ARCHITECTURE BASICS

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CATEGORIES OF COMPUTERS

- Servers
  - back-office machines
  - drive internet traffic and database access
  - low visibility
  - targeted marketing to IT professionals
  - market variation: Wintel, Apple, Linux, Unix
  - smallest category of the computer industry
    - 3 million shipped in 2018 (statista.com)

CATEGORIES OF COMPUTERS

- Personal Computers
  - general purpose computers
  - most familiar category to general public
  - highly visible marketing campaigns
  - consumers buy these as “computers”
  - market dominated by Wintel and Apple
  - middle category of the computer industry
    - 400 million tablets, laptops, PCs shipped in 2018 (statista.com)
    - 1.6 billion smart phones shipped in 2018

CATEGORIES OF COMPUTERS

- Embedded Computer Systems
  - special-purpose computer-controlled systems
  - largest category of the computer industry
  - very low visibility to average member of the public
  - computers around people without recognition
  - largest section of the computer industry
    - tens of billions shipped in 2018
      (icinsights.com, Research Bulletin, MCU sales)

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CATEGORY REQUIREMENTS

- Personal computers:
  - rich multi-media interaction
  - easy-to-use input and output devices
- Servers:
  - high-speed database access
  - high-speed networking
  - multi-user processing
- Embedded systems
  - Small footprint
  - Low power
  - Low cost

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DESIGN OPTIMIZATION

- Different requirements lead to different choices
- Engineering design optimizes:
  - speed
  - size
  - power
  - cost
- Computer architecture is design and thus a large part of architecture is optimizing based on requirements.

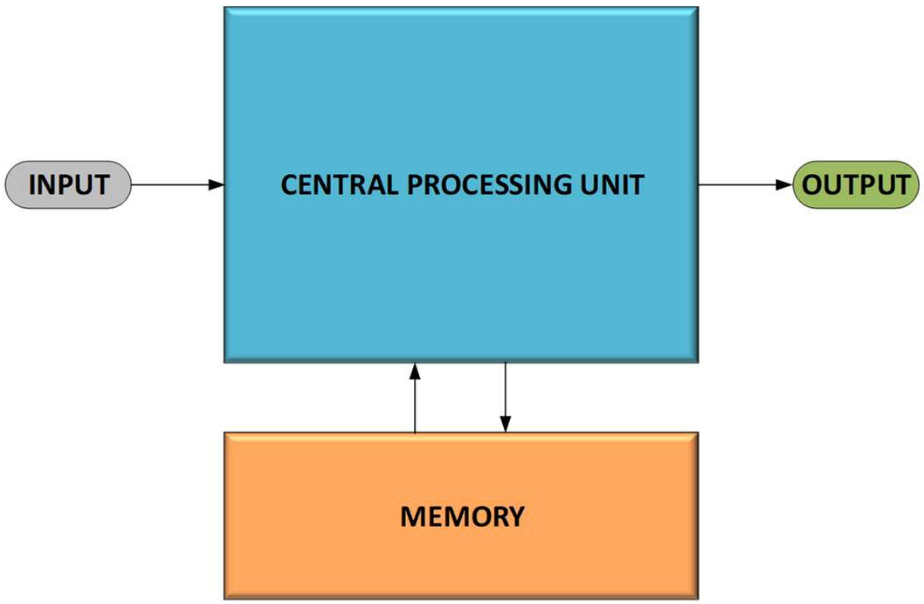
FIVE PARTS OF ANY COMPUTER

- Input
- Output
- Memory
- Arithmetic circuits
- Control circuits

- Derives from the EDVAC project of Eckert and Mauchly
- First stated in a paper by John Von Neumann

FIVE PARTS OF ANY COMPUTER

- The EDVAC paper documents the first stored program computer.
- Stored program computers hold a program as voltages in memory.
- Von Neumann's paper influenced all later machines – including those built today.



