What is Computation?

BBM 101 - Introduction to Programming I

Hacettepe University
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Some may think:

Computer science is just about learning technology

Some may think:

~~Computer science is just about learning technology~~
Computer science is about logic, problem solving, and creativity

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First computer: 1943

Ada Lovelace

First computer: 1943
First computer program: 1843

Slide credit: code.org

What is Knowledge?

- **Declarative knowledge**
  - Axioms (definitions)
  - Statements of fact

  "y is the square root of x if and only if y*y = x" — *does not help to find the square root!*

What is Knowledge? (cont'd.)

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- **Imperative knowledge**
  - How to do something
  - A sequence of specific instructions (what computation is about)

  Babylonian method
  Get x as an input
  1. Begin with an arbitrary positive number y_0 — *(an initial guess)*
  2. If $y_n^2 \approx x$, stop — *(found the solution - y_n)*
     Else let $y_{n+1} = (y_n + x/y_n)/2$ — *(use the arithmetic mean to approximate the geometric mean)*
  3. Repeat step (2)

What is Knowledge? (cont'd.)

- **Another example** – Estimating greatest common divisor (gcd)

  Declarative definition
  "d is the gcd of a and b if and only if d is the largest possible integer satisfying a = d*x and b = d*y with x and y being two positive integers"

  Imperative definition: Euclid's formula
  Get 2 positive integers a and b, a>=b as input
  1. Divide a by b, call the remainder R
  2. If R = 0, stop — *(found the solution - b)*
     Else let a = b and b = R
  3. Repeat step 2

  Use Euclid's formula to compute gcd(48,18).

What is a Computer?

- A device that executes a sequence of computations and instructions.

- Modern computers are electronic and digital.

- Does pencil and paper count as a computer?

Programs

- These sequences of instructions and computations is called a **program**.

- We will be designing programs in this course.

- These programs will be based on **algorithms**.
  - **Algorithm** - a step-by-step problem-solving procedure.

Where did the Term 'Computer' Originate?

- The definition from The Oxford Dictionary:

  "Computer (noun). A person who makes calculations, especially with a calculating machine."

Courtesy of the Library of Congress

Fixed Program Computers

- Developed to solve a specific problem (set).

- Very old roots, old perspectives, …
  - Abacus
  - Antikythera Mechanism
  - Pascaline
  - Leibniz Wheel
  - Jacquard's Loom
  - Babbage Difference Engine
  - The Hollerith Electric Tabulating System
  - Atanasoff-Berry Computer (ABC)
  - Turing Bombe
  - etc.

Abacus (500 BC)

- First pocket calculator
- Still used by businessmen in Asia.

© Ken Seet / CORBIS

Antikythera Mechanism (100 BC)

- First analog computer
- An ancient mechanical computer designed to calculate astronomical positions

© Rien van de Weygaert

© Antikythera Mechanism Research Project

Pascaline (1642)

- Blaise Pascal, 1642
- A mechanical calculator for performing two arithmetic operations: addition and subtraction
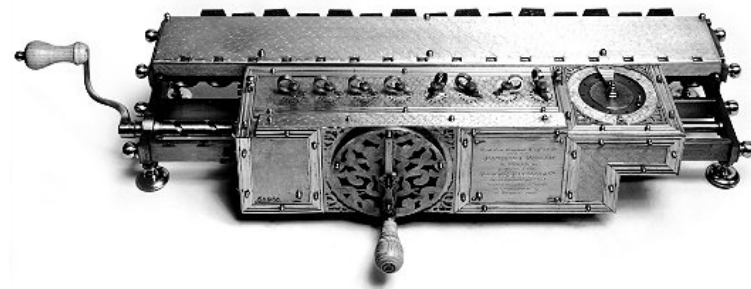

© Britannica

© Mark Richards

Leibniz Wheel (1694)

- Gottfried Wilhelm von Leibniz, 1694
- A mechanical calculator for performing all four arithmetic operations: addition, subtraction, multiplication and division

