What do an eighteenth century fabric maker, a nineteenth century countess and the twentieth century author of James Bond novels have in common? They are all figures in the

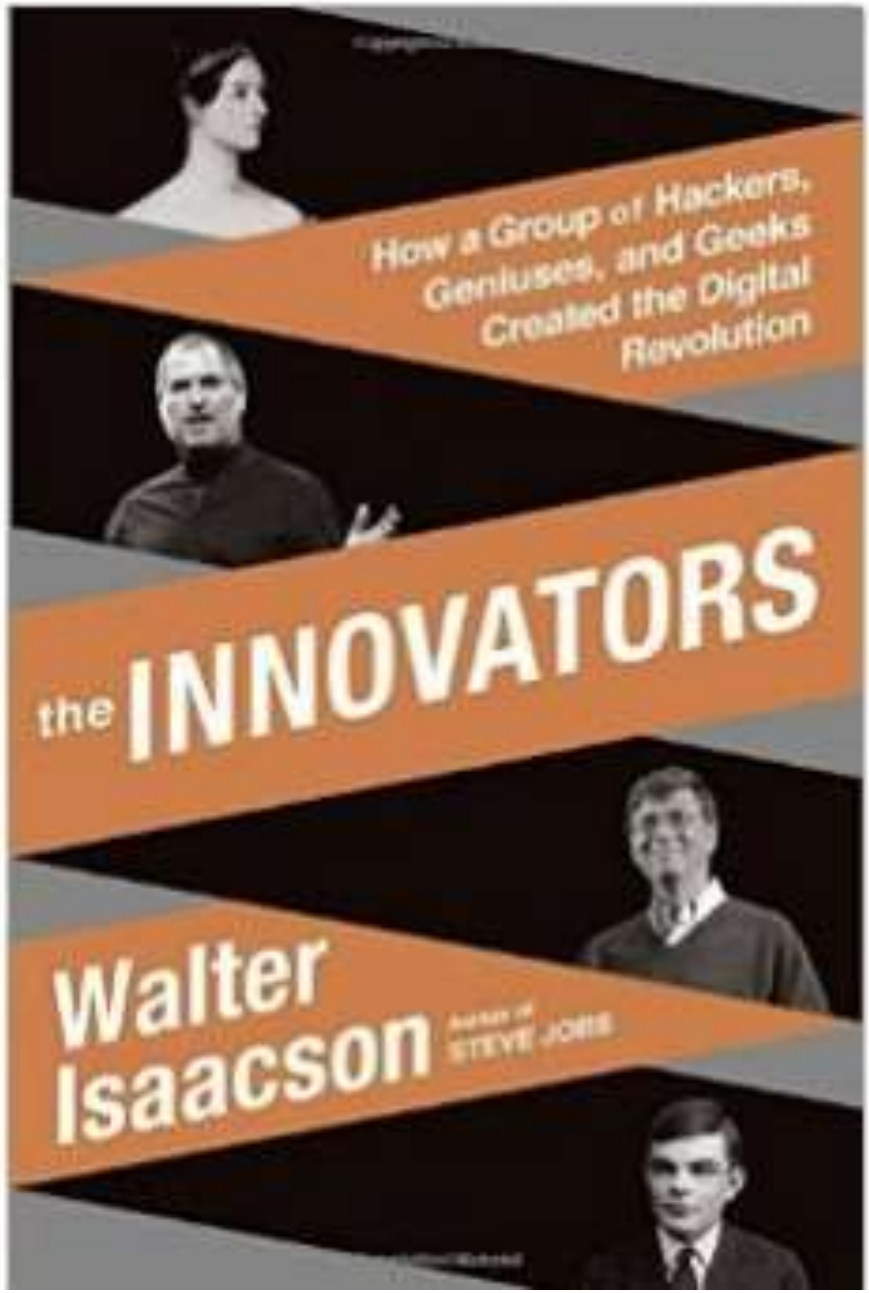
# History of Computing Part One

***The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution***

**by**

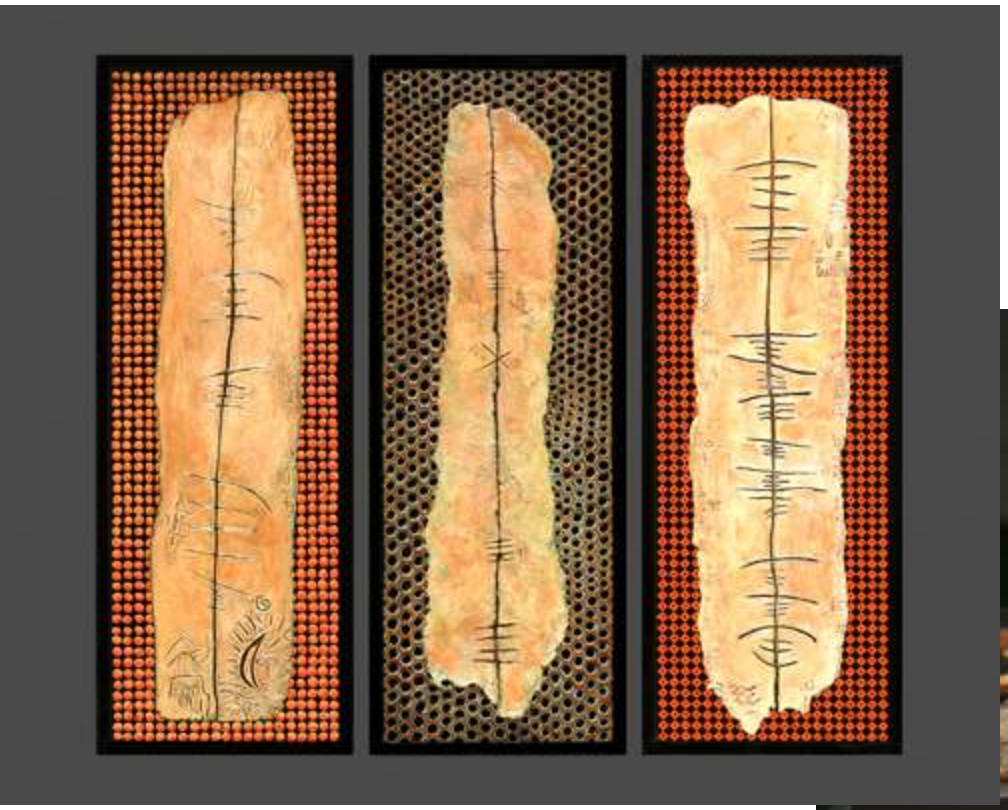
**Walter Isaacson**

**(2014)**

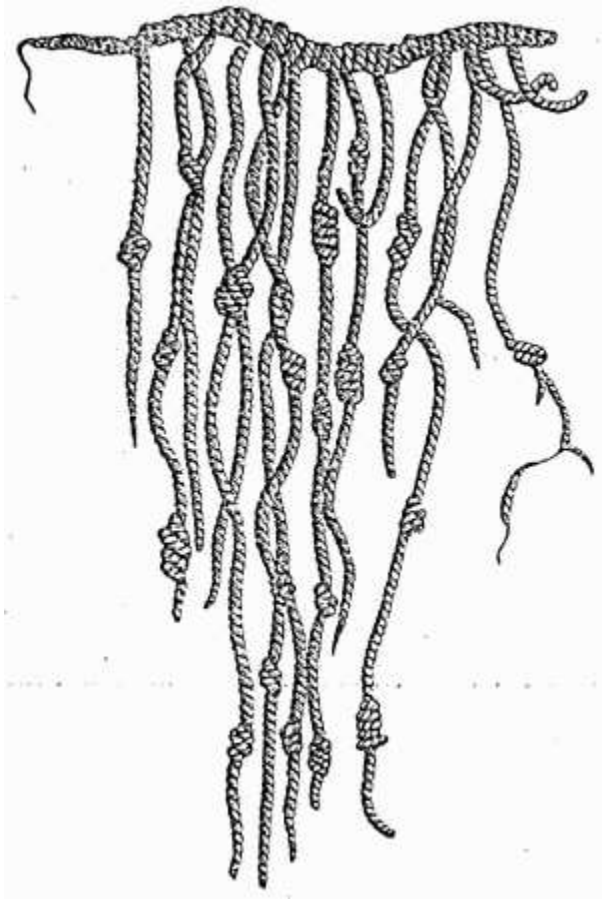



The Beginning

# Tally Sticks



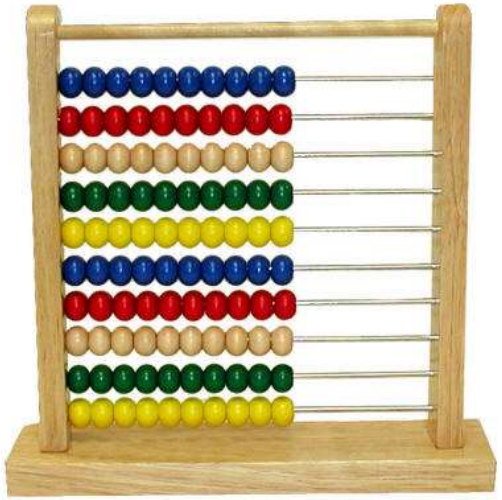
# Quipu



# Abacus

2400BC - The first known calculator was probably invented by the Babylonians as an aid to simple arithmetic around this time period.

# Abacus



This laid the foundations for positional notation ( orders of magnitude, for example, the "ones place", "tens place", "hundreds place") and later computing developments.

# Developments in Mathematics

- **c. 500 BC - First known use of zero by mathematicians in ancient India.**
- **c. 300 BC – Indian mathematician, scholar and musician Pingala first described the binary number system, which is now used in the design of essentially all modern computing equipment.**
