Lecture 2: Electronic Computing 1940 - 1970

Stephen M. Maurer
Goldman School of Public Policy
smaurer@berkeley.edu

Policy

A Tipping Industry
- Managing Monopoly.
- Standards, innovation, lock-in.

A Divided World
- Military/scientific *vs.* Commercial/governance.

Patents
- Finding New Uses.
- Ex post monopoly price.
- Reward sometimes inadequate.
- Raising capital.

Policy

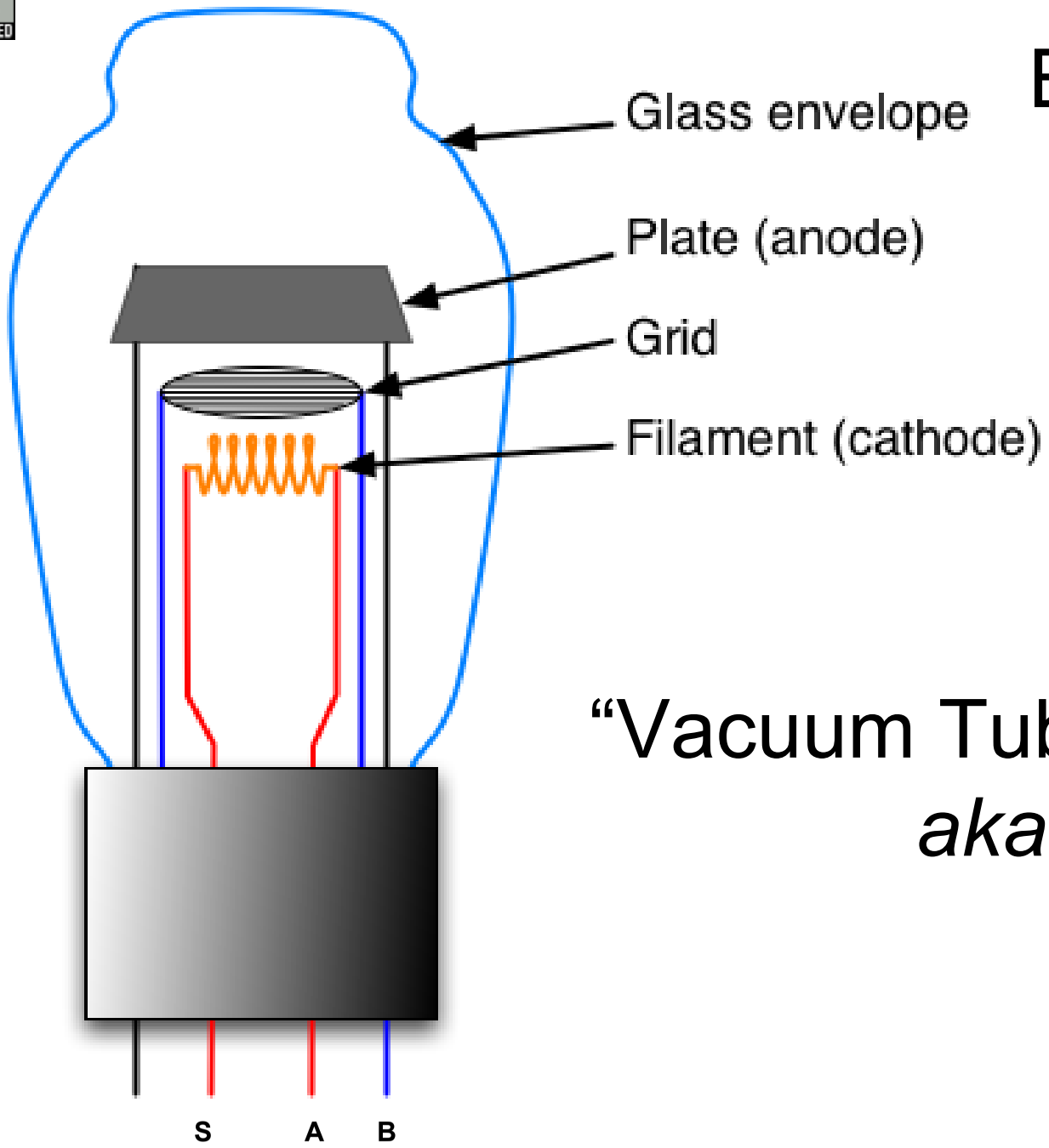
- Prizes
  - No monopoly
  - Specifying the prize condition
  - Raising Capital
- Grants & Contracts
  - When the sponsor knows “v”
  - Agency problems

Wartime

Overview

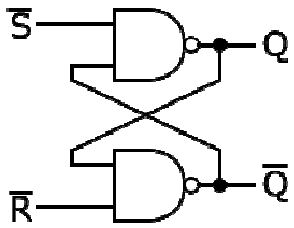
- Going Electronic
- Vannevar Bush and OSRD
  - World War I Experience
  - Organizing Work the Big Science Way
- Ultra, Bletchley Park & All That
  - Colossus (1500 vacuum tubes)
- Stibbitz and ENIAC

Electronics

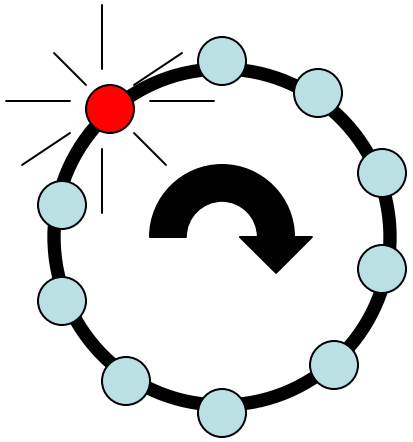


"Vacuum Tubes,"
aka "Valves"

