Charles Babbage

A brief introduction about the life of Charles Babbage and his machines: The Difference and Analytic Engine

James Tam

Charles Babbage (1791 – 1871)

- Considered by many to be the grandfather of the computer age (Williams).
- The technology of the day was primitive.
- But his ideas were advanced (~1940s).
  - The speed of his devices matched technology decades into the future
  - Zuse and Aitken machines

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Background

- Born into a wealthy banking family
  - He had time to be productive researcher
- He excelled at his work
  - Primarily known for his work in computation/devices
    - But he excelled at other areas:

    - Member of the Royal Astronomical society, founder of the Royal Statistical Society.

Image: colourbox.com

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Research

- Babbage was a very active (and eclectic!) researcher and he published papers in the following fields:
  - Optics
  - Atmospheric observations
  - Electricity and magnetism
  - The operation of life insurance companies
  - Cryptography
  - Geology
  - Metal working
  - Taxation systems
  - The design of light houses
  - The operation of light houses

James Tam

An Inquisitive Child

- Even as a young child Babbage had an intense curiosity about how mechanical devices worked.

Images: colourbox.com

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An Inquisitive Adult

- Babbage's interests and curiosity was not just limited to mechanical devices.

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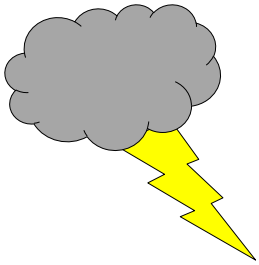
An Inquisitive Adult (2)

- New 'experiment'



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An Inquisitive Adult (2)

Yea

Nay

"I remember well the observation was made, but I have no recollection as to the state of the door" - Passages from the Life of a Philosopher (Charles Babbage)

Images: colourbox.com

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Budding Mathematician

- Boarding school days

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Preparation For College

- Babbage's father decided that his son should attend Cambridge.
- The father hired a tutor to prepare Babbage for what to expect in college.

Cambridge

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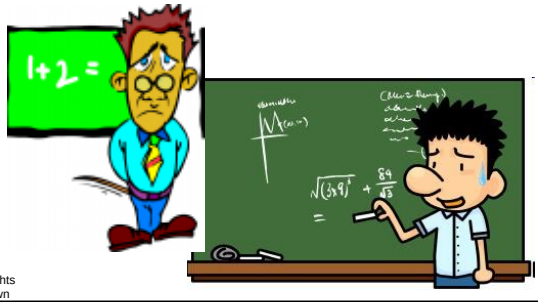
Life At Cambridge

- Babbage quickly discovered he had a deeper knowledge of mathematics than his tutors



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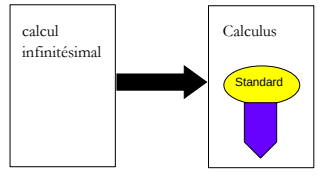
Life At Cambridge (2)

- Babbage then spent most of his time at college reading the papers of great mathematicians and meeting with other advanced students:
  - George Peacock
  - John Herschel
  - Together they translated and added substantially to a text by LaCroix



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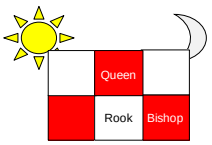
Cambridge: Recreational Activities

- However Babbage didn't spend all his time studying and had an active social life, "…in fact, his social life was so active that it is a wonder that he had time for any studies at all." (Williams)
- Chess club



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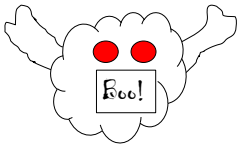
Cambridge: Recreational Activities (2)

- Cambridge ghost club



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Cambridge: Recreational Activities (3)

- Extractors club

Rules from "History of Computing Technology" (Williams)

- *Every member must communicate his address to the Secretary at least once every six months.*
- *If this communication was delayed beyond 12 months, it would be taken for granted that his relatives had shut him up as insane.*
- *Every effort legal and illegal shall be made to get him out of the madhouse (hence the name "extractors").*
- *Every candidate for admission shall produce six certificates to be kept on file – three that he is sane and three that he is not.*

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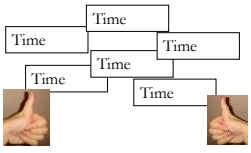
Cambridge: Recreational Activities (4)

- Why these social clubs?



