Computer Architecture

Virendra Singh
Associate Professor
Computer Architecture and Dependable Systems Lab
Department of Electrical Engineering
Indian Institute of Technology Bombay
http://www.ee.iitb.ac.in/~viren/
E-mail: viren@ee.iitb.ac.in

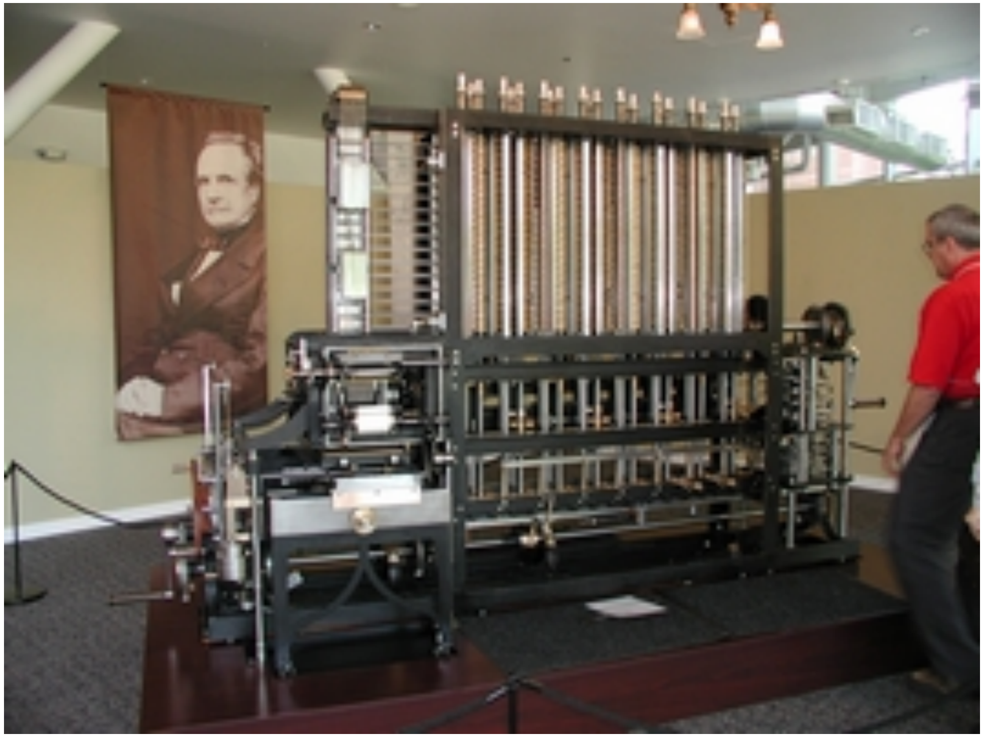
Computer Organization

Historic Events

- 1623, 1642: Wilhelm Strickland/Blaise Pascal built a mechanical counter with carry.
- 1823-34: Charles Babbage designed difference engine. http://www.youtube.com/watch v=0anlyVGeWOI&feature=related

Babbage's Difference Engine

- Babbage Difference Engine
  - Hand-cranked mechanical computer.
  - Computed polynomial functions.
  - Designed by Charles Babbage in the early to mid 1800s.
    - Arguably the world's first computer scientist, lived 1791-1871.
  - He wasn't able to build it because he lost his funding.



- His plans survived and this working model was built.
  - Includes a working printer!

http://www.computerhistory.org/babbage/

Historic Events

- 1943-44: John Mauchly (professor) and J. Presper Eckert (graduate student) built ENIAC at U. Pennsylvania.
- 1944: Howard Aiken used "separate data and program memories" in MARK I – IV computers – *Harvard Architecture*.
- 1945-52: John von Neumann proposed a "*stored program computer*" EDVAC (Electronic Discrete Variable Automatic Computer) – *Von Neumann Architecture* – use the same memory for program and data.

Most Influential Document

- "Preliminary Discussion of the Logical Design of an Electronic Computing Instrument," 1946 report by A. W. Burks, H. H. Holdstine and J. von Neumann. Appears in *Papers of John von Neumann*, W. Aspray and A. Burks (editors), MIT Press, Cambridge, Mass., 1987, pp. 97-146.

Theory of Computing

- Alan Turing (1912-1954) gave a model of computing in 1936 – *Turing Machine*.
- Original paper: A. M. Turing, "On Computable Numbers with an Application to the *Entscheidungsproblem**," *Proc. Royal Math. Soc.*, ser. 2, vol. 42, pp. 230-265, 1936.
- Recent book: David Leavitt, *The Man Who Knew Too Much: Alan Turing and the Invention of the Computer (Great Discoveries)*, W. W. Norton & Co., 2005.