- **c. 100 BC - Chinese mathematicians first used negative numbers.**

# The Antikythera Mechanism

An analog computer designed to predict astronomical positions and eclipses for calendrical and astrological purposes, as well as the cycles of the Olympic Games.

# The Antikythera Mechanism

Recovered in 1900 from a shipwreck off the Greek island of Antikythera.

Believed to have been designed and constructed by Greek scientists between 100 BC to 205 BC.

After the knowledge of this technology was lost at some point in Antiquity, technological artifacts approaching its complexity and workmanship did not appear again in Europe until the development of mechanical astronomical clocks in the fourteenth century.

Front panel of a 2007 reproduction

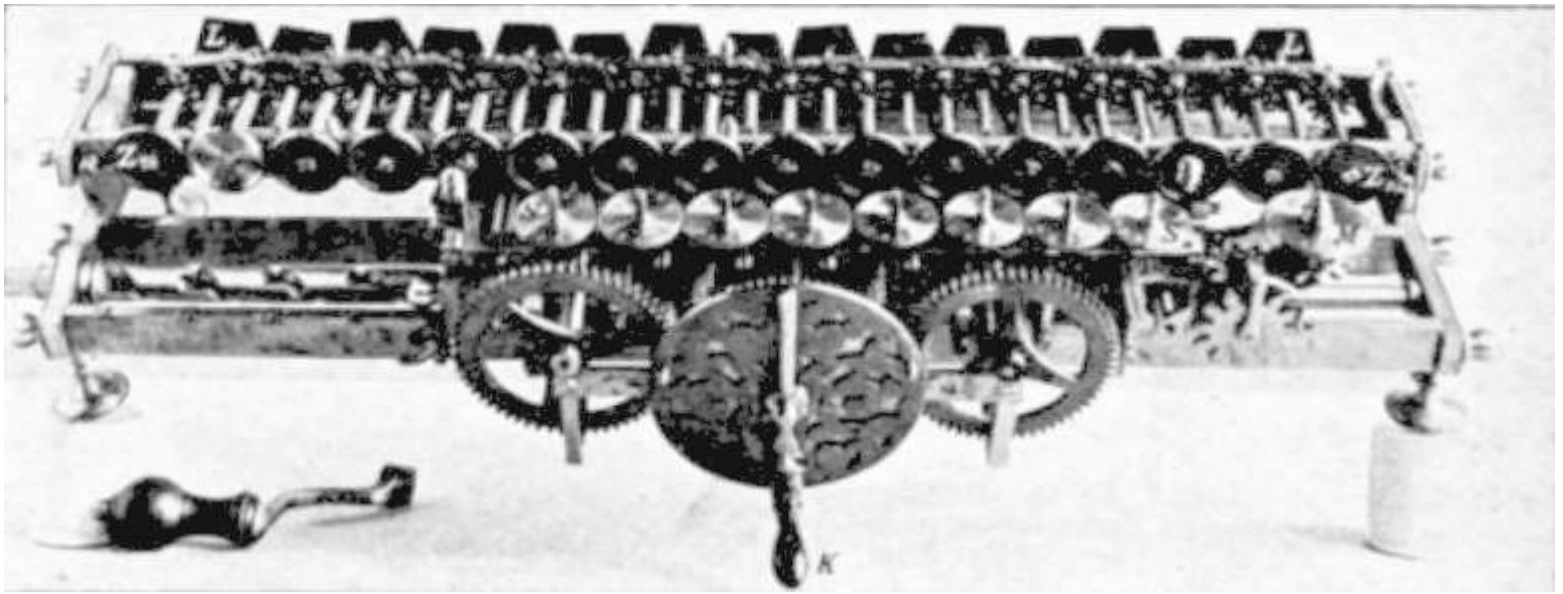
# Pascal's Mechanical Calculator

In the 1640s, Blaise Pascal, the French mathematician and philosopher, created a mechanical calculator to reduce the drudgery of his father's work as a tax supervisor. It became the first calculator to be patented and sold commercially.

