History of Computing

CSE P590A (UW)
PP190/290-3 (UCB)
CSE 290 291 (D00)

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Viewpoint

- Beyond Heroes and Mythology
- What Worked, What Didn’t, and Why.
- (For Business)
- For Public Policy

A *Very* Simple Policy Model

The Commissar Model: $(v - c) > 0$

Choosing Incentives to Get There

“No dominant incentive mechanism.”

Preview

A History of (v – c) to 1970:

- A History of "v."
  - Technology improves.
  - Society uses more data.
  - Inventors notice existing uses.
- A History of "c."
  - Spreading R&D costs over bigger markets.
  - Gears, vacuum tubes
  - Integrated circuits and software.

Lecture 1: Computing to 1940

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Prehistory: Data & Civilization

An honest man has hardly need to count more than his ten fingers, or, in extreme cases, he may add his toes and lump the rest. I say, let our affairs be as two or three, and not as a hundred or a thousand; instead of a million count half a dozen, and keep your accounts on your thumbnail.”

- Henry David Thoreau

The "v" in (v - c).

Data for Governance

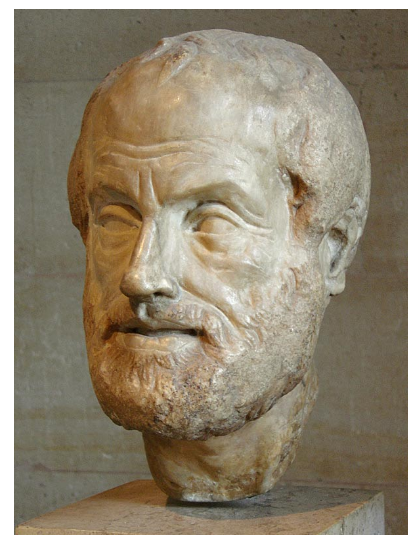
- Irrigation Cultures (*ca.* 3000 BC)
- Egypt (*ca.* 1500 BC)
- Roman Imperial Household (1st Century AD)

Data for the Military

- Military paybooks (1500 BC)
- Philip II (382 – 286 BC)
  and Alexander (356 – 323 BC)
- Ptolemy I (d. 246 BC)

Data for Research

- Aristotle (384 – 322 BC)
  ~ 400 books
- Library of Alexandria (283 BC)
  750,000 papyri



Collapse:

Dark Ages (AD 476 – 1000)
Medieval Life
Renaissance (14th – 16th Centuries AD)
    Warfare & Commerce

Reemergence

Commerce, States, Empires

Philip II (1527 – 1598)

- 18 hour workdays
- Inbox: 2000 pp./day
- Outbox: 300 memos/day.

Thirty Years' War (1618 – 1648)

Gustavus Adolfus
(1594 – 1632).

And something new: Big Science Problems

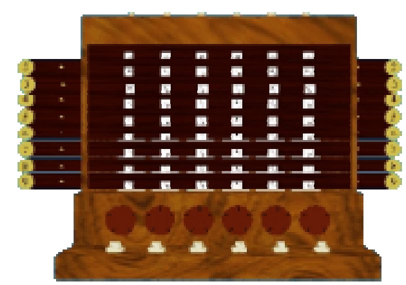
Tycho Brahe (1546 – 1601)

Computing Trig Functions

Wilhelm Schickard (1623 – 24)

Professor of Mathematics, Astronomy and Hebrew

Designed machine for Kepler that could add, subtract, multiply, and divide.



Source: http://www.gris.uni-tuebingen.de/projects/schickard/index.html

Origins:
17th – 18th Centuries

Blaise Pascal (1623 – 62)

Mathematical Prodigy

Wheelbarrow

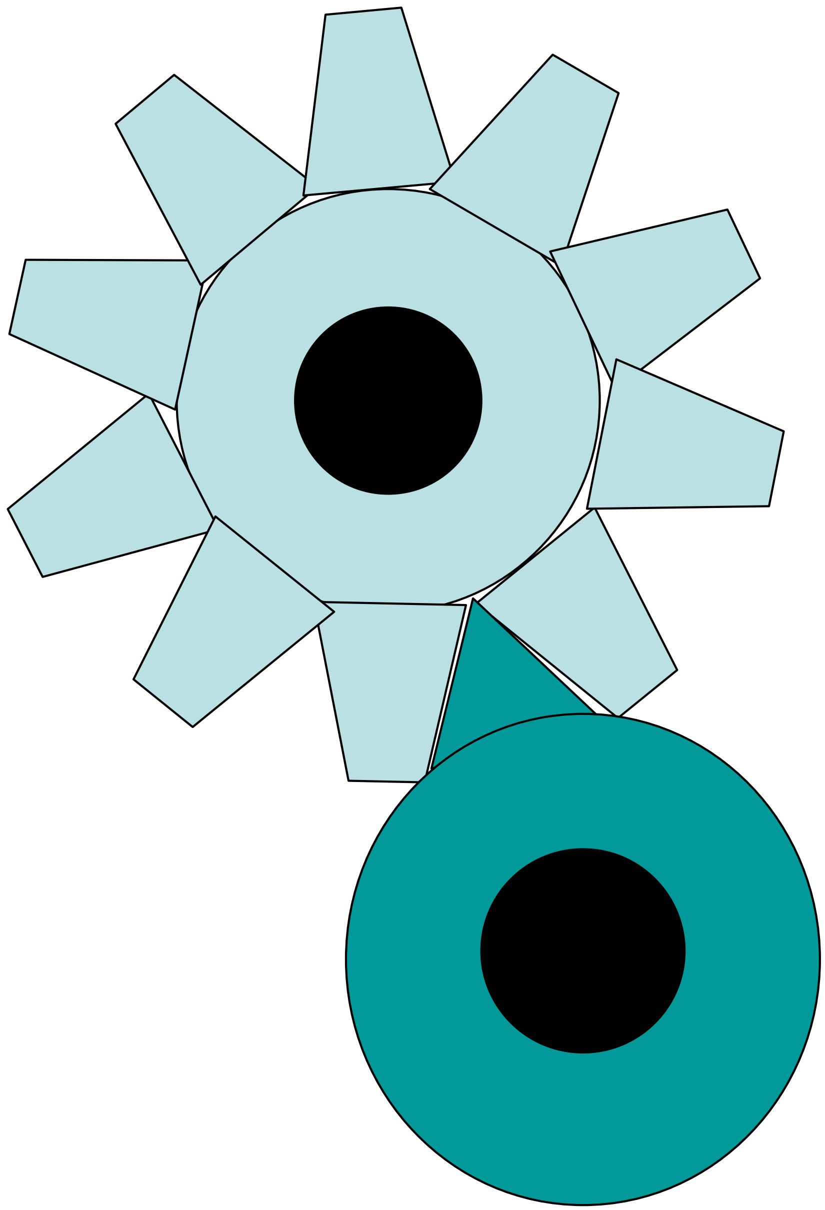
Hydraulic Press

Barometer

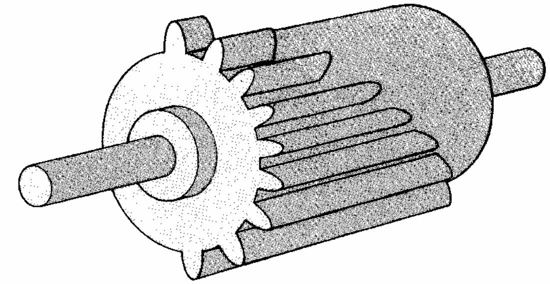
Probability Theory

Etienne Pascal's Tax Headache

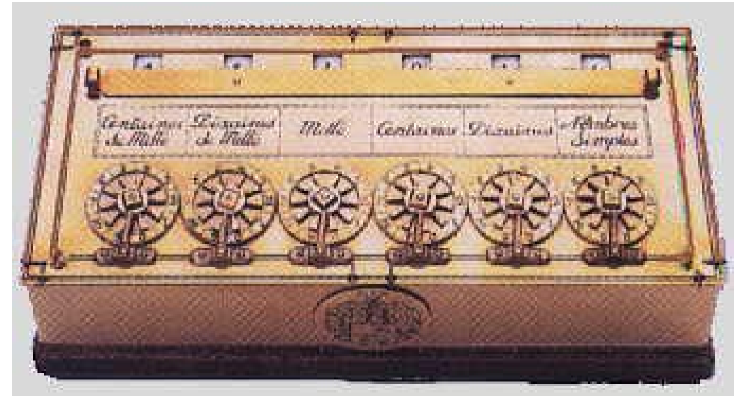
Prototype (1642) & Patent (1645)
Adding and Subtracting