Electronic Logic

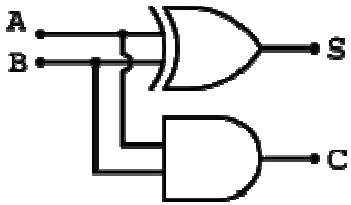


Flip-Flop



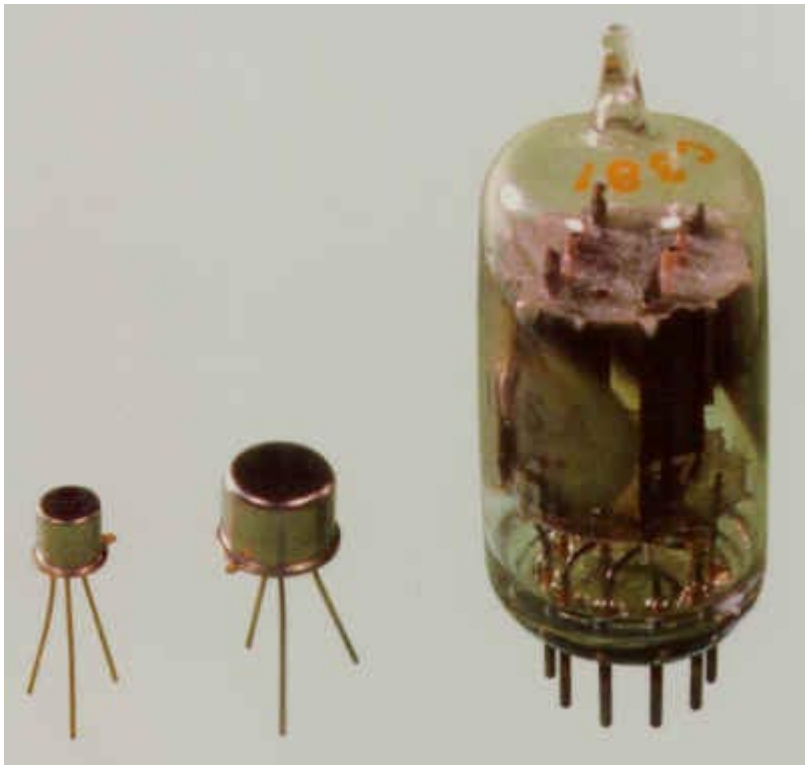
A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

Binary Arithmetic



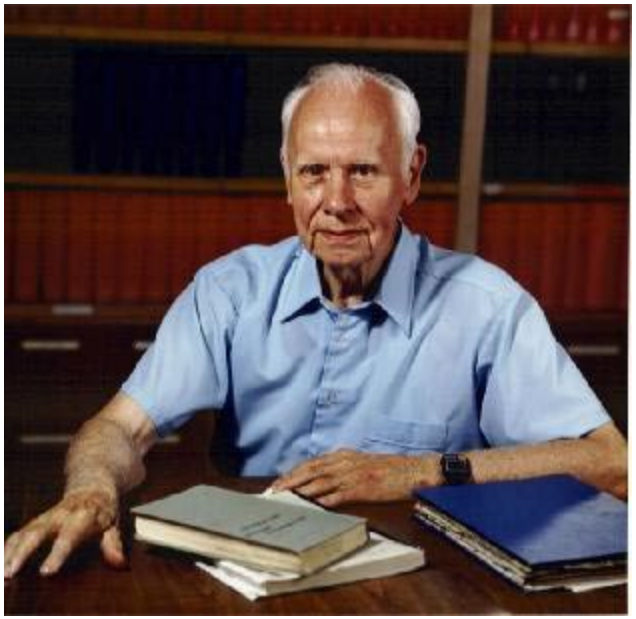
Half-Adder

S = AxorB
C = AandB



Vacuum Tube (Or Relays or Transistors)

George R. Stibitz



Bell Labs (1937)
- Telephone Relays
- Binary Arithmetic

K-Model (1938)

Model 1 (1939) - $20,000

Models 2-5 (1940 - 45)
- Paper tape, error checking, multiplication tables, & storage registers.

NACA and Aberdeen

Atanasoff-Berry

"ABC Computer"

Iowa State (1937 – 39)

Arithmetic – Base 2 Logic

Memory – Drum, Condensers
+ "Jogging"

Output – Cards

No "if" statement.

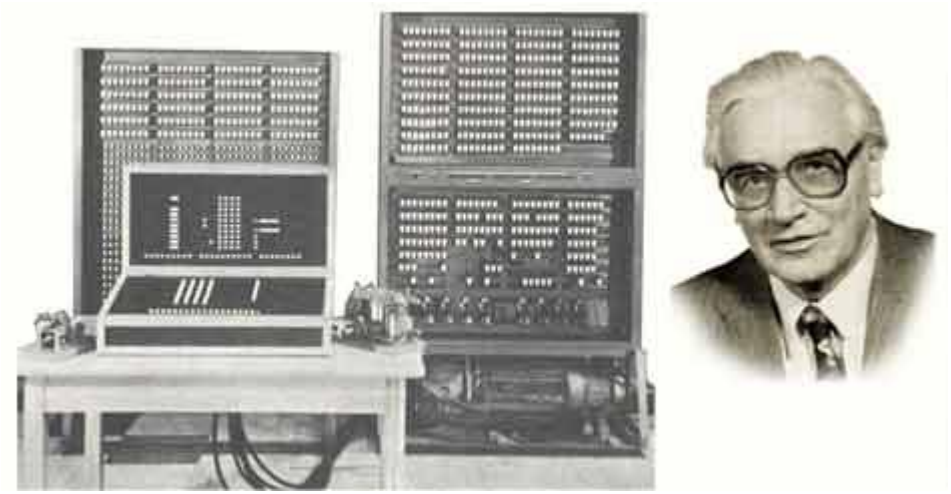
Proposed 300 vacuum tube machine was never completed.

