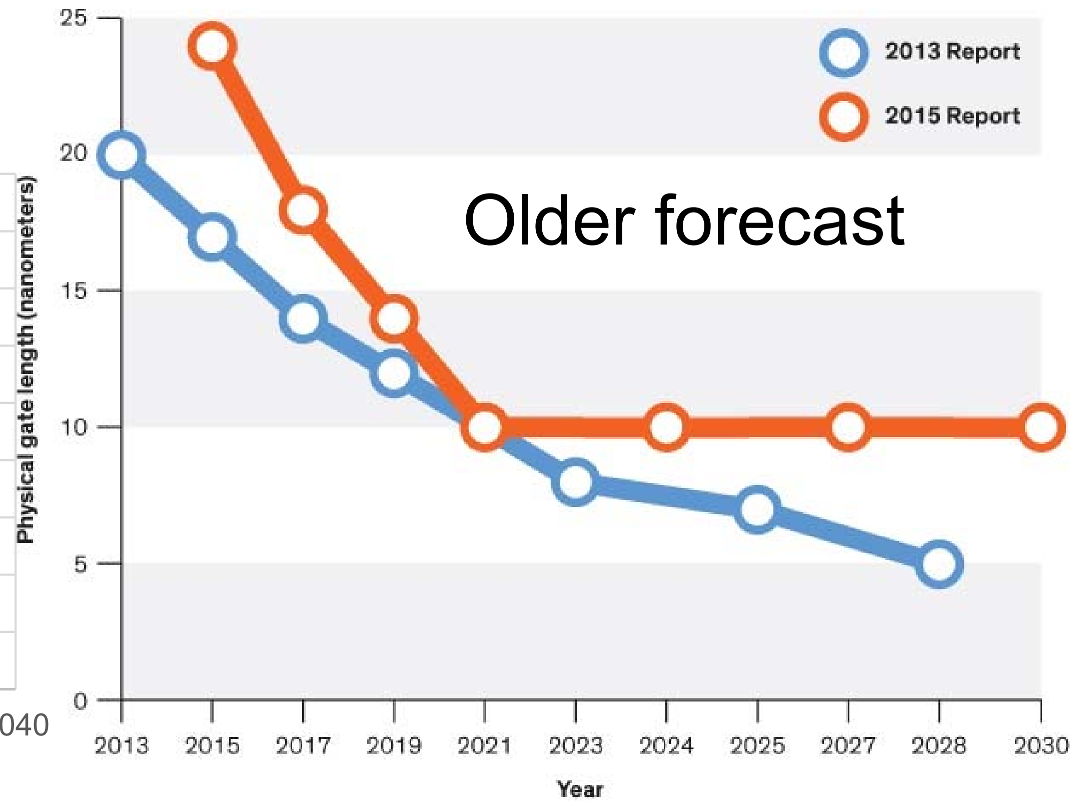
Intro to CEG2x36 …

- In this course HW&SW get together at the lowest level
- What will you learn in this course ?
  - How digital systems work
  - How digital systems are designed to execute SW programs
  - You will design many yourselves!
- Computer engineering is a very dynamic field
  - Chips double in speed every 18 months (Moore's Law), due to
    - Decreasing transistor sizes
    - Increasingly efficient computer architectures
- Performance / Power tradeoff
  - Performance = (frequency * IPS) / # of instructions
  - $\text{Power}_{\text{MOS}} = 0.5 * \text{capacitance} * \text{voltage}^2 * \text{frequency}$

Transistor Size

- 10 µm – 1971
- 6 µm – 1974
- 3 µm – 1977
- 1.5 µm – 1982
- 1 µm – 1985
- 800 nm – 1989
- 600 nm – 1994
- 350 nm – 1995
- 250 nm – 1997
- 180 nm – 1999
- 130 nm – 2001
- 90 nm – 2004
- 65 nm – 2006
- 45 nm – 2008
- 32 nm – 2010
- 22 nm – 2012
- 14 nm – 2014
- 10 nm – 2017
- 7 nm – 2018
- 5 nm – 2019
- 3 nm - 2021





SIA (Semiconductor Industry Association) Roadmap

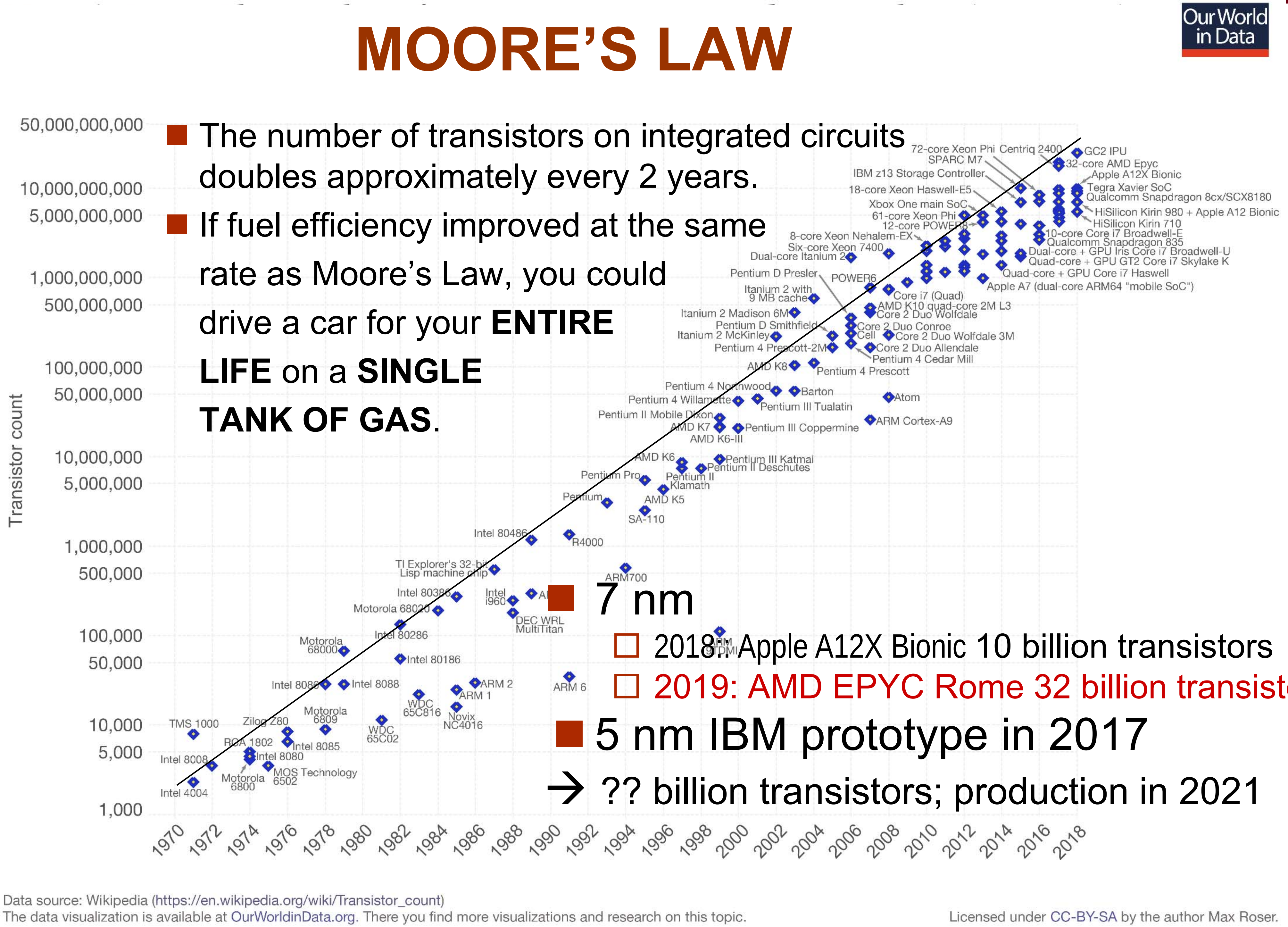
Years:	1999	2001	2003	2006	2008	2012	2014	2017	2018	2019	2021
Gate length (nm)	180	130	90	65	45	22	14	10	7	5	3
Transistors per cm^2 (millions)	14	16	24	40	64			100	126	173	300
Chip size (mm^2)	800	850	900	1000	1100	1300					