10's Counter

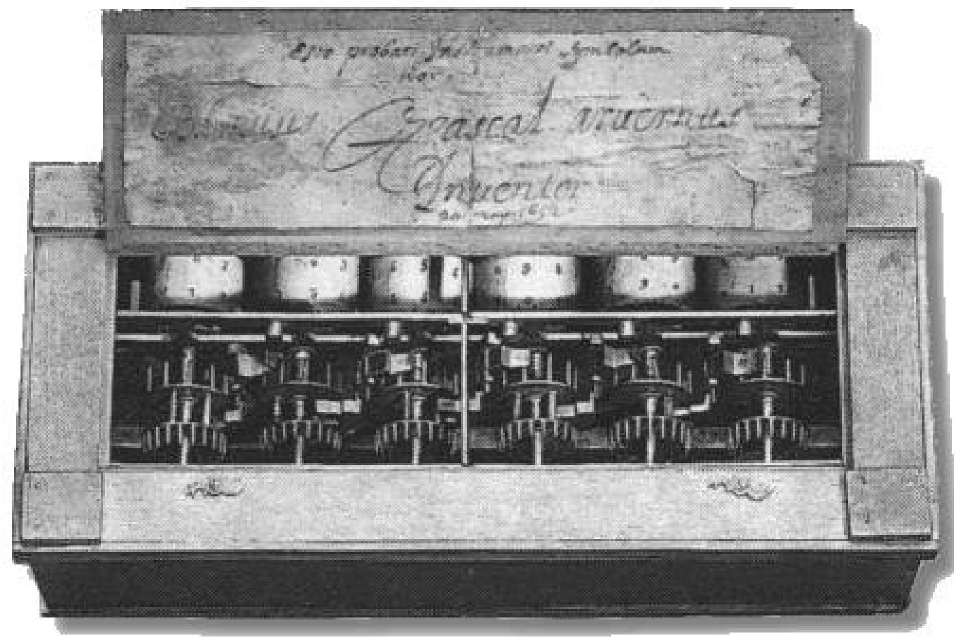


1's Counter



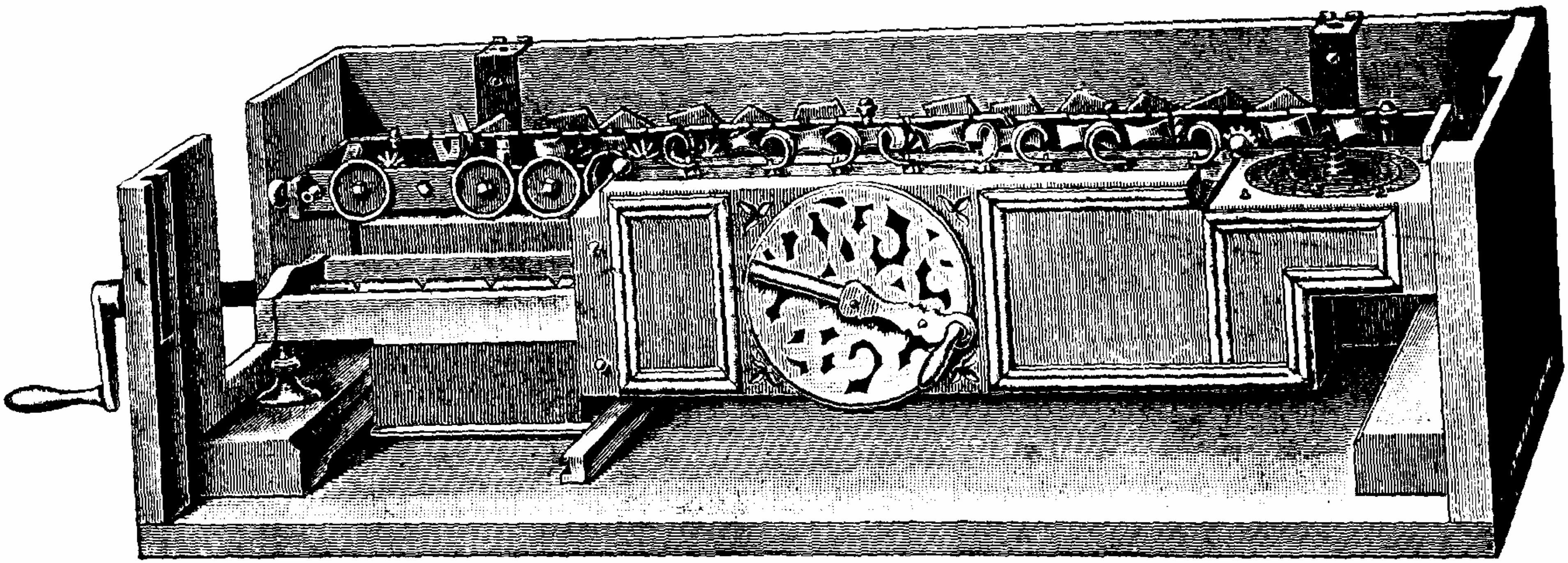
Business Plan

Demonstrations & Financing
50 “Pascalines” built through 1652
Cost: 100 livres each.



Slow, temperamental.

Gottfried Leibnitz (1643 – 1716)



Concept: 1671
Definitive Machine: 1694

Gottfried Leibnitz

Goal: “It is unworthy of excellent men to lose hours like slaves in the labor of calculation, which could easily be passed on to anyone else if machines were used.”

Incentives: Aide to Elector-Archbishop of Maintz

Why Didn’t It Work?

Technology

- Gears: Tolerances, Slack and Binding.
- Performance Inadequate?
- A Circular Argument?

Economics

- Spreading R&D Costs
- Was the Market Big Enough?
- How Much Computing Did the World Need?

19th Century Sequel

Thomas de Colmar (1820)
- Arithmometer
- 7 figure accuracy, $150 each.
- Engineers and insurance companies.

Rise of Big Business:
- Nabisco (1893), Travelers Insurance (1883), Firemen’s Fund (1863), Alcoa (1888)

Dorr E. Felt (1887)
- Keyboard
- Comptometer

William S. Burroughs

Burroughs Adding Machine Company, later Unysis

Printing calculators
Sold to banks and clearing houses at $220 each.
1,000 machines/year by 1900.
130,000 machines/year by 1908.
58 Models, “One Built for Every Line of Business”

Success: Improved technology base.
Market penetration is (reasonably) fast.
R&D can now be spread over huge markets.

A Robust Technology
The Manhattan Project

A Success Story for Patents?

Determining private needs.

But: (v – c) for very expensive inventions.

But: *ex ante* vs. *ex post* efficiency.

But: Government as buyer?

But: Financing and information asymmetry.

19th Century: The Idea of Computers

From Automata to Weaving

Pre-History

- Myth: Haephestus, Golem, Albertus Magnus
- Library of Alexandria
- Medieval Clocks
- Leonardo DaVinci (1452-1519)
- Julian Turianno (ca. 1556)
- Hans Bullman (ca. 1547)
- Rene Descartes & “Soulless Machinery”

Basil Bouchon

- Punched Cards (1785)

De Vaucanson (1709 – 82)

- Automata
- Director of State Silk Mills (1741)

Joseph Marie Jacquard (1752 – 1834)

Fishing net machine – Prize and patent
Pattern Loom (1806) – Prize + Royalty
Lyons Riots (1810)
11,000 looms in operation by 1812

Policy

Serendipity: Playthings turn out to be useful

- Patents won’t work - Patronage and reputation
- Lead users?

Late Stage Innovation

- Patents vs. Prizes

Charles Babbage

Charles Babbage (1792 – 1871)
Banking/Establishment roots
Obsessions: Automata, Mistakes,
Street Musicians.

Other Projects

- Chess Player
- Penny Post
- Actuarial tables
- Speedometer
- Cowcatcher
- Physics, Geology, Mathematics
- Lucasian Professor of Mathematics (Cambridge)

Ada, Countess of Lovelace (1815 – 52)

Difference Engine

- Difference Engine
  - Errors in Tables
    - Firing and Navigation Tables
    - Gaspard de Prony (1755-1839)

Method of Differences

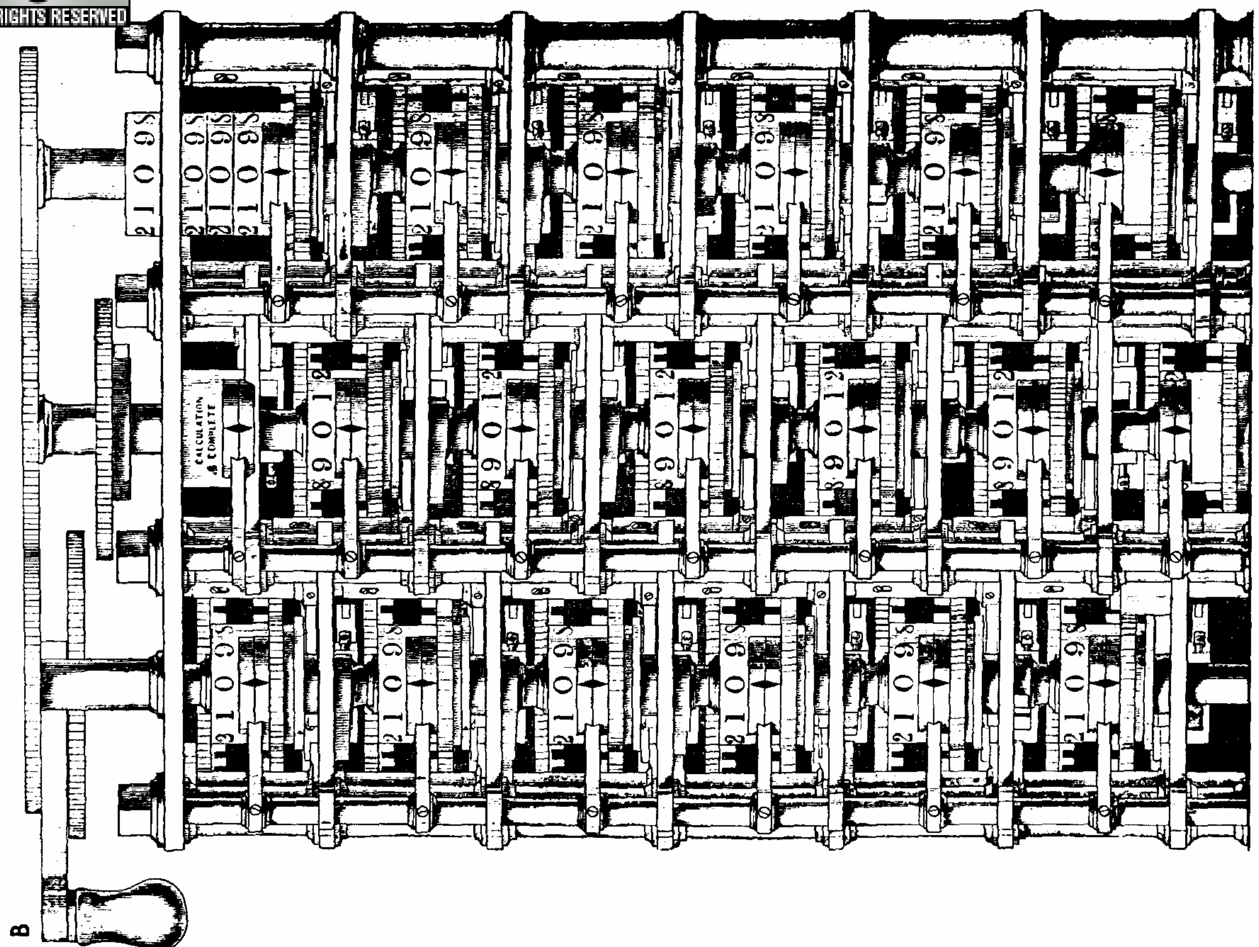
Thomas Harriot (1560 -1621)

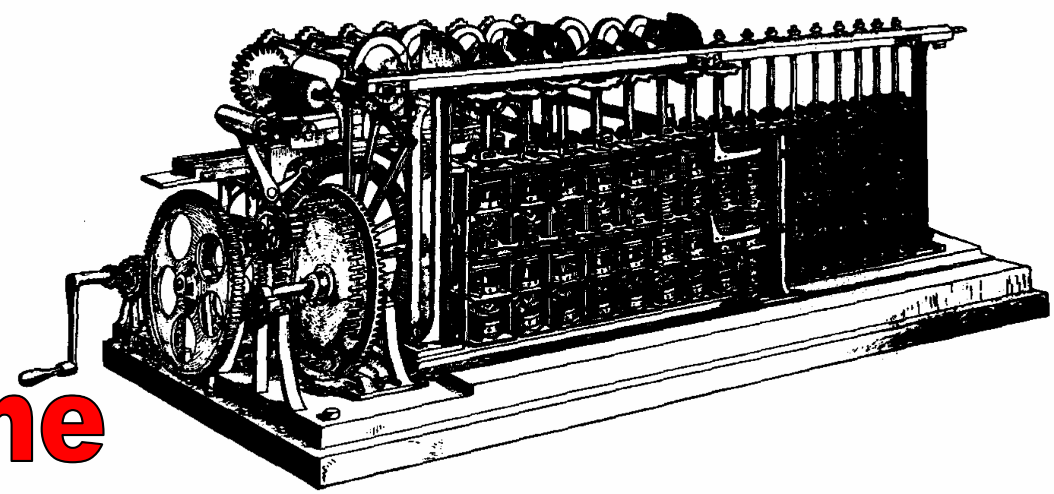
Number	Cube	1st Diff.	2d Diff.	3rd Diff.
1	1	--	--	--
2	8	7	--	--
3	27	19	12	--
4	64	37	18	6
5	125	61	24	6
6	216	127	36	6

etc., *etc.* ...

