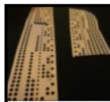
The Mechanical Monsters

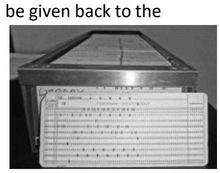
Physical computational devices from the early part of the 20th century

James Tam



Punch Card Based Machines

- Different machines would use different forms of encoding.
- The programmer would use a machine to punch the information for a program onto card or tape.
- Typically the program would then be given to a computer operator so the program would be run.
- After a delay the results would then be given back to the programmer for analysis.



File images: James Tam

Link to extra optional video: video of punch cards and punch tape

James Tam

Video #1: The Use Of Computers During World War II

- Video link not available (original video could not be found)

James Tam

Mechanical Monsters: Groups

- The Zuse machines (Z1 – Z4)
- Bell Relay Computers
- The Harvard Machines
- The IBM calculators

James Tam

The Zuse Machines

- Machines:
  - Z1
  - Z2
  - Z3
  - Z4
- Originally Zuse's machine was called the V1 (Versuchsmodell-1/Experimental model-1)
- After the war it was changed to 'Z' (to avoid confusion with the weapons being developed by Wernher von Braun).

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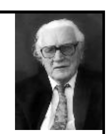
Konrad Zuse (1910-1995)



- Born in Berlin he had childhood dreams of designing rockets that would reach the moon or planning out great cities.
- He trained as a civil engineer.
  - As a student he became very aware of the labor needed in the calculations in his field.

= (x * y) / (z +(a1 + b))

Image: http://www.konrad-zuse.net

James Tam

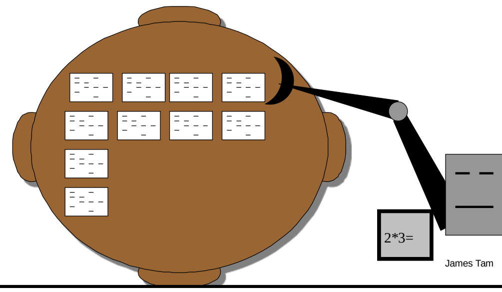
Konrad Zuse (1910-1995): 2

- Zuse was the first person "…to construct an automatically controlled calculating machine." – "A history of modern computing" (Williams)
  - Not electronic
  - Didn't have a stored program in memory (instructions came from external tape).
- Many of his earlier machines were personally financed or funded by friends and family (limited $$$).
- After finishing school he began work in the aircraft industry.

James Tam

Zuse: Early Designs

- In order to automate the process of performing calculations Zuse envisioned a mechanical machine.



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Zuse: Early Designs

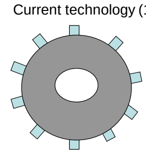
- Based on this early design Zuse came up with a design that included only three parts:
  - Control
  - Memory
  - Calculator

James Tam

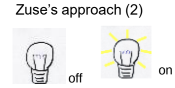
Z1: Origins

- Zuse was not familiar with the design of other mechanical computers.
  - This was a good thing!
  - Zuse had to largely build his design from scratch

Current technology (10)



Zuse's approach (2)



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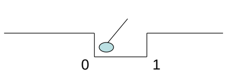
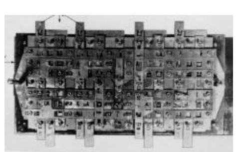
Z1: Memory

- Memory consisted of strips of metal with slots cut into them.
- A pin would rest on one side of the slot





http://www.techbites.com/

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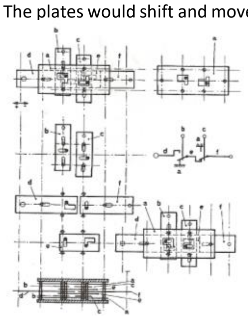
Z1 Memory

- The plates would shift and move (mechanical memory).



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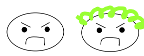
Z1: Development 'Lab' 1936

http://www.techbites.com/



Mr. and Mrs. Zuse

James Tam

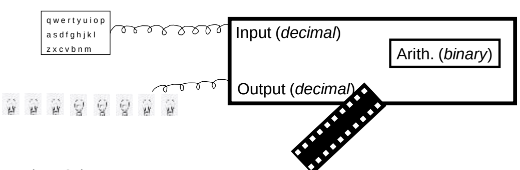
Z1: Specifications

- Storage capability:
  - Memory 64 x 22 bit locations (Source: Interational Federation for Information Processing (IFIP 2013) Horst Zuse: pp 287 – 296)
- Clock speed:
  - 1 MHz (Source: "Giants of Computing" by Gerard: pp 281 – 284 (Springer-Verlag London 2013)