* *The question of decidability, posed by mathematician Hilbert.*

History Continues

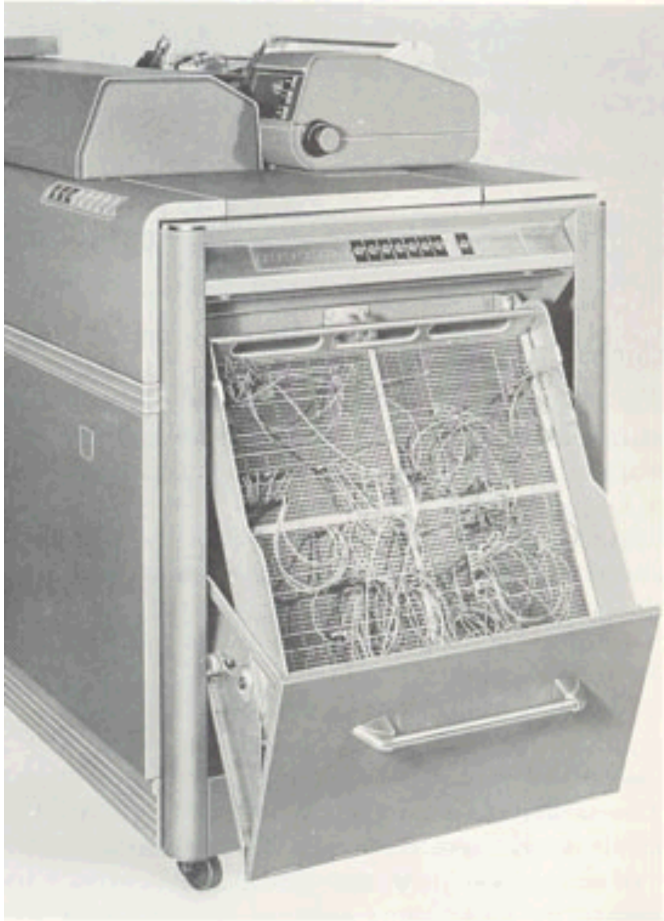
- 1946-52: Von Neumann built the IAS computer at the Institute of Advanced Studies, Princeton *– A prototype for most future computers*.
- 1947-50: Eckert-Mauchly Computer Corp. built UNIVAC I (Universal Automatic Computer), used in the 1950 census.
- 1949: Maurice Wilkes built EDSAC (Electronic Delay Storage Automatic Calculator), the first stored-program computer.

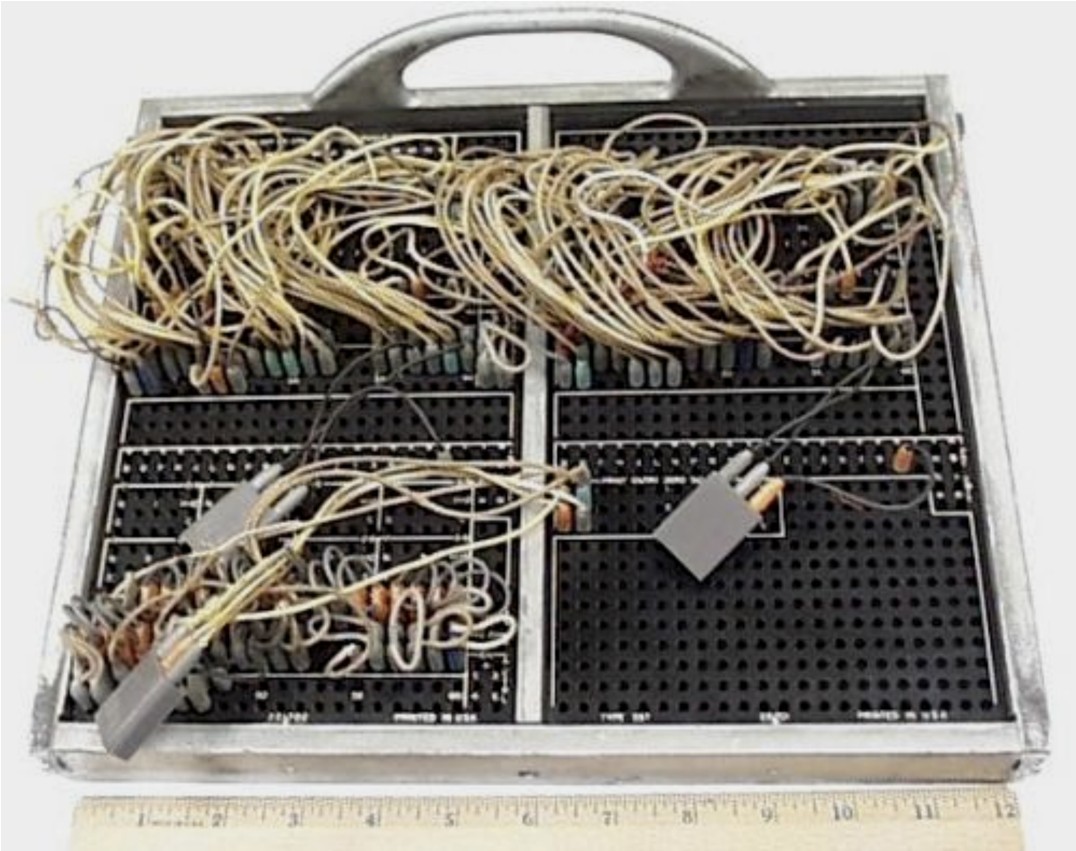
What was Computing Like?

