18-447 Lecture 1: Intro to Computer Architecture

James C. Hoe
Dept of ECE, CMU
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Announcements: Everyone must hand in a course survey on 1/26
Read P&H Ch1
Review P&H Ch3 for next Lecture
No lab this week

Handouts: - Handout #0: Course Survey
- Handout #1: Course Info

Course Logistics

- Handout #0: Course Survey
  No kidding. Turn it in, or else.
- Handout #1: Course Info.
  - Please refer to blackboard for updates and announcements
- Lecture Schedule Online
  - http://www.ece.cmu.edu/~ece447/H0x-schedule.htm
  - Reading assignments are due before lecture
    If an Rx prescription said to take a medication on an empty stomach, would you wait until after a meal to take it? Ans: It is probably not going to kill you. It is probably not as effective. It is probably still better than not taking it.
  - Pay attention to exam dates. The time to resolve conflicts is right now.

What is 18-447?

- 15-213: Introduction to Computer Systems
  - "C" as a model of computation
  - interact with the computer hardware through OS
  - what about the details below the abstraction?

Can it hurt you to not know what is going on below?

Somehow a program ends up executing as digital logic

- 18-240: Fundamentals of Computer Engineering
  - Digital logic as a model of computation
  - gates and wires as building blocks
  - what about the details below this abstraction?

We will have to save that for another course

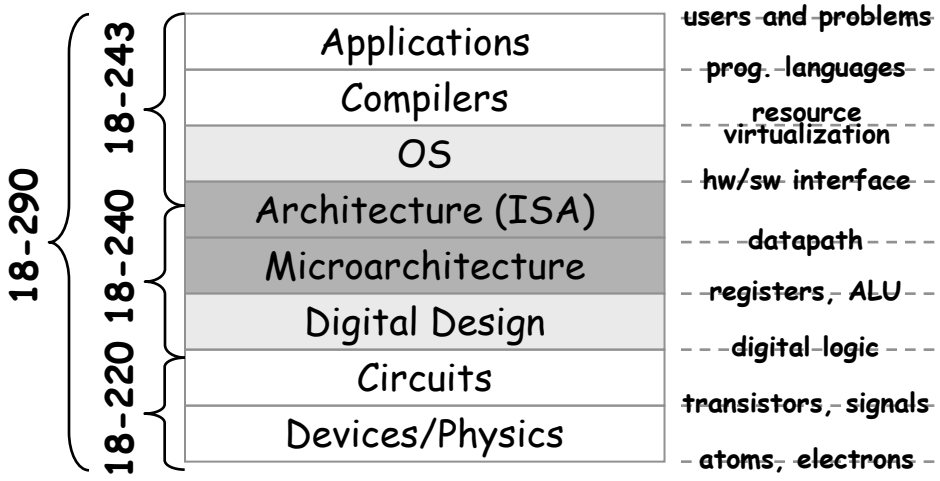
18-447: Fuzzy to Concrete

15-213

- Computer Architecture
  - how to present precisely the functionality of a computer to a programmer
  - By the same token, this is also the most abstract "design spec" for the hardware guys
- Computer Organization
  - how to assemble
  - how to evaluate
  - how to tune
- Computation Structures
  - digital representations
  - processing, storage and I/O elements