James Tam

The Z1 (2)

- Overview of the architecture



Control: data and instructions (35 mm tape)

Helmut Schreyer

www.atariaarchives.org

James Tam

The Z1 Memory

- The memory worked well but the complex routing of the ALU made the transport of information between the parts of the machine problematic:

Image: https://commons.wikimedia.org (Source: Nevit Dilmen)

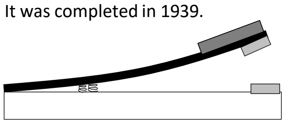
Memory: Sheets of metal

Location: Cramped Berlin apartment (corners?): Image courtesy of James Tam

James Tam

The Z2

- Designed to overcome the signal routing and reliability problems of the mechanical memory by using relays
- It was completed in 1939.



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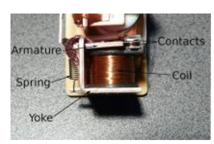
Actual Relays

Telegraph relay:
http://www.sparkmuseum.com



Computer relay:
http://en.wikipedia.org/wiki/Relay
(public domain)

James Tam

Relay Memory

- The relay based memory was more reliable than the mechanical metal sheets.
- And the resources were easier to obtain than vacuum tubes.
- The initial design was to entirely use relays but was unfeasible:
  - $2/relay * thousands of relays
  - Rebuilt second hand relays were used instead
- However even the Z2 was not reliable enough to be put into actual use
- It's one major contribution was to get funding from to allow for further work (Z3)

Z2: Alternate Memory

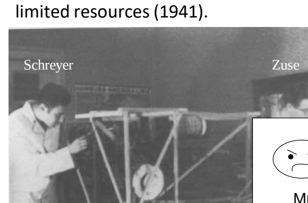
- Schreyer wanted to build the Z2 with vacuum tube memory
  - A demo of a portion of the computer did use vacuum tubes
  - But during the war the tubes were scarce and the Z2 would have needed 1000 tubes
  - The military wouldn't provide the tubes because of the development time needed.

Z2 Spec

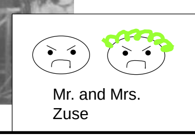
- It was very similar to the Z1
- (Source: "Giants of Computing" by Gerard: pp 281 – 284 (Springer-Verlag London 2013)
  - Clock speed: 3 MHz
  - Memory: 64 memory locations (each 16 bits in size)

The Z3

- Although the work was funded by the German Aeronautical Research Institute, Zuse was not provided with a workspace or technical staff.
- As was the case with the Z1, he completed his work with limited resources (1941).

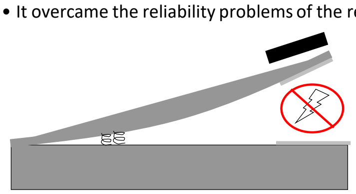


"A History of Computing Technology" (Williams)



The Z3 (2)

- This machine was similar to the Z1 and Z2 (input, output and control)
- It overcame the reliability problems of the relay-technology



The Z3 (3): Source Williams

- It was a relatively fast machine (considering the limited resources and relative isolation of Zuse)
  - Additions: 0.25 – 0.3 seconds
  - Multiply: two numbers every 4 – 5 seconds
  - (Comparable to the speed of the Harvard Mark I which was developed two years later with much greater resources)
- It was developed on a relatively modest budget:
  - 1940s currency: 25,000 RM (~$6,500 US)
- But it wasn't practical for large scale problems (limited memory): 64 words
- 5 - 10 MHz[1]

1: Dalle calcolatrici ai computer degli anni Cinquanta
https://books.google.ca/books?id=p5GszzXR550C&pg=PA177&redir_esc=y#v=onepage&q&f=false

The Z3 (5)

- The original was destroyed by the allies in 1943-1944.
- Zuse made a copy in the 1960s which is on display in a museum.

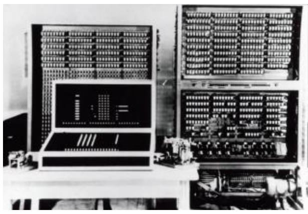
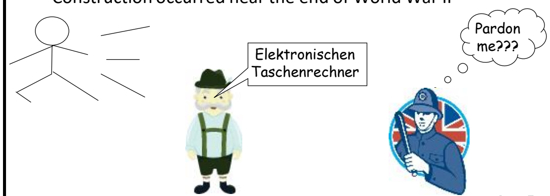


Image: www.computerhistory.org

James Tam

The Z4

- Essentially the same as the Z3 (save that the word size was larger).
  - Z3: 22 bits (1=sign, 14=mantissa, 7=exponent), 5 – 10 MHz
  - Z4: 32 bits, 40 MHz (Source unconfirmed)
- Construction occurred near the end of World War II



Clipart: www.colourbox.com

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The Z4

- After the war the Z4 was completed and a few upgrades were added (e.g., conditional branch).
- In 1950 it was the only operational computer in Europe and one of the few in the entire world (Williams).
- It continued to provide useful service until 1960.