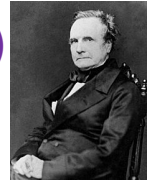Courtesy of the Deutsches Museum, München

Jacquard's Loom (1801)

- 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
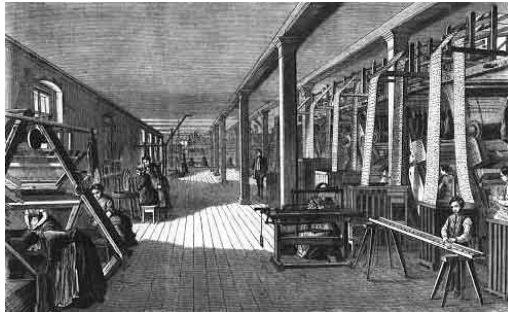

A Jacquard Loom workshop - Germany, 1858.

Babbage Difference Engine (1832)

- Charles Babbage, 1832

- A mechanical calculator designed to tabulate polynomial functions (can be used for solving polynomial equations, curve fitting, etc.)

- A working difference engine was built in 1991 to celebrate the 200th anniversary of Babbage's birth (London Science Museum).

- It could hold 8 numbers of 31 decimal digits each and could thus tabulate 7th degree polynomials to that precision.
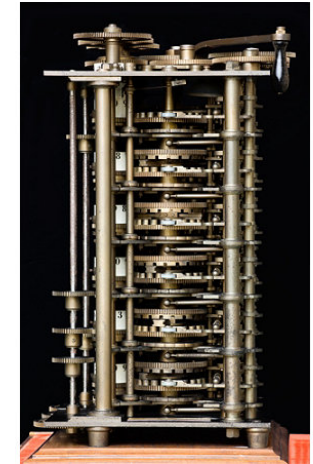
© Mark Richards

The Hollerith Electric Tabulating System

- **1880 Census.** Took 1,500 people 7 years to manually process data.
- **Herman Hollerith.** Developed counting and sorting machine to automate.
  - Use punch cards to record data (e.g., gender, age).
  - Machine sorts one column at a time (into one of 12 bins).
  - Typical question: how many women of age 20 to 30?

Hollerith tabulating machine and sorter

punch card (12 holes per column)

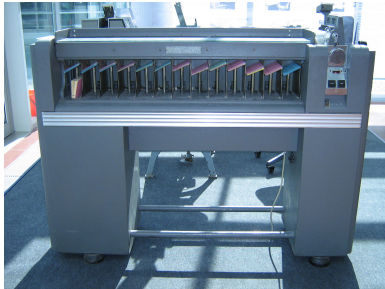- 1890 Census. Finished months early and under budget!

Modern Punch Cards

- Punch cards. [1900s to 1950s]
  - Also useful for accounting, inventory, and business processes.
  - Primary medium for data entry, storage, and processing.

- Hollerith's company later merged with 3 others to form Computing Tabulating Recording Corporation (CTRC); the company was renamed in 1924.

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IBM 80 Series Card Sorter, 1949
(650 cards per minute)

Adopted from: Sedgewick and Wayne

Atanasoff-Berry Computer (ABC) (1939)