John Vincent Atanassof

Clifford Berry

Konrad Zuse

Z1 Binary Addition (1936).
Mechanical, punched tape.
Z2 Relays (1940).
Z3 Programmable (1941).
2600 relays.
Z4 Refined Z3 (1945)
2000 vacuum tubes.



ENIAC

1939: Fuses instead of vacuum tubes.

1941: An electronic Differential Analyzer

- $486,804.22
- 200,000 man hours

174kw, 17468 vacuum tubes, 500,000 soldered joints, 70,000 resistors, 10,000 capacitors.

Completed in the Fall of 1945, used on “The Super.”

John Mauchly

Presper Eckert

ENIAC

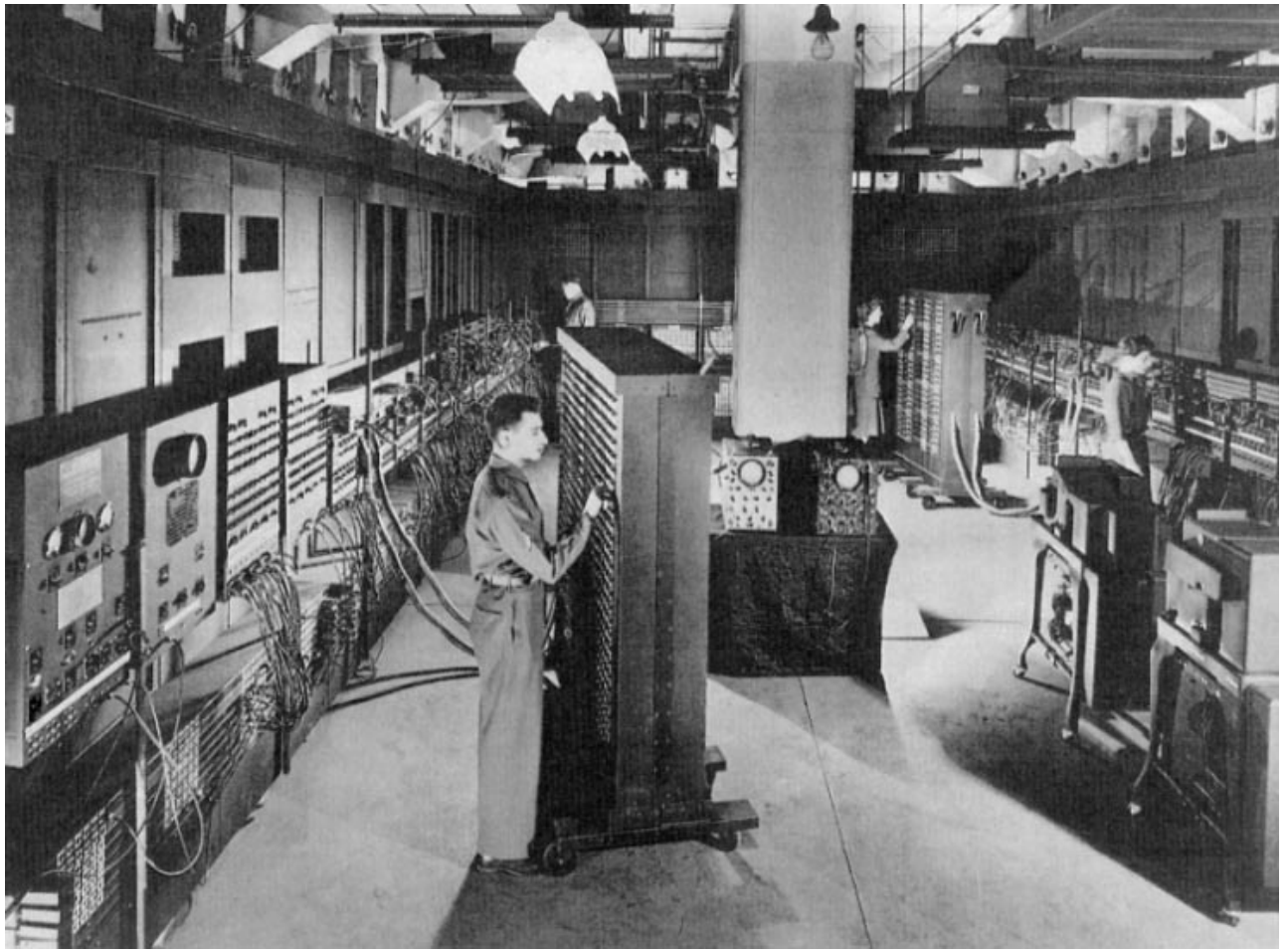
Math Units

- 20 accumulators
  - Flip flop “wheels” + Tables

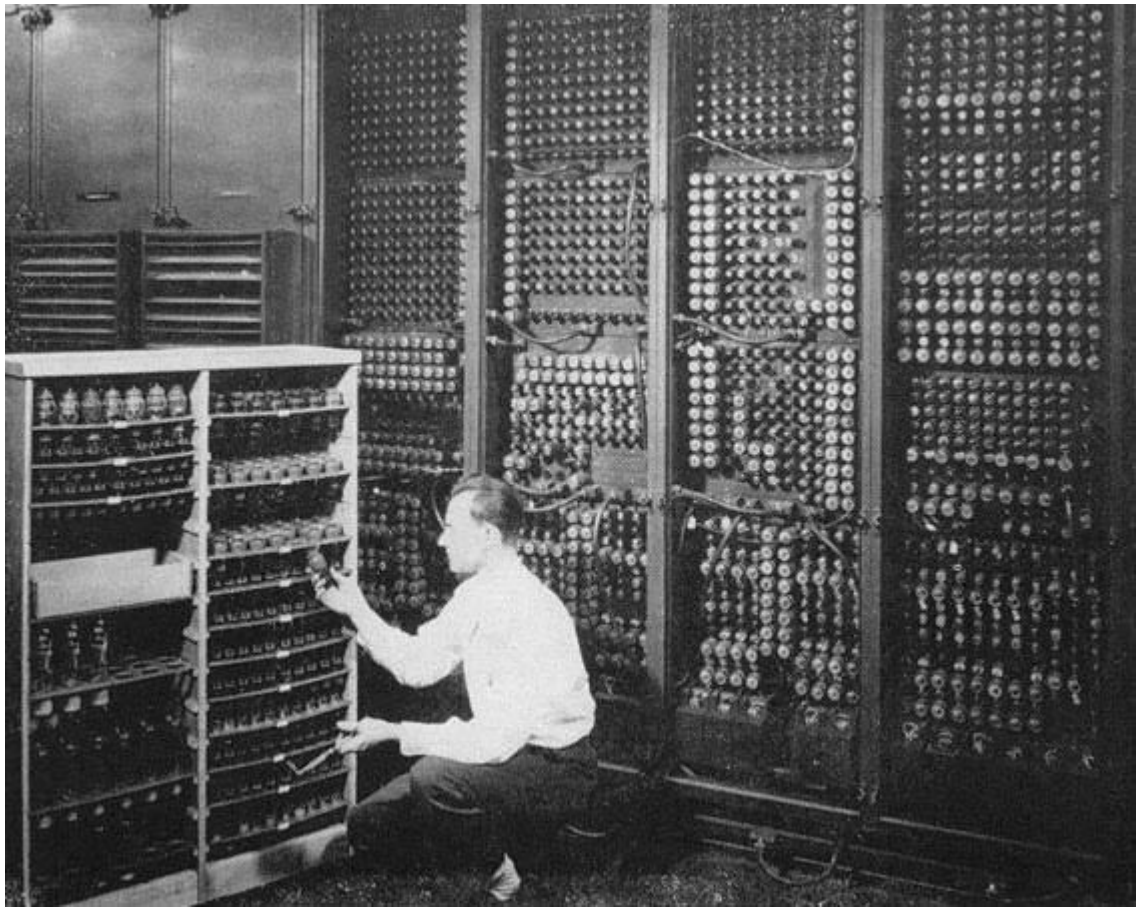
Memory

Program

- Plug board, cables, switches.



ENIAC



Looking Ahead

The Software Concept

The magnetic drum/disk idea (1944)

John von Neumann (1903 – 1957)

First Draft of a Report on the EDVAC (1945)

Policy

The Wartime Research Miracle

- OSRD, National Labs
  - Money
  - The Research Backlog + Focused Projects
  - Industry/Academic Cooperation
  - Big Science Research Model
  - … and Wartime Ethics?

A Role For Patents?

Eckert and Mauchly leave The Moore School.

An essential incentive?
Commercial vs. academic machines.

S. Reid Warren (Moore School): "[The School's patent policy] was very, very naïve. We didn't go out of our way to help people, and our general attitude was, 'Let's make it so it's helpful to the human race and so on.'"

The First Computer Companies

Postwar

New Government Needs

- Weapons Physics & “The Super”
- Cryptography & Intelligence
- Air Defense

- Business Machines?
  - Punch cards dominant until 1962.

Commercializing Computers

- Fragile, Expensive, Unreliable

Technology Trajectory

Internal Memory

1945: Delay lines, Cathode ray tube, drum memory.

1949: Magnetic core.

External Memory

1945: Paper tape, cards, drum.

1950s: Plastic tape, disks.

CPU

Vacuum tubes, transistors (1947), integrated circuits (1959).

University & Government Machines

Moore School Summer School & von Neumann "First Draft."

