Lesson Outline

◆ Computer Architecture (in a nutshell)
◆ The Vacuum Tube
◆ The UNIVAC
◆ IBM 701 “Defense Calculator”
◆ IBM 650 “Magnetic Drum Data Processing Machine”
◆ Hardware Advancements
  • Ferrite Core Memory
  • Magnetic Tape Storage
◆ Engineering Research Associates
◆ Other Small Computer Manufacturers
Lesson Outline

- **Programming**
  - Machine Language
  - Assembler Language
  - FORTRAN
  - COBOL
  - ALGOL

- **Printers**

- **The Disk Drive**

- **The IBM 1401 Data Processing System**

- **Control Data Corporation**

- **Digital Equipment Corporation (DEC)**

- **The Transistor**
Computer Architecture (in a nutshell)

Central Processing Unit (CPU)

- ALU
- Registers
- Cache
- Control

Bus

Main Memory ("RAM")

- Insts. & Data
- DMA

I/O Controllers

Bus

I/O Devices
Central Processing Units
Main Memory
Computer Attributes

- Word Length
  - Usually in bits, maybe in characters

- Register Structure
  - Accumulator, Index Register(s), General-purpose Registers

- Addressing

- Memory Size

- Floating Point Arithmetic

- I/O Architecture
  - Channels

- Processing Speed
  - Cycle time
  - MIPS
  - FLOPS (Megaflops, gigaflops, teraflops)

<table>
<thead>
<tr>
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<th>Exponent</th>
<th>Units</th>
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<tr>
<td>Kilo</td>
<td>$10^3$</td>
<td>(thousand)</td>
</tr>
<tr>
<td>Mega</td>
<td>$10^6$</td>
<td>(million)</td>
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<tr>
<td>Giga</td>
<td>$10^9$</td>
<td>(billion)</td>
</tr>
<tr>
<td>Tera</td>
<td>$10^{12}$</td>
<td>(trillion)</td>
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<tr>
<td>Peta</td>
<td>$10^{15}$</td>
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<tr>
<td>Exa</td>
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<tr>
<td>Milli</td>
<td>$10^{-3}$</td>
<td>(1 thousand)</td>
</tr>
<tr>
<td>Micro</td>
<td>$10^{-6}$</td>
<td>(1 millionth)</td>
</tr>
<tr>
<td>Nano</td>
<td>$10^{-9}$</td>
<td>(1 billionth)</td>
</tr>
<tr>
<td>Pico</td>
<td>$10^{-12}$</td>
<td>(1 trillionth)</td>
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</table>
The Vacuum Tube (Triode)

- Early version invented by Thomas Edison while working on light bulb
- Acts as both a switch (like a Relay) and an amplifier
  - As the latter, major component of HiFi amps for many years
- Generates a stream of electrons by heating cathode
  - Uses lots of power, generates lots of heat, relatively unreliable
  - But, much faster than relays, no moving parts
- Also called “valve”, “electron valve”, etc.
The UNIVAC

- Universal Automatic Computer
- Designed and Built by Eckert & Mauchly, working for a division of Remington Rand Corp.
- First electronic, stored-program computer to be produced and sold to the commercial market
- Used for general purpose computing with large amounts of input and output
- The first installation, in 1951, was at U.S. Census Bureau
- The first commercial customers to purchase a UNIVAC were the Prudential Insurance Company and General Electric.
- A total of 46 UNIVAC Model 1s were ultimately built for government and commercial use from 1951 to 1958
The UNIVAC

- 25 feet deep by 50 feet in length
- Contained 5,600 tubes, 18,000 crystal diodes, and 300 relays
- Had an internal storage capacity 1,000 words or 12,000 characters.
- Utilized a mercury delay line, magnetic tape, and typewriter output (and was the first computer to use buffer memory)
- Power consumption was about 120 kw
- Reported processing speed was 0.525 milliseconds for addition/subtraction, 2.15 milliseconds for multiplication and 3.9 milliseconds for division.
# Early UNIVAC Customers