It had spoked metal wheels with the digits 0 through 9 on their circumference. To add or subtract numbers, the operator used a stylus to dial a number, as if using a rotary phone, then dialed in the next number; an armature carried or borrowed a 1 when necessary.

# Leibniz' Stepped Reckoner

Thirty years later, Gottfried Leibniz, the German mathematician and philosopher, tried to improve upon Pascal's contraption with a "stepped reckoner" that had the capacity to multiply and divide.



# Leibniz' Stepped Reckoner

**Leibniz ran into a problem that would be a recurring theme of the pre-digital age:**

> Unlike Pascal, a skilled engineer who could combine scientific theories with mechanical genius, Leibniz had little engineering skill and did not surround himself with those who did. So he was unable to produce reliably working versions of his device.

**Nevertheless, his core concept, known as the Leibniz wheel, would influence calculator design through the time of Charles Babbage.**

# Jacquard Loom

Invented by Joseph Marie Jacquard in 1801

It simplifies the process of manufacturing textiles with such complex patterns as brocade, damask and matelasse.

The loom was controlled by a "chain of cards", a number of ***punched cards***, laced together into a continuous sequence.

# Jacquard Loom Video

https://www.youtube.com/watch?v=itd-4lMoXgI

James Burke, creator of Connections, talks about how the loom was improved by Joseph Jacquard. Jacquard was a French weaver and merchant. He played an important role in the development of the earliest programmable loom (the "Jacquard loom"), which in turn played an important role in the development of other programmable machines, such as an early version of digital compiler used by IBM to develop the modern day computer.

# Automatons

Some of these "self-operating machines" date back to antiquity.

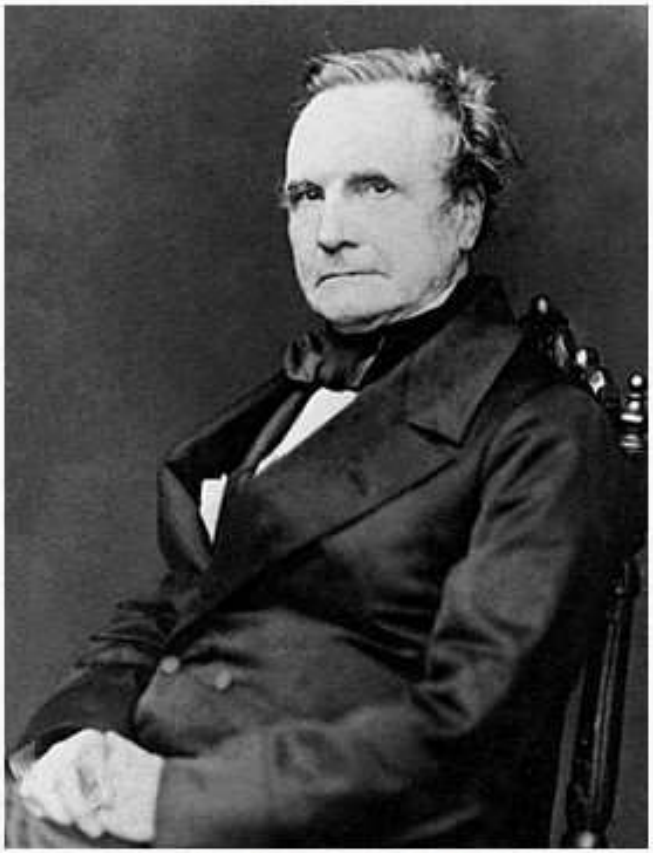
The Renaissance witnessed a considerable revival of interest in automata.

Some of these could be **‘re-programmed’** using cams, spiked wheels (music boxes), punched discs, etc.

# Charles Babbage

Charles Babbage, FRS (1791 – 1871) was an English polymath, mathematician, philosopher, inventor and mechanical engineer.

He is best remembered for originating the concept of a programmable computer.



Charles Babbage in 1860

# Charles Babbage

Babbage wanted to construct a mechanical method for tabulating logarithms, sines, cosines and tangents.

He realized even complex mathematical tasks could be broken into steps that came down to calculating "finite differences" through simple adding and subtracting (an offshoot of this is known as the ***'Babbage Principle'***).

Babbage devised a way to mechanize this process, and he named it the ***'Difference Engine'***. It could tabulate any polynomial function and provide a digital method for approximating the solution to differential equations.

# Charles Babbage

**But the project ran into two problems.**

First, Babbage and his hired engineer did not quite have the skills to get the device working.

Second, he began dreaming up something better.

# Charles Babbage

- Babbage's new idea, conceived in 1834, was a general-purpose computer that could carry out a variety of different operations based on programming instructions given to it.
- It could perform one task, then be made to switch and perform another.
- It could even tell itself to switch tasks- or alter its "pattern of action," based on its own interim calculations.

**Babbage named this proposed machine the *'Analytical Engine'*. He was one hundred years ahead of his time.**

# Charles Babbage

In 1836, Babbage made a leap that would represent a milestone in the prehistory of computers:

***"Suggested Jacquard's loom as a substitute for the drums."***

Using punch cards rather than steel drums meant that an unlimited number of instructions could be input.

In addition, the sequence of tasks could be modified , thus making it easier to devise **a general-purpose machine that was versatile and reprogrammable**.

# Charles Babbage

Few people, however, saw the beauty of Babbage's proposed new machine, and the British government had no inclination to fund it.

Babbage could generate little notice in either the popular press or scientific journals. But he did find one believer:

***Ada Lovelace***

# Ada Lovelace

- Augusta Ada King, Countess of Lovelace (1815 – 1852), born Augusta Ada Byron and now commonly known as Ada Lovelace
- Lovelace was the only child of the poet Lord Byron and his wife Anne Isabella Byron. All Byron's other children were born out of wedlock to other women.
- Byron separated from his wife a month after Ada was born and left England forever four months later.

Ada King, Countess of Lovelace, 1840

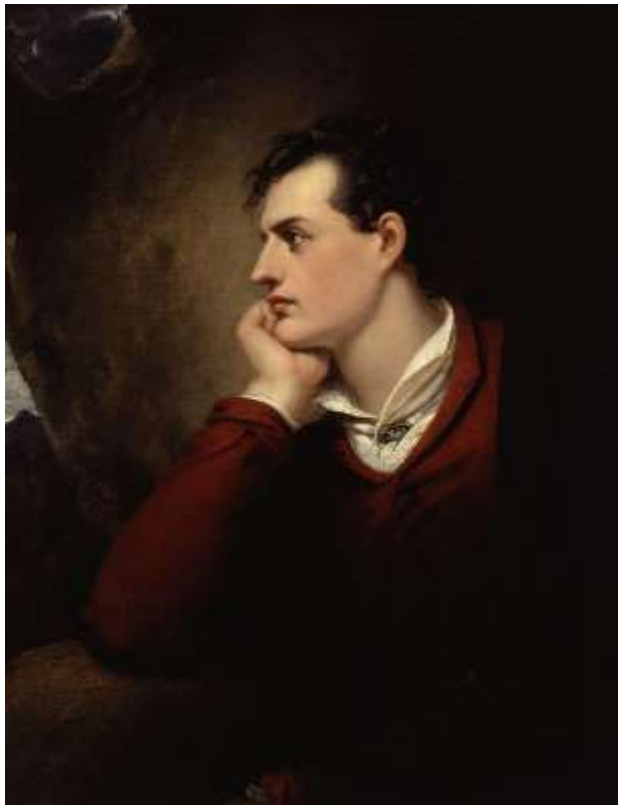
# Lord Byron

- Lord Byron, FRS (1788 – 1824) was an English poet and a leading figure in the Romantic movement. He is regarded as one of the greatest British poets, and remains widely read and influential.