MOORE'S LAW

- The number of transistors on integrated circuits doubles approximately every 2 years.
- If fuel efficiency improved at the same rate as Moore's Law, you could drive a car for your **ENTIRE LIFE** on a **SINGLE TANK OF GAS**.

- 7 nm
  - 2018: Apple A12X Bionic 10 billion transistors
  - 2019: AMD EPYC Rome 32 billion transistors
- 5 nm IBM prototype in 2017

→ ?? billion transistors; production in 2021



MOORE'S LAW: transistors / microprocessor

Date	Processor	Designer	Proc	Area	Transist count
1971	Intel 4004	Intel	10 μm	12 mm^2	2,300
1972	Intel 8008	Intel	10 μm	14 mm^2	3,500
1973	NEC μCOM-4	NEC	7.5 μm	?	2,500
1973	Toshiba TLCS12	Toshiba	6 μm	32 mm^2	2,500
1974	Motorola 6800	Motorola	6 μm	16 mm^2	4,100
1974	Intel 8080	Intel	6 μm	20 mm^2	4,500
1976	Intel 8085	Intel	3 μm	20 mm^2	6,500
1976	Zilog Z80	Zilog	4 μm	18 mm^2	8,500
1978	Motorola 6809	Motorola	5 μm	21 mm^2	9,000
1978	Intel 8086	Intel	3 μm	33 mm^2	29,000
1979	Zilog Z8000	Zilog	μm		17,500
1979	Intel 8088	Intel	3 μm	33 mm^2	29,000
1979	Motorola 68000	Motorola	3.5 μm	44 mm^2	68,000
1981	WDC 65C02	WDC	3 μm	6 mm^2	11,500
1982	Intel 80186	Intel	3 μm	60 mm^2	55,000
1982	Intel 80286	Intel	1.5 μm	49 mm^2	134,000
1984	Motorola 68020	Motorola	2 μm	85 mm^2	190,000
1985	Intel 80386	Intel	1.5 μm	104 mm^2	275,000
1986	NEC V60[26]	NEC	1.5 μm		375,000
1987	Motorola 68030	Motorola	0.8 μm	102 mm^2	273,000
1987	TI Lisp machine	TI	2 μm		553,000
1987	Hitachi Gmicro	Hitachi	1 μm		730,000
1988	Intel i960	Intel	1.5 μm		250,000
1989	Intel i860	Intel	μm		1,000,000
1989	Intel 80486	Intel	1 μm	173 mm^2	1,180,235
1990	68040	Motorola	0.65 μm	152 mm^2	1,200,000
1991	R4000	MIPS	1 μm	213 mm^2	1,350,000