James Tam

Significance Of The Zuse Machines

- The Zuse computers were the first automatically controlled calculated machines that were actually functional.
- They had comparable speeds to machines developed later (Harvard Mark I).

James Tam

Significance Of The Zuse Machines (2)

- It's also remarkable considering the working conditions:
  - Limited resources

"A History of Computing Technology" (Williams)

$$$

  - Isolation (WWII!)

James Tam

Video #2: Konrad Zuse Machine

- Workings of the Z1 from the Technikmuseum, Berlin
  - https://www.youtube.com/watch?v=RG2WLDxi6wg

James Tam

Video #3: Operation Of A Relay-Based 'Computer'

- Original video link could not be found.
- Alternate video link:
  - The 'relays' are different from computers such as the 'Z' series computing devices but you can at least see the connectivity occur between circuits.
  - Also see Video #4 to see how relays of the era operated.
  - https://www.youtube.com/watch?v=1it3kjIgocc

Bell Lab Relay Computers

- The Complex Number Calculator (Model I)
- The Relay Interpolators (Model II – VI)

The Need For Complex Numbers

- The design of electrical devices and apparatus (e.g., telephone lines) involves extensive calculation and manipulation of complex numbers.
  - Awkward to work with complex numbers on a standard computer.
  - Consequently a telephone company (Bell) developed a specialized computer to work with this type of value.
  - (The problems involving the calculation of complex numbers began to hamper growth).

George Stibitz (1904–1995)

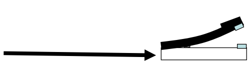

www.dartmouth.edu.ne

- Born in York, Pennsylvania.
- He received his bachelor's degree from Denison University, his master's degree from Union College in 1927, and his Ph.D. in mathematical physics in 1930 from Cornell University.
- In his later years (~late 1980s - 1990s) he turned to "non-verbal uses of the computer" (computer art: Commodore Amiga).
  - His artwork is on display at Denison University.

George Stibitz (2)

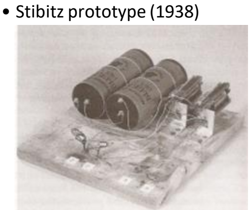
- In 1937: a mathematician working for Bell labs.
- Stibitz noted a similarity between telephone circuit diagrams and binary numbers.
- In his spare time and with cast-off parts he would experiment with electronics.

Bell junk pile



The Second Set Of Mechanical Monsters: The Bell Relay Based Computers

- Stibitz prototype (1938)



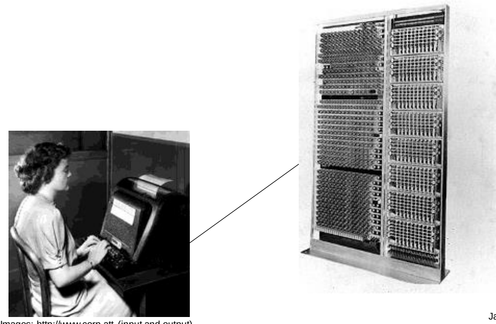
- Dr. T.C. Fry (head of Stibitz's group) just happened to be notified of the problems that the company was having dealing with its calculating load.

Image: "A History of Computing Technology" (Williams)

The Complex Number Calculator

- Work began in late 1938 after S.B. Williams was appointed to oversee the project.
  - Stibitz: came up with the idea
  - Williams: had the necessary Engineering training to design the relay circuits.
- It was completed Jan 8, 1940 and remained in daily use until 1949.
- Operations (complex numbers): add, subtract, multiply and divide.

