

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

Algorithm

► History and Etymology

Google Books Ngram Viewer

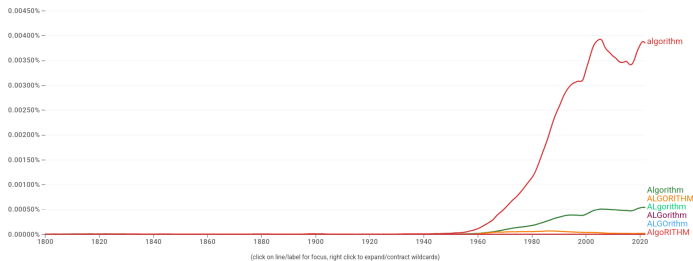
Algorithm

1800 - 2022

English

Case-Insensitive

Smoothing



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

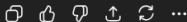
Definiteness

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