**UNIVAC installations, 1951–1954**

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<tr>
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<th>Customer</th>
<th>Comments</th>
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<td>1951</td>
<td>U.S. Census Bureau</td>
<td>Suitland, MD Not shipped until 1952</td>
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<td>1952</td>
<td>U.S. Air Force</td>
<td>Pentagon, Arlington, VA</td>
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<td>1952</td>
<td>U.S. Army Map Service</td>
<td>Washington, DC Operated at factory April-September, 1952</td>
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<tr>
<td>1953</td>
<td>New York University</td>
<td>For the Atomic Energy Commission, New York, NY</td>
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<td>1953</td>
<td>Atomic Energy Commission</td>
<td>Livermore, CA</td>
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<td>1953</td>
<td>U.S. Navy</td>
<td>David W. Taylor Model Basin, Bethesda, MD</td>
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<td>1954</td>
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<td>General Electric</td>
<td>Appliance Division, Louisville, KY. First business sale.</td>
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<td>1954</td>
<td>Metropolitan Life</td>
<td>New York, NY</td>
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<td>1954</td>
<td>U.S. Air Force</td>
<td>Wright-Patterson AFB, Dayton, OH</td>
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<td>U.S. Steel</td>
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<td>1954</td>
<td>Du Pont</td>
<td>Wilmington, DE</td>
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<td>U.S. Steel</td>
<td>Gary, IN</td>
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<td>1954</td>
<td>Franklin Life Insurance</td>
<td>Springfield, IL</td>
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<td>Westinghouse</td>
<td>Pittsburgh, PA</td>
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<td>1954</td>
<td><strong>Pacific Mutual Life Insurance</strong></td>
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<td>1954</td>
<td>Sylvania Electric</td>
<td>New York, NY</td>
</tr>
<tr>
<td>1954</td>
<td>Consolidated Edison</td>
<td>New York, NY</td>
</tr>
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</table>

*(Paul E. Ceruzzi, A History of Modern Computing)*
The UNIVAC (with Grace Hopper)
UNIVAC Tape Units and Metal Tape

- Nickel-plated bronze metal alloy ½” digital recording tape
- One eight-inch reel was equivalent to 1,400,000 characters, or almost 20,000 punched cards worth of information
UNIVAC Vacuum Tubes, Boards, and Mercury Delay Lines
UNIVAC and Walter Cronkite (and Eckert)

Correctly predicted Eisenhower’s upset victory against Stevenson in 1952 after 1% of votes were counted.
Not on the Drawing Board, Not “On Order”…

IN ACTUAL BUSINESS USE!

The Remington Rand UNIVAC is the only completely self-checked electronic data-processing system now being delivered... the only one actually proven in business use. No comparable system handles alphabetical and numeric data to turn out payrolls, control inventories, and perform the other down-to-earth routine tasks vital to American industry.

In today's competitive market, the company which cuts its overhead first comes out on top. UNIVAC is already at work in many organizations, so don't wait until 1956... 1957... or 1958 to cash in on the tremendous savings available with this large-scale electronic business system. The time to act is now, to prevent your lagging perilously behind competition in the years to come.

There's no need to wait for equipment which is “just around the corner.” Read why, in an impartial article on electronic computing for business, written by management consultants of a nationally known public accounting firm. Write to Room 1267, at the address below, for your free copy of this informative survey, “Electronics Down To Earth.”
IBM 701 Defense Calculator (1952) "Electronic Data Processing Machine"
IBM 701 Defense Calculator (1952)  
“Electronic Data Processing Machine”

Thomas J. Watson, Sr., at 701 Console  
2000 multiplications/sec. (~4X UNIVAC)
Ferrite Core Memory
Ferrite Core Memory

Users of the IBM 701 could specify the 737 Magnetic Core Storage Unit. The 737 reduced the time needed to perform Additions from 60 microseconds to 36 microseconds. The unit had a capacity of 4,096 36-bit words.