Von Neumann Architecture

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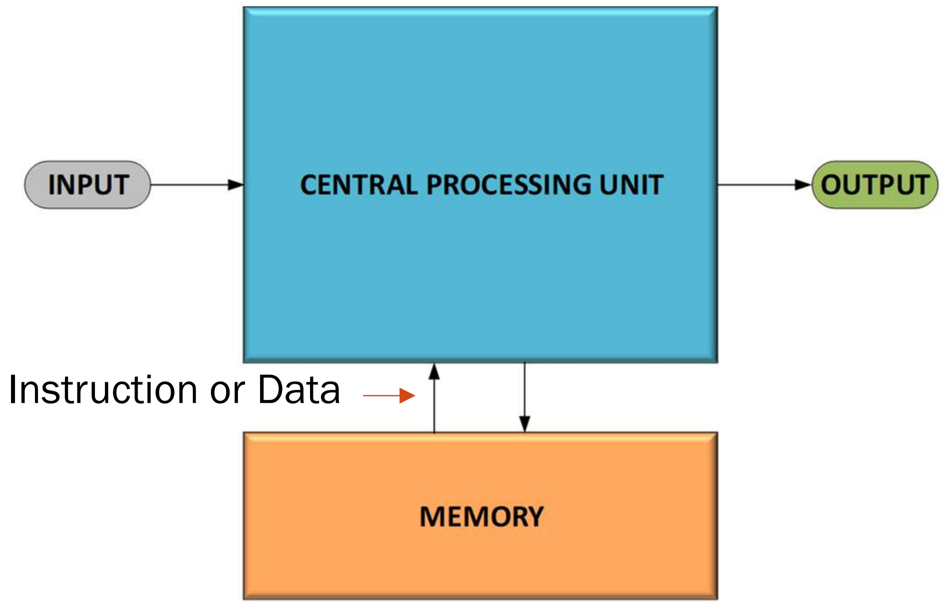
FIVE PARTS OF ANY COMPUTER

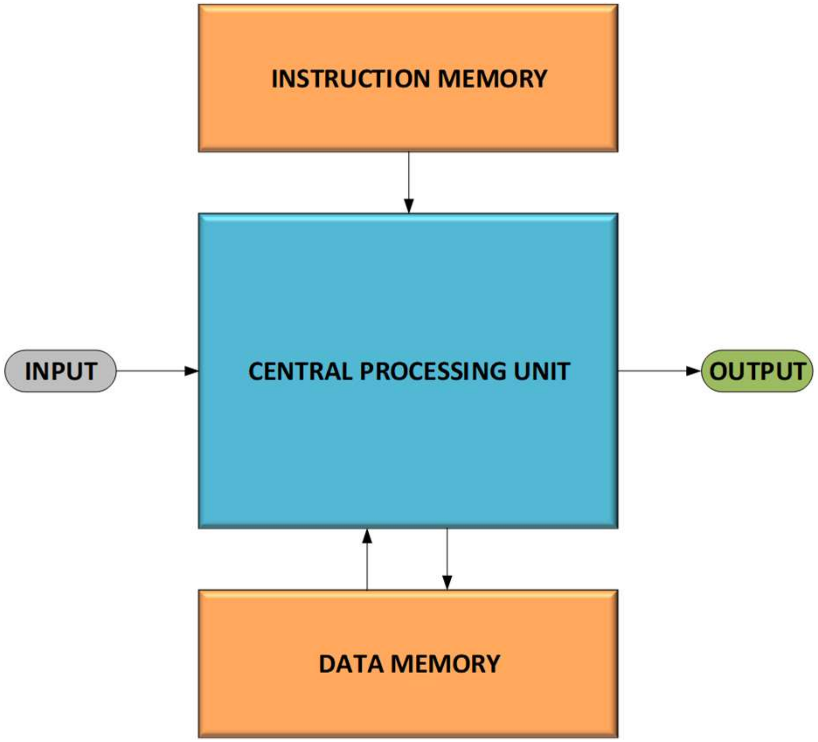
- Memory is an expensive part of a computer.
- Von Neumann proposes one memory for both data and instruction storage.
- This limits performance because at any time the memory is providing the CPU with either a new instruction or a new piece of data.
- Performance limit is the Von Neumann bottleneck.



Von Neumann Architecture

FIVE PARTS OF ANY COMPUTER

- One way to increase performance is to remove the von Neumann bottleneck.
- Howard Aiken proposed a machine called the Harvard Mark 1 that used separate memories for instructions and data.