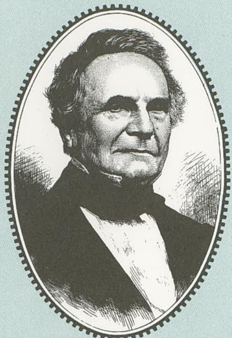
Difference Engine

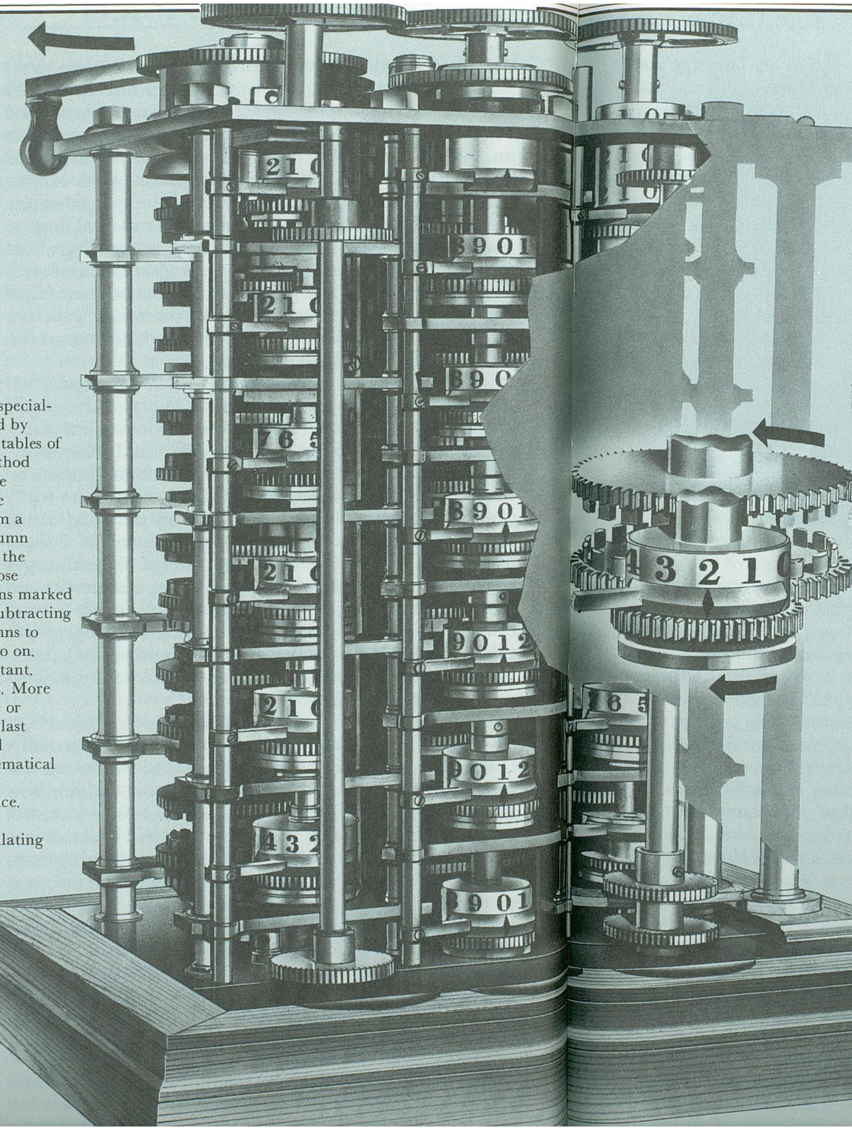
- Idea (1812) and Prototype (1820 – 22)
- Royal Astronomical Society
- Grants (£17,000), Not Patents
  - For sailors and scholars –
- Tolerances
- Terminated project in 1833.

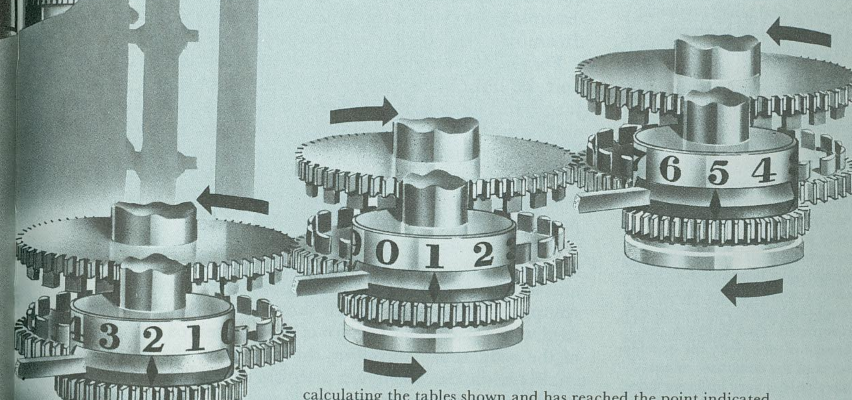




Babbage's Difference Engine







Right: The Difference Engine was a special-purpose calculating machine designed by Charles Babbage (above) to produce tables of mathematical functions using the method of differences. This is illustrated in the accompanying table, which shows the differences which can be built up from a column of squares. The left-hand column shows the numbers from 1 to 15, and the one next to it shows the squares of those numbers. Each number in the columns marked 1st and 2nd difference is formed by subtracting the two nearest numbers in the columns to the left: thus $4-1=3$, $5-3=2$ and so on. Notice that the 2nd difference is constant.

This is a simple table of differences. More complicated functions can have three or many more orders of difference. The last order is always constant. The method is useful therefore for verifying mathematical tables as discrepancies will produce variations in the last order of difference.

The Difference Engine illustrated is a simplified model capable of calculating to only two orders of difference. It is calculating the tables shown and has reached the point indicated by the arrows. The Engine consists of three registers linked together so that additions may be performed from one to the next. The initial three numbers are set in each register by hand. The first turn of the handle adds the figure in the left-hand column to the figure in the middle column; the second adds the result of this sum now shown in the middle column to the figure in the right-hand column. The cycle then starts again and is repeated as often as required. The exploded section shows how the columns act upon one another.

The diagram of number wheels (right) shows where the figures are stored. The Engine has just added the 2 in the left-hand column to 9 in the middle column. The result, 11, appears in the middle column. The next calculation will add this figure to the 25 in the right-hand column. These are the sums indicated by the arrows in the table.

Diagram of Number Wheels

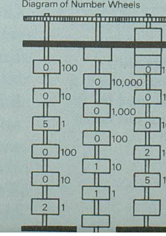


Table of Differences for the function x^2

x	x^2	1st	2nd
1	1		
2	4	3	2
3	9	5	2
4	16	7	2
5	25	9	2
6	36	11	2
7	49	13	2
8	64	15	2
9	81	17	2
10	100	19	2
11	121	21	2
12	144	23	2
13	169	25	2
14	196	27	2
15	225	29	

Christopher Evans, *The Making of the Micro: A History of the Computer* (London 1981)

Sequel

Georg Scheutz (1785 – 1873)

- Prototype (1833)
- Full scale (Paris Exhibition 1853) - Astronomy
- British copy (1859) – Life expectancy tables

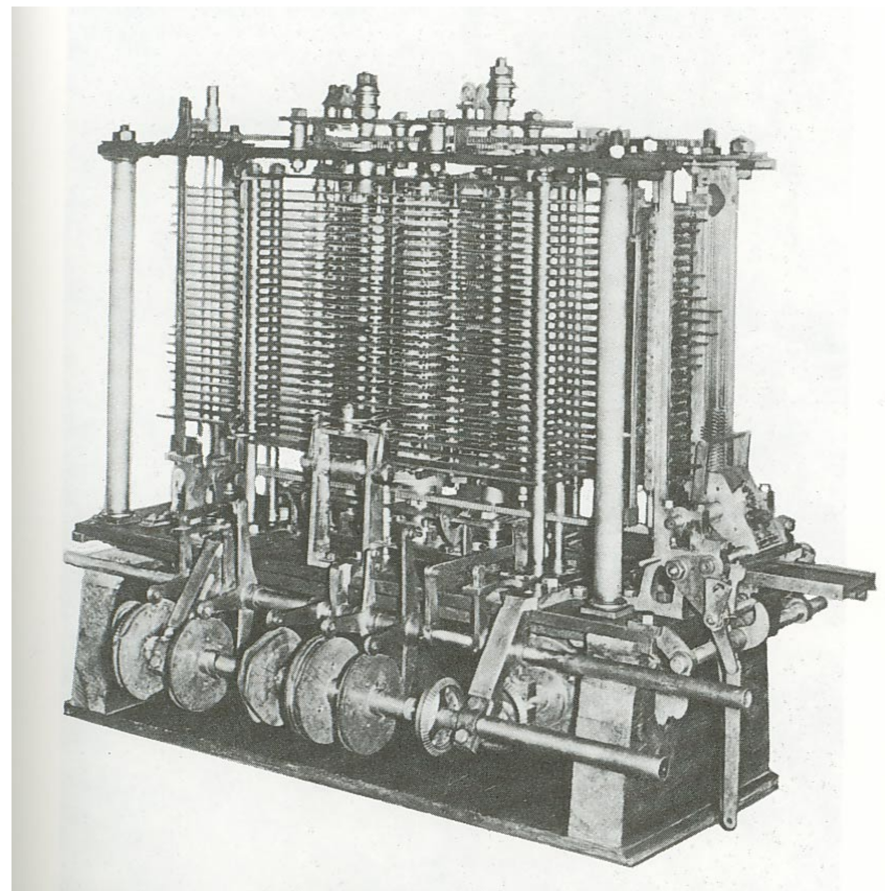
Analytical Engine

Analytical Engine

A Steam-powered, programmable machine

Moving Numbers Instead of Yarn…

1830 - 1906



Multiply (ab + c)d = ?

Number Card	Variable Card	Operation Card	Action
1			Places a on Column 1 of Store
2			Places b on Column 2 of Store
3			Places c on Column 3 of Store
4			Places d on Column 4 of Store
	1		Brings a from Store to Mill
	2		Brings b from Store to Mill
		1	Directs a x b = p
	3		Takes p to column 5 of Store
	4		Takes p into Mill
	5		Brings c into Mill
		2	Directs p + c = q
	6		Takes q to Column 6 of Store
	7		Brings d into Mill
	8		Brings q into Mill
		3	Directs d x d q = r
		10	Takes r to printer

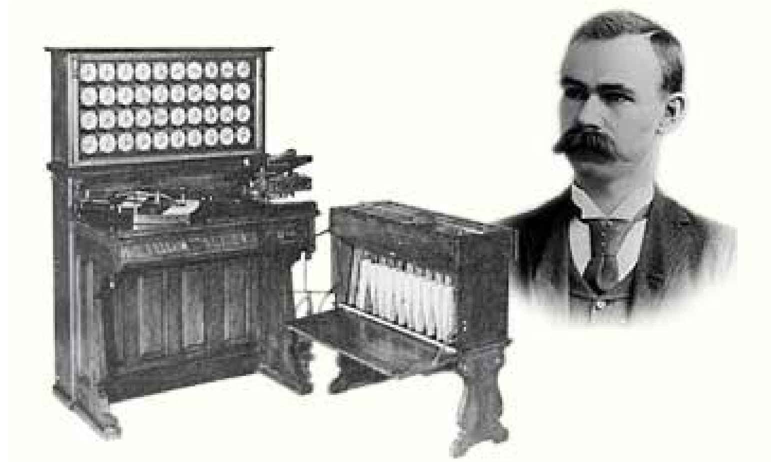
Policy

Difference Engine

- Technical difficulties?
- Asymmetric information
  - Government skepticism
  - Partial Solution: Trusted intermediaries
- Grants vs. patents
  - No commercial value
  - A Single Customer, a Single Problem
    - Judging User Needs
    - *Ex ante vs. ex post*

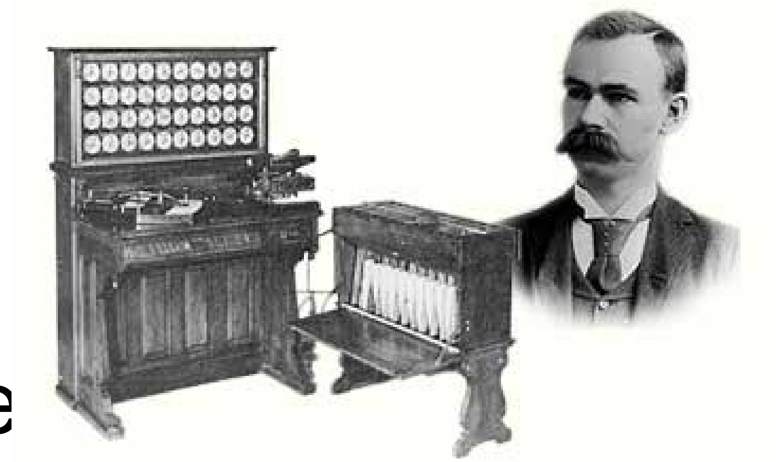
Analytical Engine

- $(v - c) < 0$?



