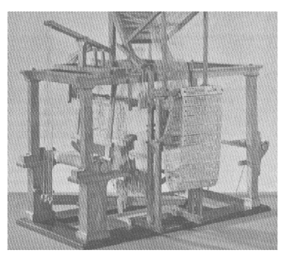
15-292
History of Computing

Charles Babbage and
his Inventions

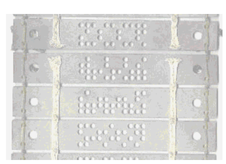
Jacquard Loom

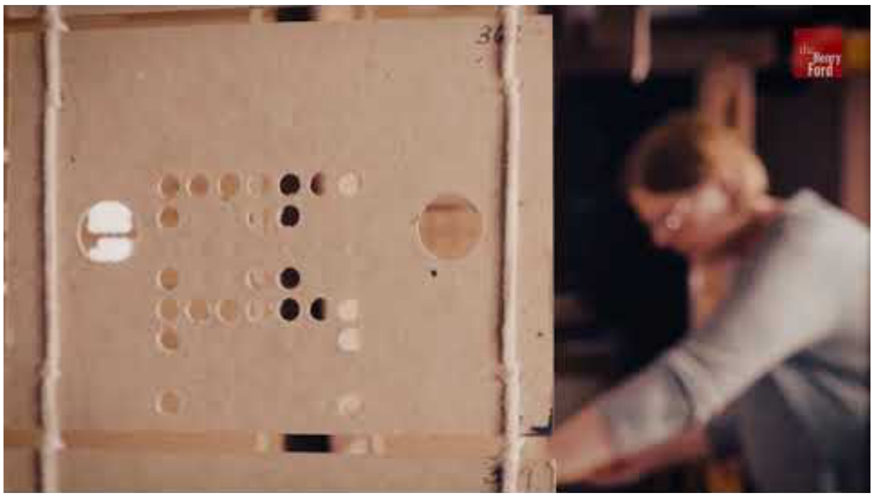


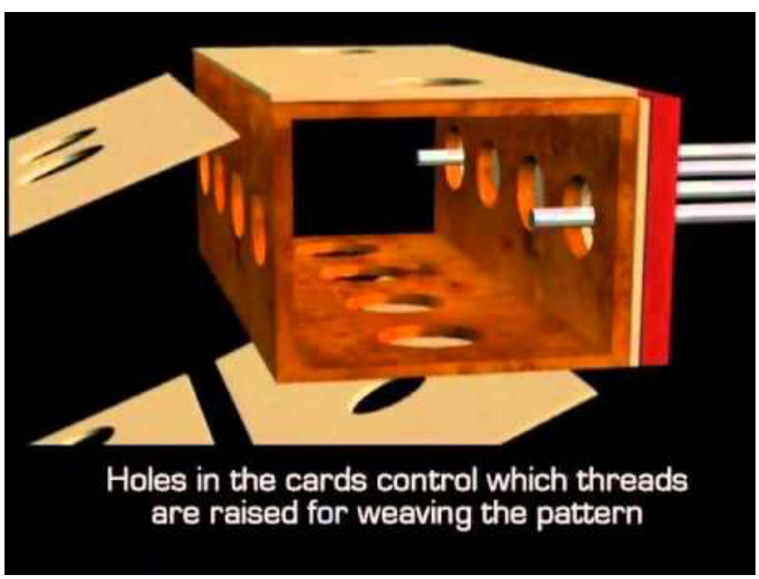
- Developed in 1801 by Joseph-Marie Jacquard.
- The loom was controlled by a loop of punched cards.
- Holes in the punched cards determined how the knitting proceeded, yielding very complex weaves at a much faster rate.