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Post College: England

- Although brilliant Babbage did not receive recognition when studying at Cambridge.
- He unsuccessfully sought lectureship appointments at universities (it's who you know rather than what you know or what you can do).
- Later in life Babbage was elected as the Lucasian Professor of Mathematics in Cambridge
  - (Outstanding chair holders)
    - Isaac Newton: 1669
    - Charles Babbage: 1828
    - Stephen Hawking: 1979

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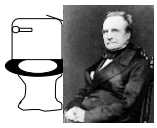
Post College: England (2)

- Although the research chair is quite prestigious Babbage's initial reaction was neither enthusiastic nor was it positive.



Images:
Babbage: http://www.mhs.ox.ac.uk/
Research chair ("the Throne": Tam

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Post College: Continental Europe

- Babbage was well known and respected in the rest of Europe.
- Elected as a member to at least 15 European scientific societies
- He was even named commander of the Italian Order of: Saint Maurice and Saint Lazarus.

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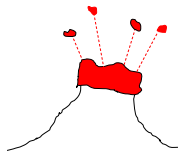
A Very Dedicated Researcher

- While in Italy Babbage wanted to study the volcano at Mount Vesuvius



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Contributions To Logarithms

- In 1826 he published his own set of logarithms (by far the most accurate published up to that date).
- He improved on the accuracy but he was a perfectionist and wanted to reduce the chances of misreading the information so he experimented with different:
  - Tried many typefaces to improve readability and to decrease the probability of an error.
  - Paper colors (151!)
  - Colors of ink (13)
  - Babbage was beyond thorough!

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Contributions To The British Rail System

- Invented the cow catcher

http://etc.usf.edu (last accessed 2016)

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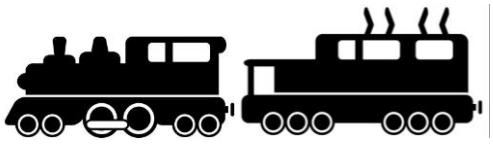
Contributions To The British Rail System (2)

- Recovery of lost rail cars.
  - Source: "Charles Babbage, Passages from the Life of a Philosopher" pp. 325 –326.



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Contributions To The British Rail System (2)

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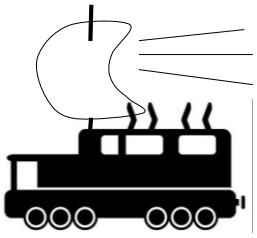

Obviously a very resourceful person!

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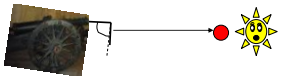
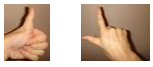
Social Life Beyond College

- He still maintained an active social life.
- Babbage was a well known member of London society (he was eagerly sought after by the London elite).
- He often had to turn down invitations (multiple).
- Guests were always treated displays of scientific or technical terms.





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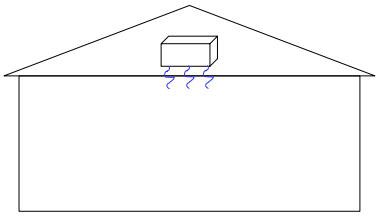
Social Life Beyond College (2)

- He designed the first "environmental control" for a residential dwelling in London.



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Social Life: Later Years

- As Babbage got older his social agenda diminished and he developed a cantankerous attitude towards life.

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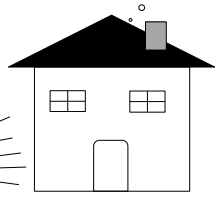

Groupies!

"Elastic virtue!" - from Williams

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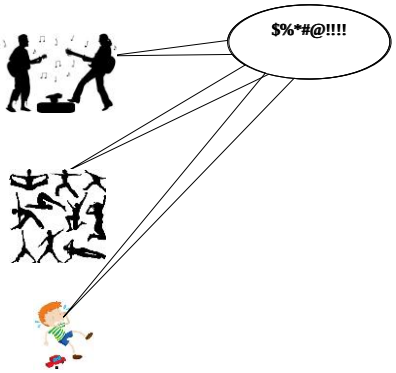
Social Life: Later Years (2)



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International Connections

- Although he was not appreciated by the common people of England Babbage had a strong reputation in the academic community on both sides of the Atlantic.