- John Vincent Atanasoff and Clifford Berry, 1939-1942
- One of the first electronic digital computing devices
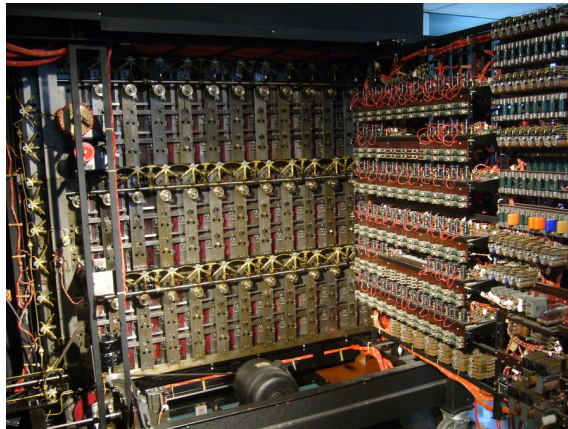- Designed to solve a system of linear equations
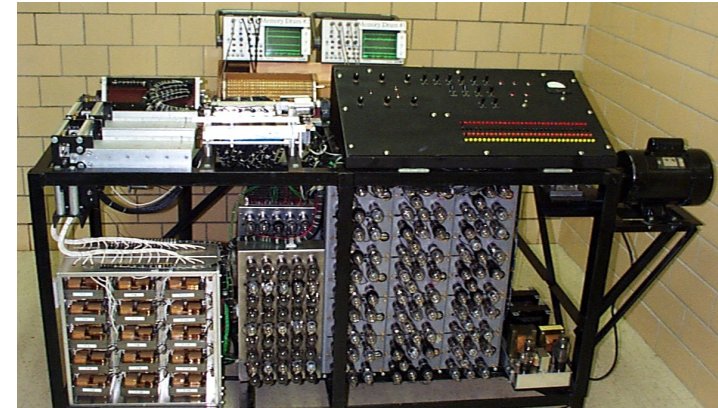
Turing bombe (1941)

- Alan Turing, 1939
- Developed to crack German Enigma codes during WW II.


Enigma machine in use

Alan Turing

- 1912-1954
- Considered the "father" of modern computer science.
- Presented formalisms for the notions of computation and computability in the 1930's.
- Worked at Bletchley Park in Great Britain during WWII to develop Collossus to help break the German Enigma Code.
- Developed the notion in 1950 of a test for machine intelligence now called the Turing Test.
- The Turing Award, the highest award in computing, is named in honor of Alan Turing.
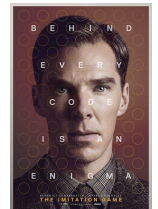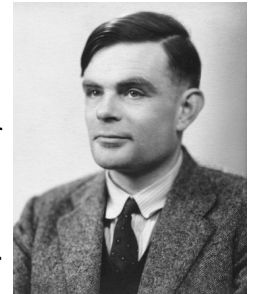
Slide credit: G. Kesden
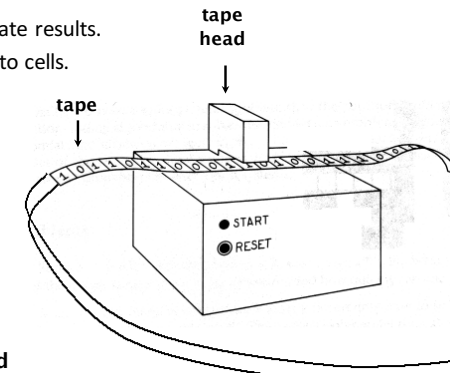
Stored Program Computers

- Problem solving

Input → **Machine** → Output
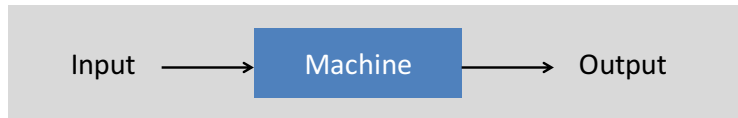
- What if input is a machine (description) itself?

- Universal Turing machines
  - An abstract general purpose computer

Universal Turing Machines

- Tape
  - Stores input, output, and intermediate results.
  - One arbitrarily long strip, divided into cells.
  - Finite alphabet of symbols.

- Tape head
  - Points to one cell of tape.
  - Reads a symbol from active cell.
  - Writes a symbol to active cell.
  - Moves one cell at a time.

tape head

tape	…	#	1	1	0	0	+	1	0	1	1	#	…
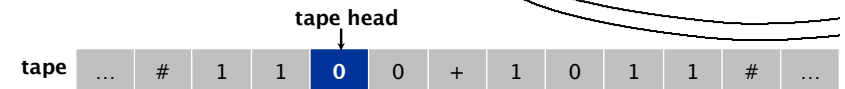
- Is there a more powerful model of computation? No!