- A data processing application involved passing decks of punched cards through electromechanical "unit record" machines.

- Repetitive sort, calculate, collate, and tabulate operations ...
  - ... were programmed with hand-wired plugboard control panels.

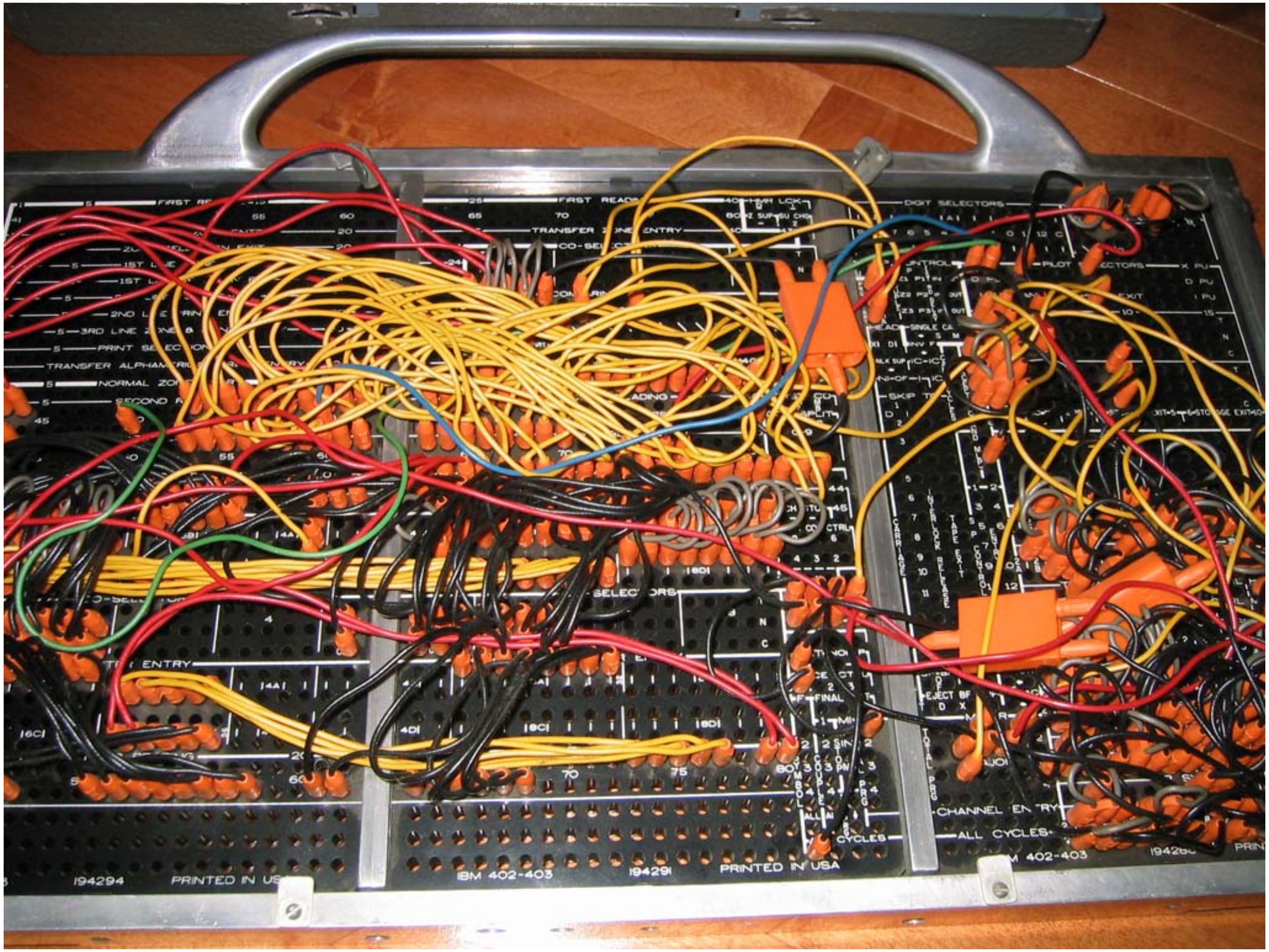
Plugboard Control Panel





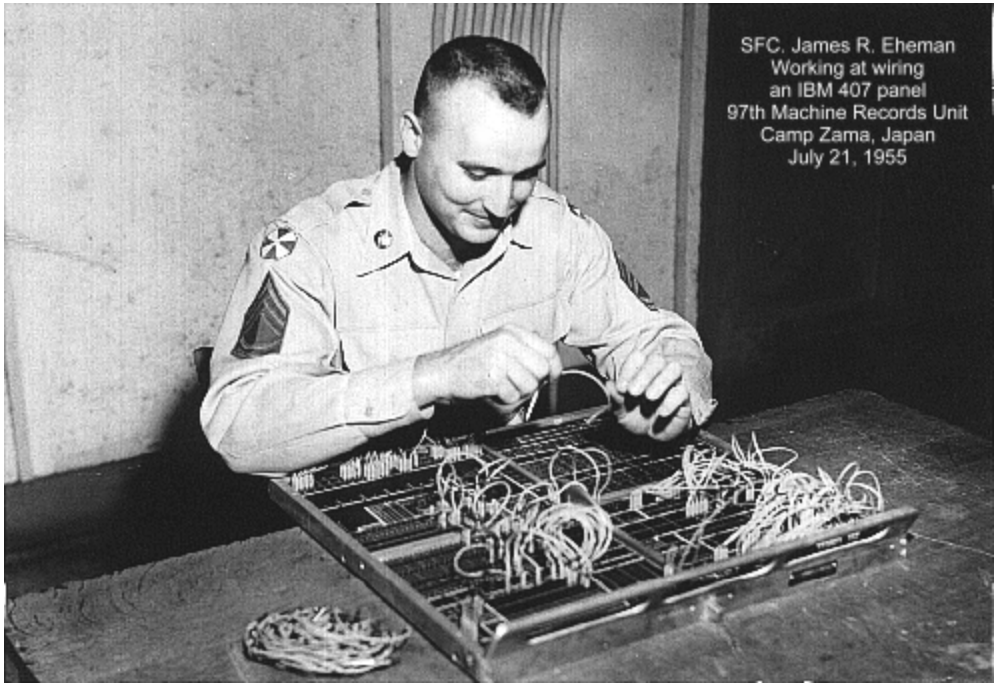