All images from Tam

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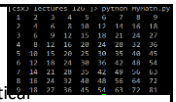
The Need For Accuracy



- During the late 1700s publication of mathematical tables began to be common place.
- They ranged calculating the results of simple operations (e.g., addition, subtraction) to something more complex (e.g., logarithms, trigonometric tables).
- Although the creation of tables were intended to reduce the labor of performing a calculation they were always full of errors.
- Example (survey of one scientist's [Babbage?] library: Williams):
  - 140 volumes of arithmetic and trigonometric tables
  - 40 volumes were sampled and the contained 3,700 known errors.

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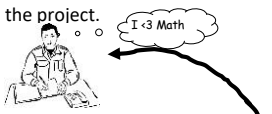
Computing New Tables

- After the French revolution (late 1700s) the new French government decided it would publish a new set of mathematical tables (prestige).
- The best French mathematicians were brought on to oversee the project.



- The work of performing the actual calculations were filled with the unemployed

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Images: Colourbox.com

Computing New Tables (2)

- To ensure accuracy numbers were computed at least twice.
- To prevent collaboration between the groups performing the calculations, each group was located in different locations scattered across France.
- But even with all of the time and effort employed the tables still contained errors.
- Sometimes tables of errata were published afterwards.
  - However sometimes the second table contained more errors than the original table it was intended to correct! (Williams)

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Computing New Tables (3)

- Some of the errors were introduced during type setting.
  - To a large extend this is why Babbage was so meticulous
    - Tried many typefaces to improve readability and to decrease the probability of an error.
    - Paper colors (151!)
    - Colors of ink (13)
  - The tables completed by Babbage in 1827 were the most accurate set of tables produced up to that time.
    - Only 40 errors (out of ? Volumes)

Computing New Tables (4)

- Other sets of tables published around that time were not nearly as accurate:
  - Dr. Hutton's famous tables 1781 contained 40 errors on a single page.
  - The Nautical Ephemeris for Finding Latitude and Longitude at Sea contained over 1,000 errors.
- The only fool-proof method of preventing errors was to remove people entirely from the task of producing the calculations and substitute them with some sort of mechanical device.

Using Differences

- It was once the main tool used by the makers of mathematical tables.
- Replaces more complex operations such as multiplication with additions and subtractions.
- Example (from Williams): Evaluating `f(x) = 2X + 3`

x	=	1		2		3
F(x)	=	5		7		9
Differences	=		2		2	

Using Differences: 2ND Difference

- $f(x) = x^2$

x	=	1		2		3		4
F(x)	=	1		4		9		16
1st diff	=		3		5		7	
2nd diff	=			2		2		2

Difference Engine

- A computing device that is able to employ the property of differences to compute a sequence of numbers.
- Mr. E. Klipstein (Frankfurt 1786 "*Description of a Newly Invented Calculating Machine [Translated title]*") included the first reference to such a device.
  - Klipstein provided a description of such a computing device in the book.
    - In the appendix written by the (Hessian) Engineering Captain J.H. Muller, he indicates that he designed some sort of Difference Engine.
    - Muller describes an even more ambitious computing device if only $$$ were available.
    - Klipstein: publishing, Muller: creation of the device but didn't produce a publication.

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Babbage's Difference Engine: Motivations

- As noted Babbage had an intense obsession for completeness and accuracy.
- One of his goals was to produce a more accurate series of mathematical tables.
- (Recall: even with a great deal of care and duplication taken to produce the tables that errors would inevitably occur so the goal was to remove the person – the source of the errors – entirely from the process).
- The idea of a Difference Engine first came to Babbage in 1812 or 1813 (student at Cambridge).

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Babbage's Difference Engine: Motivations (2)

- In the early 1820s after his experience at publishing tables of logarithms Babbage was again spurred to design a machine that would automatically produce these values.
- "Being of moderate independent means" (Williams) Babbage managed to produce a working model by 1822.
  - It could work with 6 figure numbers.
  - It could evaluate a polynomial function having a constant second difference.
  - 44 calculations per minute
- To generate additional funding and support Babbage wrote the president of the Royal Society
  - The Royal Society of London for Improving Natural Knowledge ("Royal Society")


Royalsociety.org

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Babbage's Difference Engine: Motivations (3)

- The Royal Society supported Babbage's project and sent a letter of support to the Lords of the Treasury.
  - Note: the support was not unanimous (Dr. Young: felt that the money would be better spent on investments and using the proceeds to fund more human calculators).
  - The government provided some start up funds 1,500 pounds (~$7,500).
  - Babbage made up the difference ~3,400 pounds himself ("I'll get it back!")
- Unfortunately Babbage soon discovered that there can be a significant difference between making a demonstration prototype and a fully working model.
- Fortunately Babbage was able to obtain the services of Samuel Clement.