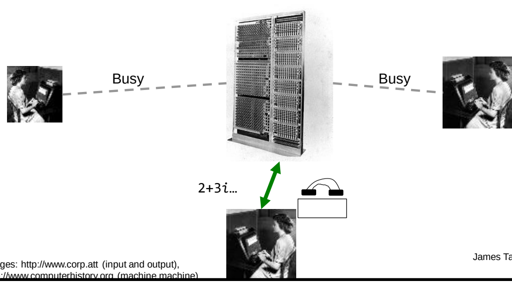
The Complex Number Calculator: Operation



Images: http://www.corp.att (input and output), http://www.computerhistory.org (machine machine)

The Complex Number Calculator: Significance #1

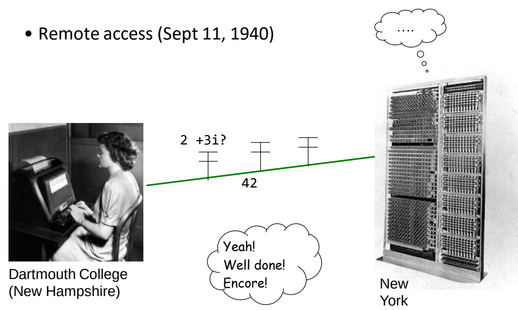
- It was the first machine to allow for *more than one* terminal connection



Images: http://www.corp.att (input and output), http://www.computerhistory.org (machine machine)

The Complex Number Calculator: Significance #2

- Remote access (Sept 11, 1940)



Images: http://www.corp.att (input and output), http://www.computerhistory.org (machine machine)

The Complex Number Calculator: Details

- It only required 450 telephone relays!
- The logic was simplified by using a special form of binary (Binary coded decimal)
  - Harder U.I. for the operators, easier for the design of the hardware logic.

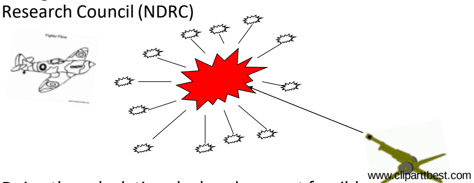
Decimal value	BCD value
0	0011
1	0100
2	0101
3	0110
4	0111
5	1000
6	1001
7	1010
8	1011
9	1100

The Complex Number Calculator: Post Results

- The machine was a technical success but Bell Labs didn't think it would a commercial success ($20,000 to develop the first model).
- No other versions were developed.

The Relay Interpolator

- After work on the Complex Number Calculator was over and Stibitz and Williams returned to their ‘day jobs’.
- The U.S. enters World War II in 1941
  - December 7, 1941 (Japanese attack on Pearl Harbor)
- George Stibitz was recruited to work on the National Defense Research Council (NDRC)



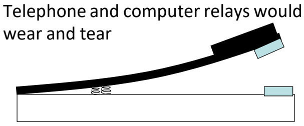
- Doing the calculations by hand was not feasible.

The Relay Interpolator (Model II)

- It was referred to as “The Model II Relay Calculator” or “Model II Relay Interpolator”.
- Completed and fully operational Sept 1943.
  - 493 relays in two racks (5’ high x 2’ wide) – Williams
  - It could produce results for addition and subtraction (via negate and add)
- It not only adequately performed the task for which it was created (AA-gun tracking) it became a general use computer throughout the second world war.
- After the was it was donated to the U.S. Naval Research lab where it was productively used until the Relay Interpolator was shut down in 1961.

The Relay Interpolator: Reliability

- Telephone and computer relays would eventually fail through wear and tear



- Stibitz was concerned that if a relay failed an incorrect result could be produced without any way of knowing about the error.
- Consequently the machine used a bi-quinary system of encoding information stored in the machine.
- Each relay would store 1 bit of information.

Bi-Quinary Encoding

- Each (decimal) digit would require 7 relays.

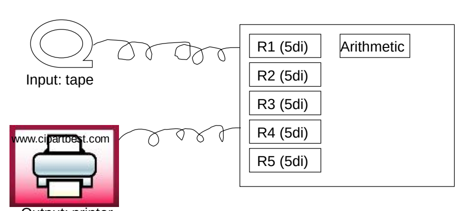
Digit	Bi-quinary coding	
0	01 00001	
1	01 00010	
2	01 00100	
3	01 01000	
4	01 10000	(1 = relay set)
5	10 00001	(0 = relay not set)
6	10 00010	
7	10 00100	
8	10 01000	
9	10 10000	

Table image: “A History of Computing Technology” (Williams)

Bi-Quinary Encoding

- Machines implementing this method of encoding information were extremely reliable.
  - “If a spec of dust got trapped in a relay contact and caused an erroneous result then, as soon as it was found and removed, the machine would take up the calculation from the point at which it had been interrupted without any effort.” (Williams)
  - The (later model V) was used continuously for 167 hours (during most of that time it was unattended).