ENIAC, EDVAC, EDSAC (Cambridge 1949), ILLIAC (Champagne-Urbana 1951), JOHNNIAC (Rand 1953), MADM (Manchester 1953), SWAC (Bureau of Standards 1950), MANIAC (Los Alamos 1952), IAS Machine (Institute for Advanced Study 1951), Ordvac (University of Illinois for Aberdeen 1951), ACE (Turing-built 1946), *etc., etc.*

University & Government Machines

Harvard Mark IV

An Wang (1920 – 1990)

Core memory (1949)

Developed by Whirlwind

Patented 1955, later licensed to IBM

Eckert & Mauchly

Electronic Control Company (1946)

Target customers:

Pari-mutuel companies, aircraft companies, insurance, atomic energy, mapping, academia, aircraft.

Convincing customers:

NAS and Bureau of Standards reports.
Census Bureau Contract (1948)

Capital, Engineering & Marketing problems

Remington Rand (1950)

Engineering Research Associates

Navy and NSA Machines

Technology

- Drum Memory Computers
  - ERA 1101 (1951) (ex-Navy)
  - ERA 1103 (1952) (ex-NSA).

Commercial Weakness

- Manuals, marketing, input-output equipment.

Remington-Rand (1952)

Going Electronic

Thomas J. Watson Sr. (1943)
Thomas J. Watson Jr. (1949)

"These development contracts are of such a nature that they will be very attractive to anyone without previous private experience or patents in the computing field; but the patent provisions make it doubtful if IBM, which has the lead in the field, can afford to participate in the program…Whereas before the war IBM was the only organization able and willing to carry on large scale development of calculators, such development is now taking place on a large scale." (1946)

R&D Initiatives

Selective Sequence Electronic Calculator (1948)

- Last electromechanical computer
- First stored program computer
- 12,500 vacuum tubes
- Used for optics, quantum physics, orbits, and hydrodynamics.

Tape Memory (1948 - 53)

- Mylar-based tape.

Magnetic drum storage (1948 – 1954)

- Harvard Seminar.

Products

IBM 603/604 (1946)

- All-Electronic Calculator
  - 300/1400 tubes.
  - Binary logic
  - 20-60 step internal memory
- 5600 machines.
- 1.5 million vacuum tubes/year.

Card-Programmed Electronic Calculator

- Northrup & “User Innovation”
- 700 built.