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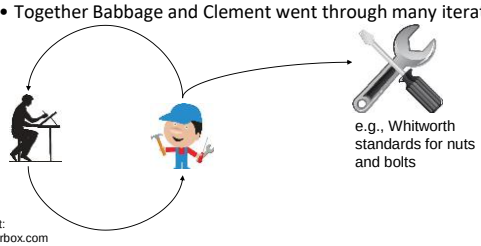
Samuel Clement And Charles Babbage: Early Years

- Clement
  - Not formally educated
  - "Good with his hands"
  - One of the best of his day
- Together Babbage and Clement went through many iterations



e.g., Whitworth standards for nuts and bolts

Clipart: Colourbox.com

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Charles Babbage: Life During The Design Process

- While Babbage and Clements were working on different parts of the Difference Engine Babbage suffered from a number of personal tragedies.
- All within the span of four years:
  - Babbage's wife, new born baby daughter and father passed away.
- These events (along with hard work on the project) result in Babbage's health breakdown and problems with the project.
  - Babbage took a break at warmer climate.
  - While there he checked his accounts and remembered the personal funds he put into the project;
  - Unfortunately there were problems when he tried to get a reimbursement from the government.
    - Where's your contract???

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Charles Babbage: Life During The Design Process (2)

- Finally after personal appeals from Babbage's friends the project was advanced an additional 1,500 pounds.
- After another personal appeal from a *very influential* friend (*The Duke of Wellington*) the project was advanced another 3,000 pounds with a suggestion that Babbage show evidence of his progress.
- Unfortunately the financial and health problems would often significantly delay work on the project.

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Samuel Clement And Charles Babbage: Later Years

- Babbage would normally travel across London when he needed to visit Clement's workshop.
- To facilitate work on the project Babbage built a new (fire proof) house that was closer.
- He expected Clement to join him at the new location but Clement refused and eventually the two had a falling out.
  - Unfortunately British law favored Clemet's position
- During this dispute work on the Difference Machine was halted
- The one positive: Babbage conceived of another machine (Analytical Engine: more later) during this time

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Babbage: Later Years

- Finally Babbage determined that it would be more efficient (i.e., cheaper) to start building a new machine with a different design than complete the original design.
- This announcement was not well received by the government.
- While the officials deliberated the current government lost it's majority position.
  - Babbage had to start dealing a whole new group of officials.
- Finally Babbage tired of the process and asked the Prime Minister to make a decision on the fate the project.
  - Unfortunately the decision (1842) wasn't favorable for Babbage
  - Maybe the Difference Engine should be used to compute the cost of producing the Difference Engine. – Paraphrasing a member of Parliament

Babbage: Later Years (2)

- Eventually the machine itself was donated to a museum.
- Ironically after abandoning Babbage's work:
  - Only a few years later the British government financed the production of a Difference Engine designed in Sweden.

Difference Engine (Cost)

- Government portion:
  - 17,000 pounds ($84,000) 1842 currency values
- Babbage's portion:
  - 20,000 pounds ($100,000) 1842 currency values

Difference Engine: Final Design

- The final machine wasn't complete (parts of it now at South Kensington Science Museum).
- "Baggage's description of the machine are difficult to follow" (Williams).
- Also the descriptions were extensive (1000 square feet of paper).

Difference Engine: Final Design (2)

- Dr. Dionysus Lardner

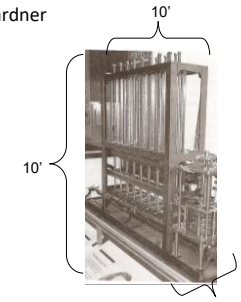

Image: "A history of Computing Technology" (Williams)

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Optional External Video:

- Demonstrating the operation of the Difference Engine and stories about the life of Babbage
  - If you don't want to watch the whole video at least check it out 1:38 to see the intricate and complex mechanisms in operation.
  - https://www.youtube.com/watch?v=BIbQsKpq3Ak

James Tam

The Scheutz Difference Engine #1

- George Scheutz: A Swede worked as an editor of a Stockholm technical journal.
  - He read an article by Dr. Dionysus Larder describing Babbage's machine.
- He quickly realized the Difference Engine would be beneficial to most every branch of science and began work.
  - He developed a 'proof of concept' components using wood, plasterboard (drywall) and wire.
- His son Edvard returned from England in 1837 and began work an actual working machine (metal).
  - By Oct 1837 father and son realized the financial costs of the project was beyond their means.
  - They petitioned the Swedish government for financial support but were unsuccessful.