IBM 407 Accounting Machine (1949)

Plugboard Control Panel



Programming a Plugboard

- "Programming" was hand-wiring plugboards.



"Hmm, should I pass this parameter by value or by reference?"

Programming a Plugboard

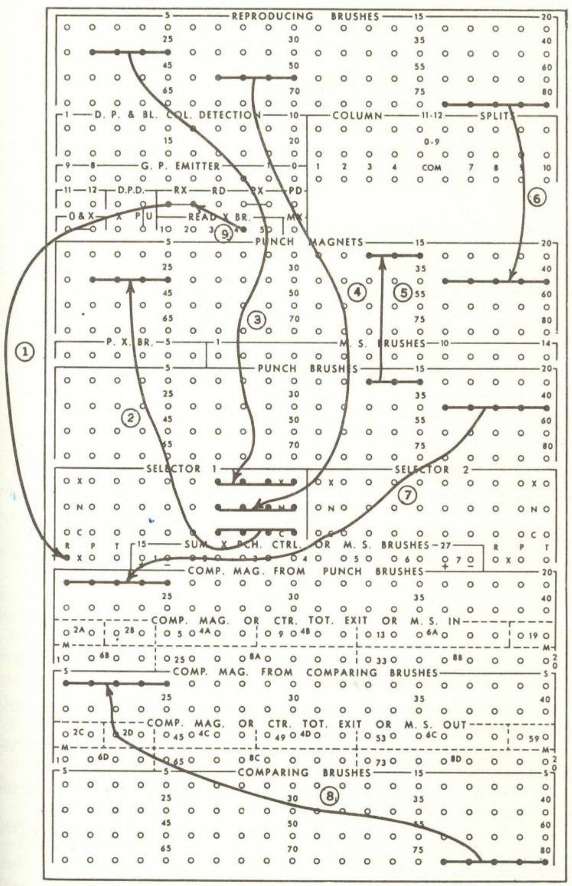


Figure 3.33 Plugboard wiring for IBM 514

- Plugboard wiring diagram
  - It doesn't look too complicated, does it?