[Jacquard-card Making.]

from Columbia University Computing History
http://www.columbia.edu/






Holes in the cards control which threads
are raised for weaving the pattern

Charles Babbage

- 1792-1871
- Known as the “(grand)father of computing”
- Mathematician, industrialist, philosopher, politician
- He wrote On the Economy of Manufactures (1832)
- He enjoyed fire.
  - he once was baked in an oven at 265°F for 'five or six minutes without any great discomfort‘
  - on another occasion was lowered into Mount Vesuvius to view molten lava
- In 1837 he published his Ninth Bridgewater Treatise, to reconcile his scientific beliefs with Christian dogma.
  - He investigated biblical miracles.
  - made the assumption that the chance of a man rising from the dead is one in 10^{12}

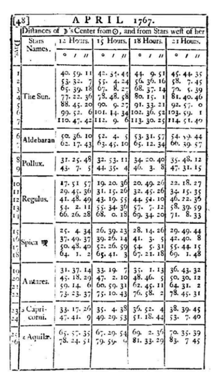
Charles Babbage

- He hated music
- Neighbors hired musicians to play outside his windows
- When Babbage went out, children followed and cursed him
- He hated street musicians and pushed for the enforcement of Babbage’s Act (1864) to silence them, causing much ridicule.
- Little known when he died
- In 1908, after being preserved for 37 years in alcohol, Babbage's brain was dissected by Sir Victor Horsley of the Royal Society
- While alive, he was belittled & marginalized by the British Press
- Years after his death, the press blamed the British government for not having the foresight to encourage (& fund) his work

- Ref: http://tergestesoft.com/~eddysworld/babbage.htm

The Table-Making Industry

- De Prony used human computers to calculate the Tables du Cadastre (1790)
  - Logarithmic tables using metric system to survey land & assess taxes for Napoleon's France
  - Devised his table-making operation using the principles of mass production
- Babbage worked on table-making project for the Nautical Almanac
  - For astronomers & navigators
  - Found the work tedious & error-prone
  - Key step in calculations: the method |of finite differences



[48] APRIL 1767.

Distances of ☽'s Center from ☉, and from Stars west of her

Days.	Stars Names.	12 Hours. ° ′ ″	15 Hours. ° ′ ″	18 Hours. ° ′ ″	21 Hours. ° ′ ″
1	The Sun.	40. 59. 11	42. 34. 44	44. 9. 51	45. 44. 35
2		53. 32. 7	55. 4. 24	56. 36. 16	58. 7. 45
3		65. 39. 18	67. 8. 27	68. 37. 14	70. 5. 39
4		77. 22. 36	78. 48. 58	80. 15. 1	81. 40. 46
5		88. 45. 20	90. 9. 27	91. 33. 21	92. 57. 0
6		99. 52. 6	101. 14. 34	102. 36. 52	103. 59. 1
7		110. 47. 42	112. 9. 6	113. 30. 25	114. 51. 40
6	Aldebaran	50. 36. 10	52. 4. 5	53. 31. 57	54. 59. 44
7		62. 17. 43	63. 45. 10	65. 12. 34	66. 39. 57
8	Pollux.	31. 25. 48	32. 53. 11	34. 20. 40	35. 48. 12
9		43. 7. 5	44. 35. 4	46. 3. 8	47. 31. 15
10	Regulus.	17. 51 57	19. 20. 36	20. 49. 26	22. 18. 27
11		29. 45. 36	31. 15. 26	32. 45. 26	34. 15. 35
12		41. 48. 49	43. 19. 55	44. 51. 10	46. 22. 36
13		54. 2. 11	55. 34. 36	57. 7. 12	58. 39. 59
14		66. 26. 28	68. 0. 18	69. 34. 20	71. 8. 33
15	Spica ♍	25. 4 34	26. 39. 23	28. 14. 26	29. 49. 44
16		37. 49. 37	39. 26. 14	41. 3. 5	42. 40. 8
17		50. 48. 40	52. 26. 59	54. 5. 31	55. 44. 15
18		64. 1. 2	65. 41. 3	67. 21. 18	69. 1. 48
19	Antares.	31. 37. 14	33. 19. 7	35. 1. 13	36. 43. 32
20		45. 18. 29	47. 2. 10	48. 46. 5	50. 30. 12
21		59. 14. 6	60. 59. 31	62. 45. 11	64. 31. 2
22		73. 23. 37	75. 10. 43	76. 58. 2	78. 45. 31
23	δ Capricorni.	33. 17. 26	35. 4. 38	36. 52. 4	38. 39. 45
24		47. 41. 9	49. 29. 53	51. 18. 44	53. 7. 40
25	ε Aquilæ.	65. 57. 35	67. 29. 54	69. 2. 36	70. 35. 39
26		78. 24. 51	79. 59. 9	81. 33. 29	83. 7 45