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Image: www.atariarchives.net

The Scheutz Difference Engine #1 (2)

- The Scheutz's proceeded with the funds they had available.
- 1840:
  - Compute to the first difference 5 digit numbers
- 1842:
  - Extended the machine to compute to third order of difference
- 1843:
  - Printing device attached
  - Submitted to Royal Swedish Academy of Science
    - Well received but accolades were not backed by $$$
    - It only remained a conversation piece for the next few years
- 1851:
  - At the prompting of friends George Scheutz again petitioned the government for funding
  - After a fairly long and complex process

Scheutz Difference Engine #1 (3)

- 1853:
  - The "Tabulating machine" was completed
  - It was regarded as being so successful that a second grant (equal to the first) was recommended (and given!)

"A history of Modern Computing" (Williams)

  - This version of Difference Engine attained many 'firsts'

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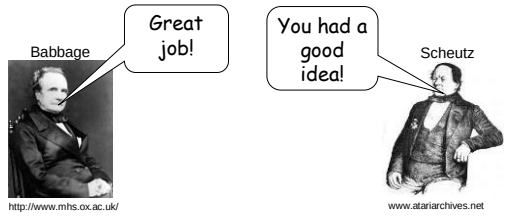
Scheutz Difference Engine: #1 (4)

- Brian Donkin: served on the committees of the Royal Society which: judged Babbage's progress and audited his accounts.
- He was instrumental in having the machine brought to London.



http://www.mhs.ox.ac.uk/ www.atariarchives.net

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Scheutz Difference Engine: #1 (5)

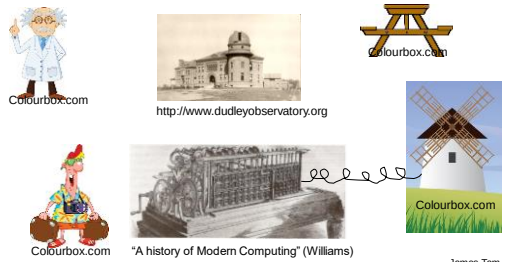
- After it's demonstration in London the Tabulating machine was shown to the scientific community (with the hope of finding a buyer).
- In Paris it won the Exhibition's Gold Medal (Great Exhibition)
- The award brought the machine to the attention of B.A. Gould (Dudley Observatory: New York).

http://www.dudleyobservatory.org

James Tam

Scheutz Difference Engine #1 (6)

  - It was purchased $5,000 by a philanthropist for the observatory.
  - Unfortunately the scientific community and the public had conflicting ideas over how the observatory should be used.



"A history of Modern Computing" (Williams)

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Scheutz Difference Engine #1 (7)

- After a period at the observatory the machine was sold to Dorr E. Felt.
- Now the machine has found a home at the: National Museum of American History Smithsonian Institution (Washington DC).

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Scheutz Difference Engine #2

- The British Register (~Statistics Canada) General wanted to publish new tables for the insurance industry.
  - The tables could be easily be approximated by certain functions (polynomials).
  - This lead to the decision to use a Difference Engine in the calculations.
- The Register General paid 1,200 pounds ($6,000) to have a Difference Engine built (Scheutz design)

Scheutz Difference Engine 2
(Tabulating machine 2)

600 different tables!

"A history of Modern Computing" (Williams)

James Tam

Other Difference Engines: Decon

- Alfred Decon (London)
- Much like Scheutz he was inspired by Lardner's description of Babbage's work.
- He constructed a partially working model (now lost)
  - It could calculate functions up to 3 orders of differences with numbers up to 20 digits.
  - It was meant to be a demonstration model rather than something to be used for actual work (there was no printout of results).
    - He build the machine for his own satisfaction or also for the amusement of his friends.
  - In the end it was either sold or given to Babbage (he owned a similar machine but it wasn't clear if it was the Decon model).

