15-292 History of Computing

Computing Advances during a Time of War (World War II)

Harvard Mark I

IBM Automatic Sequence Controlled Calculator

- *Digital* computer
  - Aiken's machine for "makin' numbers"
- Developed by Howard Aiken 1937-1943 at Harvard University
  - Inspired by Babbage
  - IBM funded the construction under the permission of Thomas J. Watson Sr.

- Constructed out of switches, relays, rotating shafts and clutches
- Sounded like a "roomful of ladies knitting"

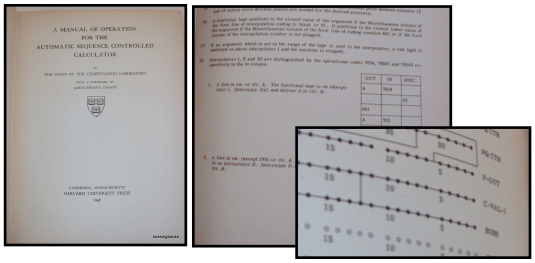
Harvard Mark I

- Contained more than 750,000 components
  - over 50 feet long
  - 8 feet tall
  - weighed approximately 5 tons
  - 750,000 parts
  - hundreds of miles of wiring
- Performance:
  - Could store just 72 numbers
  - Could perform 3 additions or subtractions per second
  - Multiplication took 6 seconds
  - Logs & trig functions took over a minute
  - Fed programs using punched tape
  - Could perform iteration (loops), not conditional branching

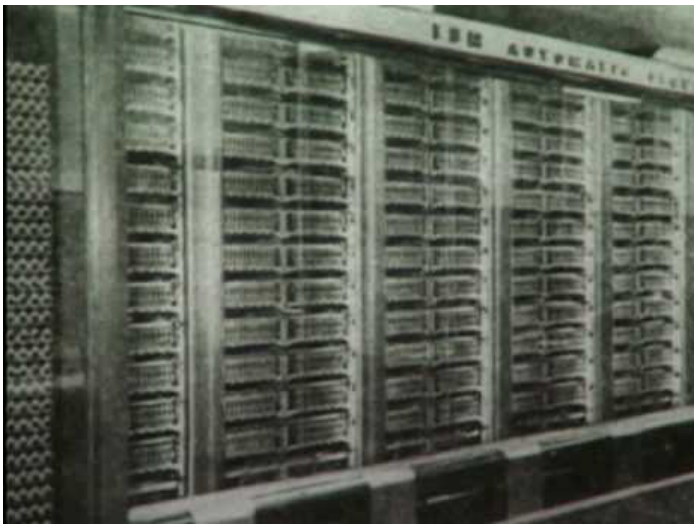
Harvard Mark I

- 1944 – started to be used for table making for the Bureau of Ships
- Intense interest from press & scientific community
  - "Harvard's Robot Superbrain" – American Weekly

- Aiken worked with Rear Admiral Grace Hopper on the programming and documentation of the machine
- Users manual was the first digital computing publication



Grace Hopper Reflects On the Harvard Mark Computers



Aiken vs. IBM

- Watson had IBM give it a facelift against Aiken's wishes
- 1944 Dedication Ceremony
  - Aiken took full credit for it, ignoring IBM's Engineer's contribution
  - Made Watson Sr. furious and he vowed "revenge"
    - Creates The Selective Sequence Electronic Calculator (later)

The Harvard Mark I

Harvard Mark II
Aiken Relay Calculator

Harvard Mark II (1947) - still electromechanical

Harvard Mark IV

Harvard Mark IV (1952) - electronic

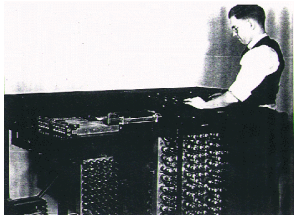
The demise of electromechanical computing