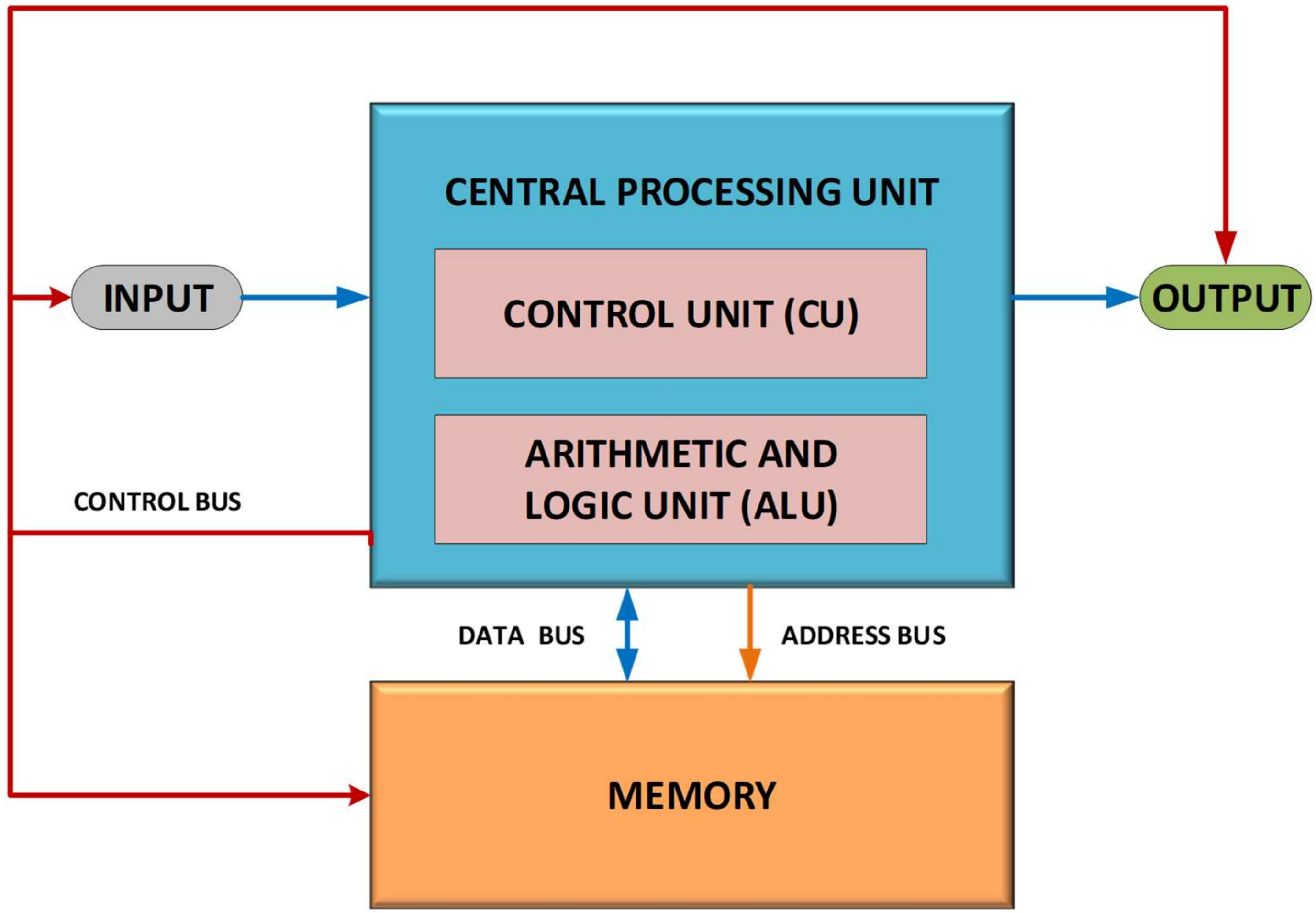


Harvard Architecture

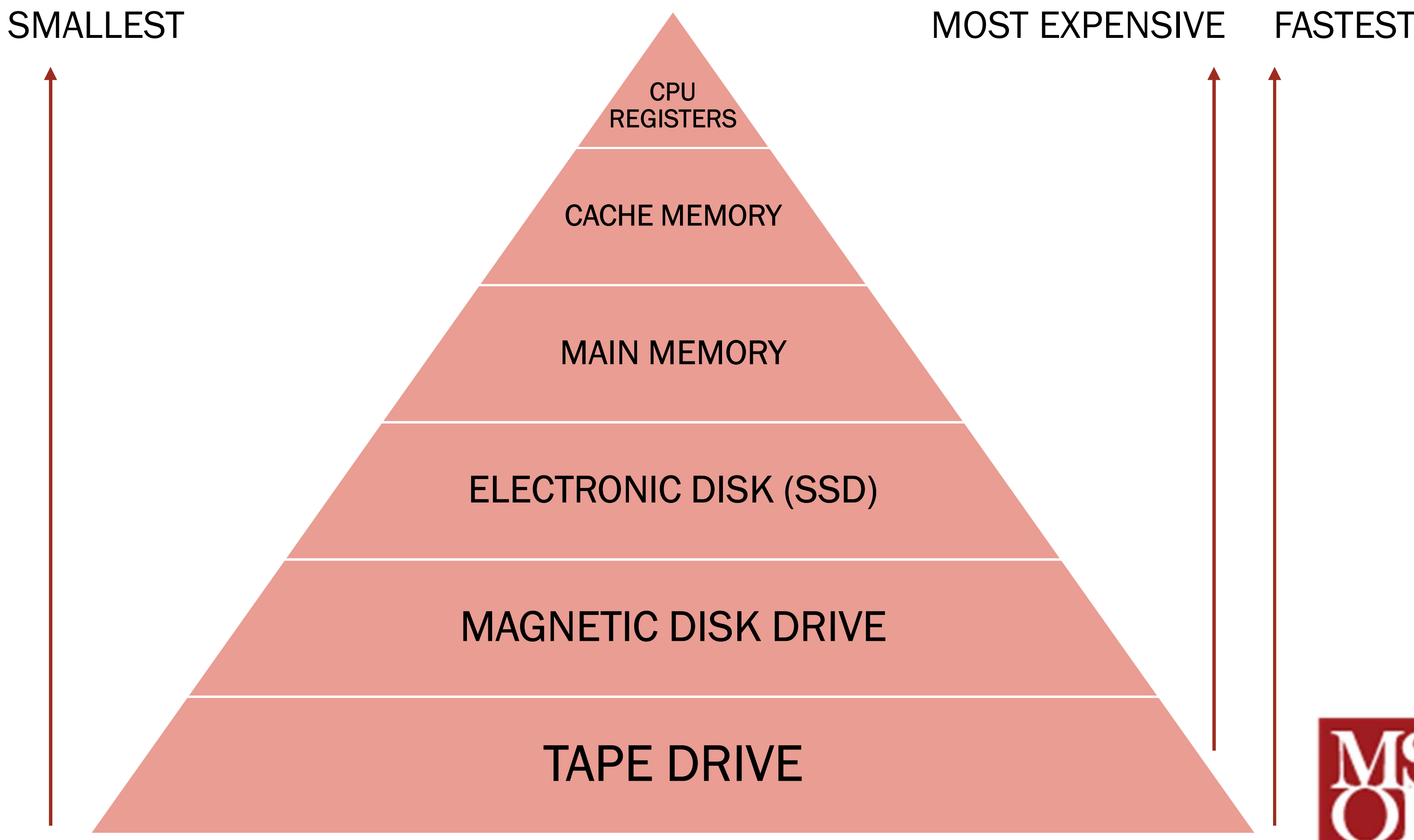
CENTRAL PROCESSING UNIT (CPU)

- Two parts from the von Neumann description
  - An arithmetic and logic unit (ALU) completes mathematics
  - A control unit (CU) decodes instructions to control calculation
- The CPU creates three numerical busses
  - An address bus requests access to memory locations
  - A data bus is used to move data between components
  - A control bus contains signals controlling components

CENTRAL PROCESSING UNIT (CPU)