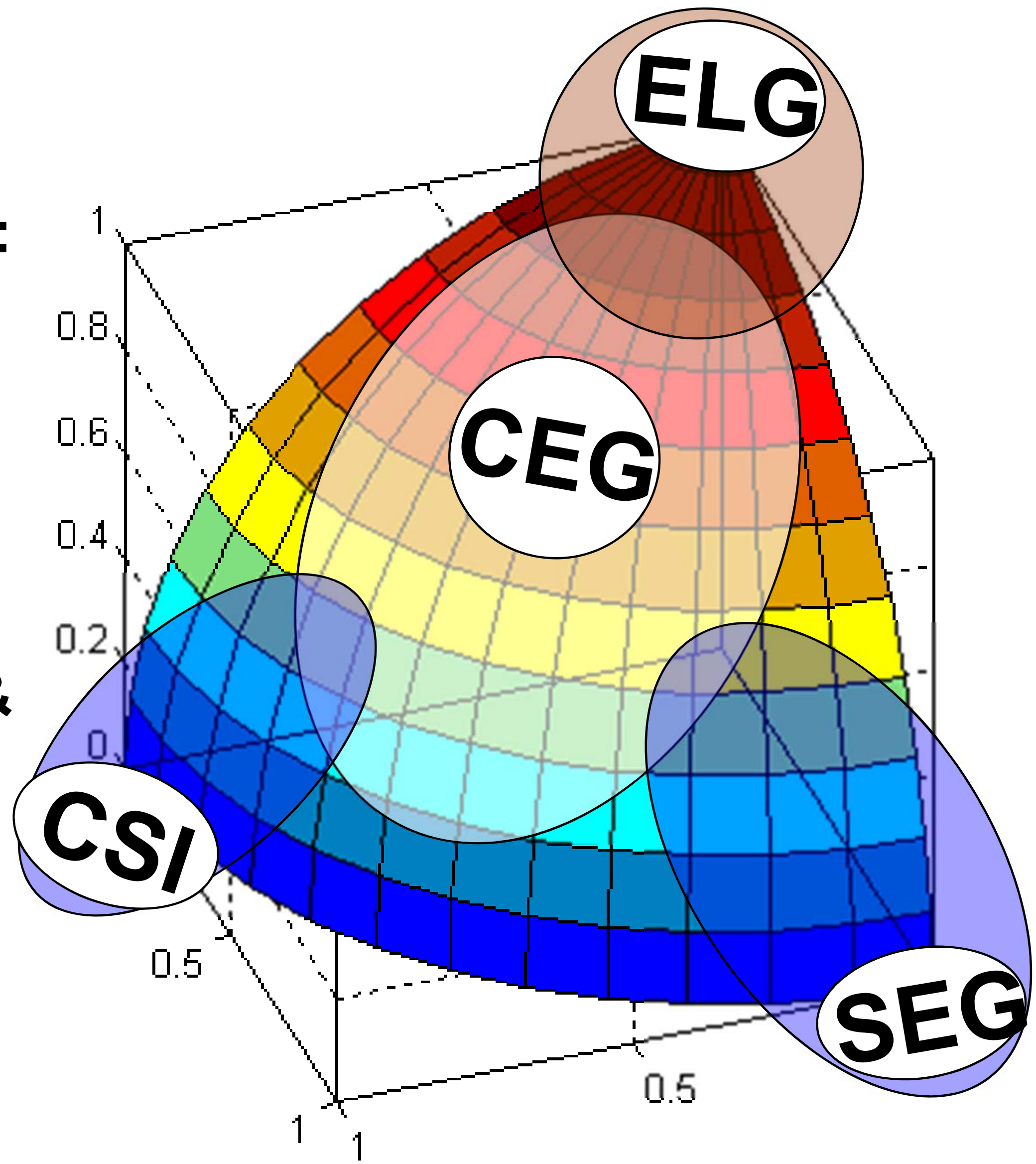
Date	Processor	Designer	Proc	Area	Transistor count
1993	Hitachi HARP-1	Hitachi	0.5 μm	267 mm^2	2,800,000
1993	Pentium	Intel	0.8 μm	294 mm^2	3,100,000
1994	68060	Motorola	0.6 μm	218 mm^2	2,500,000
1995	Pentium Pro	Intel	0.5 μm	307 mm^2	5,500,000
1996	AMD K5	AMD	0.5 μm	251 mm^2	4,300,000
1997	Pentium II	Intel	0.35 μm	195 mm^2	7,500,000
1997	AMD K6	AMD	0.35 μm	162 mm^2	8,800,000
1997	Hitachi SH-4	Hitachi	0.2 μm	42 mm^2	10,000,000
1999	AMD K7	AMD	0.25 μm	184 mm^2	22,000,000
1999	Pentium II Mobile	Intel	0.18 μm	180 mm^2	27,400,000
2000	Pentium 4	Intel	0.18 μm	217 mm^2	42,000,000
2001	SPARC64 V	Fujitsu	0.13 μm	290 mm^2	191,000,000
2002	Itanium 2 McKinley	Intel	0.18 μm	421 mm^2	220,000,000
2003	Itanium 2 Madison	Intel	0.13 μm	374 mm^2	410,000,000
2004	Itanium 2	Intel	0.13 μm	432 mm^2	592,000,000
2006	Dual-core Itanium	Intel	90 nm	596 mm^2	1,700,000,000
2008	6 core Xeon 7400	Intel	45 nm	503 mm^2	1,900,000,000
2010	8-core Xeon	Intel	45 nm	684 mm^2	2,300,000,000
2011	10-core Xeon	Intel	32 nm	512 mm^2	2,600,000,000
2012	61-core Xeon Phi	Intel	22 nm	720 mm^2	5,000,000,000
2013	Xbox One SoC	AMD	28 nm	363 mm^2	5,000,000,000
2014	18-core Xeon	Intel	22 nm	661 mm^2	5,560,000,000
2015	32-core SPARC M7	Oracle	20 nm		10,000,000,000
2016	72-core Xeon Phi	Intel	14 nm	683 mm^2	8,000,000,000
2017	32-core AMDEpyc	AMD	14 nm	768 mm^2	19,200,000,000
2018	Apple A12X Bionic	Apple	7 nm	122 mm^2	10,000,000,000
2018	GC2 IPU	Graphcore	16 nm	825 mm^2	23,600,000,000
2019	AMD EPYC Rome	AMD	7 nm		32,000,000,000

Study programs at School of EEICS

Computer Engineering

requires mastery of both:

- ***hardware* (overlapping with Electrical Eng.)**
- ***software* (overlapping with Computer Science & Software Engineering)**



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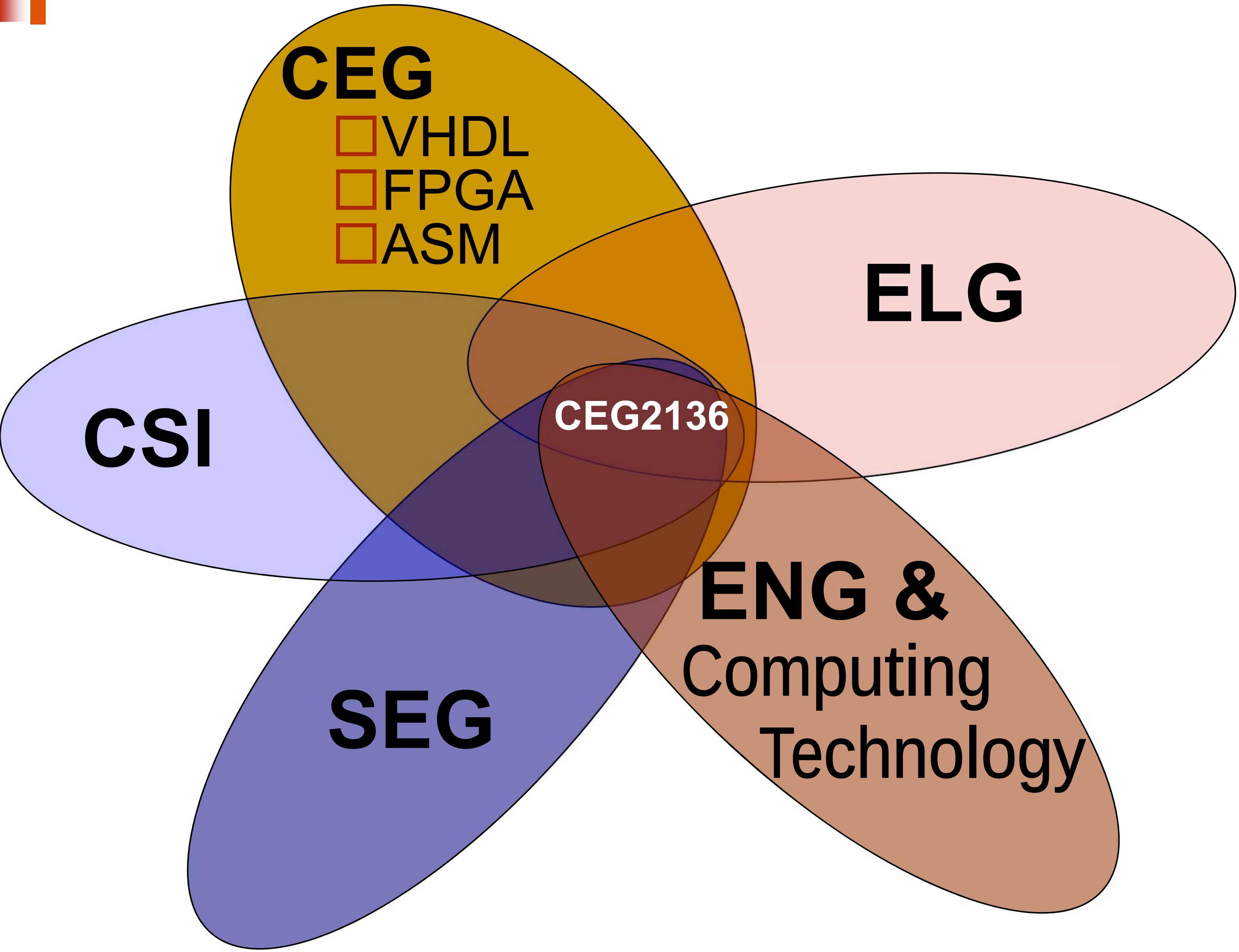