Hermann Hollerith & Punch Cards (Pt. 1)

Hermann Hollerith



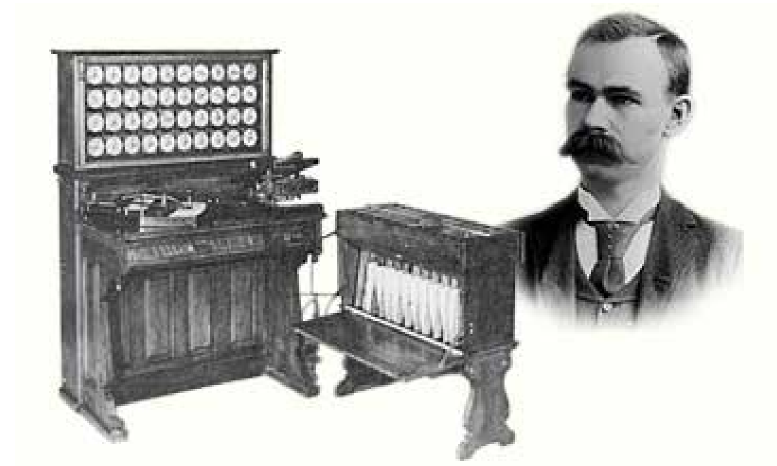
The Census Challenge

- 1880 Census
- The Populist Impulse

Consultant to Census Bureau (1879)

MIT Professor (1882)

- Started with paper tape, which could not be sorted
- Studied Jacquard Looms
- Electromechanical solution.



First Patents (1884 – 87)

Raising Capital

- Brother in law
- The Library Bureau

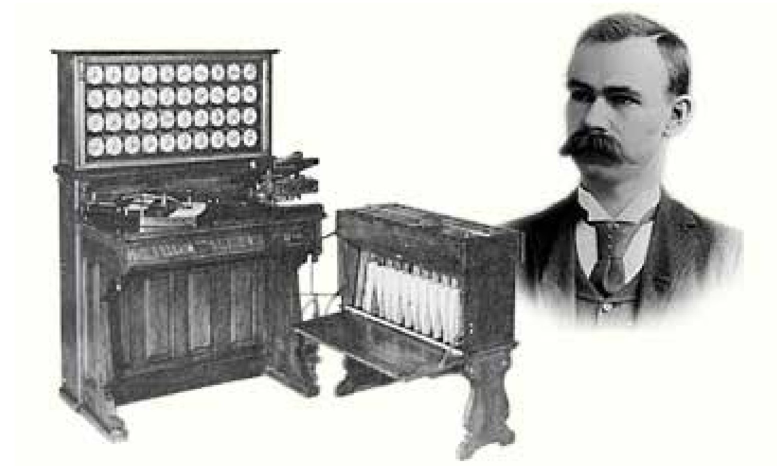
Baltimore Health Dept. (1887)

- War Department, New York, New Jersey health records.

Census

- Prize Competition and 1880 Census
- 1890 Census – Rents Machines at $1000/year + $10 penalty for down time
- 1900 Census – Complaints about “monopoly.”

Forms the Tabulating Company

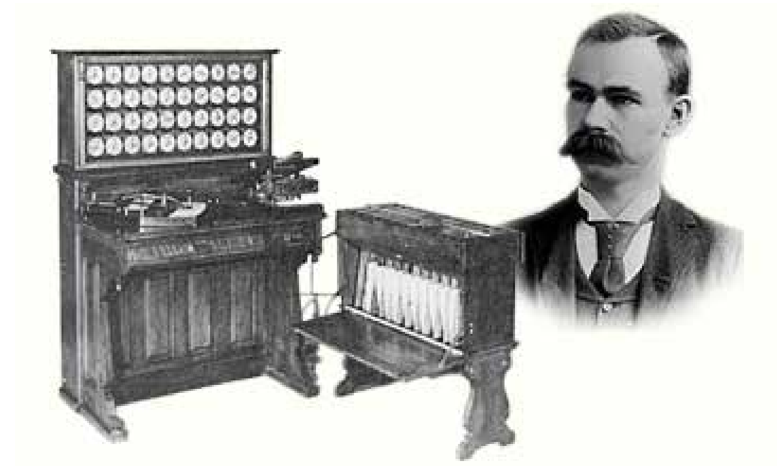


Sells to New York Central (1893 - 1895)

Free 6-month trial.
4m freight bills/year
Performs addition.

Later:

Travelers Insurance (1895), French Census, Russian Census (1896), US Steel and Marshall Field (1900), most railways (1902).



Proliferation of devices (1893 - 1914)

Accumulator, keypunch, card sorters, adding punch, printer.

Policy

Selling to Both Public and Private Sectors
- Makes “v” large enough to cover “c”?
- Who gets the benefit of civilian sales?

Asymmetric Information
- New York Railway Offer
- Renting machines
- Internal Financing & Market Implications

Types of Innovation
- New Technology vs. Finding & Meeting User Needs

1900 - 1940

New Needs (Pt. 1)

Progressive Governments

Big Business

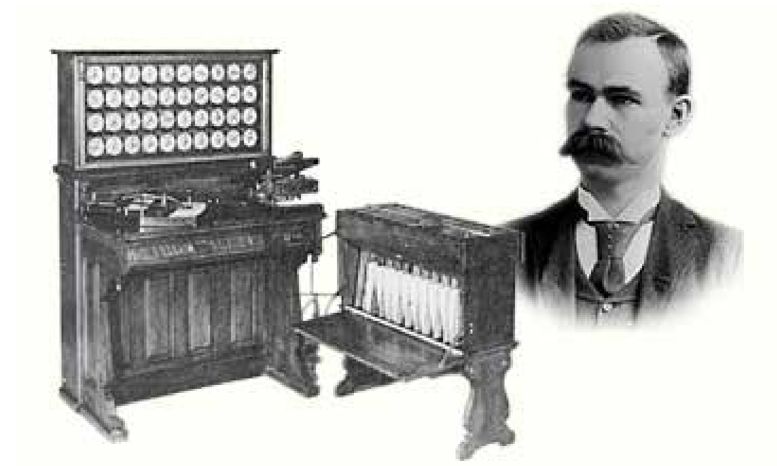
Factories, steel mills, insurance companies, electric light, traction, phone, wholesale companies, textile mills, automobile companies, railroads, municipalities, state governments.

New Needs (Pt. 1)

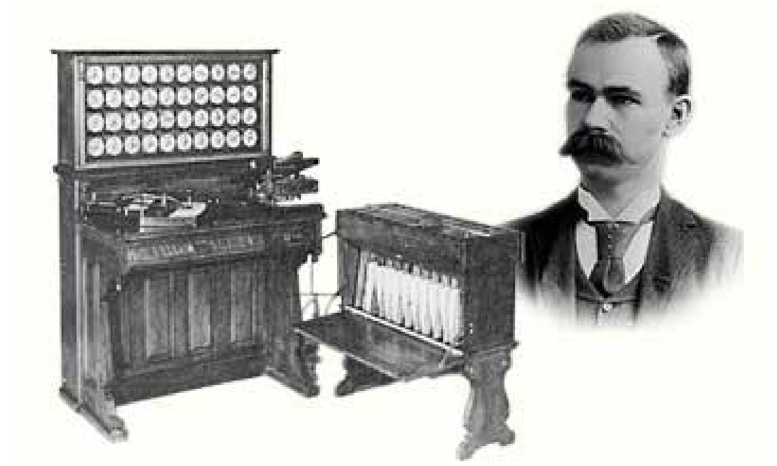
Pre-WWI: Labor costs, efficiency records, sales distribution, internal requisitions for supplies and materials, production statistics, day and piece work, fire, life and casualty risk, plant expenditures and sales of service, public service corporations, distributing sales and cost figures to salesmen; special reports.

“Batch Processing.”

A consequence of (v-c)?



Hollerith *Ctd…*



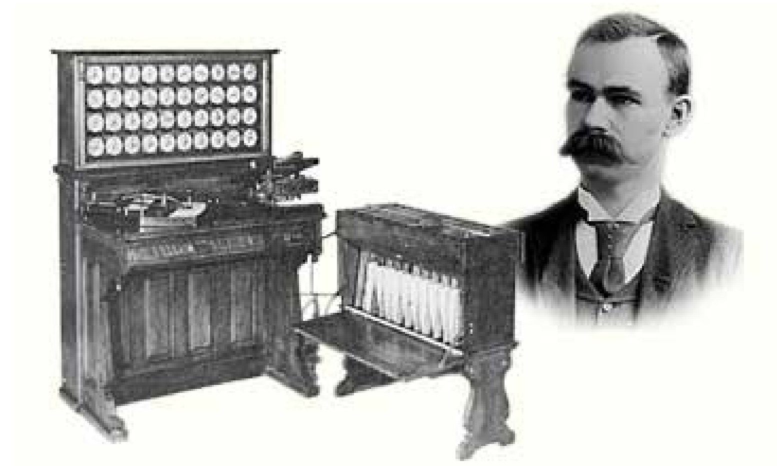
1900 Census

1901 McKinley Assassination, David Porter fired.

1905 Congress establishes $40,000 R&D Unit

1906 Census Demands lower prices
Employees keep patents, government receives free license.

1910 Census does not use Hollerith machines.



1911: James Powers establishes The Powers Tabulating Machine Company (later, Remington-Rand).

Hollerith Sell Out; Merger forms Computing Tabulating Recording Company (CTR).

Was Congress Right?

- Who benefits from commercial sales?
- *Ex post vs. ex ante* efficiency.

Schumpeterian Competition

- Joseph Schumpeter (1883 – 1950)
- Innovation vs. Monopoly
  - Monopoly funds innovation
  - Monopoly is temporary
  - Technological revolutions.
  - Long-run efficiency.

Analog Computers

New Needs (Pt. 2)

Warfare

Example 1: Firing Tables

Gravity, ground hardness, atmospheric density, Coriolis effect, density changes with altitude.

Fifteen multiplications, square root calculated at 0.1 to 0.01 second intervals. Check function every four calculations. Five days by hand.