Data Processing

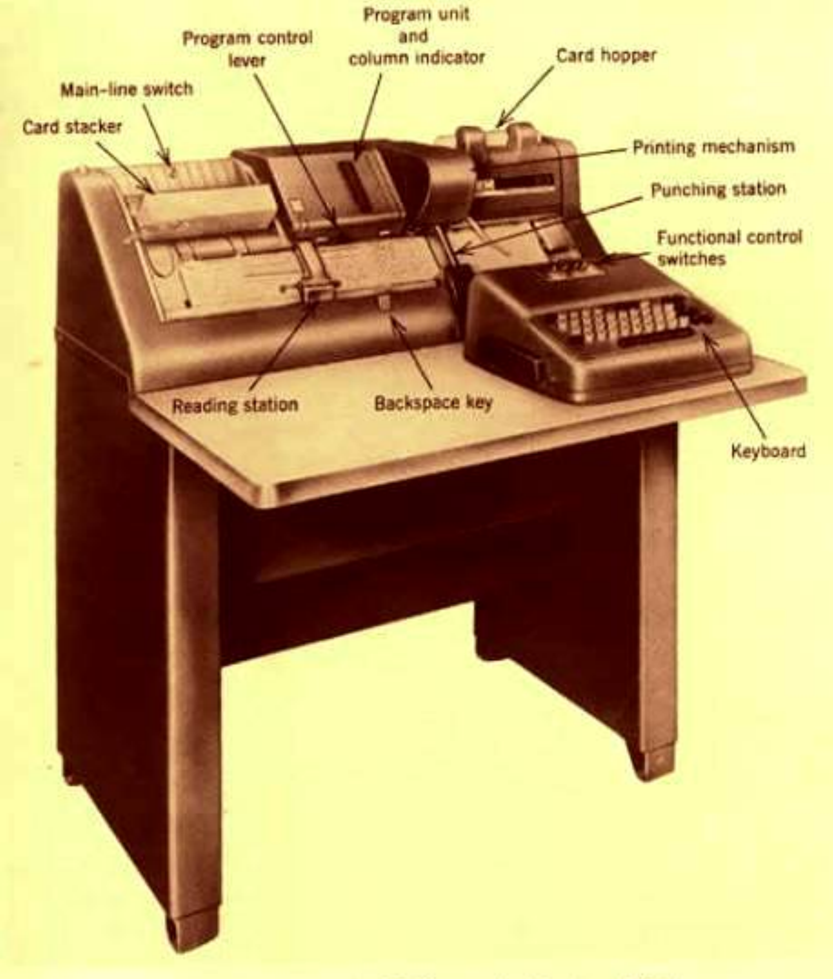


FIGURE 4.11 IBM 026 Keypunch (Courtesy IBM).

- Cards were punched manually at a keypunch machine.
  - Or they were punched automatically by unit-record equipment under program control.

Data Processing

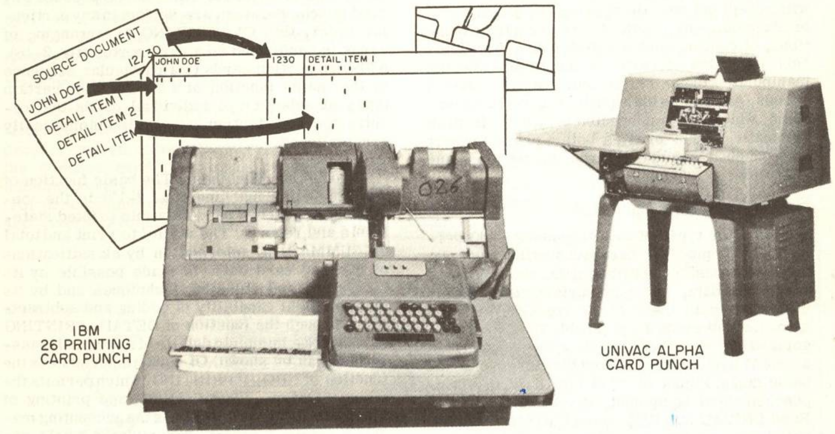


Figure 2-14.—Converting source data to punched cards.

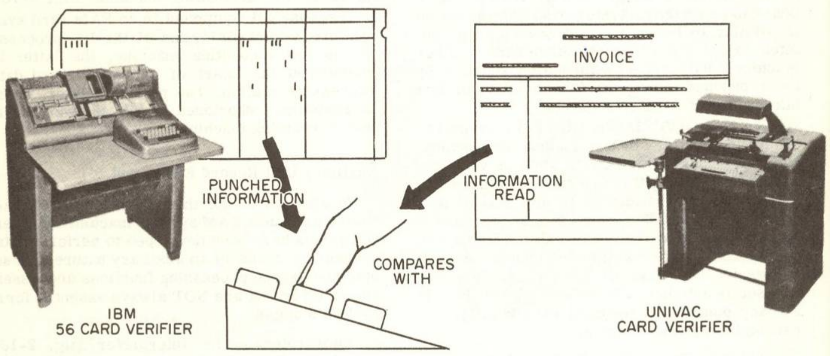


Figure 2-15.—Checking the accuracy of the original keypunching.

