What is Computation?

BBM 101 - Introduction to Programming I

Hacettepe University
Fall 2016

Fuat Akal, Aykut Erdem, Erkut Erdem

Some may think:

Computer science is just about learning technology

Computer science is about logic, problem solving, and creativity

First computer: 1943

Slide credit: code.org
What is Knowledge?

- **Declarative knowledge**
  - Axioms (definitions)
  - Statements of fact
    
    \[ y \text{ is the square root of } x \text{ if and only if } y \cdot y = x \]
    
    **does not help to find the square root!**

- **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 \( y_n^2 = x \), 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)

Another example – Estimating greatest common divisor (gcd)

**Declarative definition**

\[ d \text{ is the gcd of } a \text{ and } b \text{ if and only if } d \text{ is the largest possible integer satisfying } a = d \cdot x \text{ and } b = d \cdot y \text{ with } x \text{ and } y \text{ being two positive integers} \]

**Imperative definition: Euclid’s formula**

Get 2 positive integers \( a \) and \( b \), \( a \geq b \) as input

1. Divide \( a \) by \( b \), call the remainder \( R \)
2. If \( R = 0 \), stop
   Else let \( a = b \) and \( b = R \)
3. Repeat step 2

(found the solution - \( b \))

Use Euclid’s formula to compute \( \text{gcd}(48,18) \).
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.

Where did the Term ‘Computer’ Originate?

- The definition from The Oxford Dictionary:
  “Computer (noun). A person who makes calculations, especially with a calculating machine.”

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.

Antikythera Mechanism (100 BC)
- First analog computer
- An ancient mechanical computer designed to calculate astronomical positions

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

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

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.

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?

- 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.
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.

---

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.

---

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 Colossus 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.
Stored Program Computers

• Problem solving

![Flowchart of Input, Machine, and 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.

• Is there a more powerful model of computation? No!

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

Adopted from: Sedgewick and Wayne

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.

Adopted from: Sedgewick and Wayne
Church-Turing Thesis: Evidence

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

<table>
<thead>
<tr>
<th>Model of Computation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced Turing Machines</td>
<td>Multiple heads, multiple tapes, 2D tape, nondeterminism</td>
</tr>
<tr>
<td>Untyped Lambda Calculus</td>
<td>Method to define and manipulate functions</td>
</tr>
<tr>
<td>Recursive Functions</td>
<td>Functions dealing with computation on integers</td>
</tr>
<tr>
<td>Unrestricted Grammars</td>
<td>Iterative string replacement rules used by linguists</td>
</tr>
<tr>
<td>Extended L-systems</td>
<td>Parallel string replacement rules that model plant growth</td>
</tr>
<tr>
<td>Programming Languages</td>
<td>Java, C, C++, Perl, Python, PHP, Lisp, PostScript, Excel</td>
</tr>
<tr>
<td>Random Access Machines</td>
<td>Registers plus main memory, e.g., TOY, Pentium</td>
</tr>
<tr>
<td>Cellular Automata</td>
<td>Cells which change state based on local interactions</td>
</tr>
<tr>
<td>Quantum Computer</td>
<td>Compute using superposition of quantum states</td>
</tr>
<tr>
<td>DNA Computer</td>
<td>Compute using biological operations on DNA</td>
</tr>
</tbody>
</table>

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 somewhere other than the next instruction

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