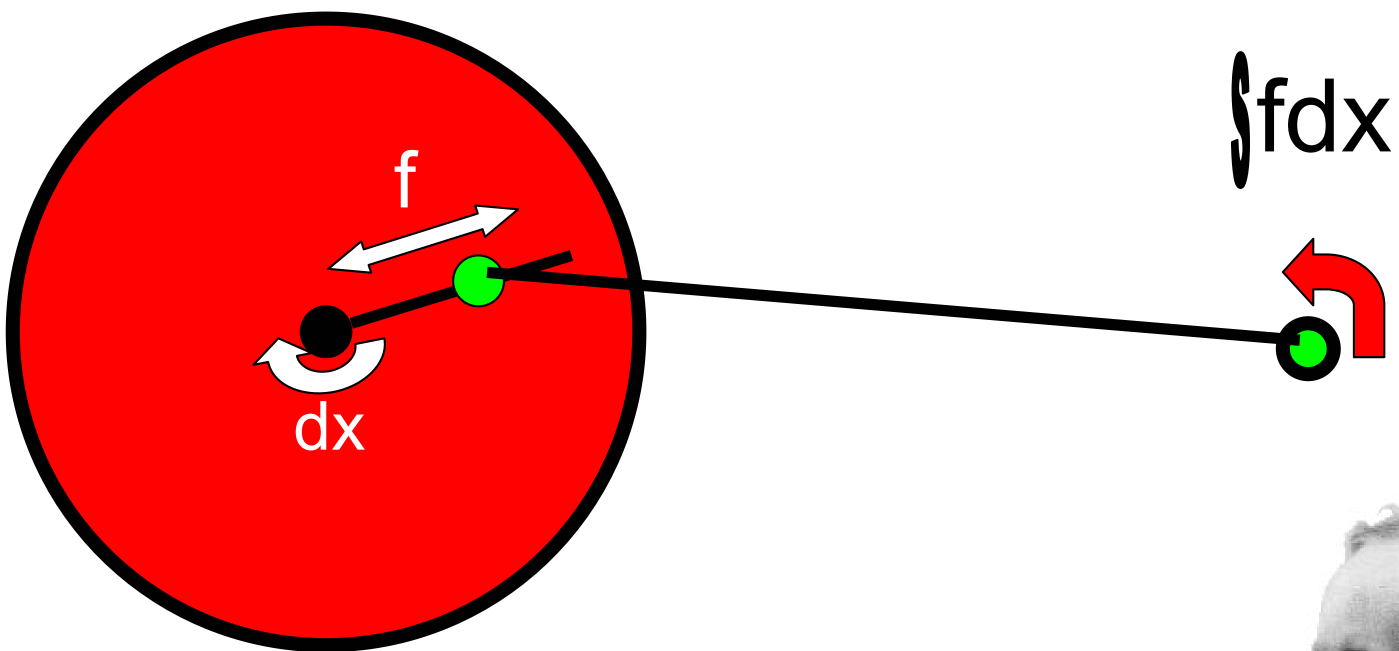
2-4000 trajectories per firing table

Example 2: Atomic & Hydrogen Bombs

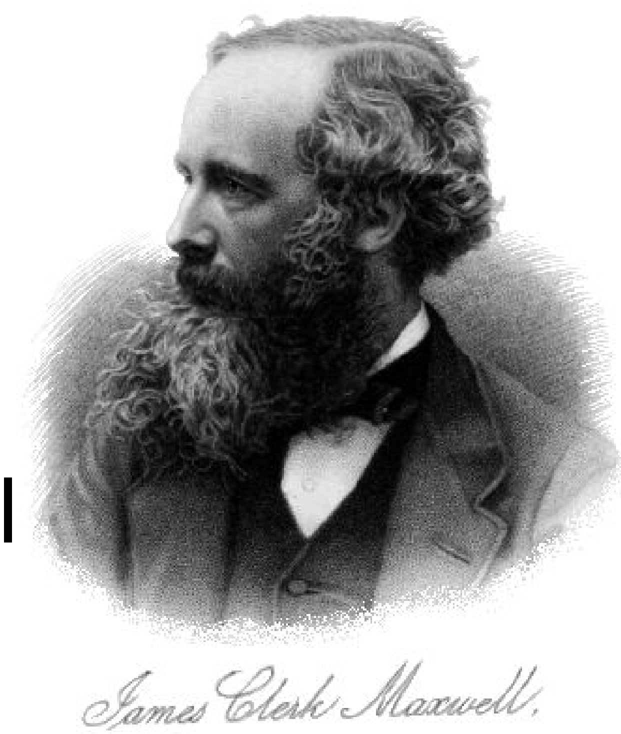
New Needs (Pt. 2)

Big Science

(Mostly astronomy)

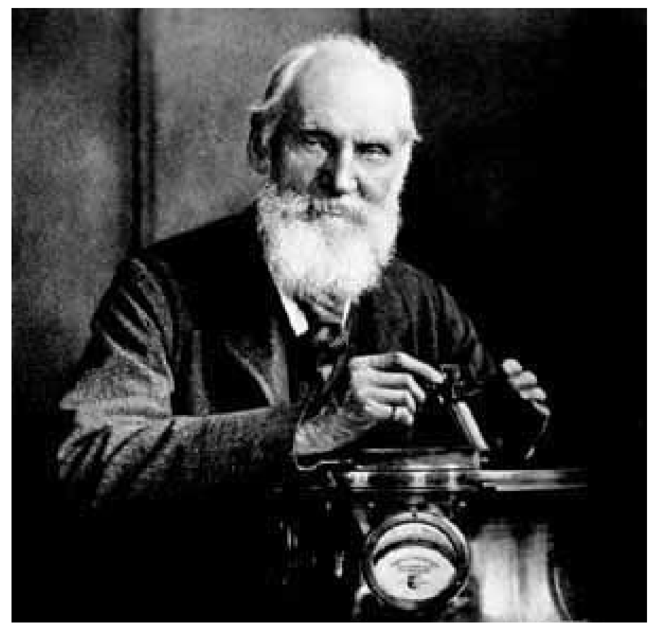


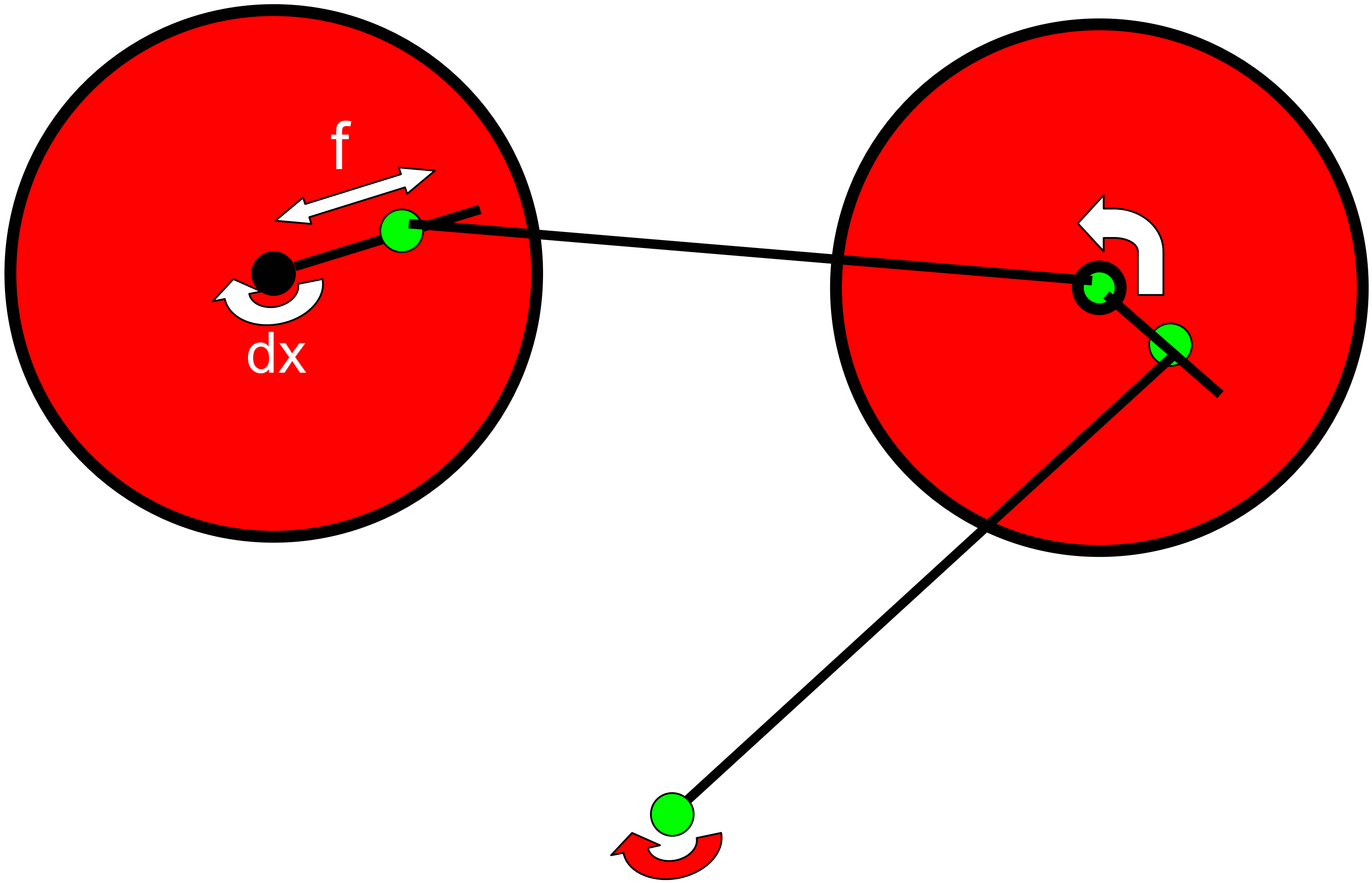
James Clerk Maxwell
(1831 – 1879)



Sir William Thomson, Lord Kelvin
(1824 – 1907)

2d order equations
Tide tables.





The Torque problem

Vannever Bush

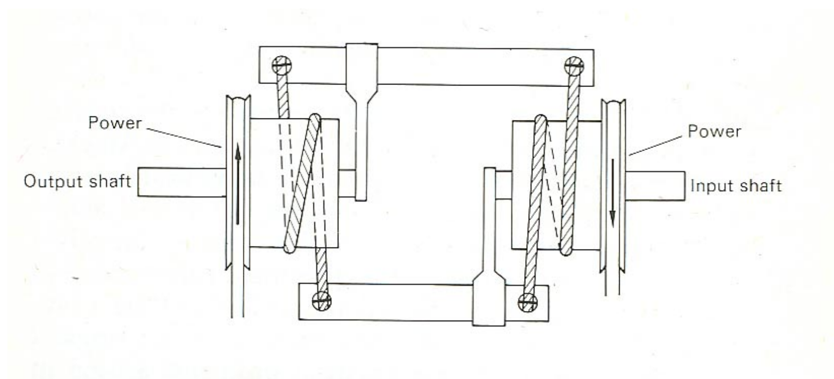
(1890 – 1974)

