Informatics 2:
Introduction to Algorithms and Data Structures

Lecture 1: Overview of Course Content

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What are algorithms and data structures?

Informatics 2 – Introduction to Algorithms and Data Structures

Algorithms are basically *methods* or *recipes* for solving various problems. To write a *program* to solve some problem, we first need to know a suitable *algorithm*.

Data structures are ways of storing or representing data that make it easy to manipulate. Again, to write a program that works with certain data, we first need to decide how this data should be stored and structured.

Tasks calling for algorithms

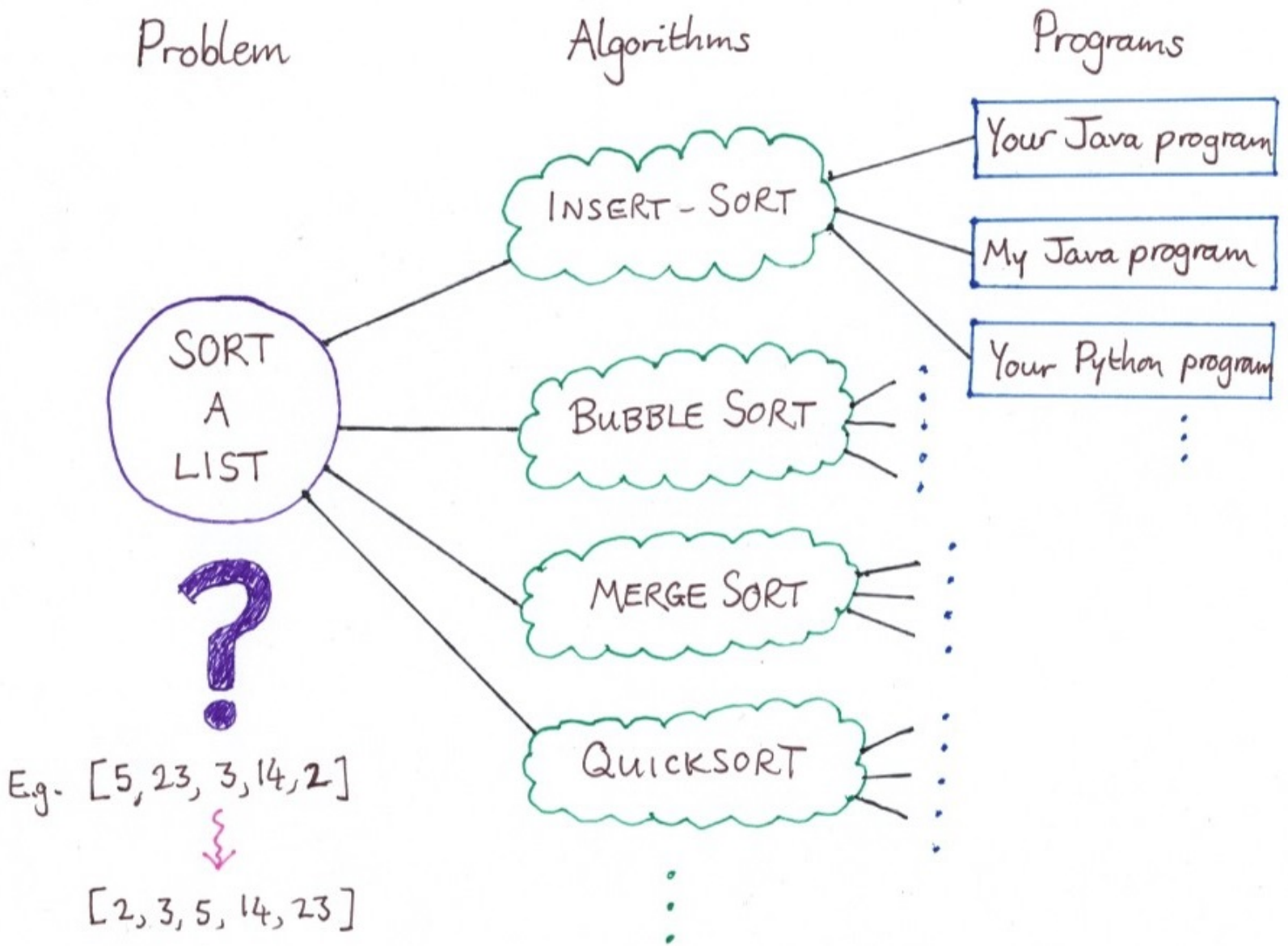
How would you efficiently ...

- Sort 1000000000 names into alphabetical order? (Databases)
- Visit all web pages reachable from a given starting page? (Search engines)
- Find the shortest/fastest/cheapest route from A to B? (SatNav)
- Find the longest substring shared by two (long) strings? (Genetics)
- Tell whether a 100-digit number is prime or not? (Cryptography)

In some cases there's an 'obvious' method.