CEG
VHDL
FPGA
ASM
ELG
CSI
CEG2136
ENG &
Computing
Technology
SEG

HARDWARE

ITI1100 Digital Systems I
Combinational & Sequential Logic Circuits

CEG2136 Computer Architecture I
ALU, CPU, Memory, computer organization

CEG3136 Computer Architecture II
Microprocessors, I/O, Embedded

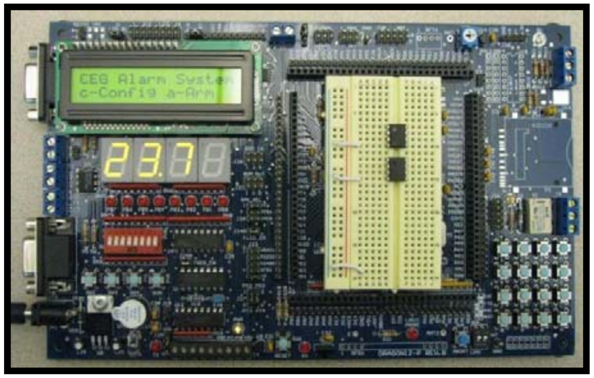
CEG3155 Digital Systems II
FSM, ASM, VHDL, PLD, FPGA

CEG3156 Computer Systems Design

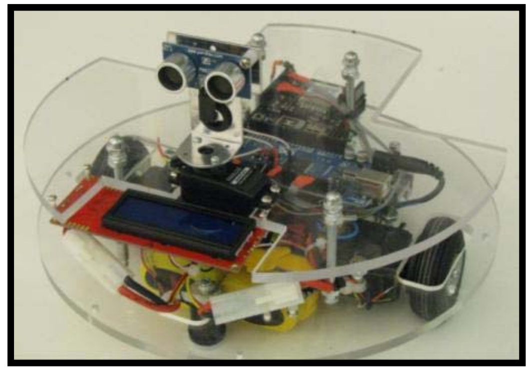
CEG4136 Computer Architecture III
Multiprocessor Systems

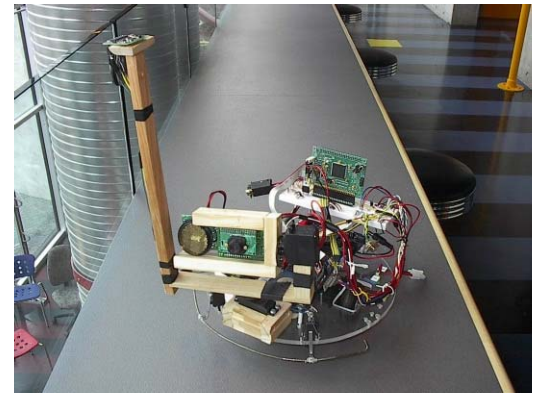
CEG4912 Computer Engineering Design Project I
CEG4913 Computer Engineering Design Project II

Computer Engineering Design



CEG3136 – Computer Architecture II



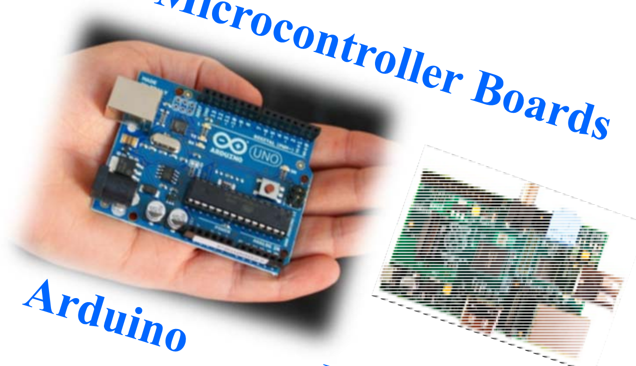


CEG4912/CEG4913 – Capstone Design Project

Unmanned Airplane (UAV)

Wind Turbine

Microcontroller Boards

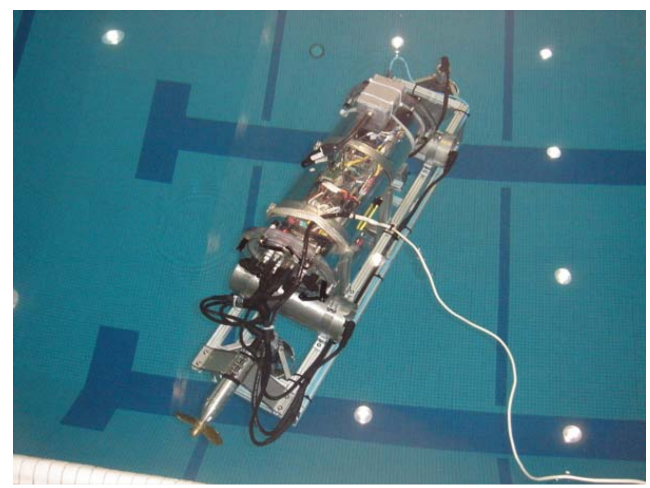


Arduino

Raspberry Pi

www.GreenEngineers.ca

Autonomous Underwater Vehicle



Topics of discussion

- Computer Engineering
- **Course Organization**
- Brief History of Computers

Course Syllabus and More @ Virtual Campus

- Provides:
  - Information on Instructor and TAs
  - Lecture, tutorial, lab schedules
  - Course Description and prerequisites
  - Course Objectives
  - Text book
  - Grading
  - Information on labs
  - Course Outline

Course Organization

- Course offered over 12 weeks.
  - Last lectures before midterm and final exams will be used for review and preparation.
  - Module notes will be available on the Virtual Campus.
- Timetable: https://uocampus.public.uottawa.ca/psp/csprpr9pub/EMPLOYEE/HRMS/c/UO_SR_AA_MODS.UO_PUB_CLSSRCH.GBL?languageCd=ENG

- **Description**
  - Design a digital computer to execute a given instruction set. Design of digital computers. Register transfer and micro-operations. Designing the instruction set, CPU and CPU control. Basic machine language programming. Using pipelines for CPU design. Designing the memory unit. Designing Input-Output subsystem.
- **Objectives** By the end of the course, students:
  - Will understand the computer elements and the fundamentals of computer organization, and will get knowledge on the principles of computer architecture.
  - Have gained experience with basic design at various levels, from instruction set architecture (ISA) to datapath and control logic; small projects will be developed by using modern CAD environments and will be practically implemented on PLDs or FPGAs.
  - Developing programs in machine language that run on their own designed/built computers, students will sense and understand the interface between the software and computer hardware.
- **Prerequisite**: ITI 1100 (Digital Systems I)
- **Text: M. Morris Mano, "Computer System Architecture"**, 3rd edition, Prentice Hall, 1993.

