188 701 Advanced Computer Architecture

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Advanced Computer Architecture

Grading

Midterm Exam	35%
Final Exam	45%
Assignment	20%

Advanced Computer Architecture

References:

1. Patterson, D. A. and Hennessy, J. L, , Computer Organization and Design, Morgan Kaufmann.

2. Hennessy, J. L. and Patterson, D. A., Computer Architecture: Quantitative Approach, Morgan Kaufmann.

Historical Perspective

° **Decade of 70's (Microprocessors)**

- **Programmable Controllers**
- **Single Chip Microprocessors**
- **Personal Computers**

° **Decade of 80's (RISC Architecture)**

- **Instruction Pipelining**
- **Fast Cache Memories**
- **Compiler Optimizations**

° **Decade of 90's (Instruction Level Parallelism)**

- **Superscalar Processors**
- **Aggressive Code Scheduling**
- **Low Cost Supercomputing**
- **Out of Order Execution**

Technology => dramatic change

° **Processor**
- logic capacity: about 30% per year
- clock rate: about 20% per year

° **Memory**
- DRAM capacity: about 60% per year (4x every 3 years)
- Memory speed: about 10% per year
- Cost per bit: improves about 25% per year

° **Disk**
- capacity: about 60% per year

Technology => Dramatic Change

° **Processor**
- 2X in performance every 1.5 years; 1000X performance in last decade

° **Main Memory**
- DRAM capacity: 2x / 2 years; 1000X size in last decade
- Cost/bit: improves about 25% per year

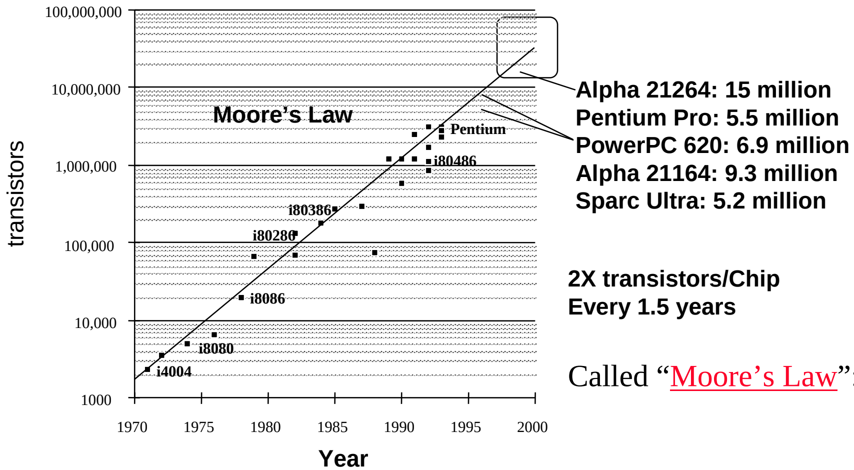
° **Disk**
- capacity: > 2X in size every 1.5 years
- Cost/bit: improves about 60% per year
- 120X size in last decade

Technology => Dramatic Change

° **Moore's Law**

Gordon Earle Moore: Co-founder & former Chairman of Intel Corp. describes an important trend in the history of computer hardware that the number of transistors that can be inexpensively placed on an integrated circuit is doubling approximately every two years.

Trends: Microprocessor Capacity



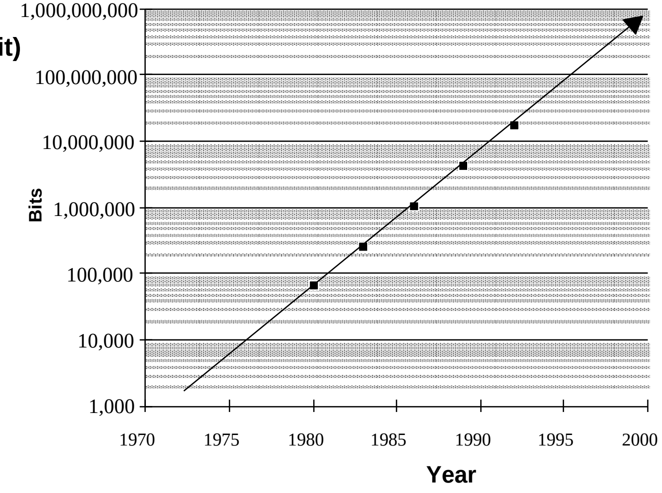
2X transistors/Chip Every 1.5 years

Called "Moore's Law":