Often there's a non-obvious method that's much more efficient.

Problems, algorithms, programs



There were algorithms before there were computers

'Algorithms' are so named after Muhammad al-Khwārizmī, a 9th century Persian mathematician who wrote an important book on methods for arithmetic in decimal notation.
(E.g. $+$, $-$, long $\times$, long $/$, $\sqrt{\ }$.)

Even earlier, there was Euclid's *greatest common divisor* algorithm:

$$\begin{aligned}\text{GCD}\,(4851, 840) &= \text{GCD}\,(840, 651) = \text{GCD}\,(651, 189)\\ &= \text{GCD}\,(189, 84) = \text{GCD}\,(84, 21) = 21.\end{aligned}$$

But now that we have computers, algorithms are everywhere!

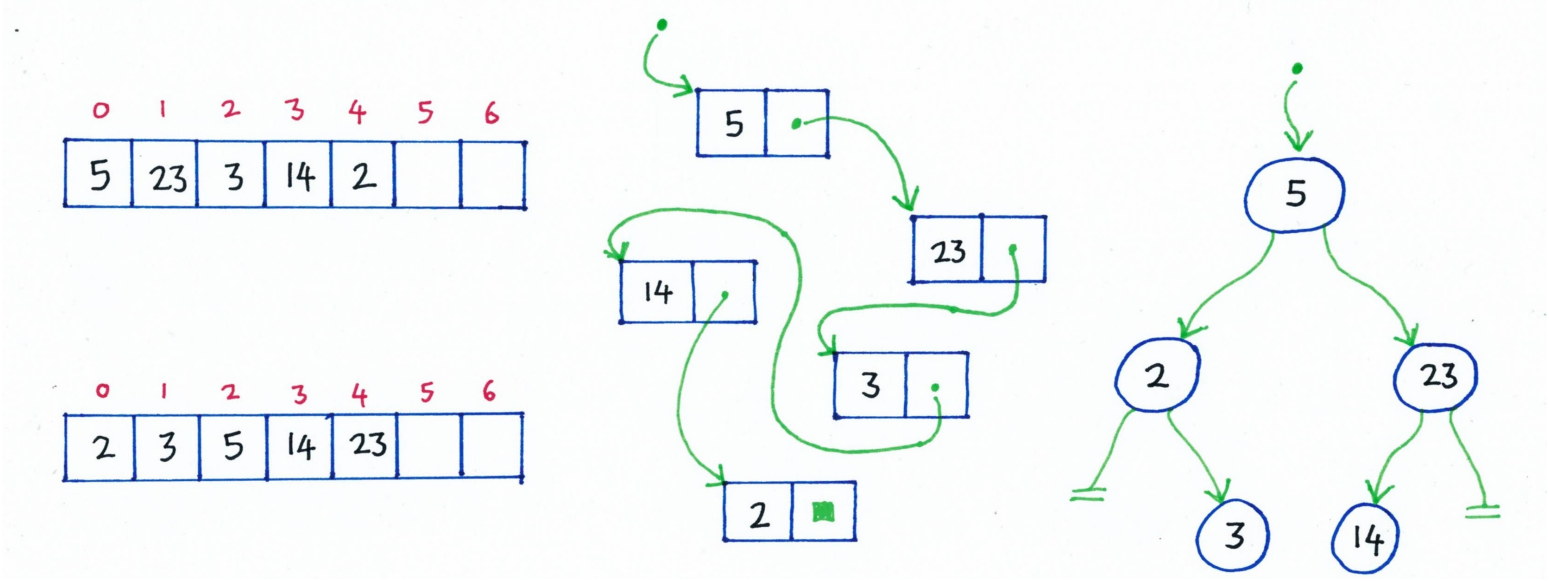
Quiz question

Which of the following is not a true statement about algorithms?

1. Typically, the same algorithm can be implemented in many different programming languages.
2. Some old algorithms are still considered to be very efficient.
3. Some algorithms work OK on small examples, but don't scale up to larger ones.
4. In order to design an *algorithm* for tackling some problem, you first need to write a *program* that solves it.

Data structures

How might you store a set of numbers (e.g. $\{5, 23, 3, 14, 2\}$) in a computer? In an array (sorted or not)? As a linked list? As a tree?



Which of these make it easy . . .

- To test whether a given number (e.g. 11) is in the set?
- To add or remove a member of the set?

Our choice of data structure may depend on which of these operations are most important for us.

What makes computers go faster?

Combination of . . .

- Hardware technology (e.g. processor speeds)
- Parallel processing (doing several things at once)
- Compiler techniques (e.g. optimization of machine code)
- Advances in algorithms / data structures.

In this sense, algorithms / data structures are a technology.

E.g. what's behind the current 'ChatGPT explosion'?