18-240

Computer System Abstractions

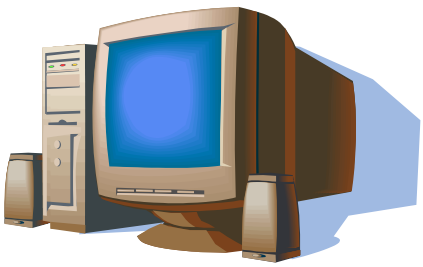


To use an abstraction properly you must understand the limits of the abstraction

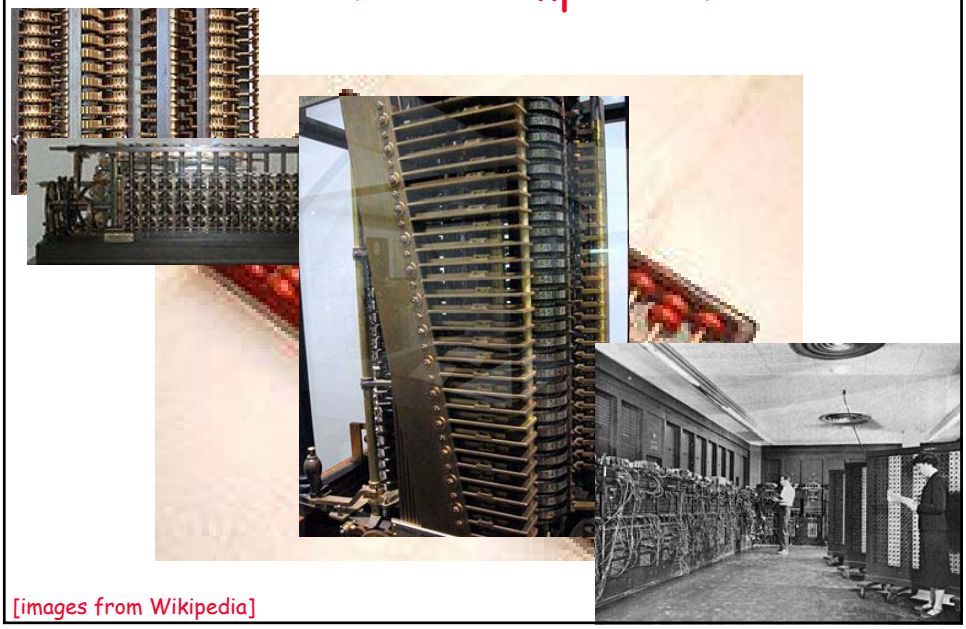
What is a Computer?

- **Computer, 2. a.** A calculating-machine; esp. an automatic electronic device for performing mathematical or logical operations; freq. with defining word prefixed, as *analogue*, *digital*, *electronic computer*.

  --- Oxford English Dictionary



Is this a "computer"?



[images from Wikipedia]

More Familiar Computers

[images from Wikipedia]

Where is the computer?

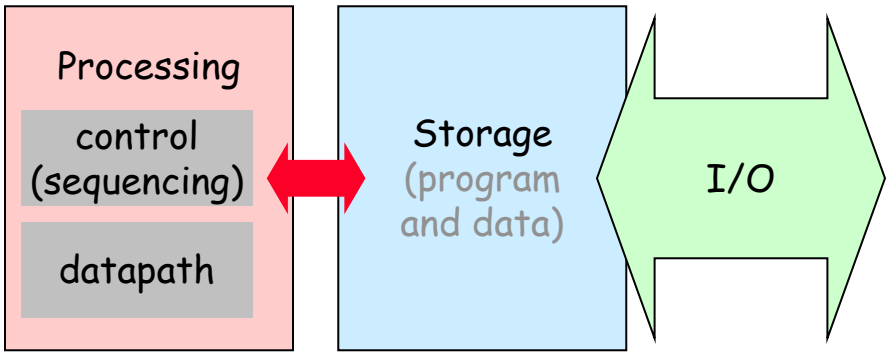
Modern computing is as much about providing enhanced capabilities as data processing!!

[images from Wikipedia]