- Computers like the Mark I were quickly eclipsed by electronic machines
  - Electronic machines had no moving parts
- Mark I shortcomings
  - was brutally slow
  - "Babbage's Dream Come True"?
    - ran 10 times as fast as Babbage's Analytical Engine would
    - could not perform decision making (branching)
    - within 2 years electronic machines were working 1000 times faster
- In 1947, how many electronic digital computers did Aiken predict would be required to satisfy the computing needs of the entire U.S.?
  - 6

Reconstruction

The Atanasoff-Berry Computer (ABC)

- By John Vincent Atanasoff (designer) and Clifford Berry (his grad student, the builder) at Iowa State University during 1937-42
  - the first US *electronic* digital computer?
  - used binary arithmetic
  - regenerative memory
  - parallel processing
  - separation of memory and computing functions

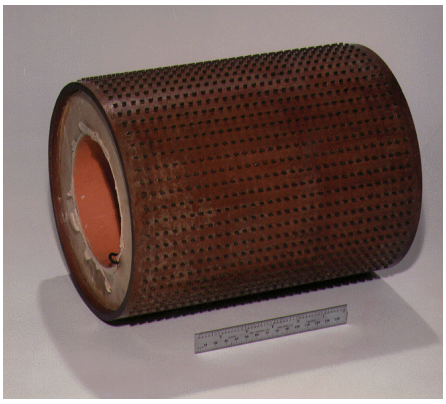


Clifford Berry with the ABC (Ames Laboratory, DOE)

- How did Atanasoff get the idea?
  - Iowa was a dry state, so he drove 189 miles to Illinois and got a drink of bourbon at a roadhouse
  - neon lights sparked the idea

John Vincent Atanasoff

- 1903-1995
- Given $650 to start work on his ideas of an electronic computer in 1937.
- Was called to war effort at the Naval Ordnance Lab in Washington DC
  - had to give up ABC
- Returns in 1948 to Iowa State to find the ABC dismantled.
- Receives the National Medal of Technology from President George Bush in 1990



The only surviving fragment of the original ABC built in 1939.
(Ames Laboratory, DOE)

Reconstruction & Operation

World War II (WWII)

- At start of WWII (1939)
  - US Military was much smaller than Axis powers
  - German military had best technology
    - particularly by the time US entered war in 1941
  - US had the great industrial *potential*
    - twice the steel production as any other nation, for example
- A military and scientific war
  - Outcome was determined by technological developments
    - atomic bomb, advances in aircraft, radar, code-breaking computers, and many other technologies

Konrad Zuse

- German Engineer
- Z1 – built prototype 1936-1938 in his parents living room
  - did binary arithmetic
  - had 64 word memory
- Z2 computer had more advances, called by some first fully functioning electro-mechanical computer
  - convinced German government to fund Z3
- Z3 funded and used by German's Aircraft Institute, completed 1941
  - Z1 – Z3 were electromechanical computers destroyed in WWII, not rebuilt until years later
  - Z3 was a stored-program computer (like Von Neumann computer)
  - never could convince the Nazis to put his computer to good use
- Zuse smuggled his Z4 to the safety of Switzerland in a military truck
- The accelerated pace of Western technological advances and the destruction of German infrastructure left Zuse behind

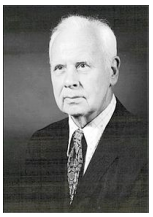
Konrad Zuse

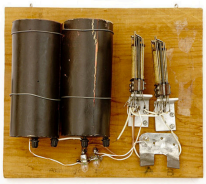
Z3

George Stibitz

- Electrical Engineer at Bell Labs
- In 1937, constructed electrical digital calculator out of odds and ends in his kitchen
  - called it the “Model-K”
  - did binary arithmetic, used lights to display result
- Bell Labs saw the potential
  - Completed Stibitz Complex Number Calculator in 1939
- Would be the foundation for digital computers