- **Lab Work**:
  - 4 labs have been organized.
  - You will be working in groups of 2 students.
  - The same group will work together throughout the semester.
  - A lab report is expected from each group.
  - The report should be prepared according to the guidelines found in the lab manual.
- **The mid-term exam will take place in the second lecture after the study break;** it is a closed book exam and covers material presented in the weeks prior to the mid-term**.**
- **The final exam** is also closed book and will cover all material studied during the term.
- Grading:

Quizzes	10%
Lab work	20%
Midterm Examination	25%
Final Examination	45%

Course Outline

1. Digital Logic Circuits. (Chapter 1)
2. Digital Components. (Chapter 2)
3. Data Representation. (Chapter 3)
4. Register Transfer and Micro-operations. (Chapter 4)
5. Basic Computer Organization and Design (Chapter 5
6. Programming the Basic Computer. (Chapter 6)
7. Microprogrammed Control. (Chapter 7)
8. Central Progressing Unit (CPU). (Chapter 8)

Course on Virtual Campus

- You will have access to:
  - Announcement page;
  - Course syllabus;
  - All course material;
  - Labs instructions;
  - Assignments tool that allows you to submit lab reports electronically;
  - Grading

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Topics of discussion

- Computer Engineering
- Course Organization
- **Brief History of Computers**
  - http://www.computerhistory.org/timeline/
  - http://www.computerhistory.org/

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Logic Algebra

- **George Boole** (1815 – 1864)

  The genius inventor of the *Boolean Logic* was born in the wrong time!?

1847: “The Mathematical Analysis of Logic“

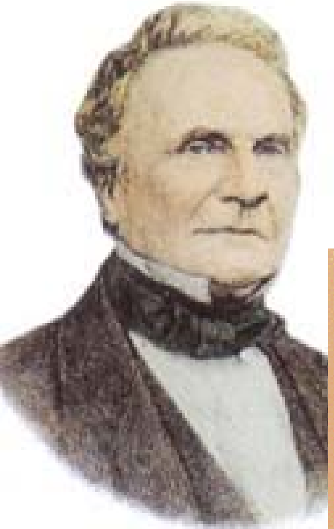
Claude Shannon (1916-2001)

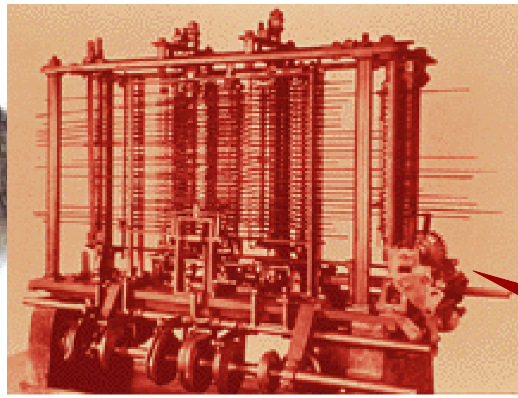
Circuits with relays solve Boolean algebra problems

1937: EE master's thesis at the Massachusetts Institute of Technology

1938: “A Symbolic Analysis of Relay and Switching Circuits,” <u>IEEE Transactions</u>

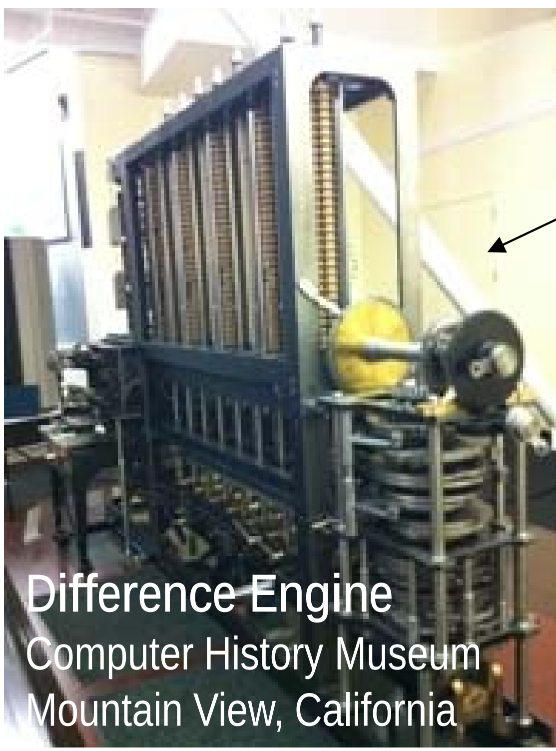
Charles Babbage (1791-1871)





- British mathematician: designs the first fully automatic calculating device, the Difference Engine (1822)
- 1837: First programmable calculator: steam-powered mechanical Analytical Engine, conceived but he never actually completed because of funding problems.

The design included a CPU ("mill", capable of conditional branching) and memory ("store", holding up to 1000 50-digit numbers), and could read programs from punched cards.



Difference Engine
Computer History Museum
Mountain View, California

- First programmers: Charles Babbage and Ada (daughter of Lord Byron).

Herman Hollerith

- 1879 - engineering graduate of the Columbia University School of Mines
- 1882: mechanical engineering professor at Massachusetts Institute of Technology (MIT)
- 1890: used punched cards (Joseph Marie Charles *dit* Jacquard) for processing US census data
- 1896: founded the Tabulating Machine Company, forerunner of Computer Tabulating Recording Company (CTR), which through mergers and acquisitions grew into the International Business Machines (IBM) Company.