- He travelled widely across Europe, especially in Italy where he lived for seven years.

- Later, Byron joined the Greek War of Independence fighting the Ottoman Empire, for which Greeks often revere him as a national hero. He died at age 36 from a fever contracted while in Missolonghi, Greece (Ada was 8 at the time).

- The most flamboyant and notorious of the major Romantics, Byron was both celebrated and castigated in life for his aristocratic excesses, including huge debts, numerous love affairs with more than one gender, rumours of a scandalous liaison with his half-sister, and self-imposed exile.



# Byron’s Frankenstein Connection

- In the summer of 1816 Lord Byron settled at the Villa Diodati by Lake Geneva, Switzerland, with physician John William Polidori, poet Percy Bysshe Shelley, and Shelley's future wife Mary Godwin.

- Kept indoors by the "incessant rain", Byron proposed that they "each write a ghost story". Mary Shelley produced what would become *‘Frankenstein, or The Modern Prometheus’*, and Polidori produced *‘The Vampyre’*, the progenitor of the romantic vampire genre.

# Back to Ada Lovelace

- Ada's mother remained bitter towards Lord Byron and promoted Ada's interest in mathematics and logic in an effort to prevent her from developing what she saw as the insanity seen in her father
- Ada described her approach as "poetical science“ and herself as an "Analyst (& Metaphysician)".
- Her mathematical talents led her to an ongoing working relationship and friendship with fellow British mathematician Charles Babbage, and in particular Babbage's work on the Analytical Engine.

Ada King, Countess of Lovelace, 1840

# Ada Lovelace's Notes

In her *"Notes"*, Ada explored four concepts that would have historical resonance later when the computer was finally born.

# Ada Lovelace - One

- The first was the principle of a **general purpose machine**, one that could perform not only a preset task but instead could be programmed and re-programmed to do a limitless and changeable array of tasks.

- This emphasized the distinction between Babbage's original **Difference Engine** and his proposed new **Analytical Engine**.

***"The Analytical Engine weaves algebraical patterns just as the Jacquard loom weaves flowers and leaves."***

# Ada Lovelace - Two

- The all purpose machine did not need to be limited to math and numbers. She noted that a machine such as the Analytical Engine could store, manipulate, process, and act upon anything that could be expressed in symbols: words and logic and music and anything else we might use symbols to convey.

- A computer operation, she noted, could alter the relationship not just between numbers but between any symbols that were logically related.

**This makes the conceptual leap from machines that were mere calculators to ones that we now call computers.**

# Ada Lovelace - Three

- She figured out in step-by-step detail the workings of what we now call a computer program or algorithm.
- She helped to devise the concepts of:
  - **Subroutines** (a sequence of instructions that performs a specific task, such as computing a cosine or calculating compound interest, and can be dropped into larger programs as needed)
  - **Recursive Loops** (a sequence of instructions that repeats itself), and
  - **Conditional Branching** (changing to a different path of instructions if certain conditions are met).

# Ada Lovelace – Three (con't)

- She created a table and diagram showing exactly how the algorithm would be fed into the computer, step by step, including two recursive loops.
- It was a numbered list of coding instructions that included destination registers, operations, and commentary - something that would be familiar to any C + + coder today.

**It was mainly on the basis of this diagram that Ada has been accorded by her fans the accolade of *"the world's first computer programmer."***

# Ada Lovelace - Four

- There was one other significant concept that she introduced in her "Notes," which harked back to the Frankenstein story produced by Mary Shelley after that weekend with Ada's father Lord Byron.

- It raised what is still the most fascinating metaphysical topic involving computers, that of artificial intelligence:

**Can machines think?**

# Ada Lovelace – Four (con't)

**Can machines think?**

- Ada believed not. A machine such as Babbage's could perform operations as instructed, she asserted, but it could not come up with ideas or intentions of its own.

***"The Analytical Engine has no pretensions whatever to originate anything. It can do whatever we know how to order it to perform. It can follow analysis; but it has no power of anticipating any analytical relations or truths."***

- A century later this assertion would be dubbed ***"Lady Lovelace's Objection"*** by computer pioneer Alan Turing.

# Ada Lovelace

Ada Lovelace also developed a vision on the capability of computers to go beyond mere calculating or number-crunching, while others, including Babbage himself, focused only on those capabilities.

Her mind-set of *"poetical science"* led her to ask questions about the Analytical Engine examining how individuals and society relate to technology as a collaborative tool.

# Ada Lovelace

- In the 1840s, Ada flirted with scandals including rumours of affairs and her love of gambling. The gambling led to her attempt in 1851 to create a mathematical model for successful large bets. This went disastrously wrong, leaving her thousands of pounds in debt.

- Ada Lovelace died at the age of 36 - the same age that her father had died at - from uterine cancer. She was buried, at her request, next to her father.