This later (S/360) external memory “frame” also contained 16KB of main memory.
Magnetic Tape Storage
Announced by IBM in 1953, the 650 used a magnetic drum 4 inches by 16 inches, which turned at 12,500 RPM.

- It could use magnetic tape storage, as well as punched cards or typewriters for input/output.
- Various models were produced up until 1965. The basic unit weighed between 2,000 and 3,000 pounds and was about 5 x 3 x 6 feet in size.
- The 650 could perform addition or subtraction functions in 1.6 milliseconds, multiplication in about 13 milliseconds, and division in about 17 milliseconds.
- The 650 was extremely successful; it became the most popular medium-sized computer in America. About 1,800 were sold overall, and it was the first computer ever to sell more than 1,000 units.
IBM 650 Magnetic Drum Data Processing
Engineering Research Associates

- Group worked together for the Navy in W.W. II
- Moved to Minneapolis/St. Paul area and started ERA
  - Howard Engstrom and William Norris led the move
  - Performed (mostly secret) projects (“tasks”) for the Navy
  - Hired young UMinn graduate named Seymour Cray
- ERA Task Number 13: Design and build a general-purpose electronic computer
  - “Atlas” became commercial ERA 1101 in 1951 \( (1101_2 = 13_{10}) \)
    - ERA made advances in and used drum-based memory
    - Also sold drum memories to other small manufacturers
- In 1952, acquired by Remington Rand and merged into Univac Division
  - Renamed Univac 1101
  - Followed by 1103 in 1953
  - Per NACA, added core memory and interrupt facility
Other Small Computer Manufacturers

- **Computer Research Corporation (CRC)**
  - Former Northrop Aircraft Employees (worked on CPC)
  - Used ERA drums
  - Later acquired by NCR

- **Electronic Computer Corporation**
  - Founded by a member of original Univac team
  - Acquired by Underwood (typewriter company)

- **Consolidated Engineering**
  - Acquired by Burroughs

- **Librascope/General Precision LGP-30**
  - 113 Tubes, 1350 Diodes, size of a very large office desk

- **Bendix G-15**
  - Bendix founded by Harry Huskey, once Turing co-worker
  - Computer business later taken over by Control Data Corp.
Programming

Types of Programming Languages:

- Machine Language
  - Binary (zeroes and ones)
  - Only language the computer really “understands”

- Low-Level Language:
  - Assembly Language
    - Symbolic code for machine-level instructions
    - One machine language instruction for each assembly language statement

- High-Level Languages
  - Languages such as FORTRAN, COBOL, ALGOL, C, PL/I etc., etc.
  - One statement usually generates many machine instructions
  - Often domain-specific
    - E.g., scientific languages, business languages, string-processing languages, etc.
Programming

Contents of Main Memory:
- Instructions (in a stored-program computer)
- Data
  - Numbers (fixed decimal, floating point)
  - Characters (i.e., printable letters, numbers, symbols)
    - Character sets (ASCII, EBCDIC)
- All intermixed. How do we know which is which?

A simple sample architecture:
- 8-bit characters (bytes), using ASCII
- 4-byte (32-bit) words
- 4 General-Purpose Registers (0-3, 32 bits each)
  - Note that this requires only 2 bits of register addressing ($2^2 = 4$)
- 64KB of byte-addressable main memory (0-65535)
  - Note that this requires only two bytes of addressing ($2^{16} = 65536$)
Programming

- A simple sample architecture (continued):
  - 10 Instructions:
    - Load: copy 1 word from memory to a register
    - Store: copy 1 word from a register to memory
    - Set: set a register to a specific value
    - Add: add second register to first, result in first register
    - Sub: subtract second register from first, result in first register
    - Mul: multiply 2 registers, results in first and second registers
    - Div: divide first register by second, result in first & second registers
    - Comp: compare two registers
    - Jump: (conditionally) change next instruction pointer
    - Halt: stop program
  - This set:
    - Does only fixed-point, 32-bit arithmetic (no floating point)
    - Does not process characters (no character ops)
    - Does not handle I/O operations (and a LOT more)
Programming