Trends: Memory Capacity (1 Chip DRAM)

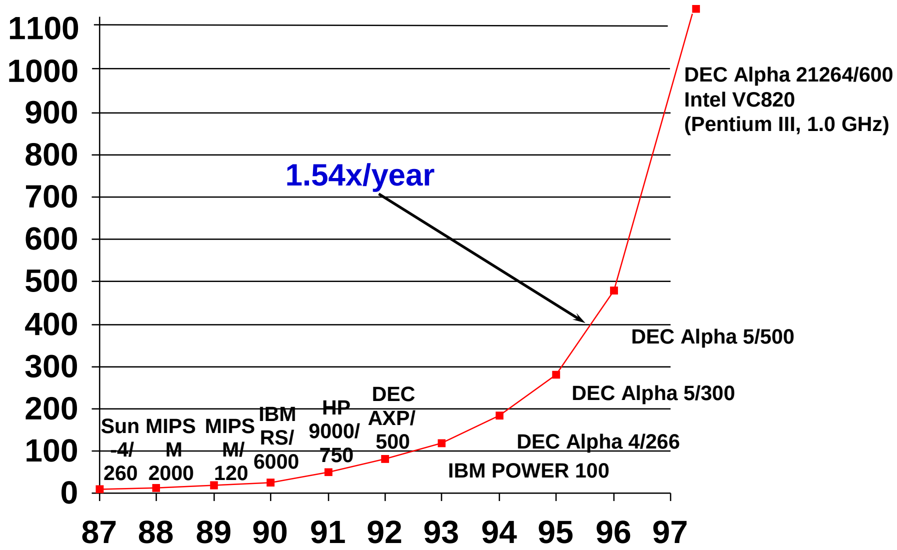
° **DRAM: Dynamic Random Access Memory**
  - where programs live while running; volatile (contrast with disk memory)

year	size(Megabit)
1980	0.0625
1983	0.25
1986	1
1989	4
1992	16
1996	64
2000	256



Now 1.4X/yr, or doubling every 2 years

Trends: Processor Performance



Why Study Computer Architecture

° **Aren't they fast enough already?**
  - Are they?
  - Fast enough to do everything we will EVER want?
    - AI, protein sequencing, graphics
  - Is speed the only goal?
    - Power: heat dissipation + battery life
    - Cost
    - Reliability
    - Etc.

Answer #1: requirements are always changing
Answer #2: technology playing field is always changing

Classes of Computers

° **High performance (supercomputers)**
  - Supercomputers – Cray T-90
  - Massively parallel computers – Cray T3E

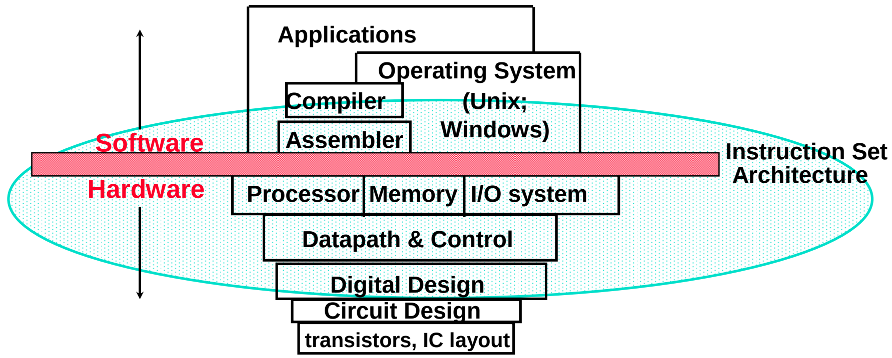
° **Balanced cost/performance**
  - Workstations – SPARCstations
  - Servers – SGI Origin, UltraSPARC
  - High-end PCs – Pentium quads

° **Low cost/power**
  - Low-end PCs, laptops, PDAs – mobile Pentiums, ARM

What is *Computer Architecture*

Computer Architecture = Instruction Set Architecture + Organization + Hardware

What is "Computer Architecture"?