Most important scientific result of 20th century?

Questions About Computation

- What is a general-purpose computer?
- Are there limits on the power of digital computers?
- Are there limits on the power of machines we can build?

David Hilbert   **Kurt Gödel**   **Alan Turing**   **Alonzo Church**   **John von Neumann**

Church-Turing Thesis (1936)

> **Turing machines can compute any function that can be computed by a physically harnessable process of the natural world.**

- **Remark.** "Thesis" and not a mathematical theorem because it's a statement about the physical world and not subject to proof.
- Use simulation to prove models equivalent.
  - Android simulator on iPhone.
  - iPhone simulator on Android.
- **Implications.**
  - No need to seek more powerful machines or languages.
  - Enables rigorous study of computation (in this universe).
- **Bottom line.** Turing machine is a simple and universal model of computation.

Church-Turing Thesis: Evidence

- 8 decades without a counterexample.
- Many, many models of computation that turned out to be equivalent.

model of computation	description
enhanced Turing machines	multiple heads, multiple tapes, 2D tape, nondeterminism
untyped lambda calculus	method to define and manipulate functions
recursive functions	functions dealing with computation on integers
unrestricted grammars	iterative string replacement rules used by linguists
extended L-systems	parallel string replacement rules that model plant growth
programming languages	Java, C, C++, Perl, Python, PHP, Lisp, PostScript, Excel
random access machines	registers plus main memory, e.g., TOY, Pentium
cellular automata	cells which change state based on local interactions
quantum computer	compute using superposition of quantum states
DNA computer	compute using biological operations on DNA

Babbage's Analytical Engine (1834, 1836)

- 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
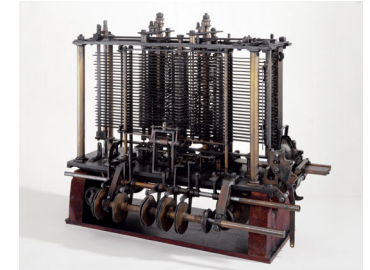

Ada Lovelace

- 1815-1852

- Daughter of poet Lord Byron

- Translated Luigi Menabrea's article on Babbage's Analytical Engine to English
  - Quadrupled its length by adding lengthy notes and detailed mathematical explanations

- Referred to as the world's first programmer
  - Described how the machine might be configured (programmed) to solve a variety of problems.
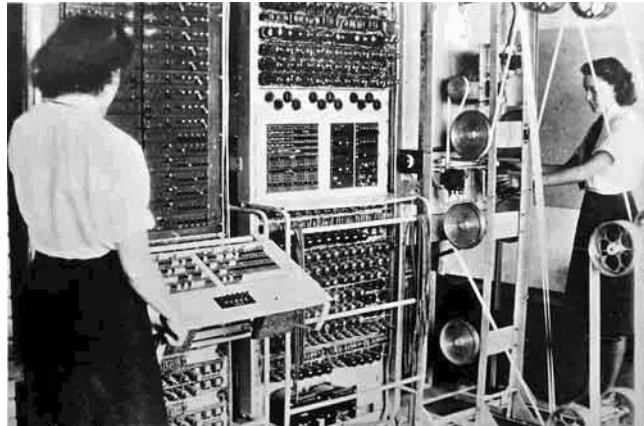

The Zuse Z3 Computer (1941)