1920s Machine

Adding voltages,
Electric meters as integrators

1930s Maxwell Machines

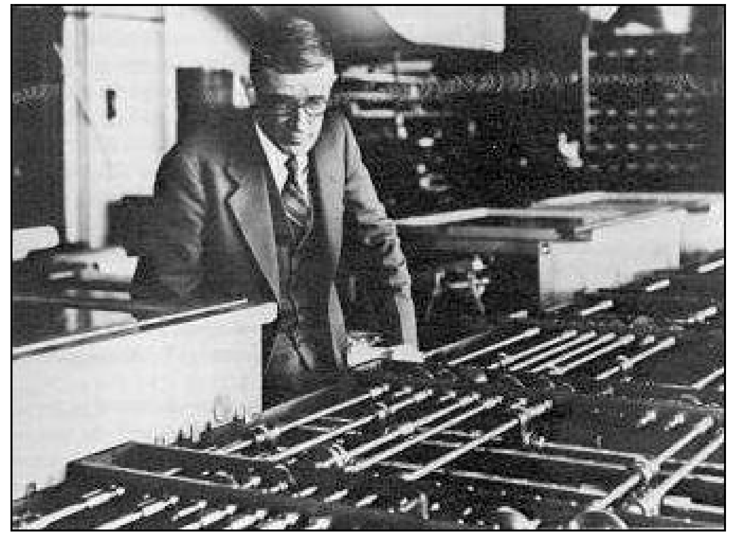
Servomotors + Torque
Amplifier

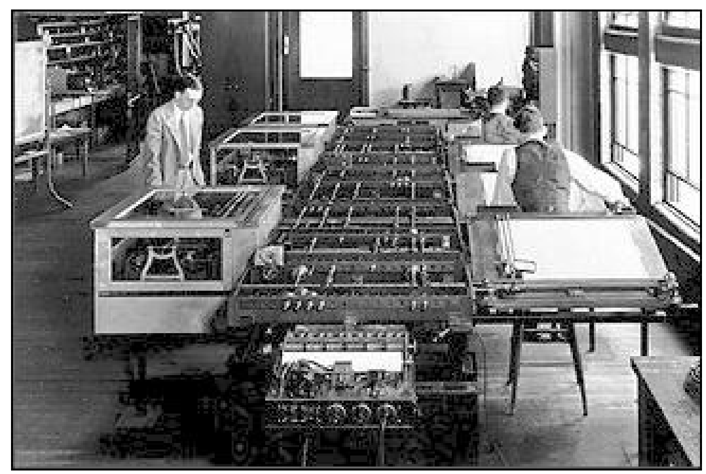


1930 Differential Analyzer

100 tons, eighteen integrators

2000 vacuum tubes, 150 motors, 200 miles of wiring.





1935 Differential Analyzer

- $85,000 Rockefeller grant.
- Electrical components
- Paper tape instructions

Cyclotron Culture: Copies at Moore School, Aberdeen, Cambridge & Leningrad.

Policy

Grant Funding

- Cyclotron culture
- No civilian applications…

The Rise of IBM

1914: Thomas J. Watson becomes CEO

National Cash Register Experience

- Central advertising, tech support, credit, and in-house R&D.
- Antitrust

1921: Patent Wars

Remington-Rand's crisis

Joint Monopoly Pricing

Litigation and Purchases

1924: CTR Becomes IBM

1928: Separate standards

Customer Lock-in.

Thomas J. Watson, Sr.
(1874 - 1956)

R&D Competition

Competition with Powers spurs R&D.

- Parallel, competing R&D teams

New Technologies

- Subtracting tabulator (1928)
- Type 600 multiplying punch (1931)
- Type 285 Numeric Printing Tabulator (1933)
- Type 405 Alphabetic Printing Tabulator (1934).

R&D Competition

A Complex and Capable Technology

- Type 405 Electric Accounting Machine (1930)
  - 55,000 moving parts
  - 75 miles of wiring
  - Dominant data processing device until 1962.
  - 1500/year manufactured through late 1960s.

New Technologies ctd. …

From Mechanical to Electromechanical to Electronic

- $F = Ma$
- Magnetic card, tape & drum research (1930s)
- Replacing Wheels with vacuum tubes.
- Electronic adder (1940)
- Electronic multiplier circuit (1941)

And New Uses…

An IBM Specialty.

Methods Research Department (1930s).

Big Government:

Social Security – “The Worlds’ Biggest Bookkeeping Job” (1936)

415 machines/120,000 square foot building.

Also: Employer reporting, public works projects.

IBM sales grow from $26m in 1936 to $45m in 1940.

Antitrust Issues

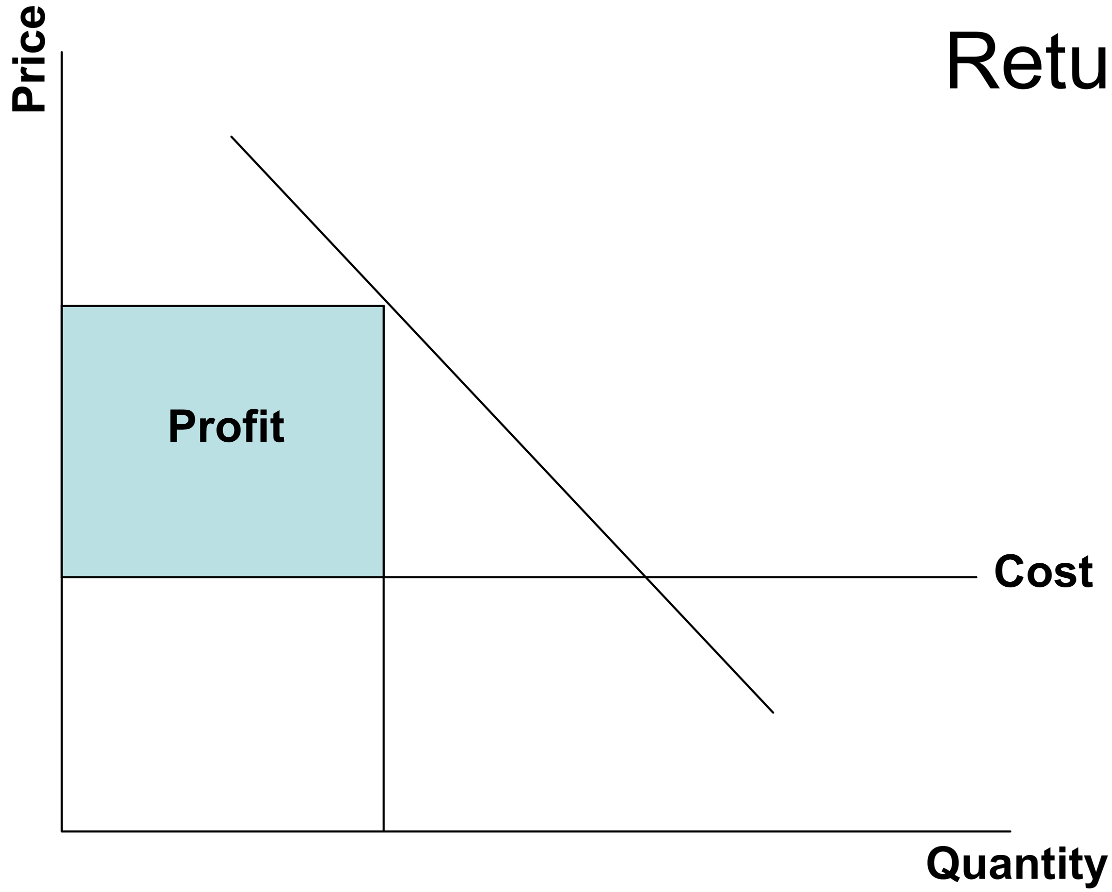
Innovation isn't everything

- *Ex ante* vs. *ex post* efficiency

Multiple Tipping Dynamics

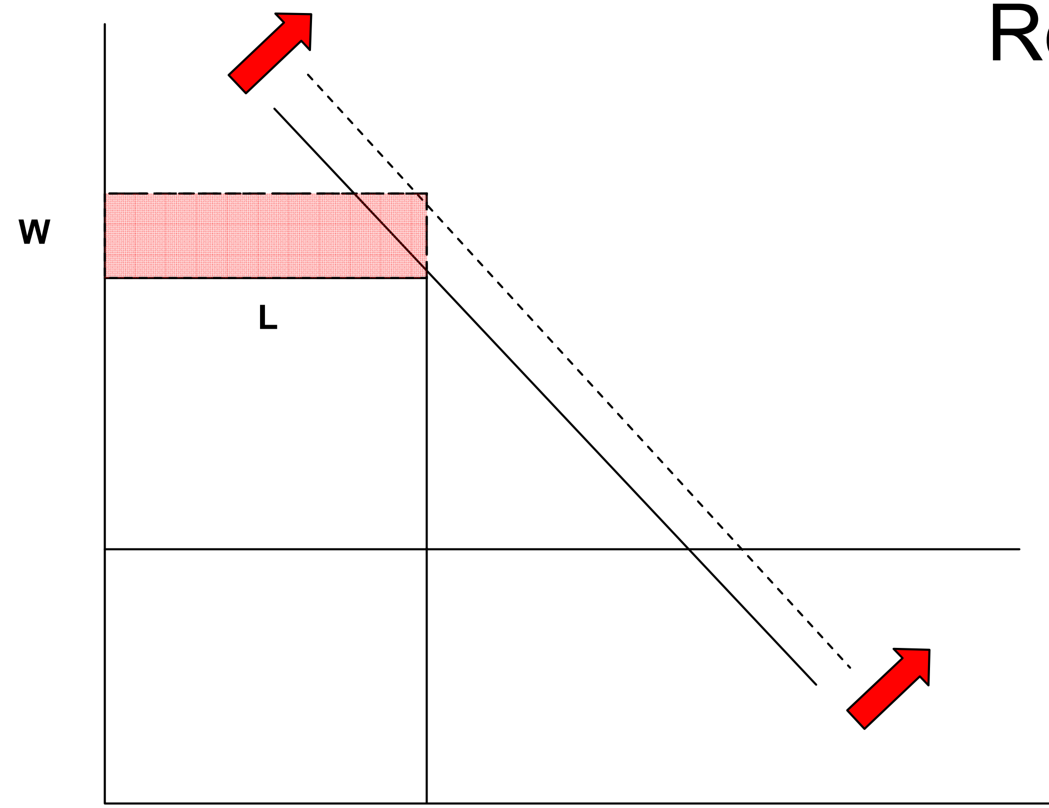
- Internal financing
- Reputation
- Complex products in a small market
- Patents
- Business cycle shocks
- Standards and customer lock-in.
- Returns to R&D

Antitrust Issues
Returns to R&D



Antitrust Issues

Returns to R&D



Reward = L x W

Antitrust Issues

- Cards and Leasing
  - Leasing
    - Internal financing/information asymmetry?
    - Barrier to entry?
  - Three bn. cards/year.
    - Price discrimination
    - Cards and The Depression.
    - Cards as Standards
  - 1936 Consent Decree
- 85% Share by late 1930s.

Academic Interactions

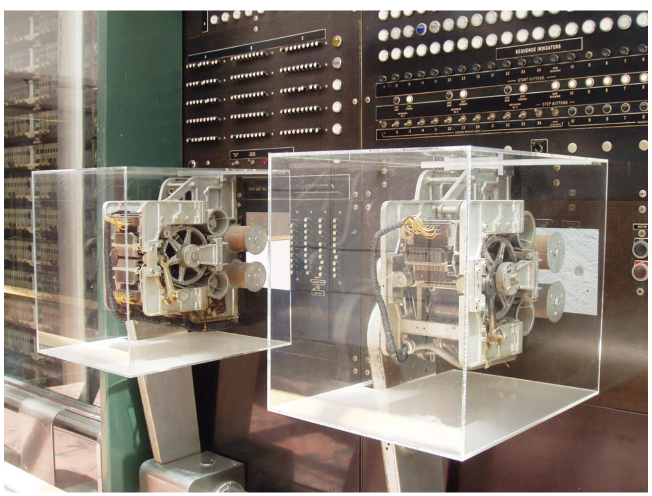
Using Tabulators to do complex scientific calculations.