- 1980s-90s: Key Machine Learning algorithms using Recurrent Neural Networks — but hardware not yet fast enough to use them at scale.
- 2000s: As hardware improves, these algorithms take the lead in language processing tasks.
- 2017: Another algorithmic breakthrough: RNNs replaced by 'Transformers'. Takes AI / Machine Learning to the next level.

(Covered in later year courses in Machine Learning etc.)

Algorithms: other recent progress

- 2017: Major breakthrough in minwise hashing problem from 1997. Led to order-of-magnitude improvement in *near-duplicate detection* in search engines (Wang/Wang/Shrivastava/Ryu).
- 2018: Ideas from adaptive sampling give exponential speed-up on many optimization problems: e.g. *taxi dispatch* (Singer/Balkanski).
- 2022: Powersort replaces Timsort as Python's sorting algorithm. Draws on algorithmic work from 1977 on binary search trees (Mehlhorn).

Rough outline of course

- Simple examples of faster/slower algorithms.
- How can we measure how 'good' an algorithm is? Approach via asymptotic analysis.
- Sorting algorithms: InsertSort, MergeSort, QuickSort, ...
- Basic data structures: Ways of implementing lists, stacks, queues, sets, dictionaries, ...
- Algorithms on graphs: depth-first and breadth-first search, topological sorting, shortest paths.
- Dynamic programming: A way to avoid repeating work. Applications, e.g. seam carving for images.
- Algorithms/data structures for language processing (e.g. of Java or Python source code). Grammars, syntax, parsing.
- What are the limits of algorithms and computation? Glance at complexity theory (intractable problems, P vs. NP) and computability theory (unsolvable problems, Turing machines, halting problem).

Programming thread: Python

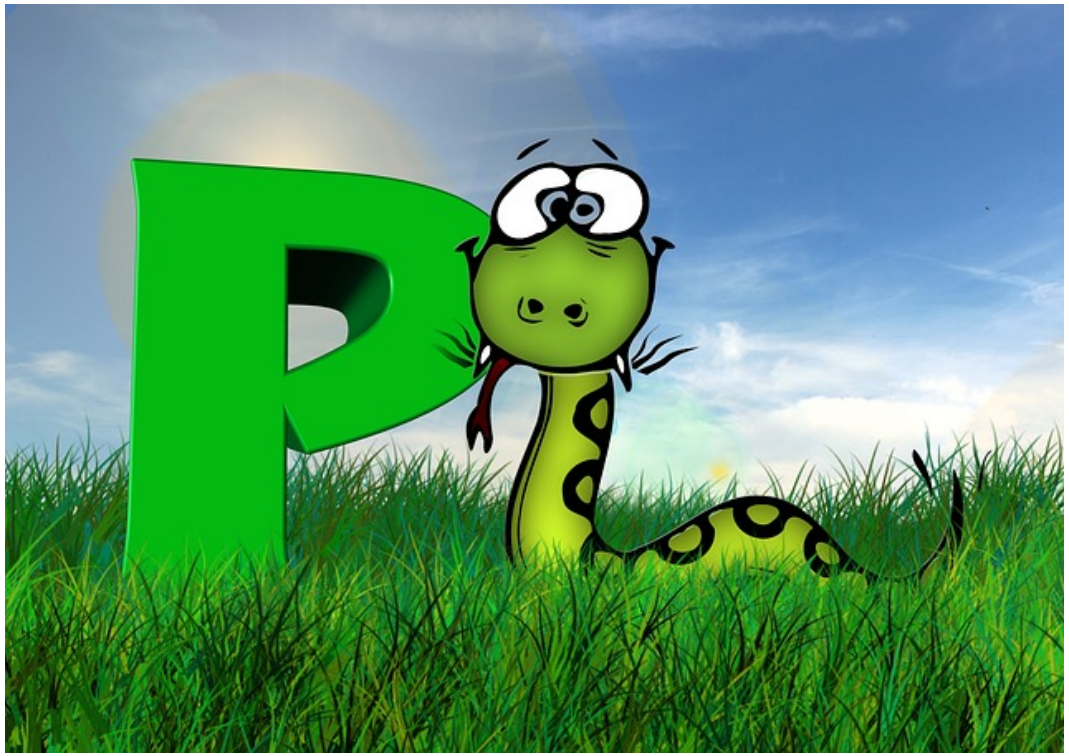
The course will emphasize the relevance of algorithms/data structures to practical programming.

We'll be using Python as our programming language. (Used in many later-year courses).

Python lab sheets tie in closely with lecture material. These are to work through at your own speed, and contain practical exercises for your own use (not submitted or marked).

The first coursework (at least) will involve Python programming.

ENJOY THE COURSE!



Reading for this lecture: Algorithms Illuminated (Preface, 1.1, 10.1); CLRS (Chapter 1).