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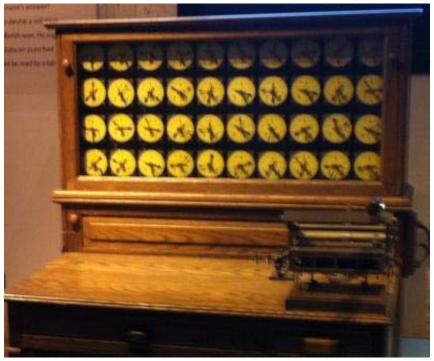
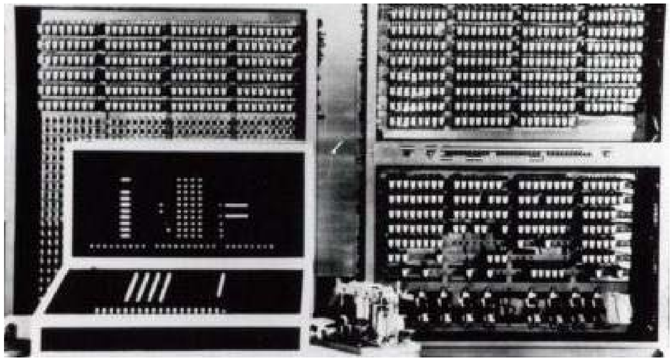
First Computers…



Alan Turing,1912-1954

- 1936: Turing Machine in "On Computable Numbers," Proc. of London Mathematical Society,
- 1941: the "Bombe"= electro-mechanical device to decipher German Enigma-machine - encrypted signals (WW II)



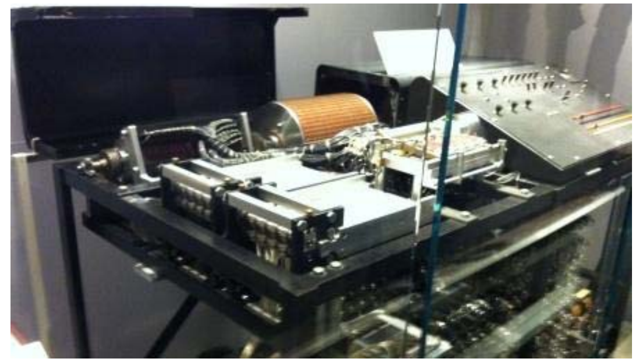
Konrad Zuse (1910–1995)

Z1 (1936)

- the first binary (electro-mechanical) programmable calculator / punched tape
- built in Zuse's parents' house

Z3 (1941)

- the first working **programmable**, binary, fully automatic **computer** (**relays**).
- It was Turing-complete!
- statistical analyses of wing flutter.



John V. Atanasoff (1903-1995) and his MSc student Clifford Berry (1918-1963) @ Iowa State University

Atanasoff-Berry Computer (ABC) the first electronic digital computing device (but dedicated, **not programmable**) with DRAM!

- 1939: proof-of-concept prototype,
- 1942: the ABC is completed

http://jva.cs.iastate.edu/reconstructionoperation.php

The COMPUTER as a concept was declared un-patentable and thus was freely open to all.

1973: Atanasoff vs Mauchly (i.e., Honeywell Company vs Sperry Rand Corporation)

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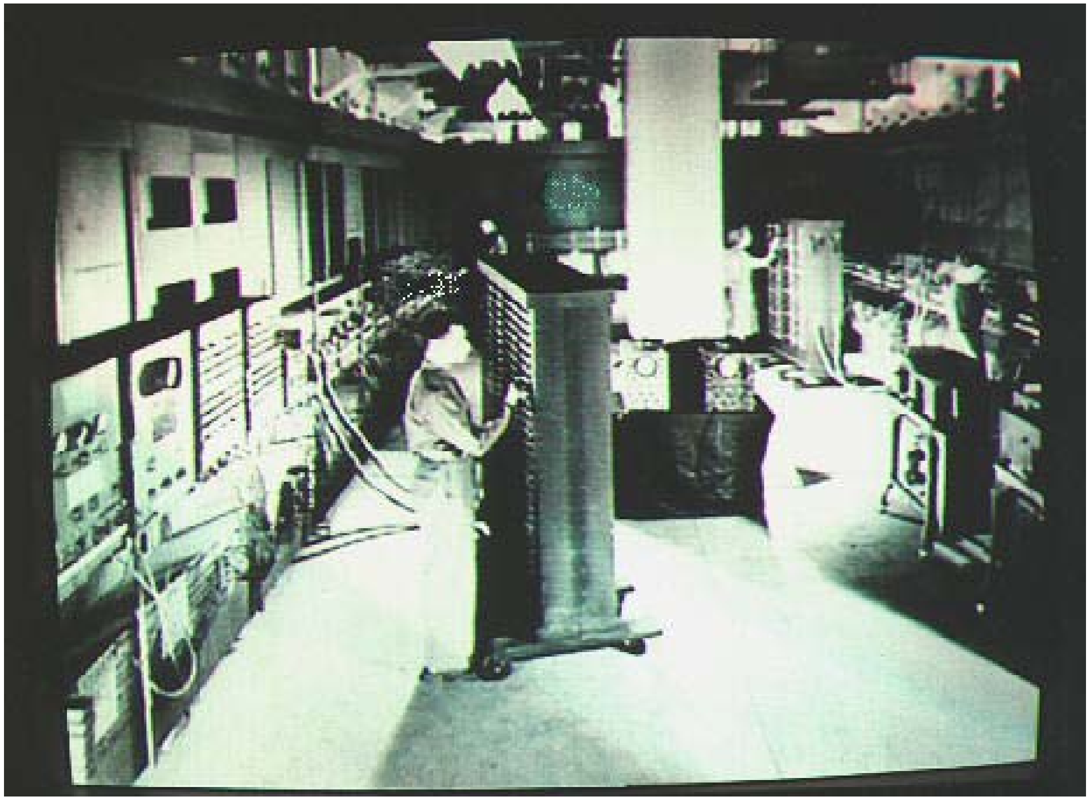
ENIAC

Electrical **N**umerical **I**ntegrator **A**nd **C**alculator



John Mauchly & Presper Eckert
1946: University of Pennsylvania
the first **general purpose electronic computer** (base 10), to calculate artillery firing tables for the US Army.

- Programmed by manipulating switches and cables
- Weighed 30 tons & used up an entire floor =167 m^2
- Dimmed the lights of the East side of Philadelphia
- 18,000 **vacuum tubes** - several tubes burned out almost every day