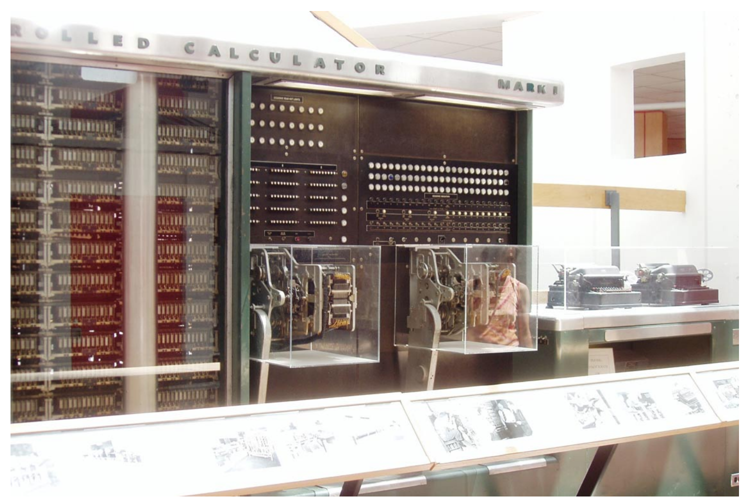
- Machine-graded Tests (1928)
- Difference Methods (1929)
- Thomas J. Watson Astronomical Computing Bureau (Columbia U.)
    - Calculation Control Switch (1936)
    - Cam-driven sequence of arithmetical operations

Academic Interactions

Howard Aiken (1900 – 1973)

- A trip to Harvard's Attic
- An electromechanical machine for calculating trigonometric functions and exponentials.
- $100,000 estimate (1939)
- $400,000 price tag (1943).

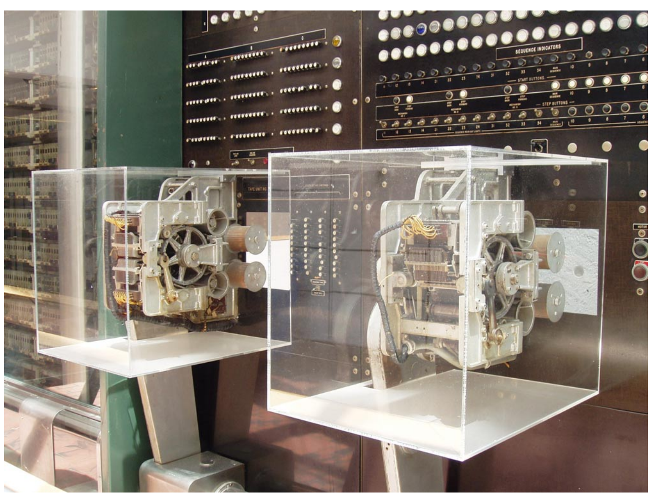


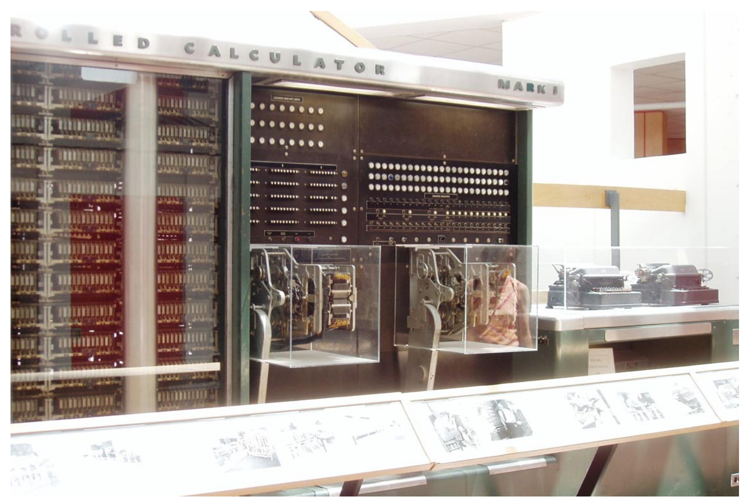


Academic Interactions

Harvard Mark I Computer

- "Babbage's Dream Come True"
  - But: No "if" branch.
- Paper tape + 1,728 counter wheels
  - But: vacuum tubes for storage.
- Wheels machined to 1/100,000 inch.
- 5 tons, 51 feet long, 530 miles of wiring.
  - "Like the roar of a textile mill…"





Policy

Schumpeterian Competition

- An Unstable World?

Academic Exploration

- Extracting benefits from IBM’s monopoly?
- Lead users?

The World at 1940

(v-c)

Looking at v:

Governance, Military, Science, Commerce.

Computers focused on military problems.

Grant funding for Military & Science

Schumpeterian dynamics for Governance and Commerce

Looking at c:

Beginning to use vacuum tubes and relays.

Modest cost savings.

Marginal cost is high.

A few large machines.

Coming Attractions

V:

Technology: True computers, new capabilities.
New Uses: Finding a civilian market.

C:

Falling Costs: Vacuum tubes, software, integrated circuits.

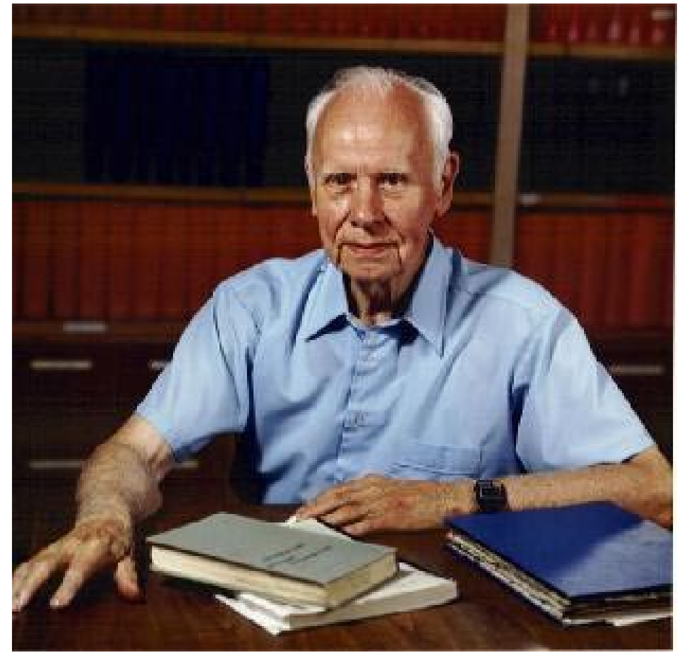
Schumpeterian competition continues…

Wartime

Overview

- 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

George R. Stibitz



Bell Labs (1937)
- Telephone Relays
- Binary Arithmetic

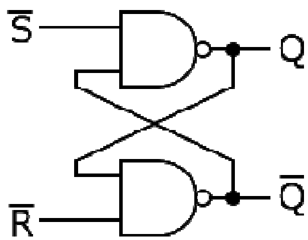
K-Model (1938)

Model 1 (1939) - $20,000

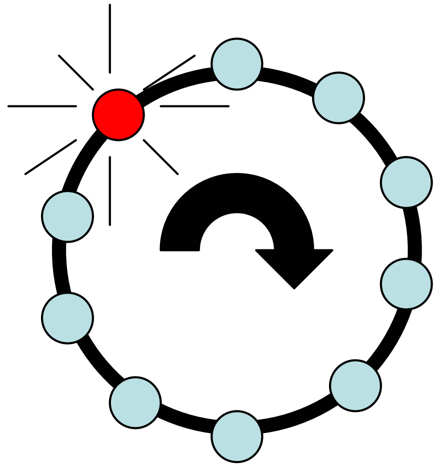
Models 2-5 (1940 - 45)
- Paper tape, error checking, multiplication tables, & storage registers.

NACA and Aberdeen

Electronic Logic

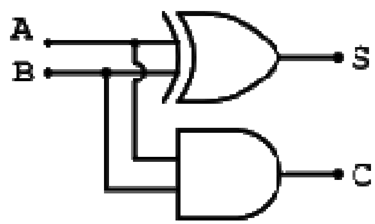


Flip-Flop



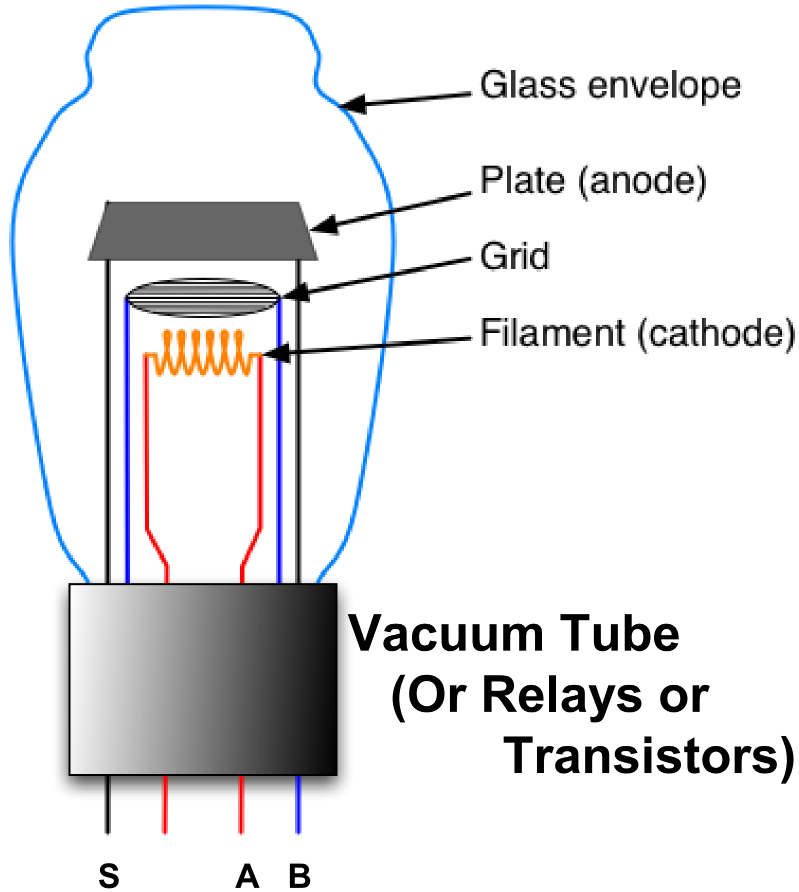
A	B	C	S
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

Binary Arithmetic



Half-Adder

S = AxorB
C = AandB



Vacuum Tube (Or Relays or Transistors)

Atanasoff-Berry

“ABC Computer”

Iowa State (1937 – 39)

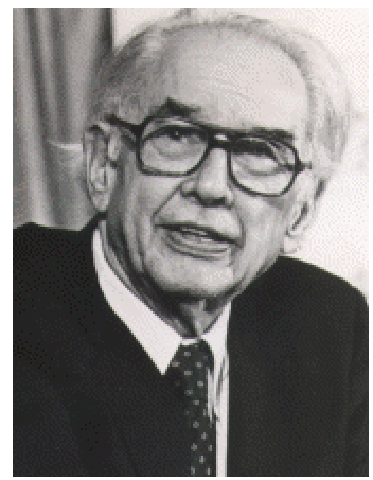
Arithmetic – Base 2 Logic

Memory – Drum, Condensers
+ “Jogging”

Output – Cards

No “if” statement.

Proposed 300 vacuum tube machine was never completed.