Method of Finite Differences

- Babbage's first computational machine was based on the method of finite differences.
  - For a polynomial f(x) of degree n, evaluated for successive integer values of x, the differences between successive values of the polynomial are values of a polynomial of degree n-1, the differences of these are values of a polynomial of degree n-2, etc., and the differences of order n are constant.
  - Given a polynomial has constant differences of order n, and the initial values of the differences of each order of the original polynomial, we can derive the values of f(x) for successive values of x using only addition.

Method of Finite Differences

Example

- Let $f(x) = x^2 + x + 1$ for our example polynomial.
- First order difference $\Delta f(x) = f(x+1) - f(x)$

  In our example:

  $\Delta f(x) = (x+1)^2 + (x+1) + 1 - (x^2 + x + 1) = 2x + 2$
- Second order difference $\Delta^2 f(x) = \Delta f(x+1) - \Delta f(x)$

  In our example:

  $\Delta^2 f(x) = 2(x+1) + 2 - (2x + 2) = 2$

Repeat this process until you reach a difference equation that is constant.

Method of Finite Differences
Example

- Evaluate the polynomial and the difference equations at $x = 0$ (least likely to cause error).
- Example:
  $f(x) = x^2 + x + 1$ $f(0) = 1$
  $\Delta f(x) = 2x + 2$ $\Delta f(0) = 2$
  $\Delta^2 f(x) = 2$ $\Delta^2 f(0) = 2$
- Babbage sets each column of the machine to one of these values. (values are stored vertically)

Method of Finite Differences
Example

- For each cycle of the machine, it computes f(x+1) given f(x) as follows:
- Recall: $\Delta f(x) = f(x+1) - f(x)$
  or: $f(x+1) = f(x) + \Delta f(x)$
  So the machine adds the Δf(x) column to the f(x) column to get f(x+1).
- But the machine also updates the difference equations too.
- Recall: $\Delta^2 f(x) = \Delta f(x+1) - \Delta f(x)$
  or: $\Delta f(x+1) = \Delta f(x) + \Delta^2 f(x)$
  So the machine adds the $\Delta^2 f(x)$ column to the $\Delta f(x)$ column to get $\Delta f(x+1)$.
- This continues across the machine for higher order eqt'ns.

Method of Finite Differences

Example

$f(x) = x^2 + x + 1$

x	$f(x)$	$\Delta f(x)$	$\Delta^2 f(x)$
0	1	2	2
1	3	4	2
2	7	6	2
3	13	8	2
4	21	10	2

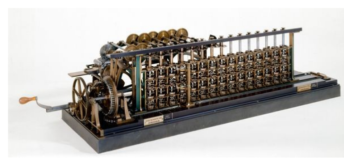
$f(4) = 4^2 + 4 + 1 = 21$

Difference Engine

- Babbage demonstrated in 1822 that this concept was feasible and could be built with enough funds.
  - Partially funded by British government for promise to improve table-making process (both cost and reliability)
  - Unfortunately, the engineering was more difficult than the conceptualization
  - Two tasks: design the Difference Engine & develop the technology to manufacture it

Difference Engine

- A prototype was built in 1833 but a complete functioning machine was never built because:
  - Babbage was a perfectionist
  - Babbage fought with his engineer Joseph Clement, who he accused of stealing his tooling designs
  - Babbage lost interest
- 1853 – Georg and Edvard Scheutz of Sweden create the first complete difference engine and the first calculator in history to be able to print out its results.