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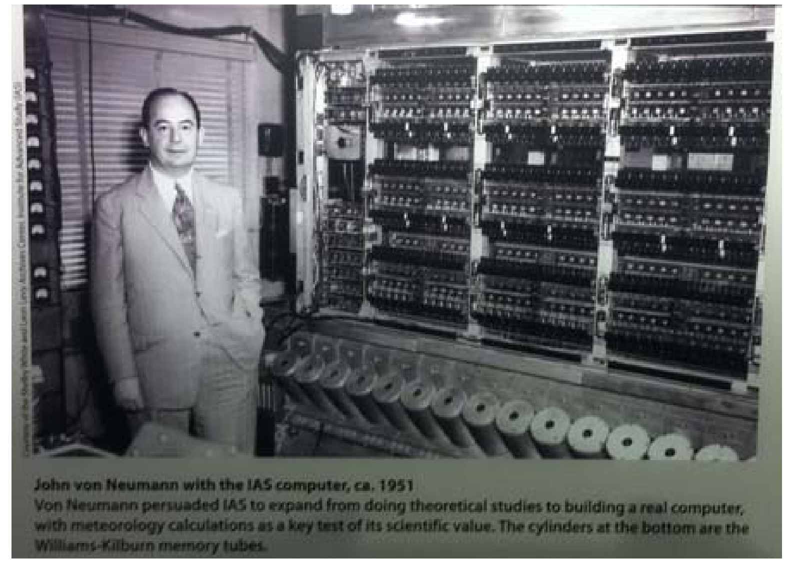
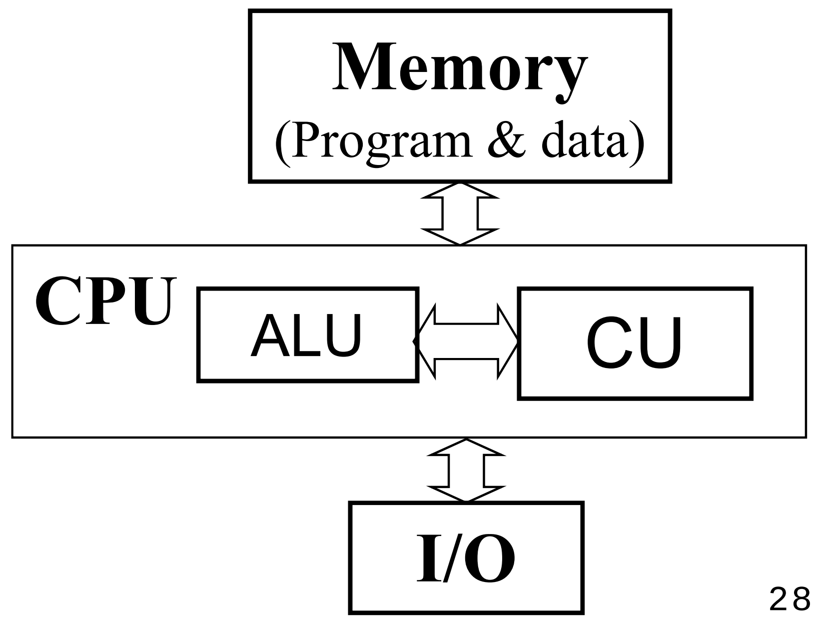
Von Neumann Architecture

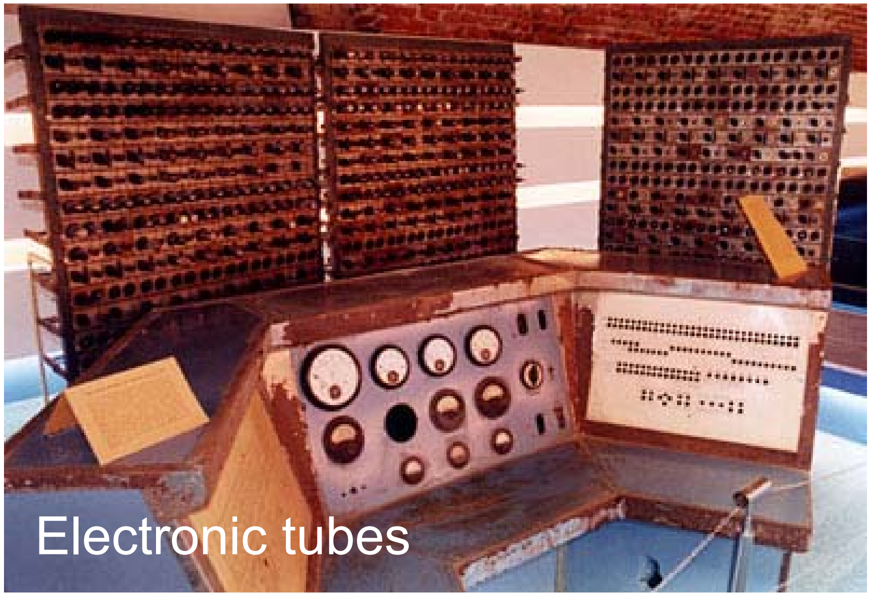
- 1945 - "First Draft of a Report on the **EDVAC**"
  conceived by John Mauchly & Presper Eckert
  - stored-program computer; base 2
- 1946 - Summer school at the University of Pennsylvania
- **Computer system =**
  - **CPU** - Central Processing Unit
    - **Arithmetic and Logic Unit**
      (**ALU** + registers = DATA PATH)
    - **CONTROL UNIT** (CU)
  - **Input / Output Unit** (**I/O**)
    - Input Unit = Keyboards, mice
    - Output Unit = printers, graphic displays
  - **Memory** (**M**)
    - Primary (cache, RAM, HDD)
    - Secondary (CD-ROM, SD)





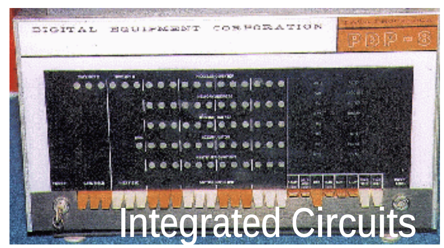
A Brief History of Computers

First Generation Electronic Computer



Second Generation (1956-1963) Electronic Computer

Third Generation (1964-1971)
IBM System/360



Third Generation
1965: **DEC PDP8**
the first minicomputer

Fourth Generation
1971: 1st microprocessor (Intel 4004)
1st DRAM (Intel 1103)

IBM Personal Computer
1981: XT / Intel 8088
1986: AT / Intel 80286

Fifth Generation : Artificial Intelligence (still under construction)

Home Computers

- family TV set
- BASIC interpreter + line editor
- K7 = external memory

1977:
Apple II by Steve Wozniak
- 1977 – 1993
- microprocessor 6510 MOS Technology

1982: Commodore 64
- Jack Tramiel founded *CBM* in Toronto
- microprocessor 6510 /MOS Technology
- 22 million C64s over 1982 – 1994 - the best selling computer of all times

1982: Sinclair (UK) ZX Spectrum
- microprocessor Z80 / Zilog
- 5 million units worldwide (not counting clones, which were numerous)
- Over 20,000 SW titles have been released since its launch in 1982

Hardware back in fashion!