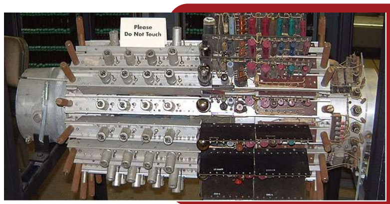


MEMORY PYRAMID

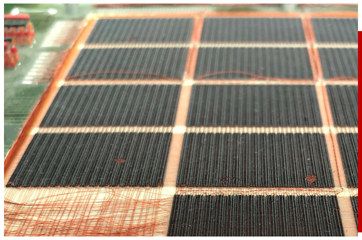


HISTORICAL MEMORY PERIODS

Vacuum Tube Memory



Mercury Acoustic Delay Memory

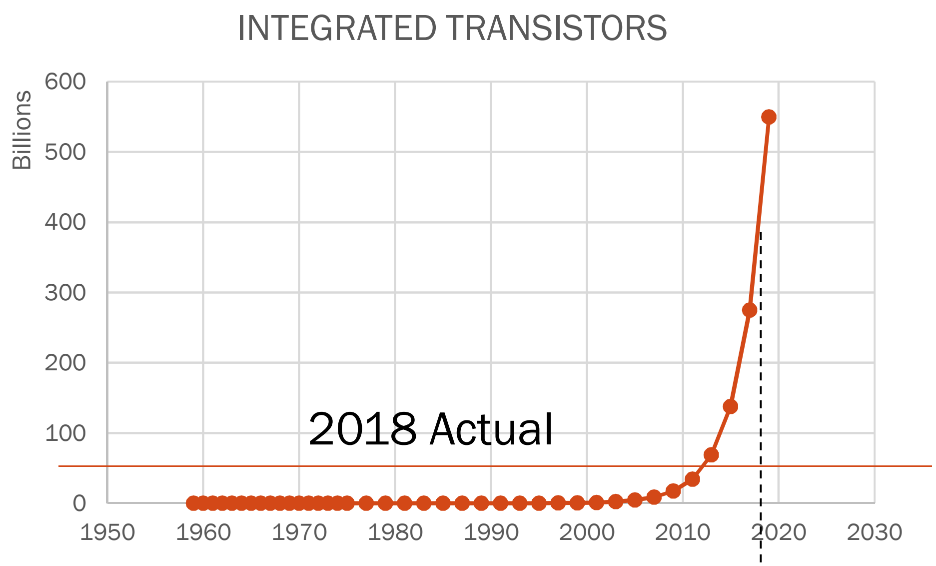


Magnetic Core Memory

Semiconductor Chip Memory

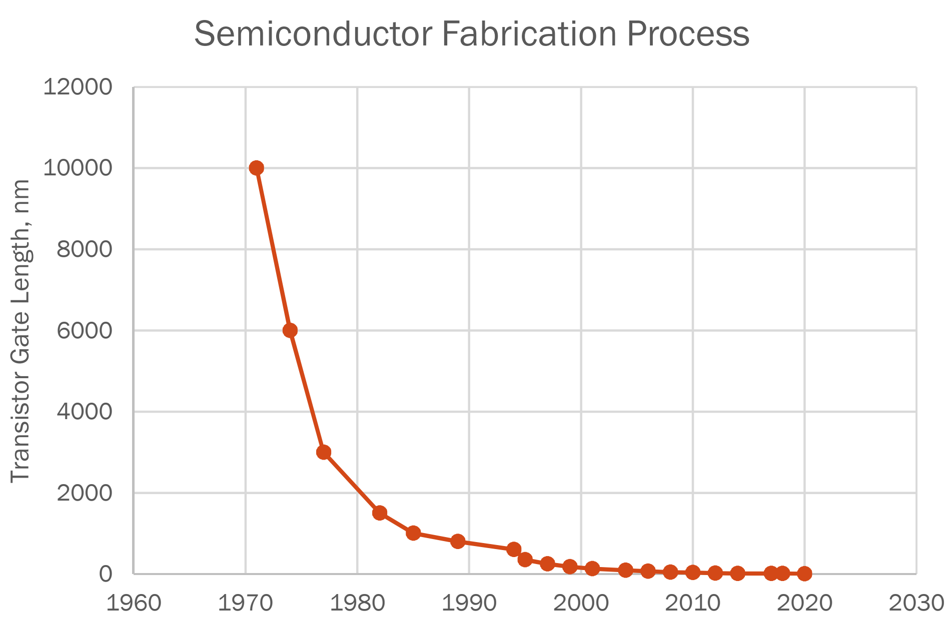
MOORE'S LAW

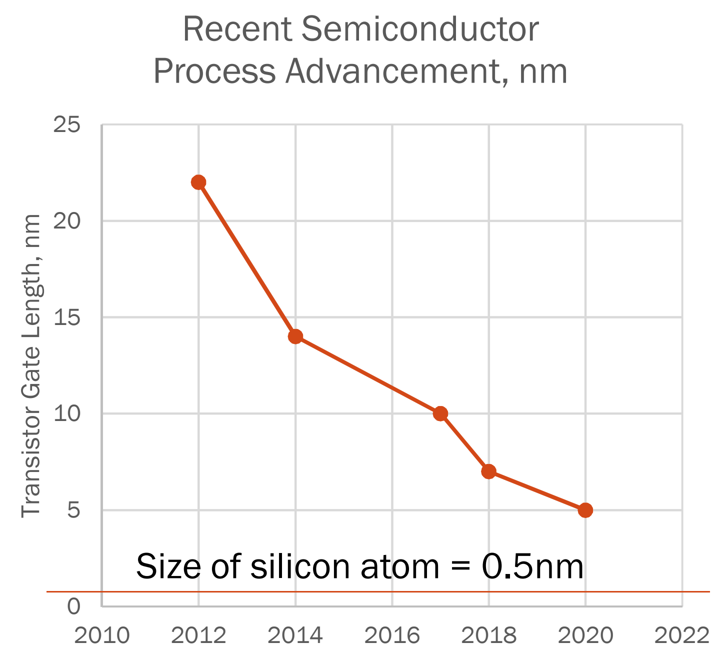
- Gordon Moore, Co-founder of Fairchild Semiconductor and Intel predicted integrated transistors would double every year (1965 paper)
- Modified to 2 years (1975)
- Moore's Law slowed in the twenty-first century.
- The largest chip in 2018 was a 50 billion transistor FPGA
- Some say we are entering the post-Moore's Law Era.



Doubling every 1 year through 1975.
Doubling every 2 years after 1975.