Early Computers

Univac

UNIVersal Automatic Computer

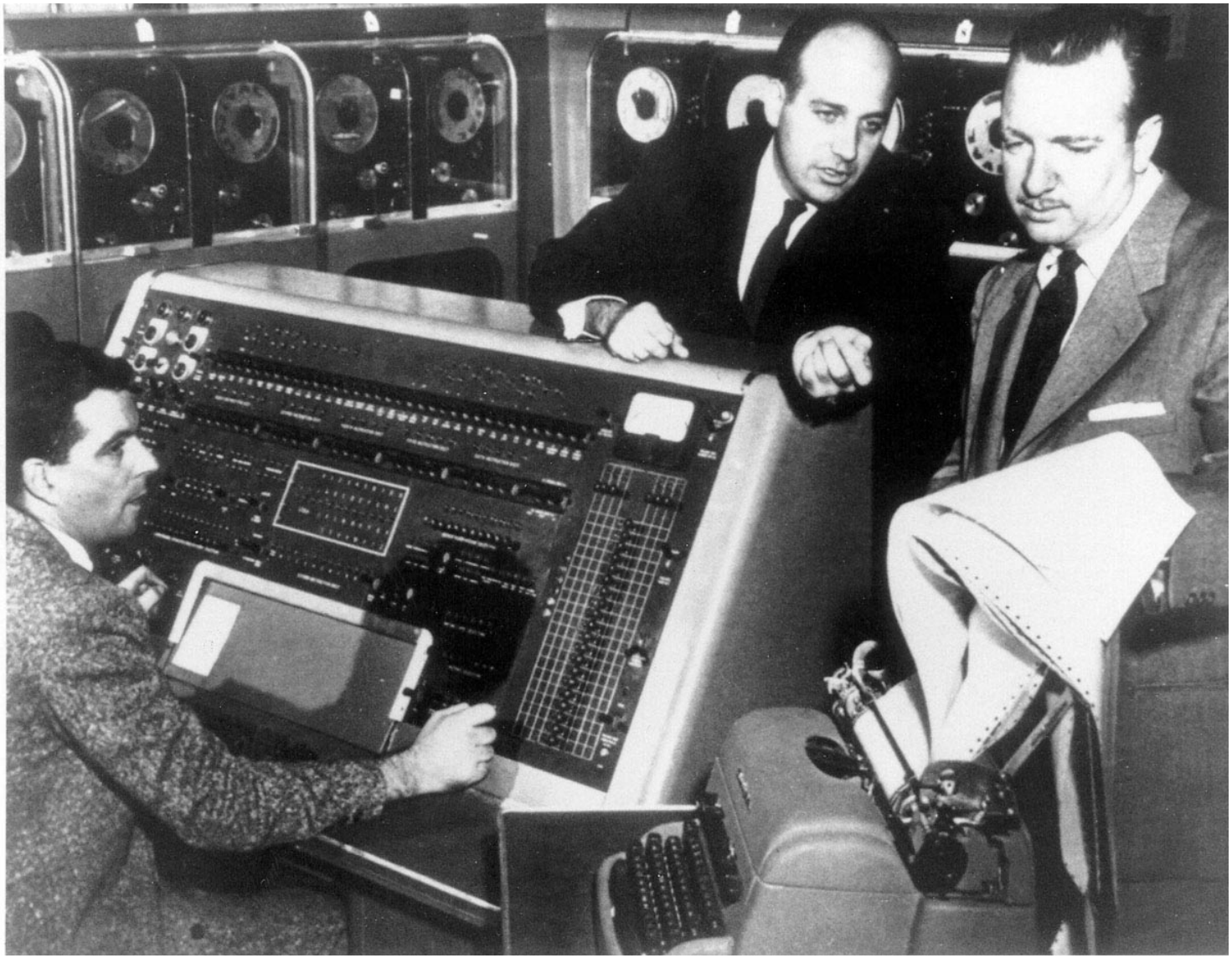
- Paper tape + Delay line memory.
- $1m each.
- Typewriter output,high speed printer (1954)

Univac

Univac

1951: First sale to Census.
1952: Eisenhower Election.

Univac



Univac

1954:

General Electric, DuPont, US Steel, USAF…

$1m each – Production problems.

20 sold by 1954.

vs. 19 IBM 701s

100s of IBM Card-Programmed Calculators.

1000s of IBM punch card machines.

Univac

"[P]erhaps the most radical idea which business is being asked to accept is the idea that a reel of tape can safely be used to carry information now being entrusted to visual card files."

Chief Actuary,
Metropolitan Life Insurance Company (1953)

Univac

Betting on Technology/Price

- Small Sales Force
  - Customers could not see value.
- Small Field Engineering Staff
  - Reliability issues.
- Perpetually changing design.
  - Missed deadlines, confused tech support.

ERA 1103

Twenty built.

Problems regarding “pricing, rental, field service, installation, customer training, and support.”

IBM 701 (1952)

"Defense Calculator"

Magnetic drum + Mylar tape + Punch Cards

19 produced for aircraft companies, government labs & universities.

IBM 701

Improved Versions: IBM 704 (1954), 709 and all-transistor 7090.

- Compatible software
- 7090 is all-transistor, originally built for USAF.

IBM 702 (1953)/IBM 705 (1954)

Delayed 1948 “Tape Processing Machine”

Cathode ray memory makes 702 competitive with Univac

705 has Magnetic Core Memory.

R&D

Transistors (1951 - 59)

Disk storage (1952 – 56)

Software

Software ~ Rental costs.

Customer Lock-In

User Innovation

- SHARE and GUIDE (1955)
- UNIVAC, Burroughs, Bendix.

Fortran (1957)

Policy

Academic Research

- Asserting patent rights against IBM?

Customer Innovation

- Monopolists and complements
- What's new about GPL?
- Tapping information about user needs.

Reliability and service.