- Cards were re-keyed on a verifier to ensure accuracy.
  - Good cards were notched at the top right edge.
  - Bad cards were notched at the top edge above each erroneous column.

Data Processing

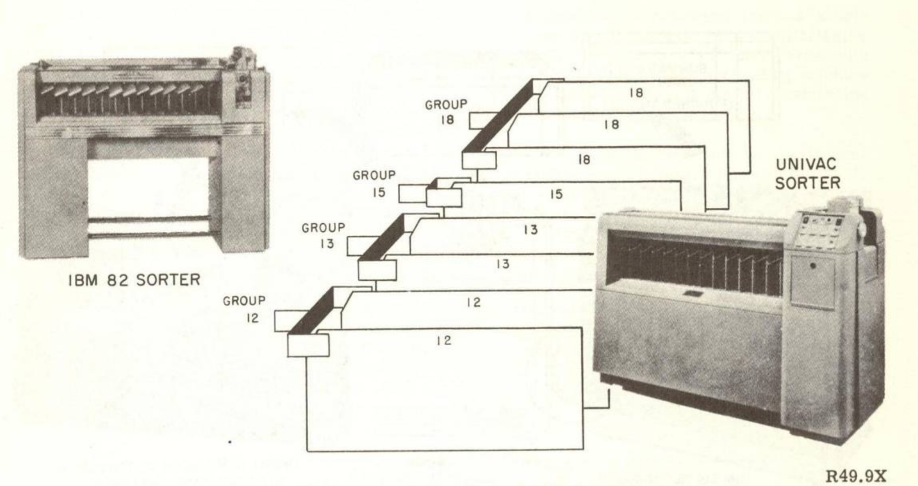


Figure 2-16.—Grouped cards in a definite sequence.

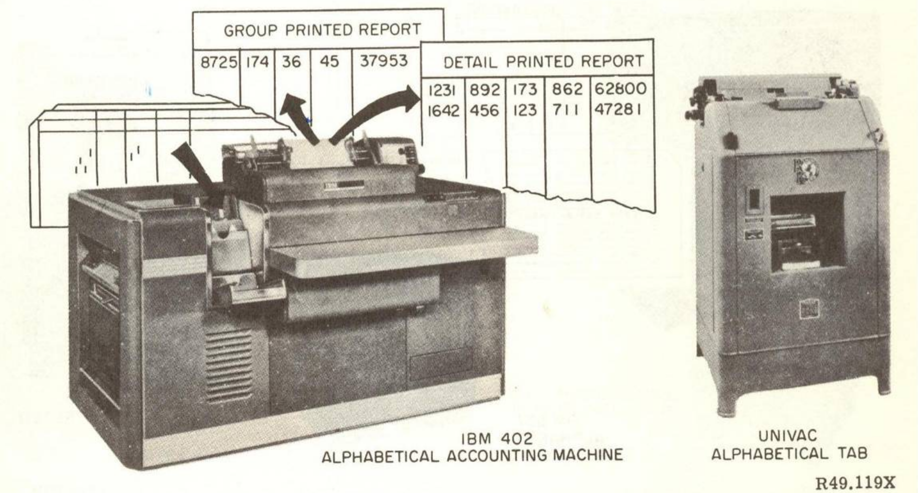


Figure 2-17.—End of the line processing.

- A sorter sorted cards one column at a time.
  - You had to run decks of cards multiple times through a sorter.
- Accounting machines performed arithmetic on card fields and printed reports.

Running a Data Processing Application ...

- ... meant passing decks of cards through a sequence of unit-record machines.
  - Each machine was programmed via its plugboard to perform its task for the application.
  - Each machine had little or no memory.
  - The punched cards stored the data records
  - The data records moved as the cards moved.