MOORE'S LAW





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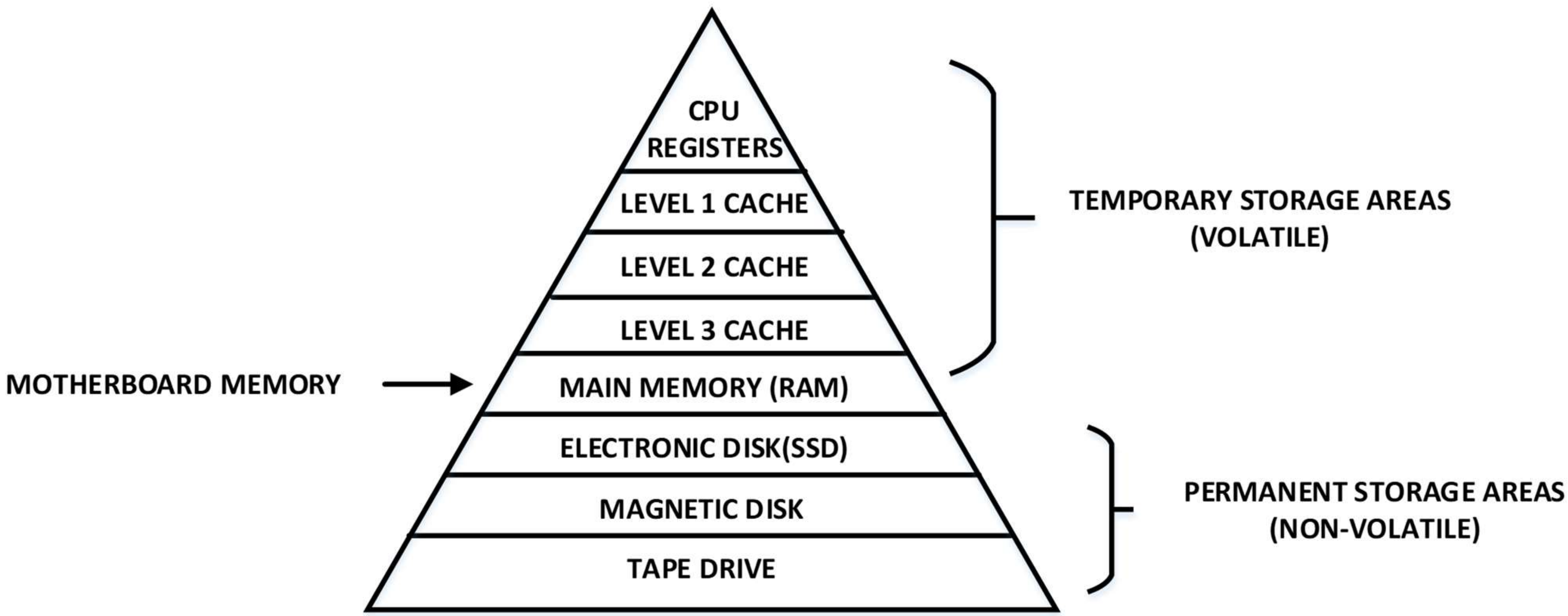
MICROPROCESSOR

- Integrated Circuit Central Processing Unit
  - arithmetic and logic unit
  - control circuits
  - CPU register file
- Modern processors also include cache memory
  - part of data flow control mechanism
  - not considered user memory

MODERN MEMORY PYRAMID



Modern microprocessors include the registers and the cache memory levels.

COMPUTER ARCHITECTURE

- Definition
  - blueprint of a computer system
  - multiple subcategories of blueprinting
- Subcategories
  - instruction set architecture (ISA)
  - micro-architecture (μA)
  - system architecture

INSTRUCTION SET ARCHITECTURE

- Programmer’s view of the computer
- Defines machine instructions
- Defines data locations
  - CPU register set
  - Memory size
  - Memory access modes

MICROARCHITECTURE

- Integrated circuit implementation of an ISA
- Interconnects components to achieve ISA
- Result is an integrated circuit microprocessor
- Example companies
  - Intel ARM
  - AMD Freescale
  - NVIDIA IBM
  - Motorola MIPS

SYSTEM ARCHITECTURE

- Board level design
- Interconnects chips to complete a computer
- Example companies
  - Dell
  - Apple
  - HP

MICROPROCESSOR

- Integrated circuit processor
- Optimization:
  - speed: generally high speed devices (GHz)
  - size: does not optimize size of system architecture
  - power: computes large width results (32, 64 bits)
  - cost: high speed increases cost
- Uses:
  - Personal computers
  - Servers
  - Some types of embedded systems

MICROCONTROLLER

- integrated circuit computer
- single chip computer
- all five parts of the computer on one chip
- optimization:
  - size: allows small system architecture
  - speed: slower (MHz)
  - power: smaller bit-widths (8, 16, 32 bits)
  - cost: lower speed and bit-width lowers cost