Relay Interpolator: Specifications



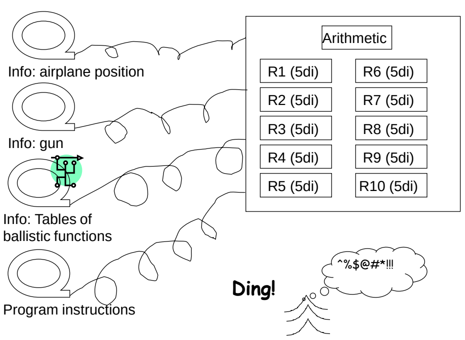
Model III ("The Ballistic Computer")

- The third of Stibitz's relay computers was also designed for the same uses as the Relay Interpolator (Model II).
  - Because of this it was usually known as the Ballistic Computer.
- The machine was being designed (1942) even before the Model II was complete.
- (Specifications from Williams)
  - Over 1,300 relays (5 frames each 5' high x 3' wide)
  - Doubled memory: 5 to 10 registers
  - It could perform addition and subtraction in the same fashion as it's predecessors but also included multiplication and division.
  - Multiplication ~1 second

Model III ("The Ballistic Computer"): 2

- It was based on the same relay based technology and bi-quinary storage of numbers with some upgrades (slide to come).
- Completed in June 1944 and remained in service until 1958.

Model III: Specifications



Reliable: Instructions (24 hours)

Model IV

- The second Ballistic Computer (officially known as "Bell Laboratories Relay Calculator Model IV" or "Error Detector Mark 22" – Navy).
- Completed in March 1945 and like the Model III it was used for ballistics calculations.
  - Model IV: added features to allow for the calculation of negative angles (*otherwise it was a Model III*)

www.ciipartbest.com

The Model V ("The Two In One")

- The Relay Interpolator and the Ballistic Computers were so successful that the U.S. government decided to back the creation of a much larger relay-based system.
  - Also there were still a backlog of needed calculations to be completed.
- There were two (nearly identical) machines built to fulfill the need
  - Each half could work on a separate problem or both halves could work together.

"A History of Computing Technology" (Williams)

The Model V ("The Two In One"): 2

- Reliable:
  - As noted data was encoded using the bi-quinary method
  - It could handle the case when an error was detected while an instruction was executed
    - The extra reliability slowed operations
    - Slowest machine (save for the Harvard Mark I) - Williams
- Specifications (Williams)
  - 44 registers
  - 9000 relays
  - 1000 square foot 'footprint')
  - 10 tons
  - 7 digit numbers
- A 'CADET' (Can't Add Doesn't Even Try) architecture for mathematical problems

Model V: Fate

- After the war, one was used for a while at Fort Bliss and later given to the University of Arizona.
- The other machine was donated to the Texas Technology College in 1958 but the delivery truck ended up in a car accident and that machine was destroyed.
- The wrecked machine was used for spare parts for the machine at the University of Arizona.

James Tam

Model VI

- After the end of WWII Stibitz left Bell
- But Bell still constructed another version of the Stibitz machines (completed in 1950).
  - It was used for the same purpose as the original Complex Number Calculator.
- It was essentially a Model V.
  - The main difference was that it could store 10 (rather than 7) digit numbers.
  - In the late 1950s it was donated to the Polytechnic Institute (Brooklyn) and later in 1961 donated to the Bihar Institute of Technology (India) where it eventually became a historical display.

James Tam

Video #4: Bell (AT&T) Computers

- A good source, it's AT&T's official technical YouTube channel:
  - It not only shows the basic design and operation of the Bell lab computer but you can also see relay technology in operation (2:59)
  - Obviously this video is highly recommended!
  - https://www.youtube.com/watch?v=a4bhZYoY3lo

James Tam

The Harvard Machines Of Howard Aiken

- The Harvard Mark I
- The Harvard Mark II
- The Harvard Mark III
- The Harvard Mark IV

James Tam

The Harvard Machines: Introduction

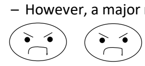
- They were developed under the guidance of Howard Aiken (1900- 1973).
  - He studied at the University of Wisconsin and eventually earned his PhD. at Harvard.
  - He also had a military background.
  - He envisioned a device that could complete many tedious calculations.
  - The current technology wasn't up to the task (by an order of magnitude).
  - Aiken was familiar with Babbage's biography.
  - He suggested several ideas to others (so they could fund the development) but he found no takers.
  - Finally with some help: Harlow Shapley (astronomer) and Theodore Brown (Harvard business school Prof.),
  - Aiken managed to get an appointment with Thomas J. Watson (1937).