James Tam

Other Difference Engines: Wiberg

- Martin Wiberg: produced a redesign of the Scheutz machine (reduced size and weight).
  - The machine was used in the production of tables that calculated interest (published in 1860).
  - A table of logarithms and trigonometric values were calculated and printed by the machine (published in 1875).
  - Eventually the machine ended up at the Academy of Science (Paris).

James Tam

Other Difference Engines: Grant

- Mr. G.B. Grant (founder of American gear cutting industry)
- With the help of his professors and Mr. J.N. Bachelder (Dudley Observatory) was able to design and build a small prototype model.
- Grant was given a grant (University of Pennsylvania) for $10,000 to build a working model for the university.
  - The design was sold to the Provident Mutual Life Insurance company where it was used to produce tables similar to those produced by the Office of the Registrar General in Britain.
  - Eventually given to the American Smithsonian (according to records it was somehow lost)

Other Difference Engines: National/Comrie

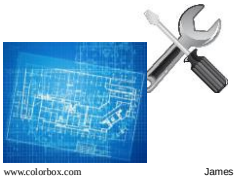
- Dr. L. J. Comrie (Nautical Almanac Office) produced a machine that proved almost 100 years after Babbage's failure (1900s)
- Included a 12 column keyboard.
- That feature, along with other features made the machine useful proving that an efficient, inexpensive Difference Engine was at last available.

Babbage's Analytic Engine: Background

- Recall:
  - While Babbage was working on the Difference Engine, often a lack of funding halted work.
  - One time it was so drastic that work halted entirely.
  - When work re-started Babbage and Clement had a dispute over Clement's new working conditions.

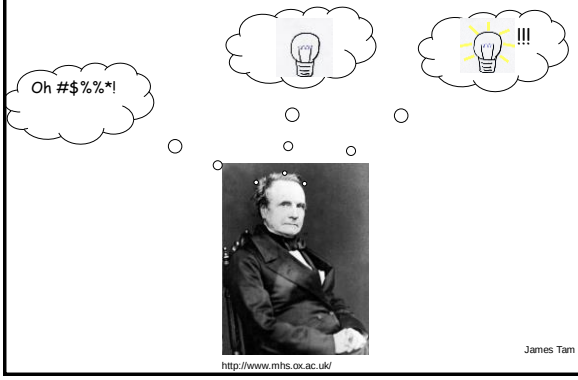
Babbage

Clement



www.colorbox.com

Babbage's Analytic Engine: Background



http://www.mhs.ox.ac.uk/

Babbage's Analytic Engine: Significance

- The Difference Engine was an important step in the development of computation.
- The Analytic Engine ushered in an entirely new and critical concept: a computing machine that was a controlled by an external program. ("A programmable device!")

James Tam

Babbage's Analytic Engine

- It's difficult to determine the exact operation of the Analytic Engine:
  - Not completed (re-created from complex diagrams)
  - Many iterations continuously produced (right up to Babbage's passing)
- A re-creation (based on the snapshot of the original machine in 1840) was produced under the direction of Major-General H.P. Babbage (1906) – the son of Charles Babbage.

"A History of Computing Technology" (Williams)

James Tam

Components Of The Analytic Engine

- Store
- Mill
- Control Barrel
- Counter Mechanism

James Tam

Analytic Engine: Implementation Of The Store

- Information was stored in registers in the form of gears.
- Each gear was used to represent a single digit and it could rotate to 10 different positions .
- Different source writings specified different storage capacities:
  - Source 1: 100 forty digit numbers.
  - Source 2: 1000 fifty digit numbers.

James Tam

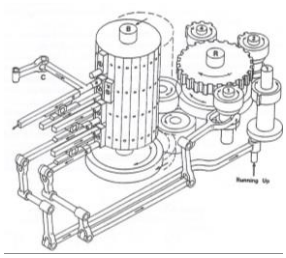
Analytic Engine: Implementation Of The Mill

- An extremely complex arrangement of gears and linkages between the gears was employed.
- Operations:[1]
  - 4 basic mathematical operations (addition, subtraction, multiplication, division), logical comparisons with the option of square roots.
- To understand the relationship between the mill and store a weaving metaphor may be used.[1]
  - Store: the location where numbers are held (value stored = a pattern in the cloth).
  - Mill: the location where numbers are 'woven' into their new patterns based upon the operation to be performed.