Babbage Difference Engine

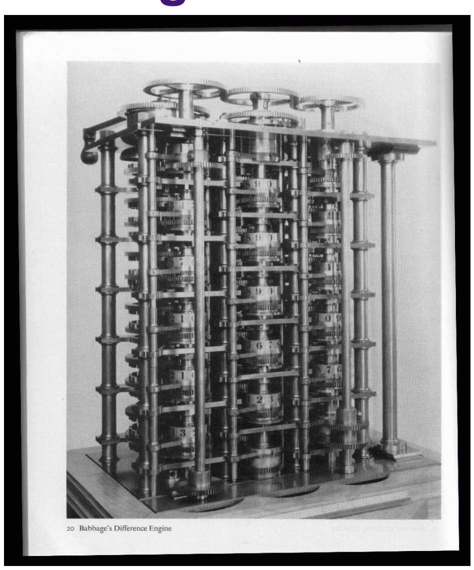


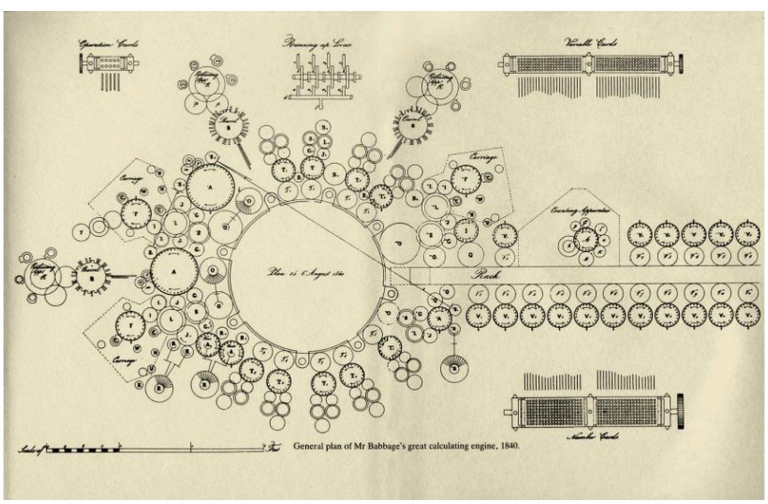
Photo of the
1832 Fragment
of a Difference Engine

fragment made by
H.P.Babbage
from parts of
Difference Engine No.1

Analytical Engine

- Designed around 1834 to 1836
  - was to be a universal machine capable of any mathematical computation
  - embodies many elements of today's digital computer
  - a control unit with moveable sprockets on a cylinder that could be modified
  - separated the arithmetic operations (done by the *mill*) from the storage of numbers (kept in the *store*)
    - store had 1000 registers of 50 digits each
  - Babbage incorporated using punched cards for input
    - idea came from Jacquard loom
- Never built by Babbage due to lack of funds and his eventual death in 1871

Babbage's Lithograph of the Analytical Engine



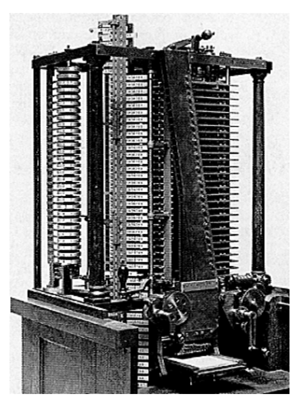
Analytical Engine

- Design included a means to perform conditional branching (decision making capabilities)
  - based on whether the difference between two values was positive or negative.
- Example: Repeat calculation if 423 < 511.