http://ei.cs.vt.edu/~history/Stibitz.html





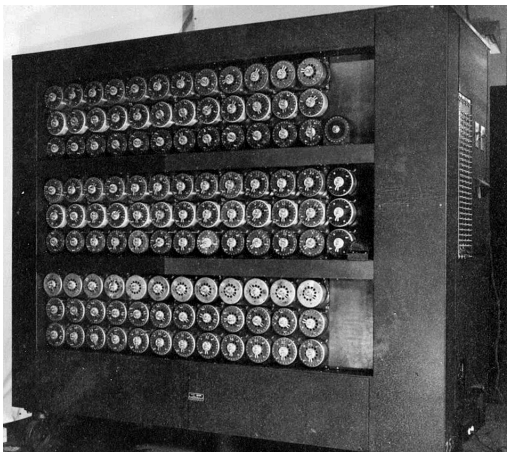
Relay Computer

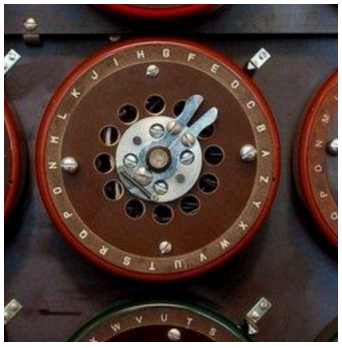
Turing's Work Continues

- Worked on the Enigma problem during WWII at Bletchley Park

- Developed the Bombe in 1940 to help decode encrypted Enigma messages by the Germans (see picture later)
  - Based on a earlier work by Polish mathematicians Rejewski, Rozycki, Zygalski
- Worked in 1941 to help break more difficult Enigma codes using statistical analysis

Bombe





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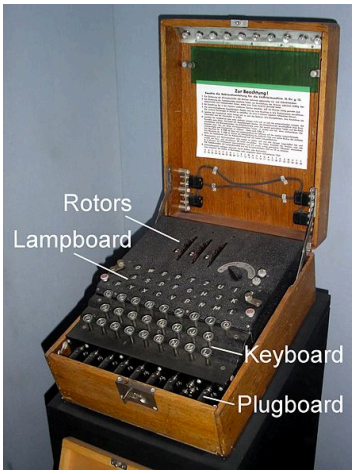
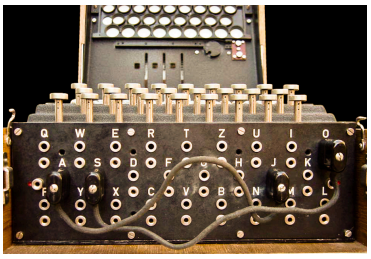
History of the Bombe

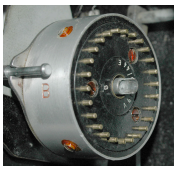
Enigma

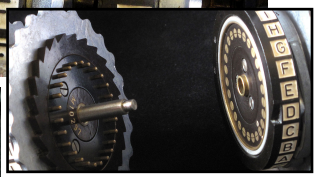
- Alan Turing works at Bletchley Park on breaking the German Enigma Code
- Made up of a front-facing plugboard followed by a set of rotors to translate and a reflector.
- Input letter using keys
- Output letter shown with lights



Enigma Components







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Enigma Components

- Plugboard (only 10 patch cables supplied)
  Allows up to 10 pairs of letters to swap.
- Rotors (several were available, 3 were used)
  For each letter that is encoded, rotor1 rotates one position.
  If rotor1 reaches its turnover position, rotor2 also rotates one position.
  If rotor2 reaches its turnover position, rotor3 also rotates one position.
  (Turnover positions varied for each rotor.)
- Reflector (several were available)
  Each letter reflects to another letter.
  There are 13 reflection pairs in a reflector.

Enigma 3-Rotor Example

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ
GITXSFAQBPOLMZKJHRECUWVDYN  plugboard