James Tam

Image: "A History of Computing Technology" (Williams)

The Harvard Machines: Introduction (2)

- Watson agreed to have IBM fund the project
  - But Watson's goal from the project differed from Aiken's.
- The machine (originally named the "IBM Automatic Sequence Controlled Calculator" but soon became known as the Harvard Mark I) was demonstrated to be operational in 1944 and it was donated to Harvard.
  - Because of Aitken's military background it was almost immediately employed in the war effort.
    - Aitken was a navy commander in the reserves was in charge of the navy computational project).
    - Grace Hopper: assigned as Aitken's aide.
  - However, a major rift developed between Aiken and Watson.



James Tam

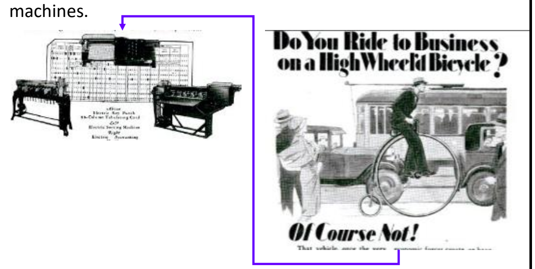
The Harvard Machines: Introduction (3)

- Aiken was well aware of the problems faced by his predecessor designers/developers (e.g., Babbage)
  - He avoided constructing machines that were too ‘cutting edge’ that employed untested/unproven technologies.
  - The mechanical components used in his machines were slower than the relay-based machines.
  - Pragmatic: “…he was willing to work with anyone’s technology so long as they paid the bills” – Williams.
  - When designing the Mark I Aiken originally approached (and was rejected by another company) ‘The Monroe Co’ – producer of traditional mechanical desktop calculators).
    - The Mark I may have been purely mechanical instead of using electricity to drive the mechanical parts had the original agreement been successful - Williams

James Tam

Harvard Mark I

- It was built from parts from standard IBM accounting machines.

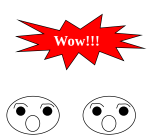


James Tam

Images: http://www-03.ibm.com/

Harvard Mark I (2) - Williams

- It was huge:
  - Size: 51’ long x 8’ high
  - Wiring required: 500 miles



- It was expensive:

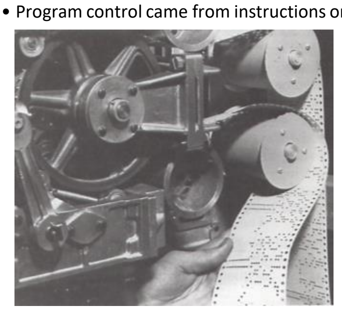
  ~$400,000 - $500,000.

James Tam

Harvard Mark I image: “The History of Computing Technology” (Williams)

Harvard Mark I (3)

- Program control came from instructions on punched tape.



James Tam

Image: “The History of Computing Technology” (Williams)

Harvard Mark I: Technical Specifications (Williams)

- The machine was motor powered.
- It contained 72 ‘registers’ each of which could stored 23 decimal digits (plus one more digit for the sign).
  - With a little rewiring the position of the decimal place could be changed (15 – 16th place default).
- Technology
  - Mechanical calculator
- Speed:
  - Additions: 0.3 seconds.
  - Multiplication: <=6 seconds.
  - Slower but more accurate than many of its peer machines.

James Tam

Harvard Mark I: Uses

- As mentioned after the Mark I was completed and set up at Harvard in May 1944 it was immediately enlisted in the war effort.
  - Recall: World War II (1939 – 1945) and Aiken held a Commander rank.
  - It was used entirely for military purposes for the duration of the war.
- After the war the Mark I was employed for research purposes.
- Eventually it was made obsolete by newer machines and dismantled in 1959.
  - Parts on display: Harvard, IBM head quarters (New York), Smithsonian (Washington DC).
- The major impact: a design model rather than the applications it was used for or the results that it produced (Williams).
  - Design model lasted until real memory (RAM) was invented.

James Tam

Video #5: Harvard Mark I

- Background information and technical information:
  - https://www.youtube.com/watch?v=bN7AdQmd8So

Video #6: Brief Biography Of Howard Aitken

- Original video link could not be found.