- New York Times: “HW is becoming the new SW”
- **Raspberry Pi** (UK) - dimension of a credit card

  - single-board computer (SBC) to stimulating the teaching of basic computer science in schools
  - Modernized version of the ‘80’s ZX Spectrum or Commodor 64
    - Broadcom BCM2835 **SoC**, which includes
    - ARM processor ■ VideoCore GPU ■ 256 MB RAM
    - Linux / SD card ■ HDMI 1080p ■ USB ■ Ethernet
- **Arduino** (Italy) open source computer HW and SW company

- **Pebble**: E-Paper Watch for iPhone & Android

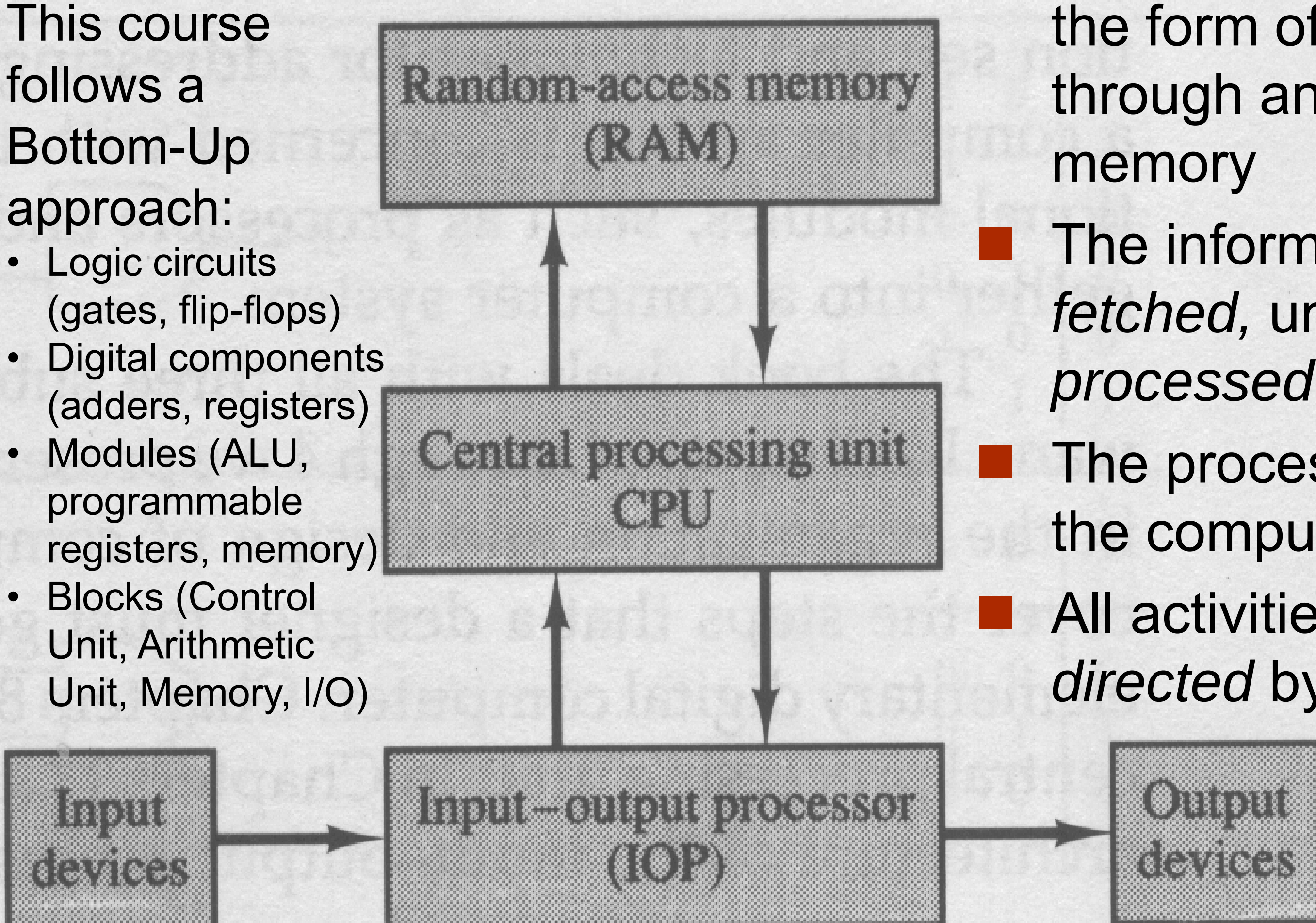
  - 2012: pledged of $100,000 goal at **Kickstarter**
  => 68,929 backers -> $10,266,846 in 1 month
  - Dec 2016: filed for insolvency
- **Smartphones**

Basic Operation of a Computer

- Computer Architecture (≈ digital computer organization) is concerned with the structure and operation of computers.
- Program: A program is a sequence of computer instructions.

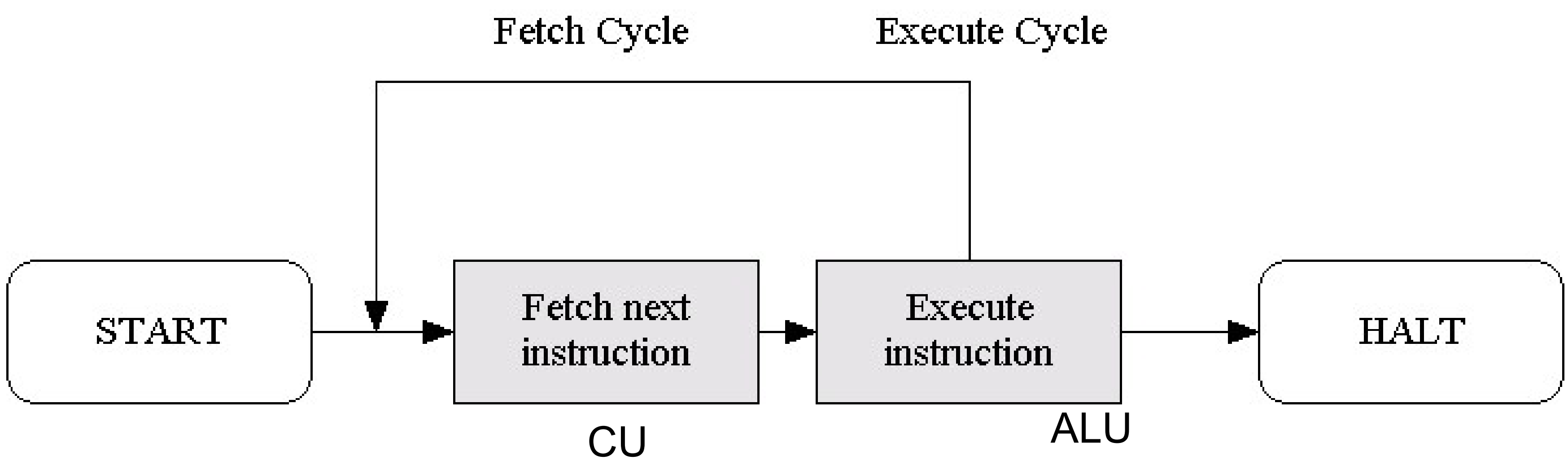
This course follows a Bottom-Up approach:

- Logic circuits (gates, flip-flops)
- Digital components (adders, registers)
- Modules (ALU, programmable registers, memory)
- Blocks (Control Unit, Arithmetic Unit, Memory, I/O)



- The computer *accepts* information in the form of programs and data through an input unit and *stores* it in memory
- The information stored in memory is *fetched,* under program control, and *processed* in an ALU
- The processed information *leaves* the computer through an output unit
- All activities inside the computer are *directed* by the control unit

Basic Instruction Cycle



- Computer performs the instruction cycle forever! (or at least until it is turned off, faces an error or is instructed to do stop)