ABCDEFGHIJKLMNOPQRSTUVWXYZ
DFHJLCPRTXVZNYEIWGAKMUSQOB  rotor1

ABCDEFGHIJKLMNOPQRSTUVWXYZ
AJDKSIRUXBLHWTMCQGZNPYFVOE  rotor2

ABCDEFGHIJKLMNOPQRSTUVWXYZ
EKMFLGDQVZTNOWYHXUSPAIBRCJ  rotor3

ABCDEFGHIJKLMNOPQRSTUVWXYZ
YRUHQSLDPXNGOKMIEBFZCWVJAT  reflector
```

(Are these valid plugboard, rotors and reflector? How would you know?)

Enigma 3-Rotor Example

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ
GITXSFAQBPOLMZKJHRECUWVDYN  plugboard

ABCDEFGHIJKLMNOPQRSTUVWXYZ
FHJLCPRTXVZNYEIWGAKMUSQOBD  rotor1

ABCDEFGHIJKLMNOPQRSTUVWXYZ
AJDKSIRUXBLHWTMCQGZNPYFVOE  rotor2

ABCDEFGHIJKLMNOPQRSTUVWXYZ
EKMFLGDQVZTNOWYHXUSPAIBRCJ  rotor3

ABCDEFGHIJKLMNOPQRSTUVWXYZ
YRUHQSLDPXNGOKMIEBFZCWVJAT  reflector
```

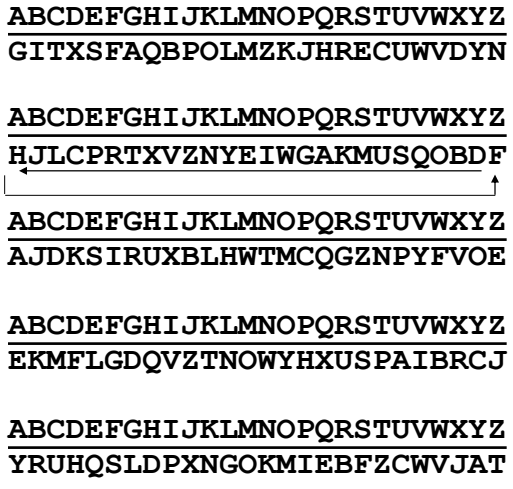
User types T. Rotor 1 rotates one position. (continued on next slide)

Enigma 3-Rotor Example

T -> C -> J -> B -> K -> N -> L -> K -> S -> E

An electrical signal goes through plugboard, then the three rotors, then reflects, then back through the three rotors in reverse, through plugboard. The E lights up.

Enigma 3-Rotor Example

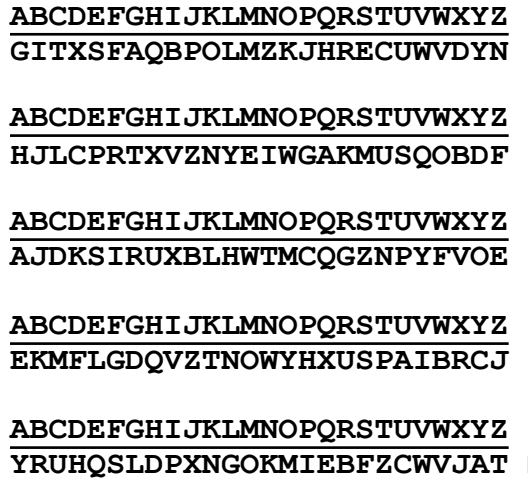


User types U. Rotor 1 rotates one position. (continued on next slide)

Enigma 3-Rotor Example

An electrical signal goes through plugboard, then the three rotors, then reflects, then back through the three rotors in reverse, through plugboard. The `W` lights up.

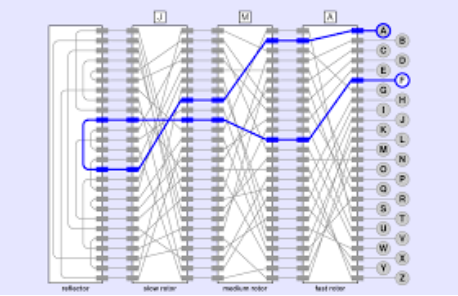
Enigma 3-Rotor Example



User types `R`. What letter lights up? (don't forget to rotate rotor1)

Decoding using Enigma

- Set the machine to its original rotor setting.
- Enter each coded letter one at a time. The electrical path that forms is the same path, just leading to the original decoded letter.