Grace Hopper (1906 – 1992)

"A History of Computing Technology" (Williams)

- She was a young lieutenant (Jg. Lt.) that was an assistant to Commander (Cmdr.) Aiken.
- She was curious and inquisitive child:

Grace Hopper (2)

- COMMODORE (REAR ADMIRAL LOWER HALF)
- CAPTAIN
- COMMANDER
- LT COMMANDER
- LIEUTENANT
- 2ND LIEUTENANT
- ENSIGN

- She received a degree in Mathematics and Physics from Vassar (New York) and eventually a PhD. from Yale.
  - In 1943 she enlisted in the Naval reserves.
  - Graduated in the top of her class in 1944.
  - She was then assigned to the project at Harvard as a junior grade naval lieutenant (second Lt.)
- She made many contributions to the development of the first compilers and the standardization of the COBOL programming language.
- At the same time she continued to be promoted through the ranks of the Navy:
  - When she attained the rank of Commodore/Rear Admiral Lower Half (1980s) she was oldest serving member. (Williams)

Video #7: Brief Biography Of Grace Hopper

- Original video link not available.

Video #8: Grace Hopper Interview

- Late Night with David Letterman:
  - A good interview because it's a TV show for everyday audiences
  - It provides you with a good idea of the real world person (JT: a feisty personality with a good sense of humor and the ability to explain technical concepts) behind all the accomplishments.
  - https://www.dailymotion.com/video/x35dsz7
  - (If I can't post the link due to copyright concerns or link is no longer available then try the search phrase: Grace Hopper on David Letterman).
  - This is another highly recommended video.

Harvard Mark II

- In 1945 the Navy asked Aiken to construct another machine for use at the Naval Proving grounds (Virginia).
- Because (as mentioned) Aiken had a flexible and pragmatic approach to design and because this machine was specifically requested by the Navy he had access to different and better resources.
  - The Mark II was based entirely on relay technology (considerable faster).

Specifications from Williams

- 0.01 second motion
- 1/3 used mechanical locks (rather than magnets to close)
- $15 each (X13,000)

James Tam

Harvard Mark II (2)

- Similar to the Bell Model V it could be split into two separate and independent parts.
- Specifications (Williams)
  - 50 data registers
  - 2 tape readers for instructions
  - 4 tape readers for data
- Speed (Williams)
  - Addition: 125 milliseconds (0.125 second)
  - Multiplication: 750 millisecond (0.75 second)

Mark II: "A History of Computing Technology" (Williams)

James Tam

Harvard Mark III

- After the war Aiken continued working on developing machines at Harvard.
- His focus was on ease of use over having an ultra high speed machine.
  - Mark I & II: increasing machine speed by a factor of 10 only resulted in a throughput of 2 to 3 times (Williams)
- Consequently the Mark III (and Mark IV) were designed more for accuracy and ease of use than hardware-based increases in speed.
  - (Aiken's boast): "…his Mark III was the slowest all-electronic machine in the world because it took 12.75 milliseconds to do a multiplication" (Williams).

James Tam

Harvard Mark III: Mathematical button board

- A special board designed to increase the ease of use for mathematicians.
- Buttons were labeled in a special mathematical notation would produce the results by automatically calling the appropriate sub-routine.

James Tam

Harvard Mark III: Technical specifications (Williams)

- First of the Aiken computers to have a stored program.
  - Stored data on 8 magnetic drums (Total data storage: 4,350 - 16 bit numbers).
  - Instructions were stored on a separate drum.
  - The separation of data and memory was known as the Harvard architecture.
- There was further move away from mechanical parts:
  - The technology was split between electronic (e.g. vacuum tubes) and electro-mechanical components
- Operational speed:
  - Multiplication: 12.75 milliseconds.

James Tam

Harvard Mark IV

- Completed in 1952.
- Incorporated many of the features of the Mark III except that it employed a different type of memory (magnetic 'core')
- It resided at Harvard but was used extensively by the U.S. Air Force.
- After finishing the Mark IV Aiken retired from designing and constructing new computer equipment.
  - Harvard instructor
  - 1961: Founded his own company (Aiken Industries)

James Tam

Image: "A History of Computing Technology" (Williams)

The IBM Calculators

1. The Punched Card Systems
2. Large IBM Calculators
3. The Selective Sequence Electronic Calculator (SSEC)

James Tam

Punched Card Systems

- Before producing computers IBM was in the business of calculating machines under different names
  - Hollerith equipment (Europe)
  - IBM (North America)
- Early punched card machines with used to enter/encode data so it could be stored and tabulated.

Image: "A History of Computing Technology" (Williams)

James Tam

Punched Card Systems (2)

- Advantages of punched cards over electrically driven desk calculators:
  - Speed (slight)
  - Accuracy (reduced human intervention).