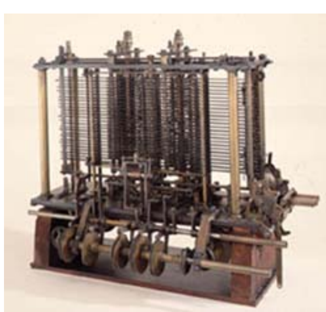
  This means check if 423 – 511 < 0 (negative)

  ```
         00000 00423
  –      00000 00511
        999999 99912
  ```
- Instructions for the Engine would be stored on punch cards strung together with loops of string to form a continuous chain.

Analytical Engine

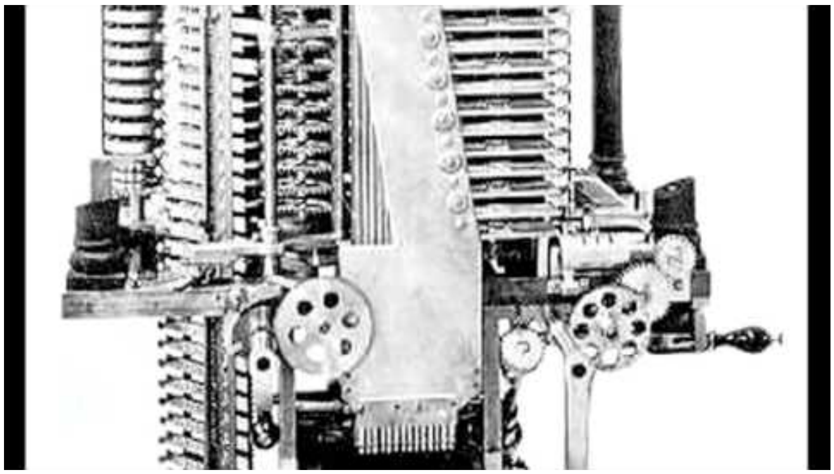


Analytic Engine completed by Babbage's son, Henry



Portion of the mill of the Analytical Engine with printing mechanism, under construction at the time of Babbage's death.

Ada Lovelace

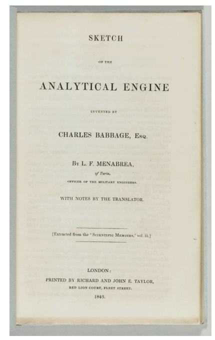


Ada Augusta Byron, Countess of Lovelace

- 1815-1852
- Daughter of poet Lord Byron
- Trained in mathematics and science at the direction of her mother (unusual for the time)
- Met Babbage when she was 17
- Studied mathematics under the supervision of Augustus de Morgan
- She understood the significance of Babbage's work, while others did not

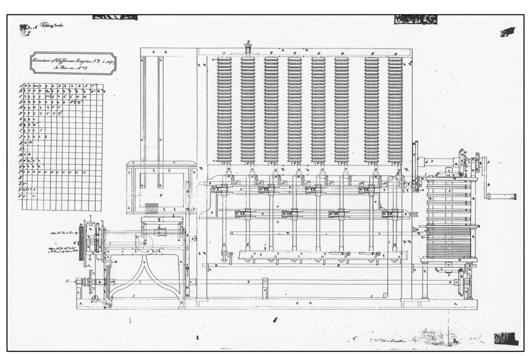
Ada Augusta Byron, Countess of Lovelace

- Translated Menabrea's *Sketch of the Analytical Engine* to English (described Babbage's machine)
  - quadrupled its length by adding lengthy notes and detailed mathematical explanations
  - Included a "program" to caculate Bernoulli numbers
- Some refer to as the world's first programmer
  - Some historians have disputed this
    - says most of the technical content & all of the programs were Babbage's
  - Weaved coded instructions on punched cards
    - based on a language that was compatible with the Analytical Engine
  - Ada programming language named for her