° **Key Idea:** ***levels of abstraction***

- hide unnecessary implementation details
- helps us cope with enormous complexity of real systems

What is "Computer Architecture"?

° ***Computer Architecture = Instruction Set Architecture (ISA)***

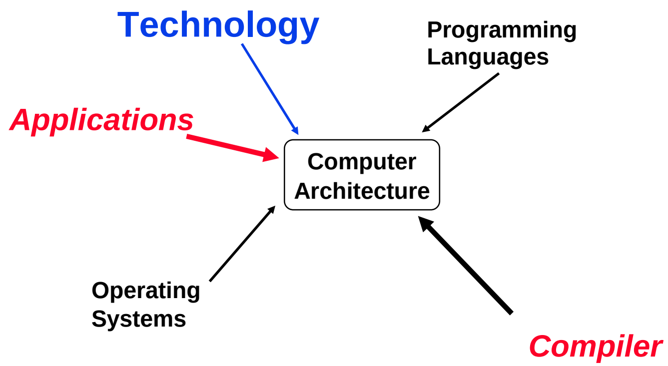
- the one "true" language of a machine
- *boundary* between hardware and software
- the hardware's specification; defines "what" a machine does;

+

Machine Organization

- the "guts" of the machine; "how" the hardware works; the implementation; must obey the ISA abstraction

Forces on Computer Architecture



Forces Acting on Computer Architecture

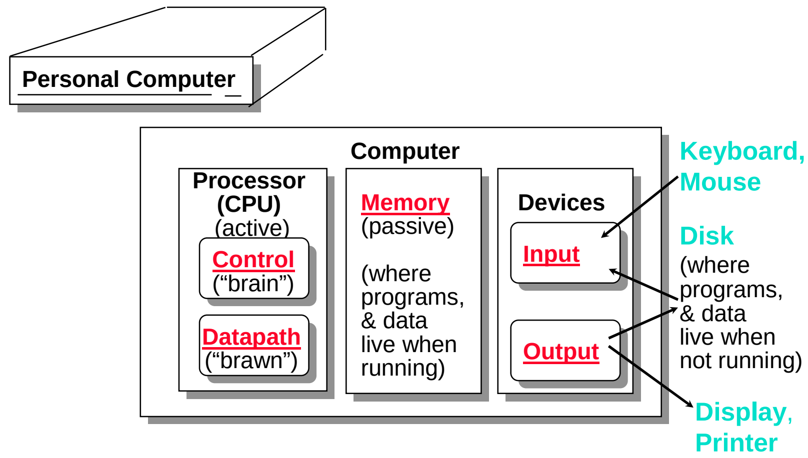
° **R-a-p-i-d Improvement in Implementation Technology:**
- IC: integrated circuit; invented 1959
- SSI → MSI → LSI → VLSI: dramatic growth in number transistors/chip ⇒ ability to create more (and bigger) FUs per processor; bigger memory ⇒ more sophisticated applications, larger databases

° **Tomorrow's Science Fiction: ubiquitous computing: computers embedded everywhere**

° **New Languages: Java, C++ ...**

Machine Organization:

5 classic components of any computer



The components of <u>every</u> computer, past and present, belong to one of these five categories

Machine Organization Perspective

° **Capabilities & performance characteristics of principal Functional Units (FUs) of the CPU**