Whirlwind & SAGE

Whirlwind & SAGE

Whirlwind

Whirlwind II/SAGE

A $500m subcontract

AN/FSQ-7

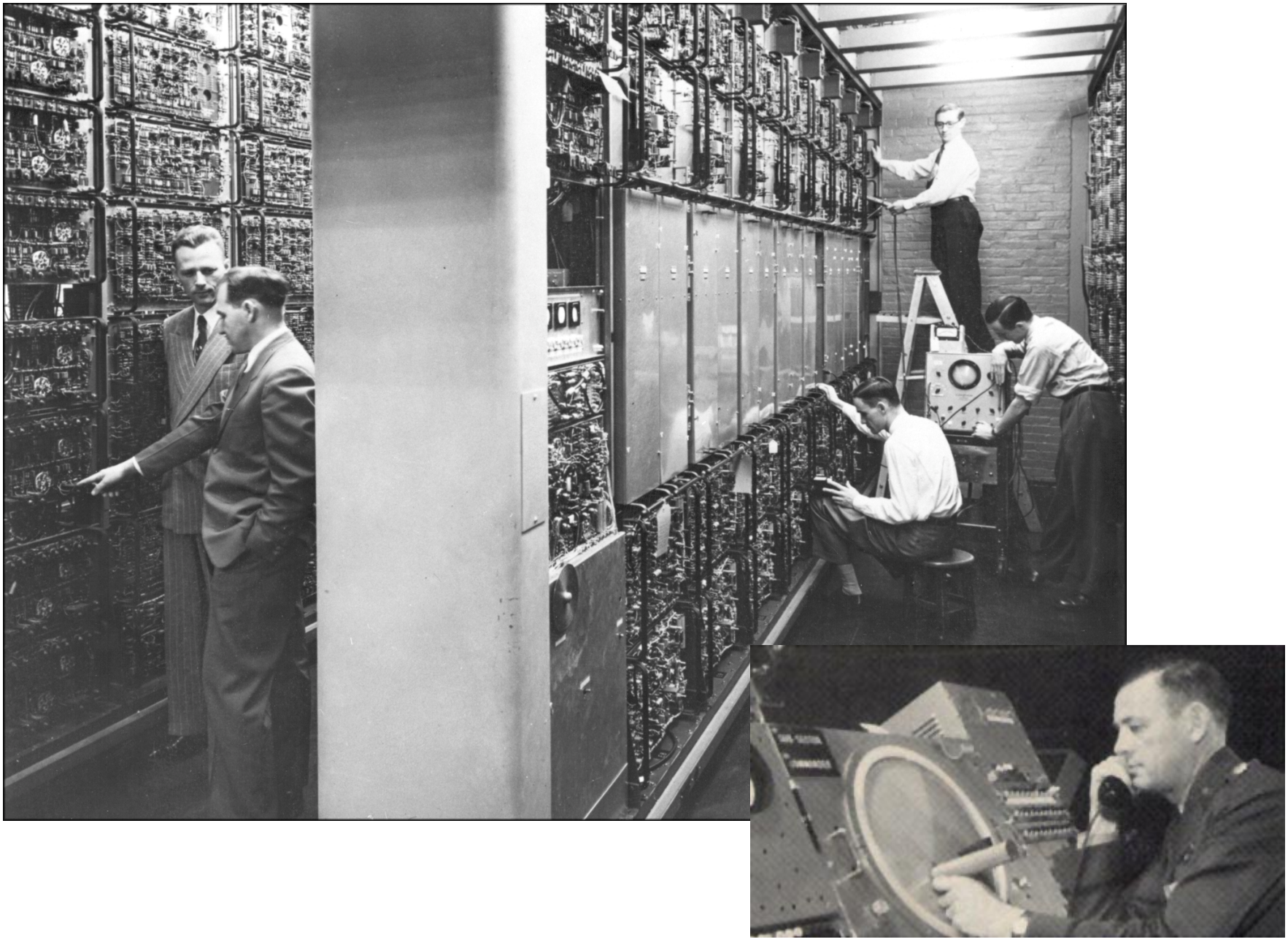
275 tons/919 miles of cable/50,000 vacuum tubes/consumed 3MW of power

800 programmers -- 20% of the world's supply

500,000 lines of code.

Magnetic core memory, large real time OS, overlapping of computation and IO functions, use of phone lines, cathode ray tube displays with light pens, high reliability.

Whirlwind II



IBM gets the Bid

"Kingpin"

"[T]he trouble with IBM would be its traditional secretiveness."

Jay Forester: In the IBM organization we observed a much higher degree of purposefulness, integration, and esprit de corps than we found in the Remington Rand organization. Also, of considerable interest to us, was the evidence of much closer ties between research, factory, and field maintenance in IBM.

IBM Gets the Bid

Benefits to IBM

Mass production of ferrite core memory

7000 employees manufacturing, installing, servicing, and improving system

SABRE ($300m) and ATC spinoffs.

Other Benefits

Lincoln Lab, DEC, Mitre Corporation, and Route 128.

Antitrust (1952 - 1956)

Grounds: Predatory Pricing, Incompatible Cards, Buying Up Patents, Using Leases to Block innovation, Binding Inventors to Exclusive Contracts.

Relief: Mandatory cross-licensing of patents.

Opening the card market.

Foster competition in repair, secondhand sales, and service bureaus.

Policy

DoJ vs. DoD

- 3 million installed vacuum tubes
- What if Remington-Rand had won?