- A simple sample architecture (continued):
  - Instruction Operation Codes (Op Codes)
    - Load: 0001 0001 (11)  
      - load  
      - reg, address
    - Store: 0001 0010 (12)  
      - store  
      - reg, address
    - Set: 0001 0011 (13)  
      - set  
      - reg, value
    - Add: 0010 0001 (21)  
      - add  
      - reg₁, reg₂
    - Sub: 0010 0010 (22)  
      - sub  
      - reg₁, reg₂
    - Mult: 0010 0011 (23)  
      - mult  
      - reg₁, reg₂
    - Div: 0010 0100 (24)  
      - div  
      - reg₁, reg₂
    - Comp: 0011 0001 (31)  
      - comp  
      - reg₁, reg₂
    - Jump: 0011 0010 (32)  
      - jump  
      - cond, address
    - Halt: 0000 0000 (00)  
      - halt
Programming

- The Problem
  - Compute n Factorial (n!)
    - $1 \times 2 \times \ldots \times (n-1) \times n$
      - $3! = 6$
      - $5! = 120$
  - We will assume:
    - The value for “n” is in a known place in memory
      - It is a value $\geq 1$
    - We only need to store the result, not display it
      - I/O is ignored for this example
Programming

- Machine Language Solution:
  - Assumes “n” stored in location 00100, result stored at 00104

<table>
<thead>
<tr>
<th>Address</th>
<th>Instruction</th>
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<tr>
<td>000000</td>
<td>11100100</td>
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<tr>
<td>000004</td>
<td>13200001</td>
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<td>000008</td>
<td>13300001</td>
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<td>000012</td>
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<td>000026</td>
<td>12200104</td>
</tr>
<tr>
<td>000030</td>
<td>00</td>
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</table>
Assembler Language Solution

n equ 00100 address of “n"
result equ 00104 address of “result”

Start
load R1, n load value of “n”
set R2, 1 will hold final result
set R3, 1 constant “1” (in this pgm)

Loop
comp R1,R3 are we done?
jump LE, Done yes…
mult R2, R1 multiply values
sub R1, R3 decrement n
jump Loop continue

Done
store R2, result save the result
halt

Note: This code generates the machine code on the prior page
Programming

• FORTRAN (FORmula TRANslator)
  • Developed by John Backus, et al., at IBM, 1954-1957
  • First implemented on IBM 704
  • Had to be as fast as a hand-assembled program
  • Standards:
    • FORTRAN II (1958), FORTRAN IV (1961), FORTRAN 66, 77
  • Implemented on virtually all computers of 1960s
  • BASIC is heavily based on FORTRAN (more later…)
Programming

- FORTRAN Solution

```
INTEGER   N, RESULT
RESULT = 1
10 IF (N .LE. 1) GOTO 99
RESULT = RESULT * N
N = N – 1
GOTO 10
99 END
```
Programming

- **COBOL (CCommon Business-Oriented Language)**
  - In early to mid 1950s, Grace Hopper worked on simplifying programming for the UNIVAC
    - A0, A1, A2:
      - Systems to “compile” pre-written routines into new program
    - B0, FLOW-MATIC:
      - First English-like data processing language
      - In wide use on UNIVAC by 1958
  - In 1959, US DoD convened group to define a business-oriented computer language
    - Burroughs, Honeywell, IBM, RCA, Sperry, Sylvania
    - USAF, Taylor Model Basin, NBS
    - Results, finalized in 1959, greatly inspired by FLOW-MATIC
    - COBOL-60 spec published in 1960
    - Many versions of COBOL since
      - ANSI COBOL, COBOL-85

“*The use of COBOL cripples the mind; its teaching should, therefore, be regarded as a criminal offense.”* - Edsger W. Dijkstra
Programming