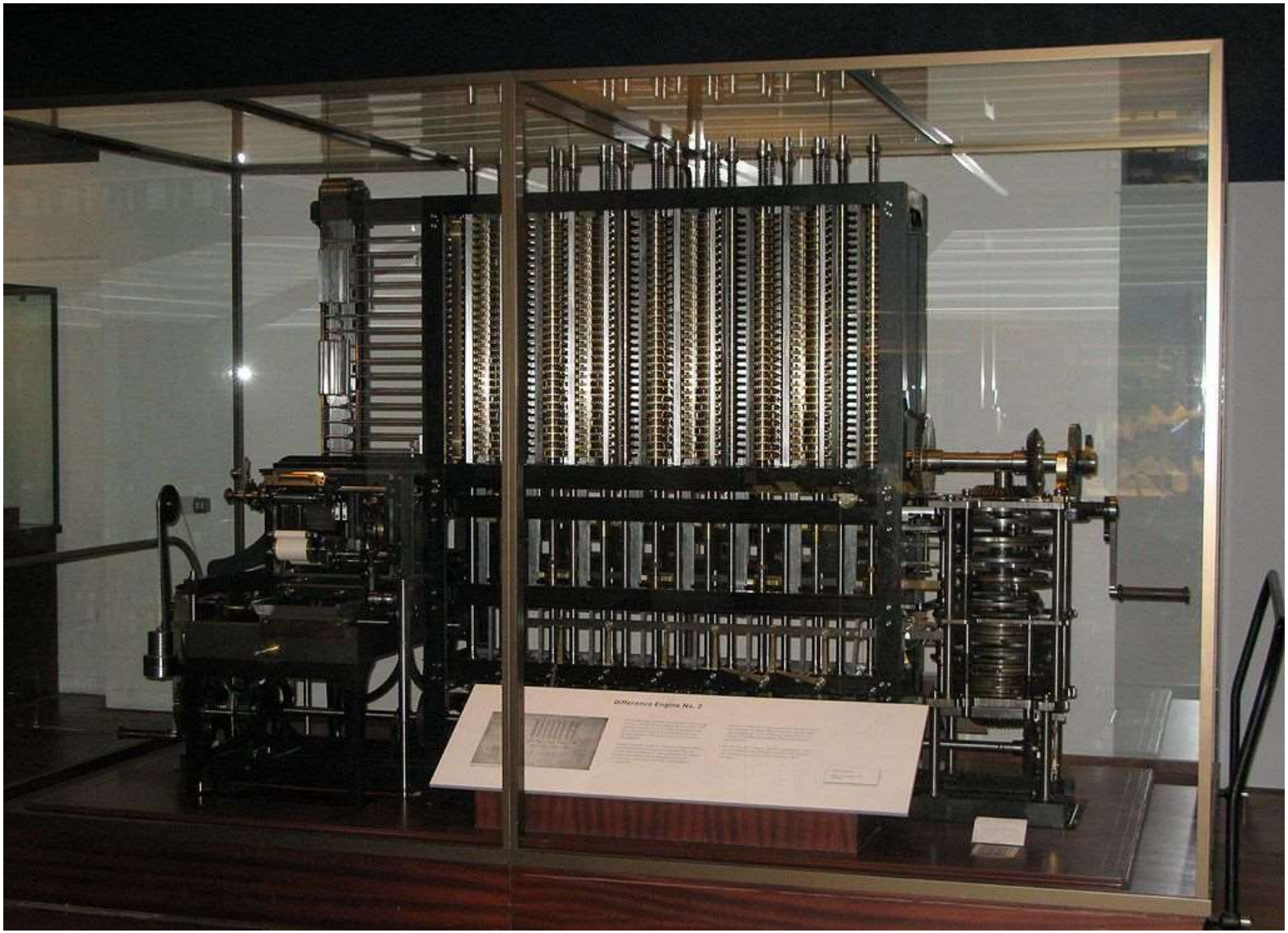
- In 1979 the ADA Programming language was introduced by Jean Ichbiah and team at Honeywell for the US Department of Defense.

# Charles Babbage

Charles Babbage published his paper about a sophisticated computer in 1837, but it took a hundred years to achieve the scores of technological advances needed to actually build one.

**“On two occasions I have been asked [by members of Parliament!], `Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?' I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question.”** - Charles Babbage,

# The Science Museum's Difference Engine No. 2, built from Babbage's design



# Babbage's Analytical Engine

- In 2011, researchers in Britain embarked on a multimillion-pound project to construct Babbage's Analytical Engine.

- Since Babbage's plans were continually being refined and were never completed, they will engage the public in the project and crowd-source the analysis of what should be built.

- They hope to complete it by the 150th anniversary of Babbage's death, in 2021.

# Herman Hollerith

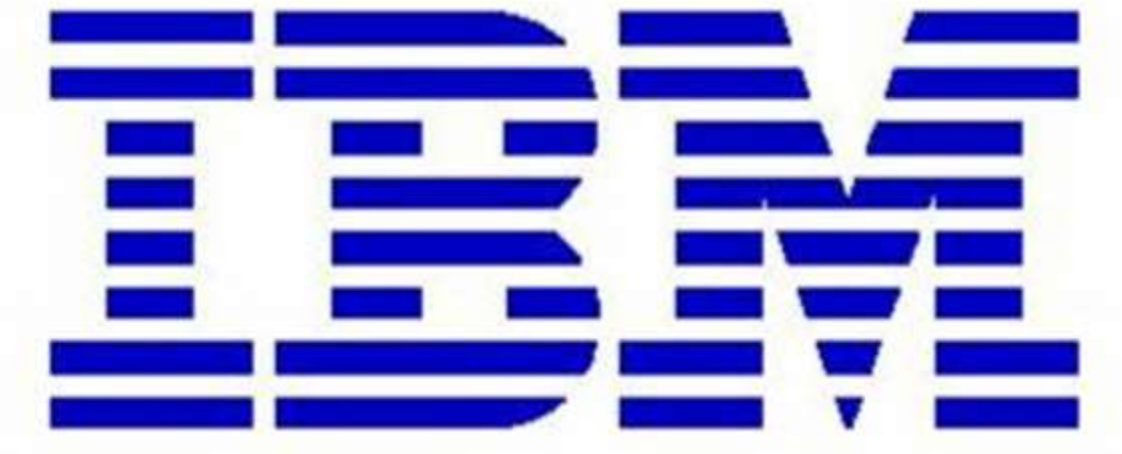
Perfecting the use of punch cards for computers came about because Herman Hollerith, an employee of the U.S. Census Bureau, was appalled that it took close to eight years to manually tabulate the 1880 census. He resolved to automate the 1890 count.

# Herman Hollerith

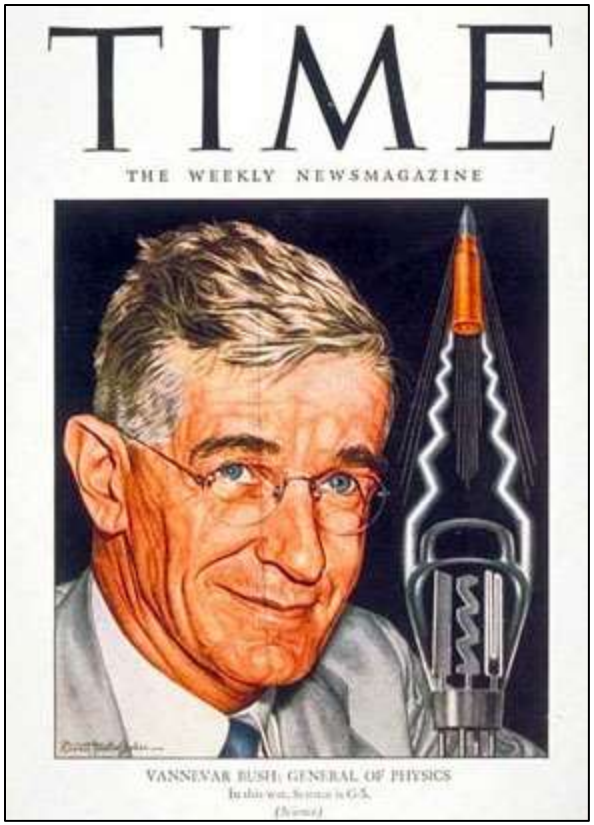
Using Hollerith's tabulators , the 1890 census was completed in one year rather than eight. It was the first major use of electrical circuits to process information.