EXAMPLES

- MICROPROCESSORS
  - Intel: 4004 (1971), 8008, 8086/88, 80286, 80386, Pentium, Core Duo, Core i5, Core i7
  - Motorola: 68000, 68020, 68030, 68040
  - PowerPC: PPC603, PPC604, PPC615, PPC640
  - MIPS: R2000, R3000, R8000, R10000
  - Sparc: Sparc, microSparc, UltraSparc
  - ARM: ARM cores from many manufacturers
  - Others: DEC Alpha, Zilog Z80, MOS65C02

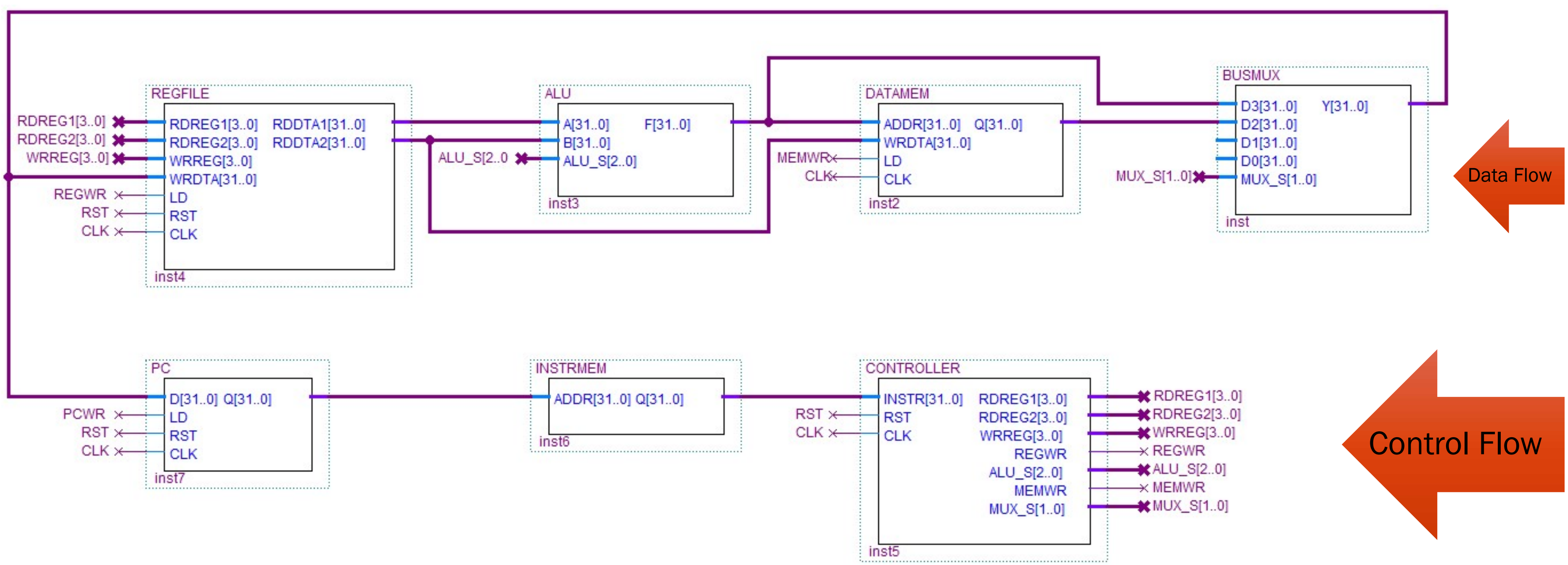
EXAMPLES

- MICROCONTROLLERS
  - Freescale: MC68HC11, MC68HC12, ColdFire
  - Intel: 8051, 80186
  - Atmel: Atmega32, Atmega64, Atmega128
  - Microchip: PICmicro, PIC16, PIC32 families
  - ARM: ARM cores in many custom µC ICs
  - MIPS: MIPS cores in many custom µC IC
  - Rabbit: Rabbit2000

CHANGE CE1911 SPC TO µP

- Replace special purpose equation FSMs with a general purpose instruction decoder.
- Replace REGA and REGB with larger set of registers.
- Add instruction memory to hold commands.
- Add data memory for significant numeric storage.