- COBOL solution

... 77 N COMPUTATIONAL PICTURE 9999999999.
77 RESULT COMPUTATIONAL PICTURE 9999999999.
...
MAIN_LOGIC.
  MOVE 1 TO RESULT.
COMPUTE_LOOP.
  IF N IS NOT GREATER THAN 1 THEN
    GO TO ALL_FINISHED.
  MULTIPLY RESULT BY N.
  SUBTRACT 1 FROM N.
  GO TO COMPUTE_LOOP.
ALL_FINISHED.
  STOP RUN.
ALGOL (ALGOritmic Language):

- Developed by a committee of European and American Computer Scientists meeting in Zurich
- Never achieved the acceptance of FORTRAN or COBOL
  - Perhaps because the US Government never required it?
  - More popular in Europe than in US
- Predecessor of many well-structured languages (Pascal, Modula-2, PL/I, C)
- Syntax described in BNF
  - Backus-Naur Form, originally by John Backus (of FORTRAN fame)
- Standards: ALGOL 58, ALGOL 60, ALGOL 68

“Here is a language so far ahead of its time, that it was not only an improvement on its predecessors, but also on nearly all its successors”
- C. A. R. Hoare
Programming

- ALGOL solution

begin
  integer n, result;
  result := 1;
  for i := n step -1 until 1 do
    result := result * i;
  end
Printers

- High-speed input and output increasingly important
  - Financial applications need billing, reports, etc.
  - Typewriter-based devices too slow
    - UNIPRINTER: 10 cps

- Univac High Speed Printer (1953)
  - Rotating Drum Printer
  - 600 lpm (10x130 cps)

- Bar Printer
  - 150 lpm (numeric), 100 lpm (alphanumeric)

- IBM 1403 Line Printer (1959)
  - 600 lpm - 1400 lpm
  - More reliable, higher quality
  - Replaceable print chains
  - Paper “print tape” for high-speed skipping
The Disk Drive: RAMAC

- Developed in 1953-55 by IBM in San Jose
  - …at 99 Notre Dame Ave.

- Model 305 Disk Storage Unit
  - RAMAC – Random Access Method of Accounting Control
  - 50 disks, 24” inch diameter, 1200 rpm
  - 5,000,000 characters (bytes) (~100KB per disk)
The Disk Drive: RAMAC

- Read-write mechanism (heads) in RAMAC:
  - One arm moved up and down the stack of disks (platters)
  - When correct location was reached, arm was inserted between platters
  - Arm has two heads, one for bottom of upper platter, the other for top of lower platter
Disk Architecture

- platters
- spindle
- track
- sector
- cylinder
- arms with read/write heads
- rotation
The Transistor

- Invented in 1947 at AT&T Bell Labs
  - William Shockley, John Bardeen, and Walter Brattain
  - Shockley left off the original patent (but believed it was his idea)
  - All three won Nobel Prize in 1956
- A transistor:
  - is a solid-state semiconductor device
  - can act as an amplifier or a switch (variable valve)
  - has many advantages over vacuum tubes:
    - Smaller size
    - Lower cost
    - Lower operating voltages
    - No warm-up period
    - Lower power dissipation
    - Higher reliability and greater ruggedness to physical shocks
    - Much longer lifetime
The Transistor

- Considered one of the greatest inventions in modern history
  - Hence the Nobel Prize
- The key active component in almost all modern electronics
- Became widely used in computers in mid to late 1950s
The Transistor

Shockley’s Legacy: The Transistor and “Silicon Valley”

- Left AT&T in 1955 to form Shockley Semiconductor in Palo Alto
  - Hired best and brightest east coast engineers
- “Traitorous Eight” left Shockley in 1957 to form Fairchild Semiconductor in Palo Alto (later in Mountain View)
  - Julius Blank, Victor Grinich, Jean Hoerni, Gene Kleiner, Jay Last, Gordon Moore, Robert Noyce, and Sheldon Roberts
- From Fairchild:
  - Robert Noyce and Gordon Moore founded Intel (1968)
  - A group founded Signetics (now Philips Semiconductor) (1961)
  - Another group, led by W.J. Sanders III, founded AMD (1969)
  - Another, led by Charles Sporck, founded National Semiconductor (1967)
  - Intel alumni Frederico Faggin, Ralph Ungermann founded Zilog
  - …many other descendents (see Fairchildren)
IBM 1401 Data Processing System