A encodes to **F**.
F decodes back to **A**.
(assuming same rotor alignment)
(image from https://web.stanford.edu/class/cs106j/handouts/36-TheEnigmaMachine.pdf)

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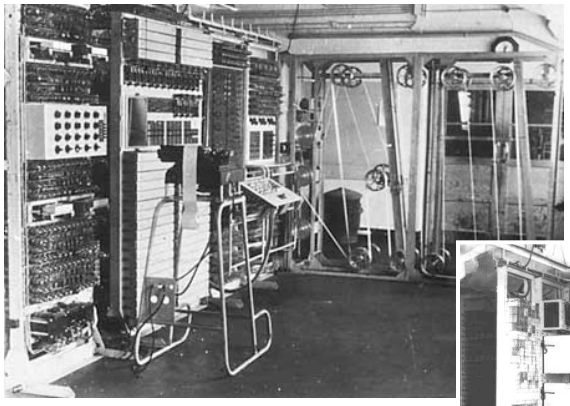
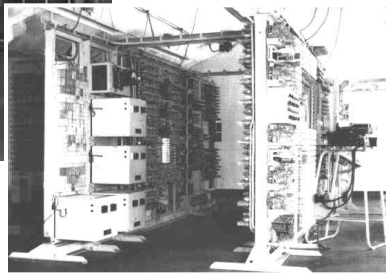
Turing's additional work

- Germans had another cipher for ultra-top-secret communications called *Geheimfernschreiber* (secret telegraph)
  - The allies called this the "Fish"
- Designed a machine called COLOSSUS that could break the Fish code in 1943
- COLOSSUS was one of the world's earliest working electronic digital computers that could be programmed
  - 1800 vacuum tubes

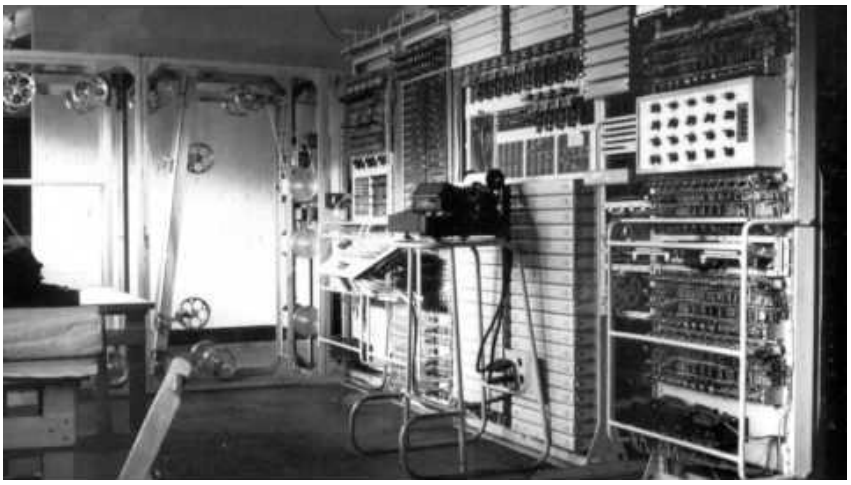
Colossus





from Tony Sale,
original curator of the
Bletchley Park Museum

History of Collosus



The Birth of ENIAC

- Collaboration between Moore School of Electrical Engineering at the University of Pennsylvania and the Ballistic Research Laboratory in Aberdeen, MD
- Both sites had Bush Differential Analyzers
- UPenn's DA was faster but not fast enough for the amount of computation needed to compute trajectory tables
- Dr. John W. Mauchly of the Moore School visits Atanasoff at Iowa State to learn about his research in electronic computing in 1941

Mauchly and Eckert

Mauchly

Eckert

from www.computer.org

Mauchly and Eckert create ENIAC

- Mauchly returns and works with Dr. J. Presper Eckert on creating an electronic computer to solve differential equations for the Ordnance Dept.
- In 1943, the Ordnance Dept. signs a contract for UPenn to develop an electronic computer based on the plans of Mauchly and Eckert
  - Eckert – chief engineer
  - Mauchly – principal consultant
  - presented by Lt. Herman H. Goldstine, mathematician
- Constructed completed in the fall of 1945 after WWII ends, and dedicated in February 1946.