CHANGE CE1911 SPC TO µP



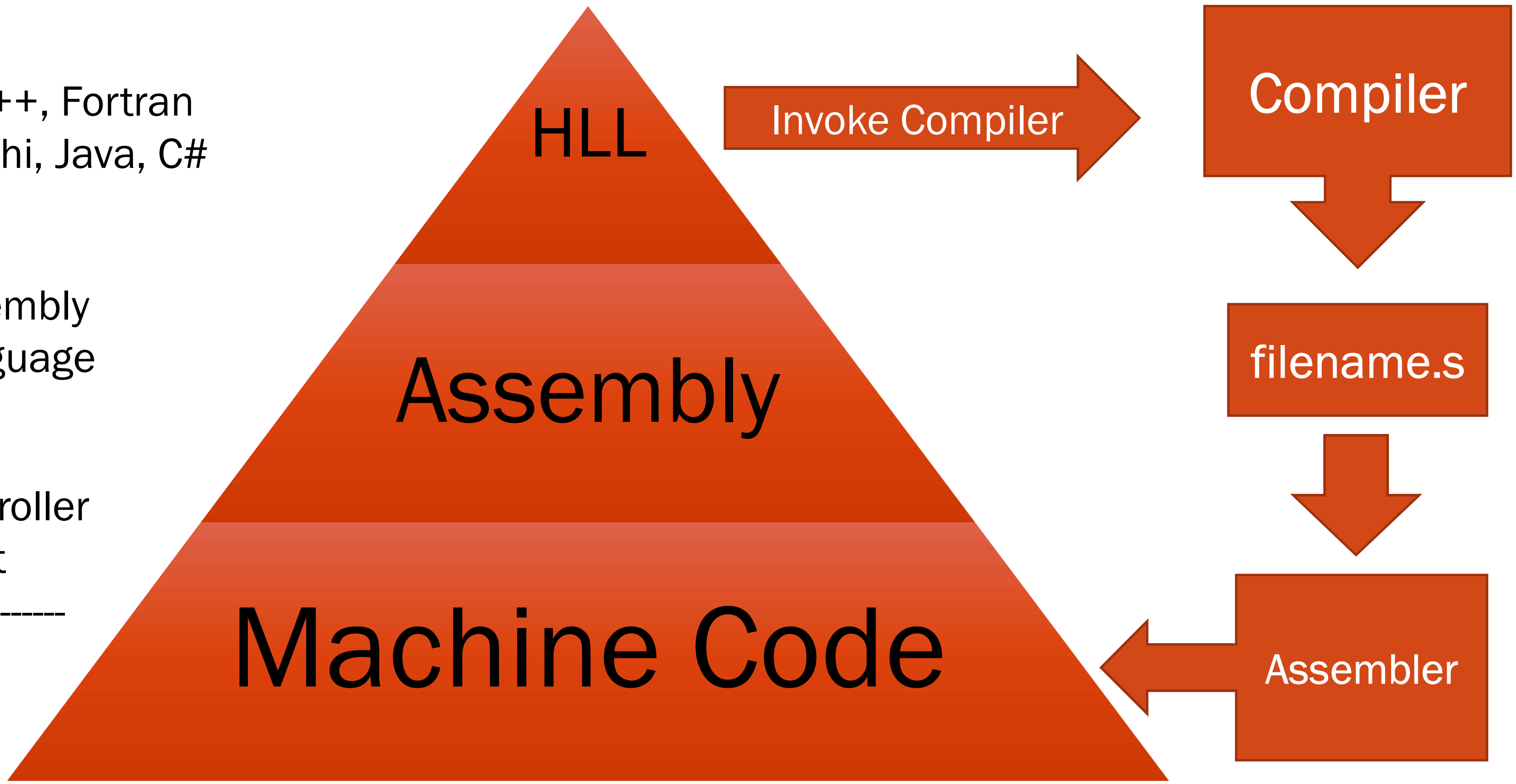
LANGUAGE PYRAMID

C, C++, Fortran
Delphi, Java, C#

Assembly
Language

Controller
Input

011
100
100



Compilers do not always include a separate assembler in the tool set.
Some compilers write machine code directly from the high level language.

BIBLIOGRAPHY

- J. von Neumann, "First draft of a report on the EDVAC," in *IEEE Annals of the History of Computing*, vol. 15, no. 4, pp. 27-75, 1993
- M. D. Godfrey and D. F. Hendry, "The computer as von Neumann planned it," in *IEEE Annals of the History of Computing*, vol. 15, no. 1, pp. 11-21, 1993
- R. E. Smith, "A Historical Overview of Computer Architecture," in *Annals of the History of Computing*, vol. 10, no. 4, pp. 277-303, Oct.-Dec. 1988
- Burks, A. W., Golstine, H. H., and von Neumann, J., "Preliminary Discussion of the Logical Design of an Electronic Computing Instrument", *Computer Structures – Readings and Examples*, McGraw Hill, New York, pp. 92 - 119

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