° **Ways in which these components are interconnected to realize the ISA**

° **Information flows between components**

° **How such information flow is controlled**

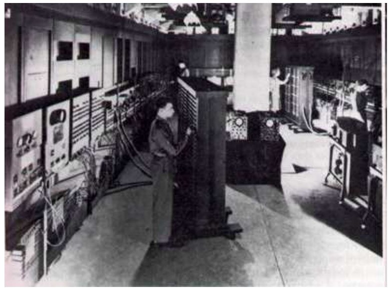
° **Levels of Machine Description**
- Register Transfer Level (RTL)
- Gate Level (Digital Design)

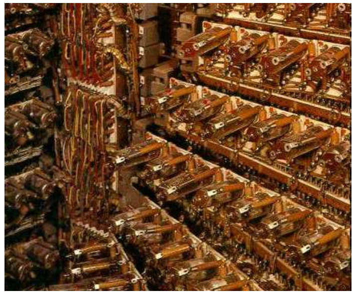
Computer Architecture and Engineering

Instruction Set Design	Computer Organization
Interfaces	Hardware Components
Compiler/System View	Logic Designer's View
-"Building Architect"	-"Construction Engineer"

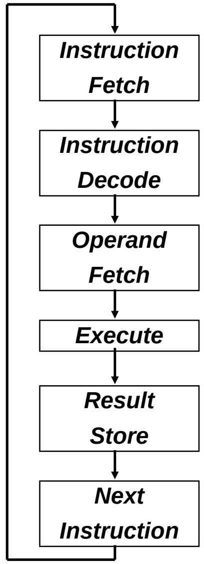
von Neumann Computer

- 1944: The First Electronic Computer ENIAC at IAS, Princeton Univ. (18,000 vacuum tubes)
- Stored-Program Concept – Storing programs as number s – by John von Neumann
- Idea: A program is written as a sequence of inst ructions, represented by binary numbers. The instructions are stored in the memory just as data. They are read one by one, decoded and then executed by the CPU.





Execution Cycle



Obtain instruction from program storage

Determine required actions and instruction size

Locate and obtain operand data

Compute result value or status

Deposit results in storage for later use

Determine successor instruction

Instruction-Set Processor Design

- **Architecture (ISA)** **programmer/compiler view**
  - **"functional appearance to its immediate user/system programmer"**
  - **Opcodes, addressing modes, architected registers, IEEE floating point**
- **Implementation (µ Architecture)** **processor designer/view**
  - **"logical structure or organization that performs the architecture"**
  - **Pipelining, functional units, caches, physical registers**
- **Realization (chip)** **chip/system designer view**
  - **"physical structure that embodies the implementation"**
  - **Gates, cells, transistors, wires**

Relationship Between the Three Aspects

- **Processors having identical ISA may be very different in organization.**
  - **e.g. NEC VR 5432 and NEC VR 4122**
- **Processors with identical ISA and nearly identical organization are still not nearly identical.**
  - **e.g. Pentium II and Celeron are nearly identical but differ at clock rates and memory systems**

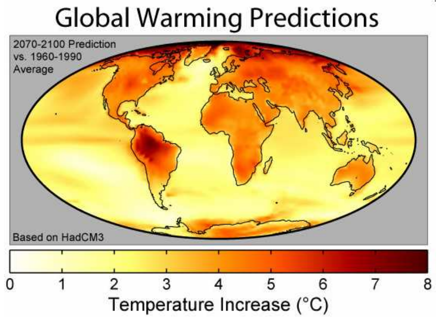
➢**Architecture covers all three aspects.**

Why Study Computer Architecture?

- **CHANGE; It's exciting!; It has never been more exciting!**
- **It impacts every other aspect of engineering and science**
- **Visit www.top500.org**

Why Study Computer Architecture?

- **Case Study: Earth Simulator**
- **The Earth Simulator (ES) was the fastest supercomputer in the world from 2002 to 2004.**
- **The system was developed for NASDA, JAERI, and JAMSTEC in 1997 for running global climate models to evaluate the effects of global warming and problems in solid earth geophysics.**
- **Total of 5120 processors and 10 TB of memory.**



Why Study Computer Architecture?

- **Case Study: Earth Simulator**