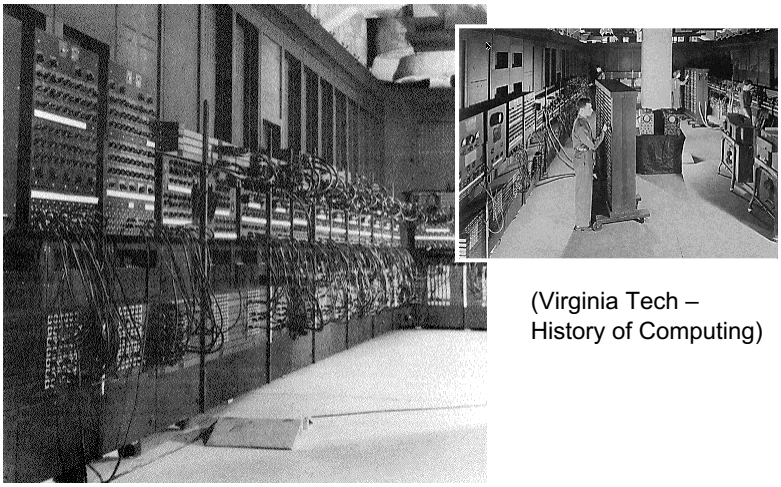
ENIAC

Electronic Numerical Integrator and Computer

- This is the most important computer we've discussed so far
  - It's creation commonly called the birth of modern computers
  - Speed left Mark I behind
    - 5000 vs. 3 calculations per second
  - it is the first true ancestor of all electronic computers used today
- Filled an entire room
  - 42 panels, each 9' X 2' X 1', three on wheels
  - organized in a U shaped around the perimeter of a room with forced air cooling
- Weighed 30 tons
- Reportedly consumed 150-200 kW of power
- Contained a huge amount of parts:
  - approx. 19,000 vacuum tubes and 1500 relays
  - over 100,000 resistors, capacitors and inductors
- Input and output via an IBM card reader and card punch

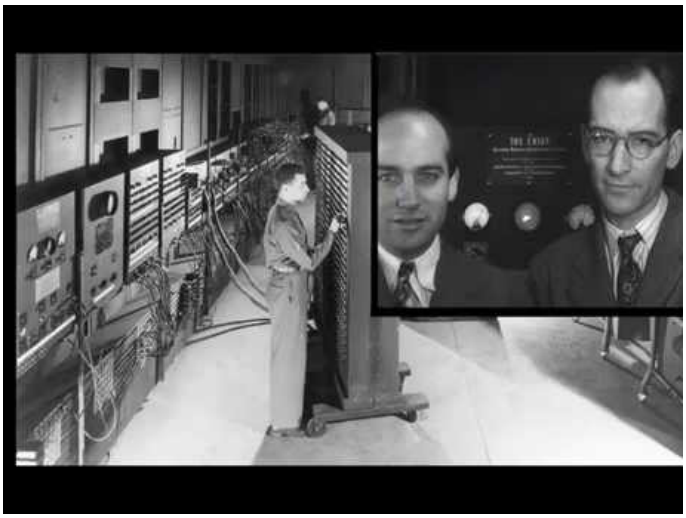
ENIAC

Electronic Numerical Integrator and Computer



(Virginia Tech – History of Computing)