1 Source: https://turing.plymouth.edu/~zshen/Webfiles/notes/CSDI1400/note2.pdf

Analytic Engine: Implementation Of The Control Barrel

- Similar to a old-time music box but instead of storing a melody this control barrel would store microcode instructions.

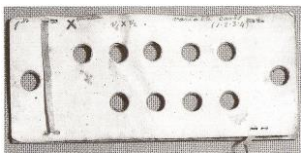


Babbage's Analytic Engine: Significance #1

- Babbage merely conceived of the Analytic Engine as an academic exercise rather than having the goal of producing a model to be used to solve actual problems.
- Significance (Metrics from Williams): Speed/advanced technology
  - Although slow by today's standards the Analytic Engine was far in advance of it's time.
  - Addition time, Analytic Engine: (3 seconds, 1 second with later version, ~1830- 1871)
  - Addition time, Harvard Mark I: 0.3 second ~World War II (1939 – 1945)

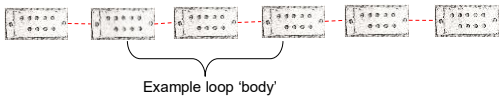
Babbage's Analytic Engine: Significance #2

- Significance: it included the concept of a stored program
- Instructions for the Analytic Engine were to be stored on a sequence of punched cards.



"A History of Computing Technology" (Williams)

Babbage's Analytic Engine: Significance #2 (2)



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

Did Babbage Ever Build An Analytic Engine?

- He viewed the design process as an academic exercise.
- Some parts were created as part of an experiment but he never built a complete machine.
- Major Henry P. Babbage (son) completed the construction of a Mill in 1906.
  - It calculated and printed many different multiples of PI to 29 decimal places as a proof of concept.
  - The mill now resides in the Science museum (London) along with some other early Babbage machines.

James Tam

Ada Augusta Countess Of Lovelace

- Daughter of Lord Byron (yes it's the famous poet!) and Annabella Milbanke (a trained mathematician!)
- Lovelace became friends with Babbage
- While in Italy Babbage wrote a description of the inner workings of the Analytic Engine (Italian).
- Lovelace produced an English translation (added extensive explanations).
- She also conceived of using the Analytic Engine for purposes other than just calculating numbers.
  - Abstract symbols = general instructions

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Image: www.computerhistorymuseum.org

Optional External Video:

- Ada Lovelace Biography, her contributions to computing and her relationship with Babbage.
  - https://www.youtube.com/watch?v=1kLsW0NLsO8

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Percy Ludgate (1883 – 1922)


www..history-computer.com

- Designed (and may have constructed) his own version of an Analytic Engine (1908).
  - The unit was controlled by instructions on paper tape.
  - Control could also occur from instructions entered on a special keyboard.
  - It could store 192 variables that were 20 digits long..
- Like Babbage's machine it was entirely mechanical however the mechanism was powered by an electric motor.
- "Unfortunately all of Ludgate's drawings and manuscripts appear to have vanished forever." (Williams: Scientific Proceedings of the Royal Dublin Society)

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After This Section You Should Know

- Who was considered to be the grandfather of the computer age and why
- Details about the background life of Babbage (early years, time at Cambridge and after)
- What was Babbage's contribution to calculus and who were the co-contributors
- Babbage's contribution to the production of logarithmic tables
- Babbage's other contributions and inventions: British Rail system
- The motivator for Babbage to produce a calculating machine
- How/when mathematical differences were used to generate results with the Difference Engine

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After This Section You Should Know (2)

- Details about pre-Babbage Difference Engines and details in the development of the Babbage Difference Engine
- Some of the challenges experienced by Babbage when producing his Difference Engine
- Details about the Scheutz difference engine (tabulating machine)
  - who produce it
  - how was it developed
  - what was its eventual fate
- Details about the Scheutz difference engine (tabulating machine 2)
  - what motivated its creation
  - how was it used

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After This Section You Should Know (3)

- Details about the Decon Difference Engine
  - what were its capabilities
  - what its eventual fate
- The significance of the National/Comrie Difference Engine
- How work on the Analytic Engine came out of some of the challenges experienced while developing the Difference Engine
- What was the purpose of the Analytic Engine and when was it designed
- The significance of the Analytic Engine
- What was Ada Lovelace's relationship with Babbage and the work on the Analytic Engine
- Who was the person who designed/developed a version of the Analytic Engine

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