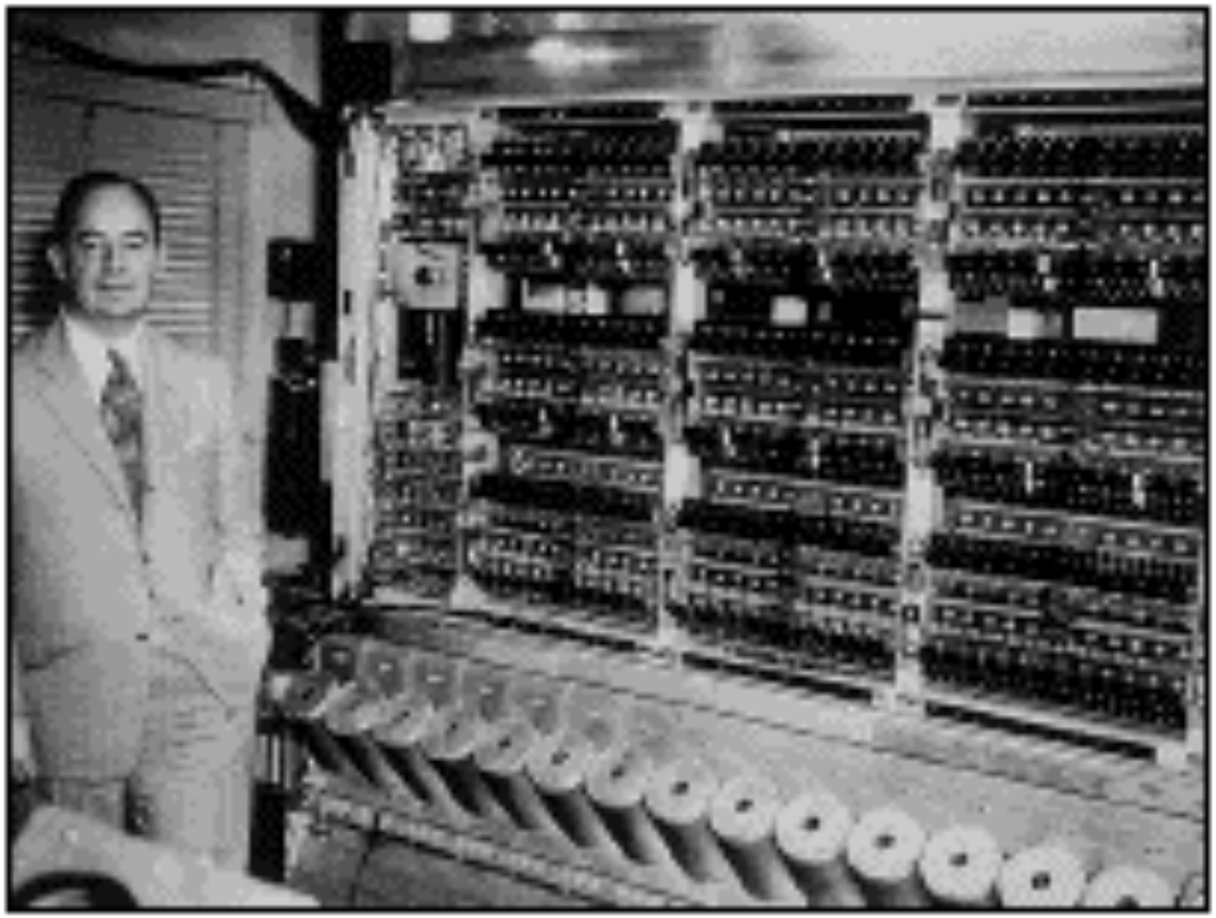
An entire work culture evolved around punched cards!

Von Neumann Bottleneck

- Von Neumann architecture uses the same memory for instructions (program) and data.
- The time spent in memory accesses can limit the performance. This phenomenon is referred to as *von Neumann bottleneck.*
- To avoid the bottleneck, later architectures restrict most operands to registers (temporary storage in processor).

Ref.: D. E. Comer, *Essentials of Computer Architecture*, Upper Saddle River, NJ: Pearson Prentice-Hall, 2005, p. 87.

John von Neumann (1903-1957)



Second Generation Computers

- 1955 to 1964
- Transistor replaced vacuum tubes
- Magnetic core memories
- Floating-point arithmetic
- High-level languages used: ALGOL, COBOL and FORTRAN
- System software: compilers, subroutine libraries, batch processing
- Example: IBM 7094

Third Generation Computers

- Beyond 1965
- Integrated circuit (IC) technology
- Semiconductor memories
- Memory hierarchy, virtual memories and caches
- Time-sharing
- Parallel processing and pipelining
- Microprogramming
- Examples: IBM 360 and 370, CYBER, ILLIAC IV, DEC PDP and VAX, Amdahl 470

C Programming Language and UNIX Operating System

1972

Now

The Current Generation

- Personal computers
- Laptops and Palmtops
- Networking and wireless
- SOC and MEMS technology
- And the future!
    - Biological computing
    - Molecular computing
    - Nanotechnology
    - Optical computing
    - Quantum computing

Running Program on Processor

$$\text{Processor Performance} = \frac{\text{Time}}{\text{Program}}$$

$$= \frac{\text{Instructions}}{\text{Program}} \times \frac{\text{Cycles}}{\text{Instruction}} \times \frac{\text{Time}}{\text{Cycle}}$$