James Tam

Punched Card Systems: Applications

- Early applications
  - Compiling statistics
  - Accounting/bookkeeping
  - Leslie J. Comrie: the first use of the Hollerith machines for large scale scientific calculation (lunar motion).
- 1929: Columbia university convinced Thomas J. Watson (senior) into founding Columbia University Statistical Bureau.
- 1930: the Statistical Bureau expanded to include work on Astronomical calculations.
- These early machines were based on the same principles as Babbage's Difference Engine.

James Tam

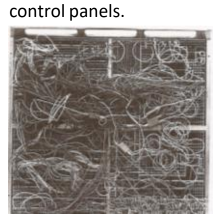
Multiplying Punch Card IBM Models

- The IBM 601 (1935) was a punch based system that could also quickly perform multiplications.
  - Relay based and could complete multiplications: ~1 second.
- The 601 rapidly evolved into several models:
  - Each successive model came with increasing abilities or improved technologies.
  - Relay based machines: 602, 602A, 603.
  - Vacuum tube based machines with programmable plug boards: 604, 605.

James Tam

Plug Board Programming

- The 604 could be 'programmed' through two plug board control panels.



Images: "A History of Computing Technology" (Williams)

James Tam

IBM’s Market Position

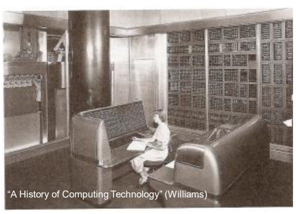
- IBM had little competition in the production of punch card equipment.
- (Remington Rand also produced punch card equipment but their punch card system was less convenient to use so the vast majority of the market went with IBM).

Large IBM Calculators

- The first was the Harvard Mark I.
- With this machine’s success IBM developed their own series of computers.
  - These other machines were all relay-based.
- IBM Pluggable Sequence Relay Calculator (IBM PSRC)
  - All were relay-based computers which were controlled by a combination of IBM plug boards and punch cards.
  - Arithmetic unit: The 4 standard mathematical operations plus square roots.
  - These machines were faster than the regular desktop punched card machines (e.g., x10 the speed of the IBM 602) ~100 milliseconds

The Selective Sequence Electronic Calculator (SSEC)

- It was one of the really large mechanical monsters produced by IBM.
  - Unveiled in 1948 but completed and running test programs before that.



The Selective Sequence Electronic Calculator (SSEC): 2

- As the SSEC was being designed another machine (ENIAC) had shown that vacuum tubes could be reliably used in a computer.
- However IBM engineers had extensive experience with relay-based technology (the punched card machines…up to and including the IBM 603).
- Final design:
  - Vacuum tubes were used in parts of the machine where speed was essential.
  - Relays were used in all other parts of the machine.
  - 8 high speed registers and the arithmetic unit ~13,000 vacuum tubes
  - 150 slower speed registers ~23,000 relays
  - Employed BCD for efficiency (only 4 vacuum tubes) were required to store a single digit

The Selective Sequence Electronic Calculator (SSEC): 3

- The use of vacuum tubes in the arithmetic unit made the SSEC the fastest of the mechanical monsters:
  - Addition: 0.004 seconds (4 milliseconds)
- When IBM developed the first electronic stored program computer (IBM 701) the SSEC was switched off.
  - The IBM 701’s capabilities exceed that of the SSEC

Option External Video: Overall Summary

- Captures the essence of the 3 projects: Zuse, Bell, Harvard.
  - https://www.youtube.com/watch?v=qundvme1Tik

After This Section You Should Now Know

- What were the 4 categories/families of mechanical monsters
- In each of the 4 categories:
  - What machines were created and by whom
  - What were some of their important technical specifications and the general appearance of the machine
  - How did the machines work/what technology was employed in their manufacture
  - Why was the significance of the machine/technology (some machines will have more information than others)
  - How were these machines used and what was their eventual fate (with the latter point not a great deal of information may be available for all machines)
  - (For the machines with their own custom encoding) how did the encoding system store information

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After This Section You Should Now Know (2)

- Who were some of the people behind the development of these machines
  - What were some of the milestones and accomplishments in their lives
  - What were some of their motivations in the design of the mechanical monsters
- Approximately when (and in what order) did milestones in the development of the mechanical monsters occur

James Tam

Source Material

- "A history of modern computing" Michael R. Williams (IEEE 1997)
- Interational Federation for Information Processing (IFIP 2013) Horst Zuse: pp 287 – 296
- "Giants of Computing" by Gerard: pp 281 – 284 (Springer-Verlag London 2013)

James Tam