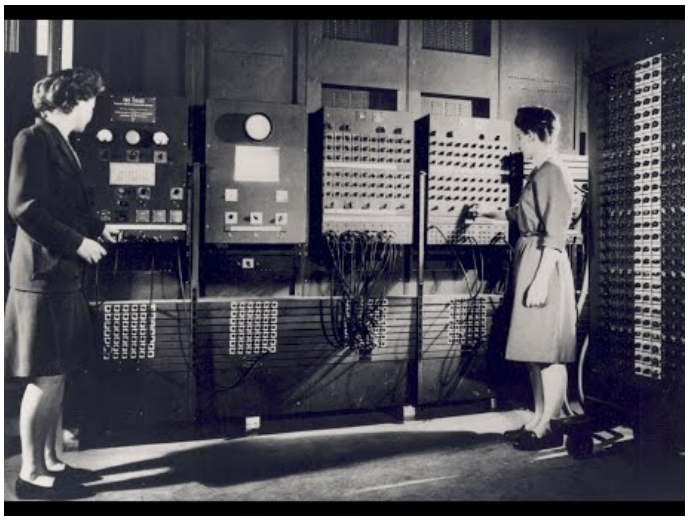
History of the ENIAC



Advantages and Disadvantages of ENIAC

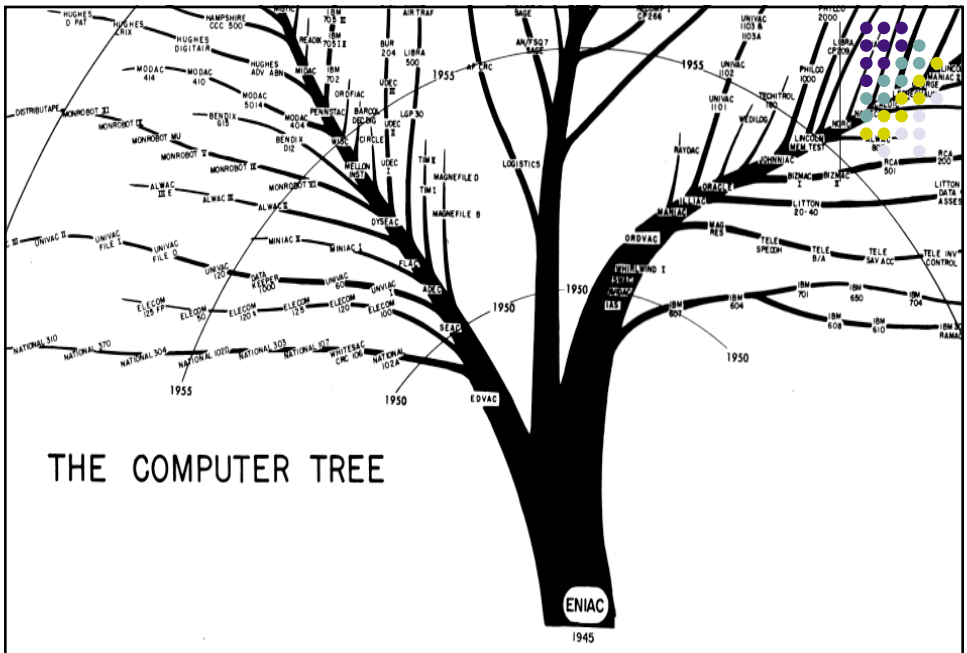
- Advantage:
  - Speed in calculation of ballistic trajectories:
    - Human with hand calculator: 20 hours
    - Bush Differential Analyzer: 15 minutes
    - ENIAC: 30 seconds
      - "could calculate the trajectory of a speeding shell faster than the shell could fly"
- Disadvantages:
  - Programming took very long
    - plugging in patch cables and setting 3000 switches
  - Vacuum tubes would burn out quickly
    - In 1952, 19,000 tubes were replaced → ~50 per day!
  - Small memory limited the types of problems ENIAC could solve – used mercury delay lines in subsequent machines
  - Used decimal system

The Women of ENIAC



ENIAC's Spawn

- The Moore School's EDVAC (completed in 1952)
- Computer experts from America & Britain attended lectures on ENIAC
  - Britain was one of the only European nations not ravaged by war
  - British computers soon followed:
    - Manchester Baby Computer (1948)
    - EDSAC (1947)
- IAS (von Neumann)
- Eckert & Mauchly's UNIVAC
- IBM & Columbia's Selective Sequence Electronic Calculator (SSEC)
- Lots of others
  - JONNIAC, MANIAC, ILLIAC, SILLIAC



http://ftp.arl.mil/~mike/comphist/61ordnance/chap7.html