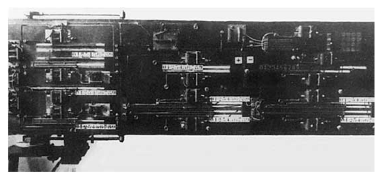
Returning to the Difference Engine

- 1846: Babbage worked for two years to design Difference Engine #2
- British Government did not fund the new design



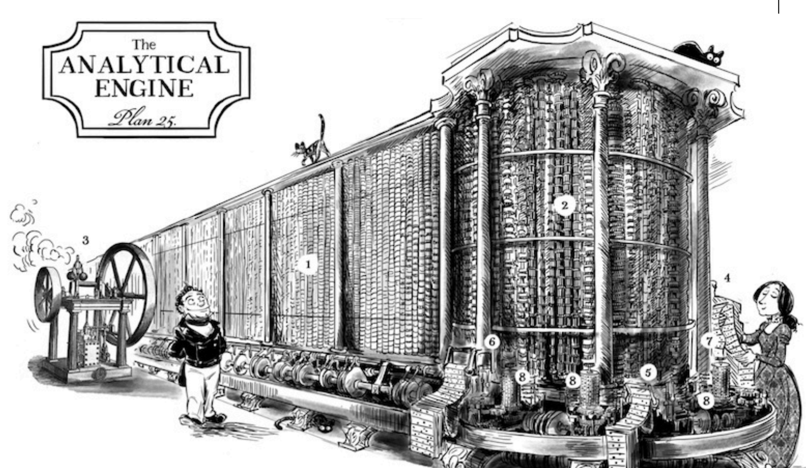
Carrying on the Vision

- Others made their own analytical engines, updating Charles Babbage's design
  - Henry P. Babbage (son)
    - created an assemblage of part of the Engine in 1910 (the mill and the printer)
  - Percy Ludgate, accountant (1883-1922)
    - replaced punched cards with perforated paper roll
    - electric motor used to drive main cyclinder
  - Torres y Quevedo
    - used electromagnetic relays to create an elementary analytical engine exhibited in Paris in 1914.



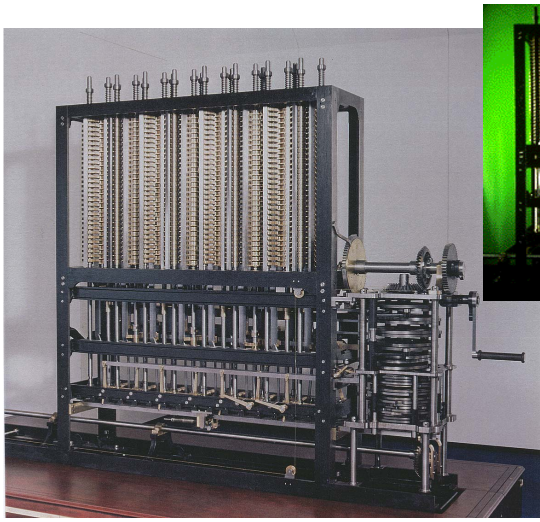
Artistic View of the Analytical Engine

(from *The Thrilling Adventures of Lovelace and Babbage*)



1. **The Store** (hard disk, or memory). 2. **The Mill** (Central Processing Unit). 3. **Steam Engine** (power). 4. **Printer** (printer, round the other side). 5. **Operation Cards**, 6. **Variable Cards** 7. **Number Cards**, (together making up the software). 8. **The Barrel Controllers** (microprograms).

Building the Babbage Difference Engine



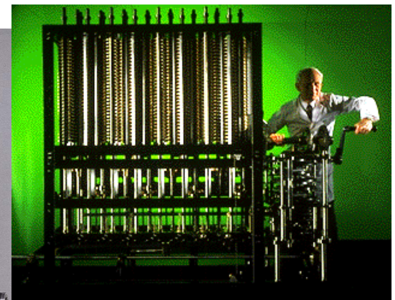


Photo of Babbage Difference Engine No. 2 constructed in 1991

On display at London's Science Museum