The Industry Takes Off: 1954 - 1960

The Crisis Year - 1954

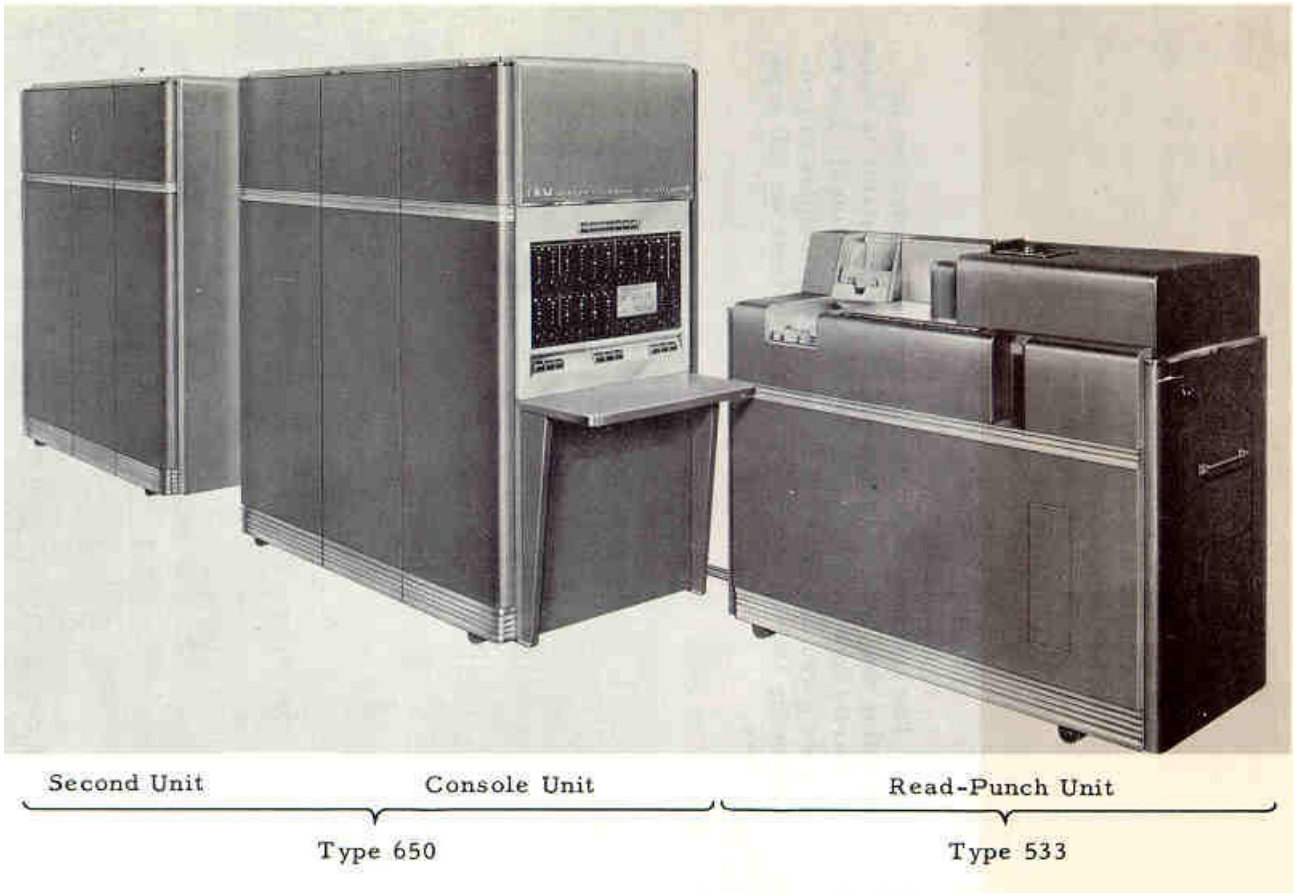
IBM 650 Magnetic Drum Calculator (1954)

Delayed 1949 project.

A scientific computer.

But: John Hancock gets first one.

1800 built. Most popular computer of 1950s.



IBM 650

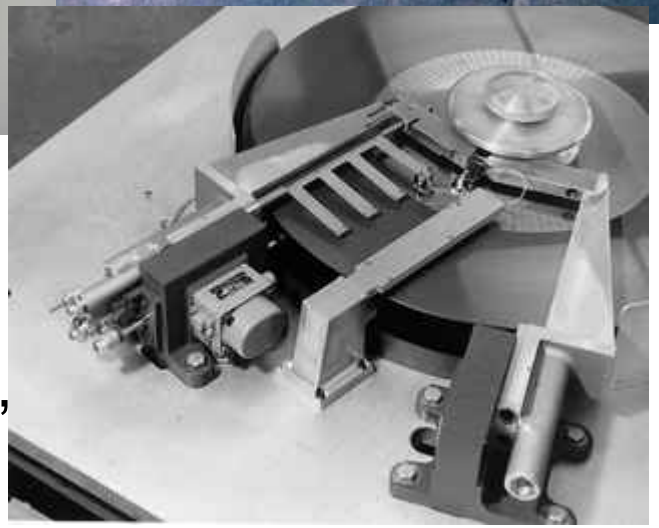
IBM Type 608 (1954)

All-Transistor/magnetic memory version of Type 604.

Improved Defense Calculator (IBM 704)

IBM 305 RAMAC (1956)

Random Access Memory Accounting Machine



Attachment for IBM 650 Drum Calculator
50 disks, 5 million characters
Potentially Interactive - “Ask Prof. RAMAC”

IBM Goes All-Solid State (1957)

IBM 1401/1410

Announced 1959

10,000 copies

Ferrite core memories, magnetic disk, high speed chain printer.

Seven Dwarfs

NCR:	Buys Northrup spinoff CRC (1954). Niche sales in banking and retail.
Honeywell:	Buys computer company (1954) and markets large vacuum tube machine (1957).
Burroughs (1956):	Purchases JPL alumni computer company, builds specialty computers for military.
Control Data (1957)	Sperry-Univac spinoff.

Seven Dwarfs

Sperry: Merges with Remington-Rand (1955)
Univac II (1958) Partial transistor, magnetic memory,film-based tape.

RCA Introduces new computer in 1955
Ferrite core but also vacuum tubes, tape drive. Transistorized computers follow.