# Herman Hollerith

The company that Hollerith founded became in 1924, after a series of mergers and acquisitions , the International Business Machines Corporation, or IBM.



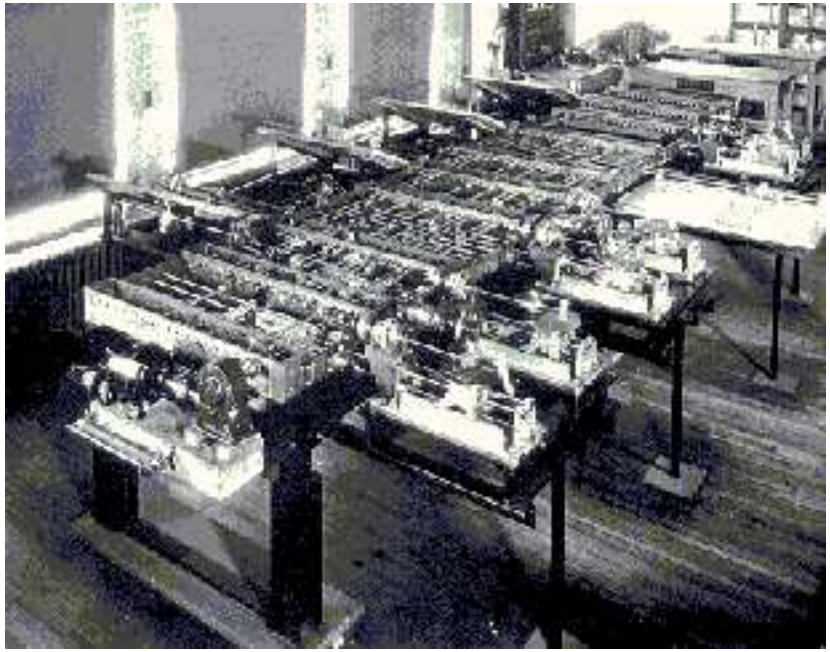
# Vannevar Bush




In 1931 MIT engineering professor Vannevar Bush was able to build the world's first analog electrical-mechanical computer. He dubbed his machine a **'Differential Analyzer'**.

# Vannevar Bush

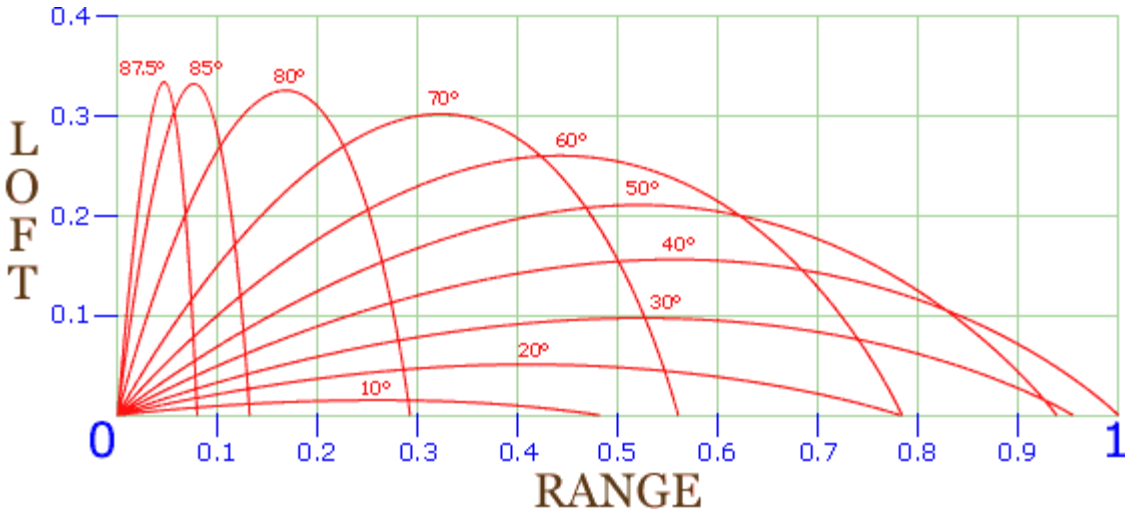
It consisted of six wheel-and-disk integrators connected by an array of gears, pulleys, and shafts rotated by electric motors.



It helped that Bush was at MIT; there were a lot of people around who could assemble and calibrate complex contraptions.

# Vannevar Bush

They proved particularly useful in churning out artillery firing tables— and in training and inspiring the next generation of computer pioneers.



# Analog Computers

## Vannevar Bush's Differential Analyzer was the last major Analog Computer.

An analog computer does not use discrete values (e.g. '0's and '1's) but rather continuous values (e.g. a sound wave, an artillery trajectory). The processes cannot be reliably repeated with exact equivalence, as they can with digital computers.

Analog computers can have a very wide range of complexity. Slide rules and nomographs are the simplest, while naval gunfire control computers and large hybrid digital/analog computers were among the most complicated.

The advent of digital computing made analog computers largely obsolete in 1950s and 1960s, though they remain in use in some specific applications, like the flight computer in aircraft.

# Vannevar Bush

- An offshoot of Vannevar Bush's work on the Differential Analyzer was some of the original work on digital circuit design theory.
- Bush invented the Memex, an adjustable microfilm viewer with a hyperlink structure analogous to that of the World Wide Web.
- Bush became Vice President of MIT and Dean of the MIT School of Engineering in 1932, and president of the Carnegie Institution of Washington in 1938.
- Bush was as head of the U.S. Office of Scientific Research and Development (OSRD) during World War II, through which almost all wartime military R&D was carried out, including initiation and early administration of the Manhattan Project.
- He founded Raytheon Corporation.

# 1937

New approaches , technologies, and theories began to emerge in 1937, exactly a hundred years after Babbage first published his paper on the Analytical Engine.

It would become an annus mirabilis (year of wonders) of the computer age.

**The result would be the triumph of the '*Four Properties*' that would define modern computing**

# 1937 and the ‘Four Properties’

- **DIGITAL** (discrete vs continuous)
- **BINARY** (‘0’s and ‘1’s)
- **ELECTRONIC** (not mechanical)
- **GENERAL PURPOSE**

# War Mobilizes Science

World War II led to major computer development on both the Allied and German sides.

The Germans failed to utilize their computers in an effective way.