Less Glamorous Computers

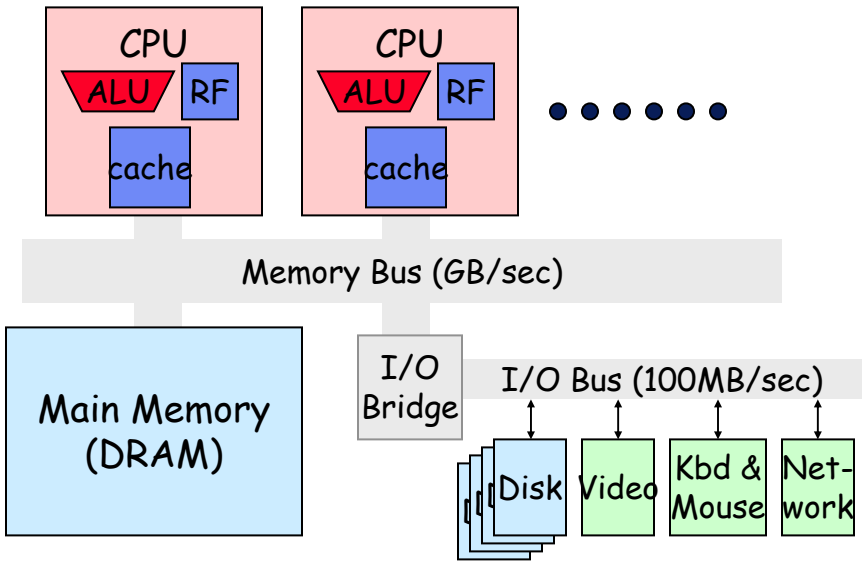
[images from Wikipedia]

So what makes a computer a computer?

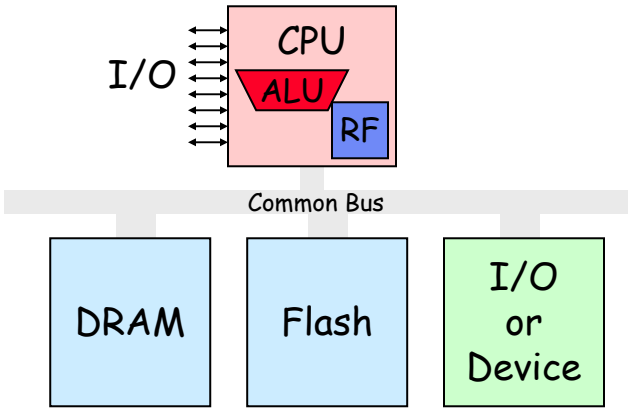


The fact that both program and data are stored (i.e., software mutable) is an extremely important detail in the evolution of computer architectures.

A Typical Computer Organization



A Simple Embedded Computer

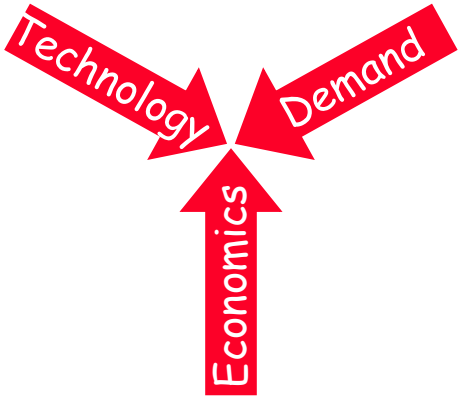


Historical Perspectives:
prelude to modern computer architecture

Always read the "Historical Perspectives" at the end of P&H chapters. They are fun.

Forces on Innovation

- Timely innovations are rarely unique or original
- Similar constraints lead to similar engineering solutions

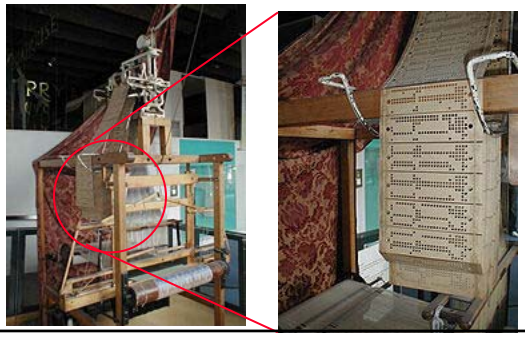


Disclaimer: does not apply to inventions that are found useful only much later

Beginnings of Digital Computing

- Industrial Revolution era's "hi-tech" in mechanization
  - steam engines
  - mechanical calculators,

  - Jacquard's loom: gears, pulleys, chains and punch cards



[images from Wikipedia]

Charles Babbage (1791-1871)