GE: Sold vacuum tubes to IBM
Builds computers for NCR
Failure to commercialize 1953 computer for USAF.

… And AT&T

AT&T: 1953 Consent Decree
Stays out of computers after 1952.
Royalty-free license on transistor

Integrated Circuits

Jack Kilby & Robert Noyce (1959).

Army Micromodule Program

"[I]f the invention hadn't arisen at Fairchild it would have arisen elsewhere in the very near future. It was an idea whose time had come."

- Robert Noyce

Courtesy Texas Instruments

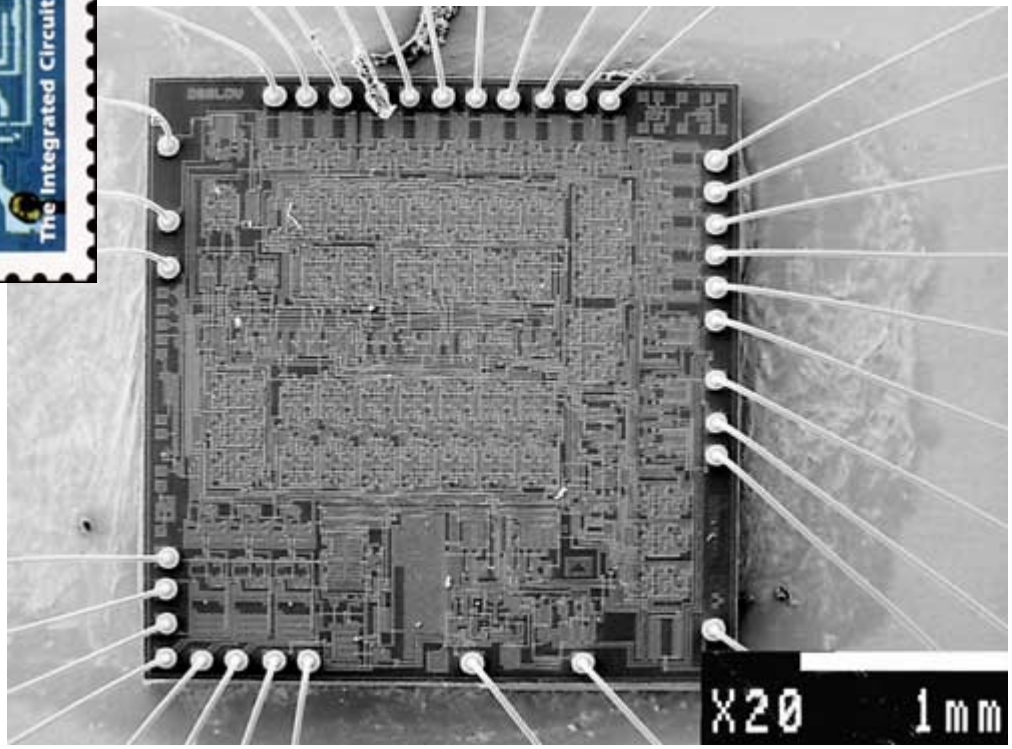
Jack Kilby
(1923- 2005)

Robert Noyce
(1928 – 1990)

Repealing Grosch's Law

$$\frac{\text{Cost}}{\text{Power}} = W^{1/2}$$

Integrated Circuits



Policy

Firehose R&D

Advantages: Market share, internal financing.

Ferrite core, disk, transistor, integrated circuit, random access, high speed printout.

Patenting the integrated circuit.

Costs and benefits…

For the Army

For the country.

The 1960s: “IBM’s 5 Billion Gamble” and the System/360

System/360

1960 Decision - Announced 1964 - Delivered 1966

Seven Different IBM Machines.

Lost economies of scale in production, marketing, and service.

Software costs.

Competitive Pressure

GE, RCA, and Honeywell.

System/360
Catching the Wave: Installed base vs. New Users

1960: 6000 US computers
1973: 100,000 computers worldwide.

IBM sales go from $1.8bn (1960) To $7.2 bn (1970).

System/360

IBM

Manufacturing Crisis.

Software Crisis.

1m lines of code + Time sharing.
$125m budget.
$500m actual cost.
5,000 staff-years.
1 year late, buggy.

IBM

R&D Priorities

Time sharing.

Integrated circuits

IBM S/370
Improved 360 family
with ICs.

New DoJ Suit
(1969)

S/360 and the 7 Dwarfs

Clones

- Honeywell and IBM 1401.
- RCA makes compatible mainframe
- Soviets too.

Niche Markets

- DEC minicomputers.
- CDC (Seymour Cray).

Plug Compatible Components

- Memorex, Telex, Ampex, Storage Technology, CalComp, Amdahl.

S/360 and the 7 Dwarfs

Computer Leasing Companies

Antitrust Suits

1971 Recession and BUNCH.

Policy

Beyond Schumpeter?

- A (Temporary?) End to Revolutions
- Absence of Large Competitors
  - Would entry pay?

DoJ's Legacy: An Open World

- IBM's Continuing Advantage
  - Market share
  - Lags
- Tapes, disk drives … CPUs?
- High prices, fast progress.

ARPA

ARPA

A Golden Age?

Money: $10 million 1962)/$15 million (1963).

Interactive computing.

ARPAnet: Carrot and Stick.

Institutions: OSRD, again?

Portfolio Management: J.C. Licklider.

John C. Licklider
(1915 – 1990)

A Golden Age?

Military, Academics as Lead Users

MIT Project MAC (1964)

Promised on-line catalogs, ordering and billing,electronic cash, medical-information systems for hospitals, centralized traffic control for cities,automatic libraries, design consoles for engineers, management consoles for companies and factories, teaching consoles for education, editing consoles for publishing, research consoles for laboratories, and computerized communities.

The World at 1970

Commerce displacing military.

IBM dominant, but vigorous R&D.

Fading information asymmetry?

Big Machines, but ICs on the horizon.

Open standards, lead users,
and roots of open source.