- Konrad Zuse, 1941
- The original Z3 was destroyed in a bombing raid of Berlin in 1943.
- Zuse later supervised a reconstruction of the Z3 in the 1960s (currently on display at the Deutsches Museum in Munich)
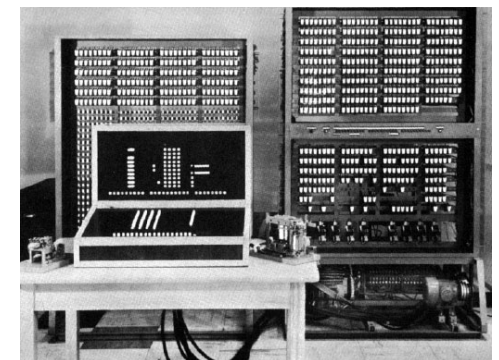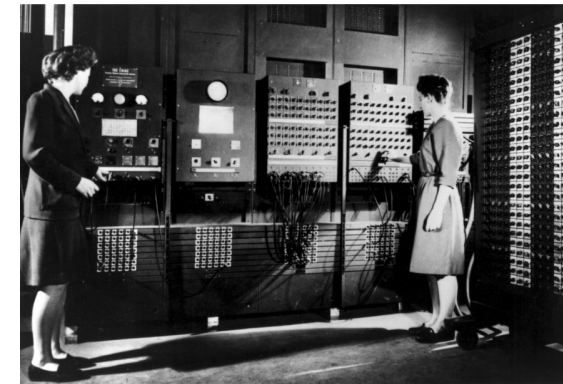
Colossus Mark 1 (UK,1944)

- The world's first electronic digital computer with programmability.

ENIAC (Mauchly and Eckert, USA, 1946)

- The first large-scale general-purpose electronic computer without any mechanical parts.
- Designed to calculate artillery firing tables for the United States Army's Ballistic Research Laboratory


EDVAC (von Neuman, USA, 1951)

- Unlike the ENIAC, it uses binary rather than decimal numbering system
- Instructions were stored in memory sequentially with their data
- Instructions were executed sequentially except where a conditional instruction would cause a jump to an instruction someplace other than the next instruction

The Computer Tree

- http://ftp.arl.mil/~mike/comphist/61ordnance/chap7.html
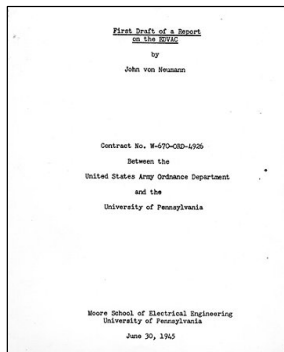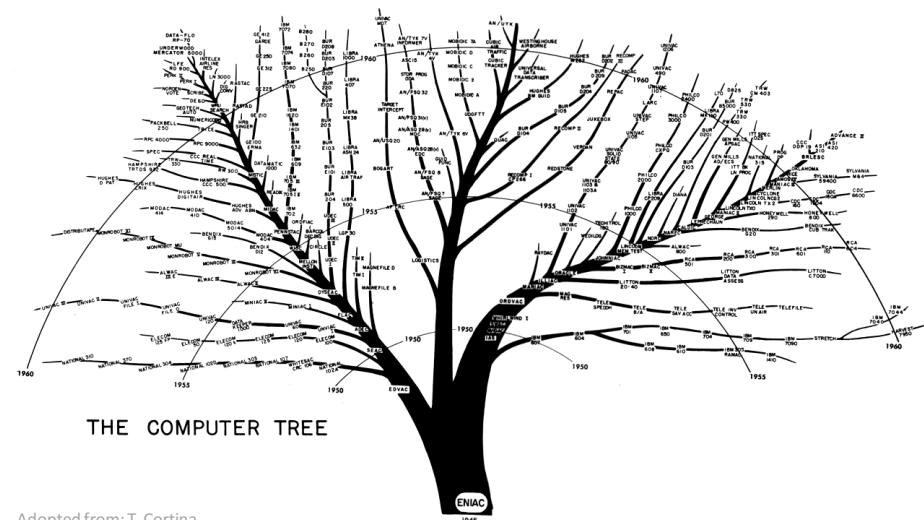
THE COMPUTER TREE

Summary

- **What is computation?**
  - What is knowledge?
  - What is a computer?
  - What is a program?
  - History of computing

The Birth of the Computer

- A TED talk given by George Dyson

http://www.ted.com/talks/george_dyson_at_the_birth_of_the_computer.html