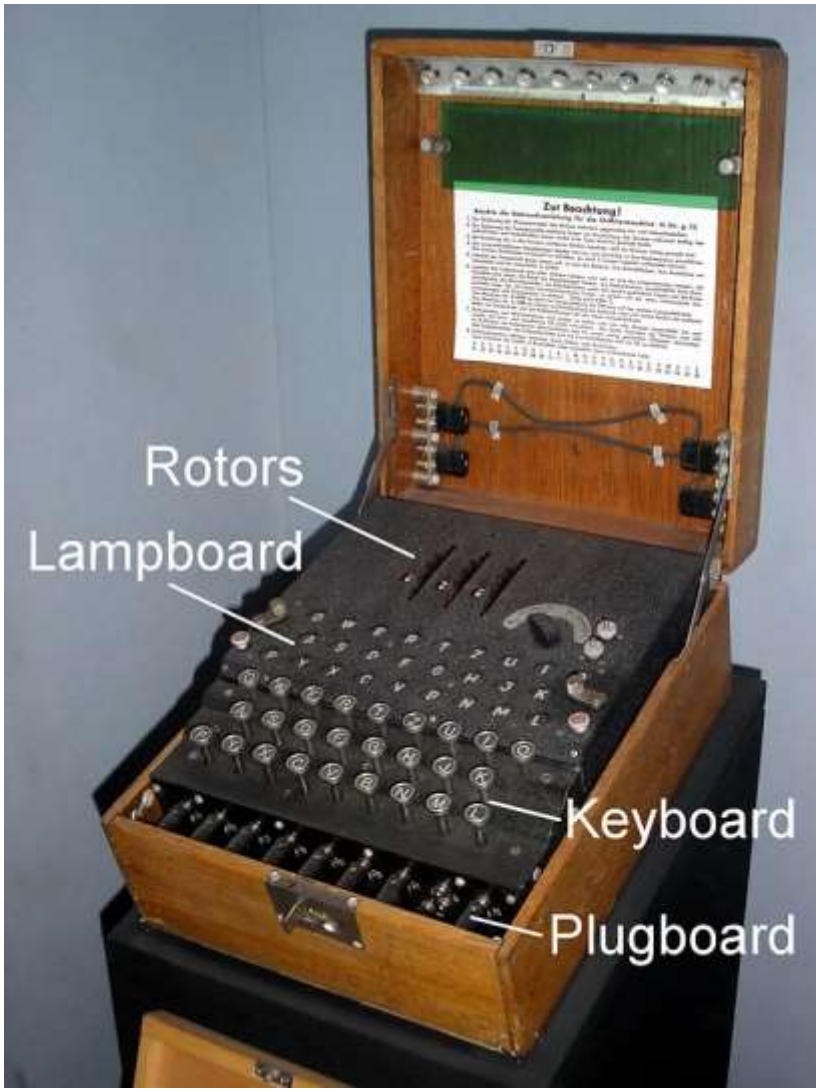
**The British and Americans used theirs to win the war.**

# War Mobilizes Science

Practical applications for computers during WWII included artillery ballistics table calculation and most especially important, ***enemy code breaking***

# Enigma

Enigma machines were electro-mechanical rotor cipher machines used primarily by the Germans for enciphering and deciphering secret messages.



# Lorenz

- The Enigma cipher was used for operational level messages in the German navy, army and air force.
- The Lorenz cipher was used for encrypted high-level telegraphic messages between the German High Command (OKW) and their army commands throughout occupied Europe.

# Breaking the Codes

Though Enigma and Lorenz had some cryptographic weaknesses, properly used the German Enigma and Lorenz ciphers should have been virtually unbreakable.

In practice it was German procedural flaws, operator mistakes, laziness, failure to systematically introduce changes in encipherment procedures, and Allied capture of key tables and hardware that enabled Allied cryptologists to succeed in breaking the code.

# Bletchley Park

- After initial assistance from the Poles in 1939, the Brits established the British Government Code and Cypher School (GC&CS) at Bletchley Park northwest of London
- It has been estimated that the work at Bletchley Park shortened the war in Europe by as many as two to four years.

# The ‘ULTRA’ Secret

The British knew the German vulnerabilities could have been remedied by relatively simple improvements in enemy procedures, and such changes would certainly be implemented had Germany had ANY hint of Bletchley's success.

Thus the intelligence Bletchley produced was considered wartime Britain's **‘Ultra Secret’** - higher even than the normally highest classification Most Secret - and security was absolutely paramount.

# The ‘ULTRA’ Secret

Any commander in the field receiving Ultra intelligence was fed a cover story crediting a non-Ultra source; at times sham scouting missions – intentionally visible to the enemy – were dispatched to "discover" German positions in fact already known from Ultra.

In some cases it was impossible to act on Ultra intelligence at all because to do so might suggest to the enemy that their communications had been penetrated.

# The ‘ULTRA’ Secret

Information on ULTRA did not even start being declassified until the 1970’s, and even today some information is still secret.

The full ULTRA story is still being pieced together by historians cross-referencing hundreds of thousands of documents, since most of those originally involved are dead or still won’t talk.

# The Dieppe Raid

- The introduction of a 4th rotor in 1942 was preventing cryptanalysis of the German naval Enigma, and led to a strong resurgence in German U-Boat attacks on the vital Atlantic convoys coming from North America.
- Thus the Allies were eager to get their hands on one to discover (and exploit) any weaknesses in the new system.

# The Dieppe Raid

A raid on Dieppe, France was carried out August 1942 as cover for a "pinch" mission overseen by Ian Fleming (best known later as author of the James Bond action espionage books) to steal one of the new German 4-rotor Enigma code machines, plus associated code books and rotor setting sheets.

# The Dieppe Raid

- The August 1942 raid was a failure and no machine was obtained.
- The new German naval Enigma code was not cracked until December of that year and was of the most serious concern, as Britain would have literally starved without the food-stocks arriving by naval convoy.
- The raid provided valuable lessons for the eventual D-Day Invasion

# The Dieppe Raid

- Of the nearly 5,000-strong Canadian contingent, 3,367 were killed, wounded or taken prisoner, an exceptional casualty rate of 68%.
- The 1,000 British Commandos lost 247 men.
- The Royal Navy lost one destroyer (HMS Berkeley) and 33 landing craft, suffering 550 dead and wounded.
- The RAF lost 106 aircraft to the 48 lost by the Luftwaffe.
- The German Army had 591 casualties.


"BENEDICT CUMBERBATCH IS OUTSTANDING"
"THE BEST BRITISH FILM OF THE YEAR"
★★★★★
"AN INSTANT CLASSIC"
★★★★★
"A SUPERB THRILLER"
★★★★
★★★★ ★★★★
THE IMITATION GAME
BENEDICT CUMBERBATCH
KEIRA KNIGHTLEY
BASED ON THE INCREDIBLE TRUE STORY
IN CINEMAS NOVEMBER 14

# The Turing Bombe

- Alan Turing, a Cambridge University mathematician and logician, provided much of the original thinking that led to the design of the cryptanalytical Bombe (an electromechanical decryption device) and the eventual breaking of naval Enigma in 1939.
- However, the German Navy introduced an Enigma version with a fourth rotor for its U-boats resulting in a prolonged period when these messages could not be decrypted.
- With the capture of relevant cipher keys and the use of much faster US Navy Bombes, regular, rapid reading of U-boat messages resumed in December 1942.