- Difference Engine, 1823: a special-purpose computer
  - evaluated polynomial functions by Newton's method of successive differences (requiring only additions)
  - eventually built by Georg and Edvard Schuetz in 1855

- Analytical Engine, 1833: a general-purpose computer
  - programmed by punch cards, "assembly language" included loops and branches
  - 1000 word data store, punch card I/O
  - unfortunately never completed (may not be feasible ever in mechanical forms....)
  - would have been 10x30 meters, powered by a steam engine

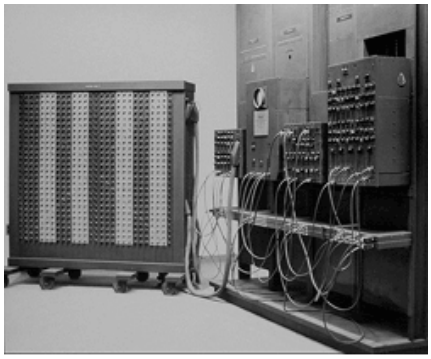
[images from Wikipedia]

100 Years of Technology Changes

- Mechanical, 1800s
  - gears, chains, pulleys, and steam power
  - punch cards!!
- Electromechanical, early 1900s
  - switches, relays
  - "acoustic" mercury delay lines
  - e.g. Harvard/IBM Mark 1, Aiken 1939~1944, 50ft long, 5ton, 750K parts, 3~6 sec per addition
    reminiscent of the Analytical Engine in "microarchitecture"
- Electrical, mid 1900s and on
  - plugboards, vaccum tubes, CRTs
  - and later came DRUM memory, core memory, transistors and so on .....

Changing demands and economics?

ENIAC, 1946
Eckert and Mauchly, U of Penn



from The ENIAC Museum, http://www.seas.upenn.edu/~museum/

- the first programmable electronic digital computer
- 18,000 vacuum tubes
- 30 ton, 80 by 8.5 feet
- 1900 additions per second
- 20 10-decimal-digit words (100-word core by 1952)
- Programmed by 3000 switches in the function table and plug-cables (became stored program in 1948 following von Neumann's advise)

Stored Program (von Neumann) Architecture

"Inasmuch as the completed device will be a general-purpose computing machine it should contain certain main organs relating to arithmetic, memory-storage, control and connection with the human operator."

--- 1st sentence, Burks, Goldstine & von Neumann, 1946

- von Neumann Architecture has come to mean
  - stored program
    - instructions in a linear memory array
    - instructions in memory can be modified just like data
  - sequential instruction processing
    - program counter identifies the current instruction
    - instruction is fetched from memory and executed
    - program counter is advanced (according to instruction)
    - repeat

Burks, Goldstein, von Neumann, "Preliminary discussion of the logical design of an electronic computing instrument",1946.

Proliferation in 40s and 50s

- From Moore School of Engineering, U of Pennsylvania
  - ENIAC, Eckert & Mauchly, 1946
  - EDVAC, von Neumann, 1944~1952
  - EDSAC, Wilkes, 1949 (first stored-program built)
  - IAS, Bigelow, 1952
  - ORDVAC, SEAC, MANIAC, JOHNIAC, ILLIAC …
- They are not alone:
  - ABC, Atanasoff and Berry, 39~42
  - Z3, Z4, Konrad Zuse late 30's early 40's
  - Colossus, Alan Turing, 1943
  - Harvard Mark I …., Aiken
- Don't forget software advances---Fortran was first done in 1954

check out http://www.computerhistory.org/timeline

Commercialization in the 50s

- UNIVAC, 1951, the first commercial computer
  contract price $400K, actual cost ~$1M, sold 48 copies
- IBM 701, 1952, shipped 19 copies
  (www-1.ibm.com/ibm/history/exhibits/701/701_customers.html)
  leased at $12K per month
- IBM 650, 1953, mass produced ~2000 units
  $200K ~ 400K
- IBM System/360, 1964 Redefined Industry!!
  - a family of binary compatible computer
    (previously, IBM had 4 non-compatible lines of computers)
  - 19 combinations of varying speed and memory capacity from $200K ~ $2M
  - still lives on today as the "highly-profitable" IBM z900 series

