

Data Structures and Algorithms

Lecture 01

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Agenda

- ▶ What is an algorithm?
- ▶ What is not an algorithm?
- ▶ How is it different from a computer program?

Sorting

Input: A collection of numbers, a_1, a_2, \dots, a_n

Output: Sorted sequence, $a_{i_1} \leq a_{i_2} \leq \dots \leq a_{i_n}$

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- ▶ Permutation Sort (aka bogosort, stupid sort)
 1. permutation-sort(A):
 2. — for B in permutations(A):
 3. — — if is-sorted(B):
 4. — — — return B

Permutation Sort Implementations

Input: 9 4 3 2 7 5 6 1 8

Output: 1 2 3 4 5 6 7 8 9

| Sorting algorithm | Permutation sort | Quicksort |
|-------------------|------------------|-------------|
| C | 0.009065 | 0.000006 |
| C++ | 0.0235205 | 0.000169816 |
| Python | 0.082750 | 0.000028 |
| Rust | 0.064399 | 0.000007 |
| Lisp | 1.802514 | 0.000073 |

Permutation Sort Implementations

Input: 5 4 2 87 1 56 83 17 9 40 25 31

Output: 1 2 4 5 9 17 25 31 40 56 83 87

| Programming language | Permutation sort (s) | Quicksort (s) |
|----------------------|----------------------|---------------|
| C | 3.275384 | 0.000006 |
| C++ | 12.2483 | 0.000215155 |
| Python | 51.157933 | 0.000020 |
| Rust | 33.138026 | 0.000009 |
| Lisp | 1140.0839 | 0.000101 |

Need for Abstraction

The time to run the programs changes depending on

- ▶ the programming language, viz., C, C++, Python, Rust, Lisp, etc.
- ▶ the underlying hardware

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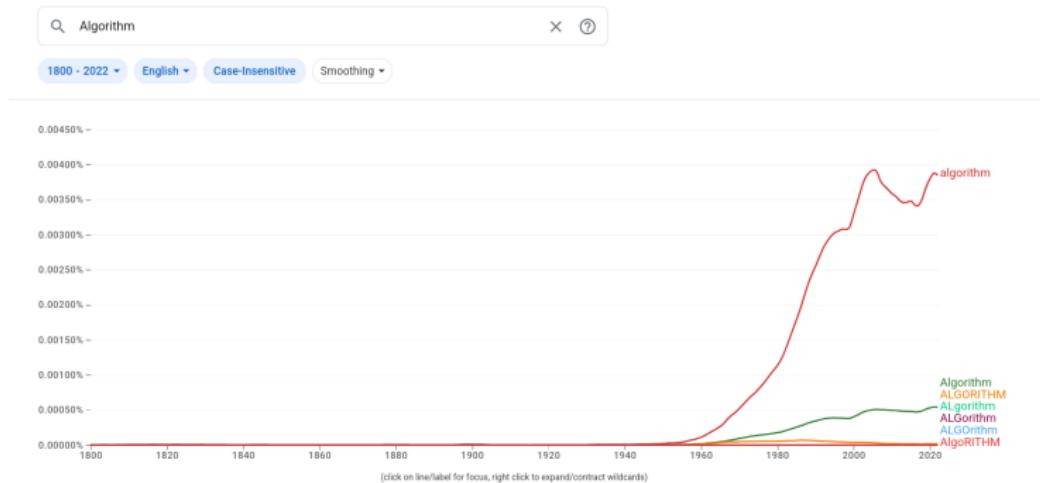
- ▶ the programming language, viz., C, C++, Python, Rust, Lisp, etc.
- ▶ the underlying hardware

A sequence of instructions which is independent of the programming language and the hardware.

Algorithm

► History and Etymology

Google Books Ngram Viewer



Algorithm and Al-Khwarizmi

The Persian polymath Muhammad ibn Musa al-Khwarizmi (c. 780–850) gave us not one, but two fundamental mathematical terms:

1. **Algorithm** — derived from the Latinized form of his name (**Algoritmi/Algorismi** from Arabic **al-Khwarizmi**, meaning "the native of Khwarazm"). In medieval Europe, **algorismus** referred to calculation using Hindu–Arabic numerals, popularized through Latin translations of his arithmetic text.
2. **Algebra** — derived from the Arabic word **al-jabr** (meaning "restoration" or "completion"), which appears in the title of his most famous work.

Properties of Algorithms

Input

Output

Finiteness

Definiteness

Does a prompt to ChatGPT qualify as an algorithm?

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Sort these numbers: 5 4 2 87 1 56 83 17 9 40 25 31

Sorted in ascending order: 1 2 4 5 9 17 25 31 40 56 83 87

⌚ ⚡ ⚡ ⚡ ⚡ ...

Program \leftrightarrow Algorithm

- ▶ Erik Demaine's analogy between the program pyramid and the algorithm pyramid

| Program | Algorithm |
|----------------------|---------------------------------|
| Programming language | Pseudocode / Structured English |
| Computer | Model of Computation |

What is a model of computation?

- ▶ Random Access Machine (RAM) model
 - ▶ Primitive (constant-time) operations: add, subtract, multiply, and integer/floating-point operations.
 - ▶ Can there be a constant time sorting operation inbuilt in the hardware?
- ▶ Other models of computation
 - ▶ Parallel RAMs, Quantum Computers, Turing Machines

What is a computational problem?

- ▶ A relation on the inputs and outputs
 - ▶ [Sorting] A sequence of numbers as the input and its sorted sequence as the output
 - ▶ [Shortest Path] A graph with a source and a target vertex as input and the shortest path between them as the output
 - ▶ [Finding Minimum] A set of numbers as input and the minimum number in the set as the output
 - ▶ [Searching] A set of elements and a query element as the input and a yes/no answer as an output

A specific algorithm: Insertion Sort

- ▶ Proof of correctness
 - ▶ Loop Invariant (Proof by Induction)
 - ▶ Initialization (Base step)
 - ▶ Maintenance (Inductive hypothesis)
 - ▶ Termination (Desired statement)
- ▶ Time complexity
 - ▶ Count the steps