# Colossus

- Colossus was the world's first programmable electronic digital computer.
- The Colossus computers were developed for British codebreakers during World War II to help in the cryptanalysis of the Lorenz cipher.
- Designed by engineer Tommy Flowers, Alan Turing's use of probability in cryptanalysis contributed to its design.

# Colossus

- The destruction of most of the Colossus hardware and blueprints, as part of the effort to maintain a project secrecy that was kept up into the 1970s, deprived most of those involved with Colossus of credit for their pioneering advancements in electronic digital computing during their lifetimes.
- A functioning replica of a Colossus computer was completed in 2007 and is on display at The National Museum of Computing at Bletchley Park.

# Japan, Purple, JN25 and Magic

- In the Pacific theater, the Japanese cipher machine dubbed "**Purple**" by the Americans, was used for highest-level Japanese diplomatic traffic. It was cracked by the US Army's Signal Intelligence Service and disseminated under the codeword **MAGIC**.
- Some Purple decrypts proved useful against Germany. Detailed reports by Japan's ambassador to Germany included:
  - Reviews of Germany's assessments of the military situation
  - Reviews of strategy and intentions,
  - Reports on direct inspections (in one case, of Normandy beach defenses) by the ambassador, and
  - Reports of long interviews with Hitler.

# Japan, Purple, JN25 and Magic

- The Imperial Japanese Navy code was called JN-25 by the Americans. By early 1942 considerable progress had been made in decrypting these messages.
- This led to the major Japanese defeat at the Battle of Midway.

# War Mobilizes Science

- 1941 - Konrad Zuse completed the 'Z3', the first operational programmable computer. The Z3 was destroyed in 1943 during an Allied bombardment of Berlin, and had no impact on computer technology in America and England.

- 1944 - The IBM Automatic Sequence Controlled Calculator was turned over to Harvard University, which called it the Harvard Mark I. It was designed by Howard Aiken and his team, financed and built by IBM. It became the second program controlled machine (after Konrad Zuse's). Used to create ballistics tables for the US Navy.

# Alan Turing

- Alan Turing, OBE , FRS (1912 – 1954) was a British pioneering computer scientist, mathematician, logician, cryptanalyst, philosopher, mathematical biologist, and marathon and ultra distance runner.
- He was highly influential in the development of computer science, providing a formalization of the concepts of "algorithm" and "computation" with the Turing machine, which can be considered a model of a general purpose computer.
- Turing is widely considered to be the father of theoretical computer science and artificial intelligence (he disagreed with **Ada Lovelace** on Artificial Intelligence).

# The Turing Machine

A Turing machine is a hypothetical device that manipulates symbols according to a table of rules. A Turing machine can be adapted to simulate the logic of any computer algorithm.

***In essence, it can do anything that's computable.***

# The Turing Test

- Turing addressed the problem of artificial intelligence, and proposed an experiment which became known as the **Turing Test**, an attempt to define a standard for a machine to be called "intelligent".
- The idea was that a computer could be said to "think" if a human interrogator could not tell it apart, through conversation, from a human being.
- Turing suggested that rather than building a program to simulate the adult mind, it would be better rather to produce a simpler one to simulate a child's mind and then to subject it to a course of education.

# Alan Turing

- Turing was prosecuted in 1952 for homosexual acts, when such behaviour was still criminalised in the UK.
- He accepted treatment with oestrogen injections (chemical castration) as an alternative to prison.
- Turing died in 1954, 16 days before his 42nd birthday, from cyanide poisoning. There is controversy as to whether it was accident or suicide.

# Alan Turing

In 2009 British Prime Minister Gordon Brown made an official public apology on behalf of the British government for "the appalling way he was treated".

Queen Elizabeth II granted him a posthumous pardon in 2013.

- 1947 - Invention of the transistor at Bell Laboratories, USA, by William B. Shockley, John Bardeen and Walter Brattain.

- 1951 - J Lyons, a United Kingdom food company, famous for its tea, made history by running the first business application on an electronic computer, a payroll system.

- 1952 - IBM introduces the IBM 701, the first computer in its 700 and 7000 series of large scale machines with varied scientific and commercial architectures, but common electronics and peripherals. Some computers in this series remained in service until the 1980s.

# Grace Hopper

Grace Hopper (1906 - 1992) was an American computer scientist and United States Navy rear admiral

She was one of the first programmers of the Harvard Mark I computer, and invented the first compiler for a computer programming language.

She popularized the idea of machine-independent programming languages, which led to the development of COBOL, one of the first high-level programming languages.

She is credited with popularizing the term "debugging" for fixing computer glitches (inspired by an actual moth removed from the computer).

# IBM and the Seven Dwarves

IBM was one of the nine major United States computer companies with

- Burroughs,
- Honeywell,
- NCR Corporation,
- Control Data Corporation (CDC),
- General Electric (GE),
- RCA and
- Sperry Rand (UNIVAC)

through most of the 1960s.

IBM's share of the market at the time was so much larger than all of the others, that this group was often referred to as "IBM and the Seven Dwarfs.“

# IBM and the BUNCH

By 1972 when GE and RCA were no longer in the mainframe business, the remaining five companies behind IBM became known as the **BUNCH**, an acronym based on their initials

**B**urroughs,
**U**nivac,
**N**CR,
**C**ontrol Data,
**H**oneywell

# IBM and the Seven Dwarves

Burroughs ----------|--- 1986 --- Unisys

Sperry Univac -------| 1955 --- Sperry Rand ---|---1971---|

Remington Rand ---|  |

RCA ----------|

Honeywell ----------|--- 1970 ------- Honeywell

General Electric (GE) --------|

NCR Corporation

Control Data Corporation (CDC) – no longer in computer business (Ceridian)

**********

Digital Equipment Corporation (DEC) - acquired in 1998 by Compaq, which subsequently merged with Hewlett-Packard 2002

# Xerox PARC

Xerox PARC (Palo Alto Research Center) has been the inventor and incubator of many elements of modern computing:

- Laser printers,
- Computer-generated bitmap graphics
- The Graphical user interface, featuring windows and icons, operated with a mouse
- The WYSIWYG text editor
- Liquid Crystal Displays (LCD's)
- Interpress, a resolution-independent graphical page-description language and the precursor to PostScript
- Ethernet as a local-area computer network
- Fully formed object-oriented programming in the Smalltalk programming language and integrated development environment.
- Model–view–controller software architecture

# Xerox PARC

After basically inventing the modern personal computer in the 1970's, Xerox has been heavily criticized (particularly by business historians) for failing to properly commercialize and profitably exploit PARC's innovations.

A number of PARC engineers left to join Apple Computer, where they were instrumental in the development of the Apple LISA and MacIntosh computers.

In 2002, Xerox spun off their Palo Alto Research Center into PARC (Palo Alto Research Center Incorporated), dedicated to developing and maturing advances in science and business concepts with the support of commercial partners and clients.

End of

# History of Computing Part One

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