- On October 5, 1959, the IBM 1401 Data Processing System was announced
  - On closed-circuit TV to 50,000 participants in 102 cities
  - 5,200 systems were ordered in the first five weeks!
    - outnumbering all existing computers in the world and ...
    - the 1401’s lifetime sales forecast

- The 1401 was the first mass-produced digital, all-transistorized, stored-program business computer that could be afforded by many businesses worldwide
  - Had 4000 characters (bytes) of core memory (could be expanded to 16,000 characters)
  - Decimal arithmetic, variable length “words”

- In September 1960 the first 1401 was shipped to Time-Life in Chicago
  - By year end, 100 systems had been delivered
  - By 1965, worldwide installations of 1401s peaked at 9,300
    - 1400 family machines (models 1410, 1440, 1460, 7010) comprised half of all computers worldwide

- First computer to deploy more than 10,000 units
  - Sold from 1959 to 1971
  - About 20,000 units built in all
IBM 1401 Data Processing System

- Card Reader/Punch, tape drive, typewriter printer, 1401 CPU, RAMAC disk, 1403 printer
IBM 1401 DPS

1401 Programmer’s Reference Card

1401 Operator’s Front Panel
Control Data Corporation

- Pre-History:
  - William Norris, Howard Engstrom founded ERA in 1946
  - ERA hired Seymour Cray from UMinn
  - In 1952, ERA was acquired by Remington Rand
    - Merged into Univac division (hence Univac 1101, 1103)
  - In 1955, RR merged with Sperry Corp., formed Sperry Rand
    - Old ERA group disliked “corporate” environment, left in 1957

- Founded Control Data Corporation (CDC) in 1957
  - In Minneapolis, MN
  - William Norris: CEO; Seymour Cray: Chief Designer

- CDC 1604 released in 1959
  - Transistor-based version of 1103 architecture
    (was sued by Sperry)
Digital Equipment Corporation (DEC)

- Ken Olsen left M.I.T.’s Lincoln Laboratory in 1957
  - Had worked on TX-2 computer: transistor-based, 64K words
- With Harlan Anderson (also from MIT), formed DEC
  - In a old mill in Maynard, MA
- Initially built transistor-based “modules” that could be used in computers
- In 1961, started their first computer:
  - PDP-1 (Programmable Data Processor)
- We will see much more of DEC later…
IBM 7090, 7094, “Stretch”

- IBM’s line of “scientific” systems
  - Electronic Data Processing machines, to IBM
  - Tube-based
  - Included 701 (1952), 704 (1955), and 709 (1958)
  - Sometimes referred to as “Mainframes” or “Supercomputers”
- In 1958, first transistorized version, 7090
  - Same architecture as 709
  - Later added 4 additional index registers, became 7094 DPS
IBM 7090, 7094, “Stretch”

- In 1956, IBM set out to build a computer 100 times faster than the 704 (then one of the fastest computers in existence), 4 MIPS.
- Project was called “Stretch”
- Pioneered many advanced computing concepts:
  - Interrupts
  - Memory Interleaving, Protection, Error Detection and Correction
  - Multiprogramming
  - Pipelining
  - Immediate operands
  - Instruction prefetch
  - Speculative execution, result forwarding
- Probably only achieved ~ 30 times 704 (1.2 MIPS)
- Fastest computer in the world for at least 5 years
- First machine (7030) shipped to Los Alamos in 1961
Bring cards to 1401 (or 707, etc.)
Read cards onto input tape
Put input tape on 7094
Perform the computation, writing results to output tape
Put output tape on 1401, which prints output