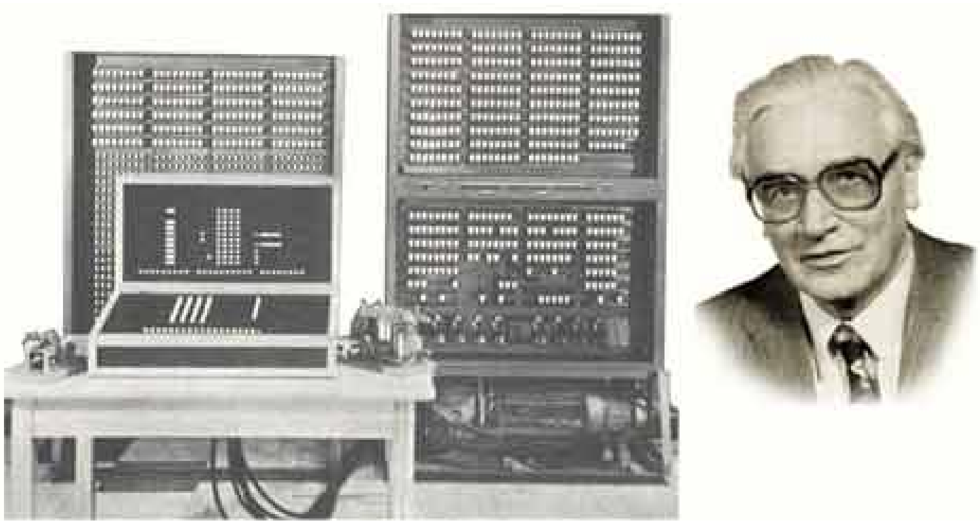


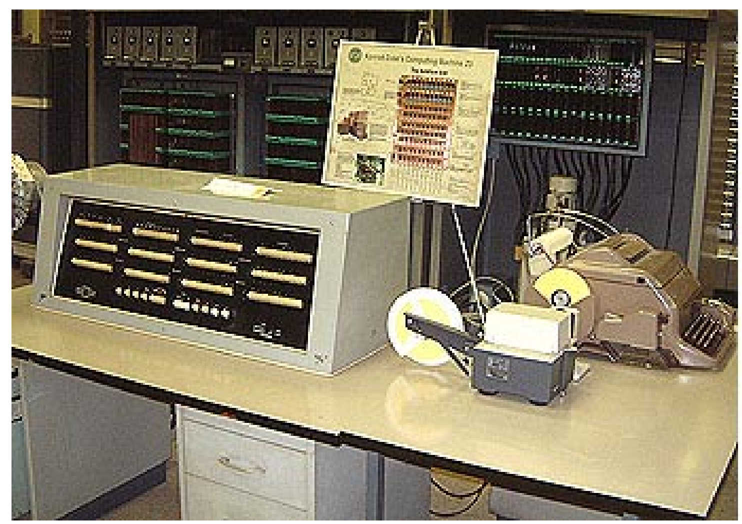
John Vincent Atanassof

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.

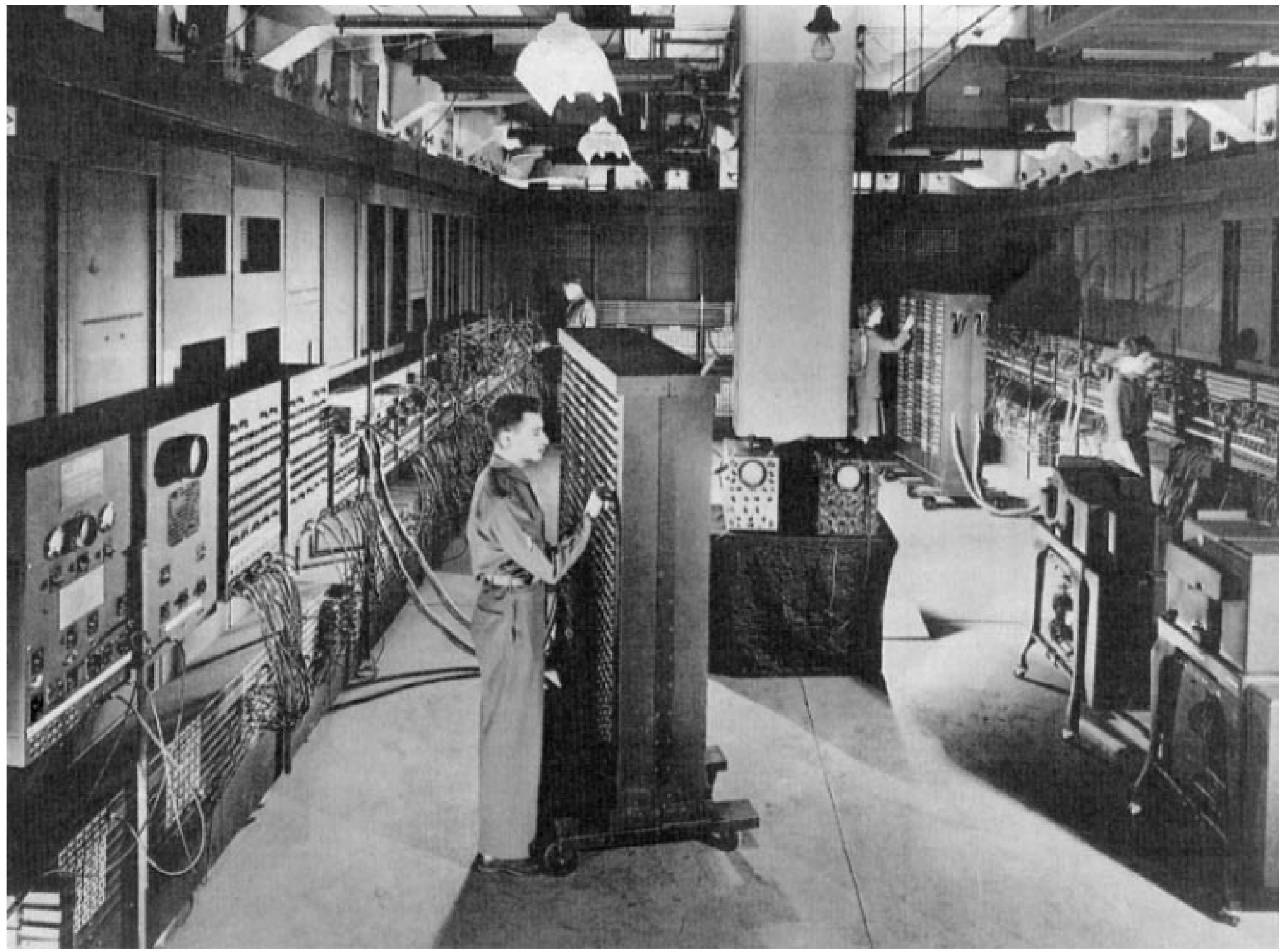
Completed in the Fall of 1945, used on “The Super.”

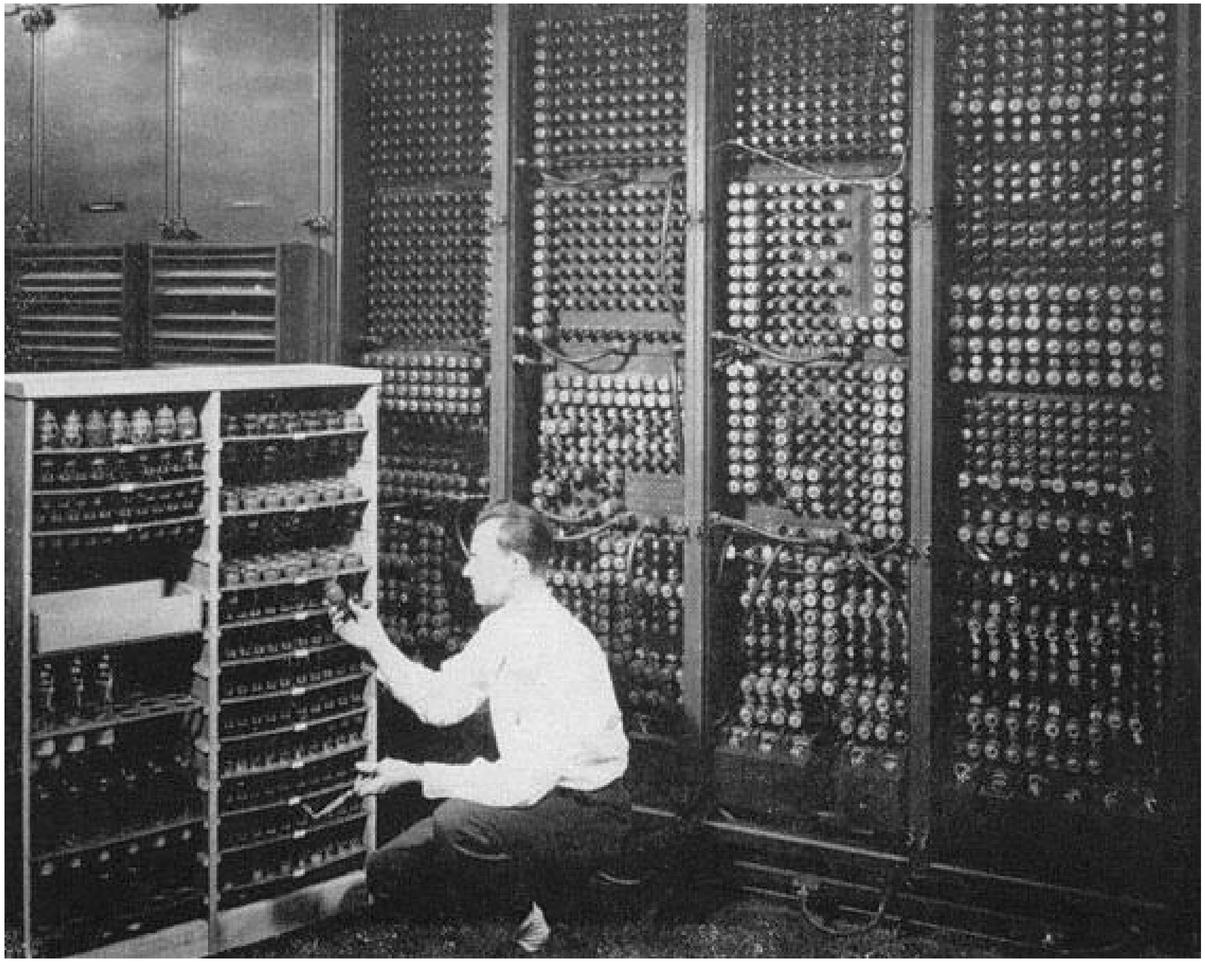
John Mauchly

Presper Eckert

ENIAC

- Math Units
  - 20 accumulators
    - Flip flop “wheels” + Tables
- Memory
- Program
  - Plug board,
  - cables,
  - switches.





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?

Policy

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 World at 1945

(v-c)

Looking at v:

- Governance, Military, Science, Commerce.
  - Computers focused on military problems.

Looking at c:

- Electronics: Vacuum tubes and relays.
  - *Modest* cost savings.
  - *Marginal* cost is high.
- A few large machines.

Winner take all dynamics

- Schumpeterian Competition?

Coming Attractions

Looking at v:

Technology: True computers, new capabilities.

New Uses: Finding a civilian market.

Looking at c:

Falling Costs: Integrated circuits and software.

Schumpeterian competition continues…

Policy Levers

- Military spending.
- Antitrust (again).