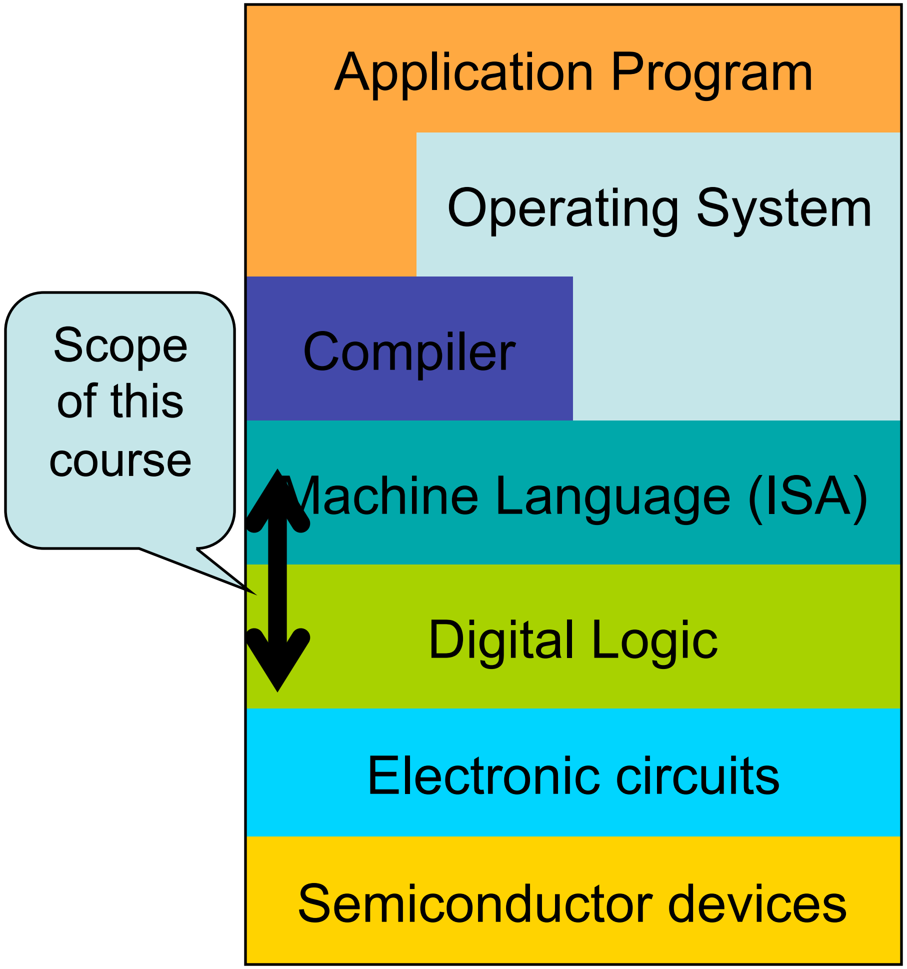
(code size) (CPI) (cycle time)

Architecture --> Implementation --> Realization

Compiler Designer **Processor Designer** **Chip Designer**

Abstraction and Complexity

- Abstraction helps us manage complexity
- Complex interfaces
  - Specify what to do
  - Hide details of how
- Goal: remove magic



Computer Architecture

- Exercise in engineering tradeoff analysis
  - Find the fastest/cheapest/power-efficient/etc. solution
  - Optimization problem with 100s of variables
- All the variables are changing
  - At non-uniform rates
  - With inflection points
  - Only one guarantee: Today's right answer will be wrong tomorrow
- Two high-level effects:
  - Technology push
  - Application Pull

Technology Push

- What do these two intervals have in common?
  - 1776-1999 (224 years)
  - 2000-2001 (2 years)
- Answer: Equal progress in processor speed!
- The power of exponential growth!
- Driven by Moore's Law
  - Device per chips doubles every 18-24 months
- Computer architects work to turn the additional resources into speed/power savings/functionality!

Some History

Date	Event	Comments
1939	First digital computer	John Atanasoff (UW PhD ’30)
1947	1st transistor	Bell Labs
1958	1st IC	Jack Kilby (MSEE ’50) @TI Winner of 2000 Nobel prize
1971	1st microprocessor	Intel
1974	Intel 4004	2300 transistors
1978	Intel 8086	29K transistors
1989	Intel 80486	1.M transistors, pipelined
1995	Intel Pentium Pro	5.5M transistors
2005	Intel Montecito	1B transistors

Performance Growth

Unmatched by any other industry !
[John Crawford, Intel]

- Doubling every 18 months (1982-1996): 800x
  - Cars travel at 44,000 mph and get 16,000 mpg
  - Air travel: LA to NY in 22 seconds (MACH 800)
  - Wheat yield: 80,000 bushels per acre

- Doubling every 24 months (1971-1996): 9,000x
  - Cars travel at 600,000 mph, get 150,000 mpg
  - Air travel: LA to NY in 2 seconds (MACH 9,000)
  - Wheat yield: 900,000 bushels per acre

Thank You