Cheaper or Faster in 60s and 70s

- Minicomputers
  - DEC PDP-8, 1965, $20K, size of large refrigerators
  - less powerful than "mainframes", 10x cheaper
  - Departmental computers, timesharing---PDP-11 and VAXs enjoyed extreme popularity in the 70s and 80s
- Supercomputers
  - performance at all cost!! (ECL, liquid-cooling, hand-built,...)
  - Biggest customers: national security, nuclear weapons, cryptography, (also aerospace, petroleum, automotive, pharmaceutical, sciences) check out www.top500.org
  - Seymour Cray, 1925~1996
    - worked on UNIVAC and later CDC 6600 and 7600
    - pioneered many of the high-performance techniques in use today
    - Cray Research Inc.→Cray Computer Corp(→Cray Inc.)

What happened to these computer lines?

Early Examples

DEC PDP 8, 1963
an early mini

Xerox Alto, 1973
an early "PC" with mouse and GUI

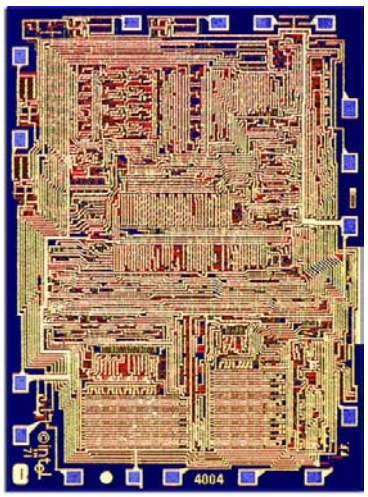
[images from Wikipedia]

Cray 3, 1993

90KW: liquid cooled by "Fluorinert"
15 GFLOPS (1 sec on Cray3 ≈ 67 years ENIAC)
$30,000,000

[images from Wikipedia]

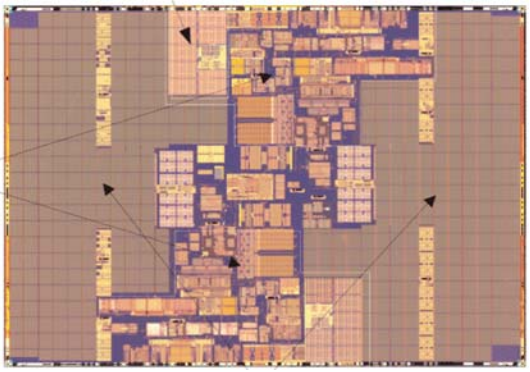
The "Killer Micros" from 70s and on



[from Molecular Expressions]

- **Intel 4004, first single chip CPU**
  - 4-bit processor for a calculator.
  - 2,300 transistors
  - 16-pin DIP package
  - 740kHz (eight clock cycles per CPU cycle of 10.8 microseconds)
  - ~100K OPs per second
- You can download the actual schematic from http://www.intel.com/museum/archives/pdf/4004_schematic.pdf

Intel Itanium (Montecito) 2004

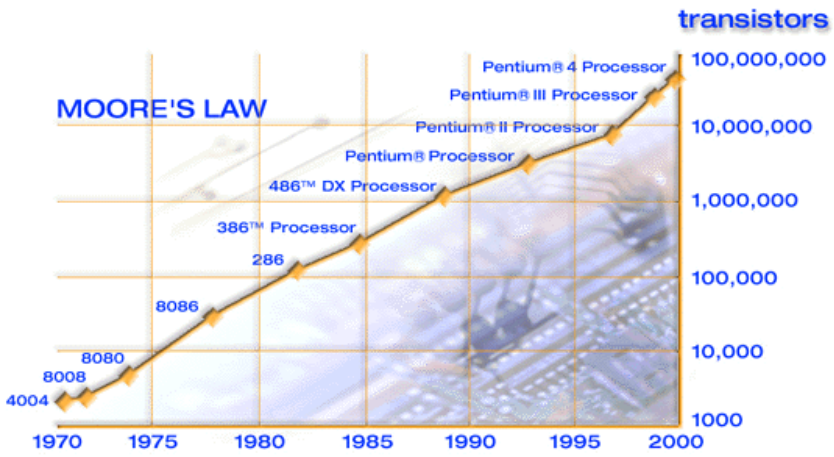


[from Best Servers of 2004, Microprocessor Report, January 2005.]

