

# 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

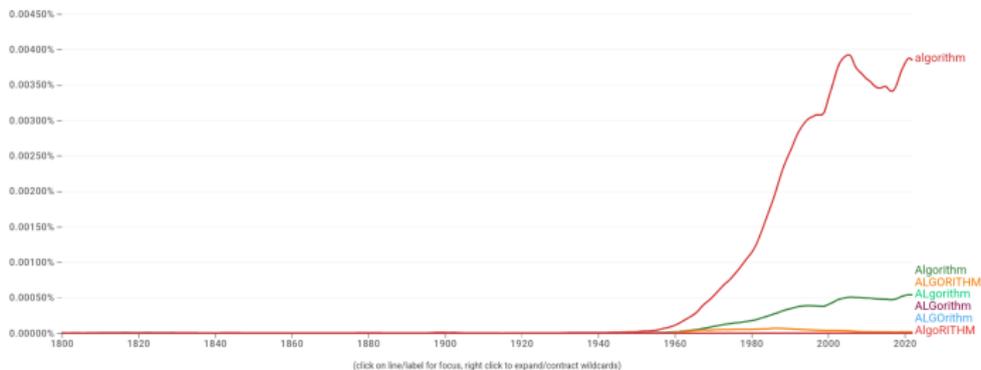
Algorithm

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?

# Does a prompt to ChatGPT qualify as an algorithm?

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