- 64-bit processor
- 1.7 billion transistors
- 1.7 GHz, issue up to 8 instructions per cycle
- 26 MByte of cache!!

In ~30 years, about 100,000 fold growth in transistor count and performance!

What Happened in Between



[http://www.intel.com/research/silicon/mooreslaw.htm]

Original article at download.intel.com/research/silicon/moorespaper.pdf

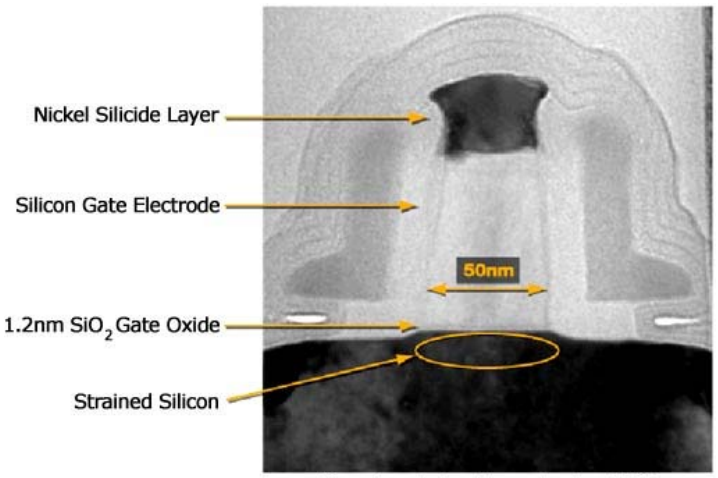
Evolution of Single-Chip Micros

	1970's	1980's	1990's	2010
Transistor Count	10K-100K	100K-1M	1M-100M	1B
Clock Frequency	0.2-2MHz	2-20MHz	20M-1GHz	10GHz
Instruction/Cycle	< 0.1	0.1-0.9	0.9- 2.0	10 (?)
MIPS/MFLOPS	< 0.2	0.2-20	20-2,000	100,000

- Assume doubling every 24 months (1971-2001):
  - total of 36,000X
  - cars would travel at 2,400,000 MPH by now
  - air travel from L.A. to N.Y should take 0.5 seconds (MACH 36,000)

Check out this great article http://www.technologyreview.com/article/21886/

End of Moore's Law?



50nm transistor dimension is ~2000x smaller than diameter of human hair

[http://www.intel.com/museum/online/circuits.htm]

distance between silicon atoms ~ 500 pm

Future of Computers

- End of Moore's law
  - future of VLSI technology after 2015 is unknown
    - Transistor size will be measured in atoms and node charge will be measured in electrons!!
    - BTW, this doesn't mean VLSI is finished, just no more scaling
  - many previously-unimportant issues will start to creep in, e.g., complexity, wire delay, >>power<< and reliability
- Non-von Neumann architectures
  - parallel and distributed processing
  - reconfigurable hardware computing
- Non-silicon technologies
  - nanotechnologies: carbon nanotubes, molecular switches
  - biological/cellular computers: DNA, proteins and enzymes
  - quantum computers: magnetic resonance and quantum dots.
- New ways of using computers!!!

Tons of Interesting Stuff Online

- NASA Ames Computer History Museum
  http://www.computerhistory.org/exhibits/online_exhibitions.html
  - check out in particular
    - microprocessor family tree
      http://www.computerhistory.org/exhibits/microprocessors
    - comprehensive timeline of computer development
      http://www.computerhistory.org/timeline
- Look up "computers" on Wikipedia
- Google it!!