

Advanced Algorithms

Master's degree in Computer Science

University of Padova

Motivation

Look around you. Computers and networks are everywhere, enabling an intricate web of complex human activities: education, commerce, entertainment, research, manufacturing, health management, human communication, even war. Of the two main technological underpinnings of this amazing proliferation, one is obvious: the breathtaking pace with which advances in microelectronics and chip design have been bringing us faster and faster hardware.

This book tells the story of the other intellectual enterprise that is crucially fueling the computer revolution: efficient algorithms. It is a fascinating story.

—Dasgupta, Papadimitriou, and Vazirani: *Algorithms*

Motivation (continued)

Not so long ago, anyone who had heard the word “algorithm” was almost certainly a computer scientist or mathematician. With computers having become prevalent in our modern lives, however, the term is no longer esoteric. If you look around your home, you’ll find algorithms running in the most mundane places: your microwave oven, your washing machine, and, of course, your computer. [...] The word “algorithm” appears somewhere in the news seemingly every day.

Therefore, it behooves you to understand algorithms not just as a student or practitioner of computer science, but as a citizen of the world.

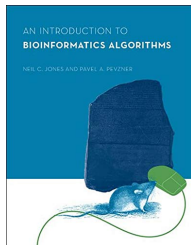
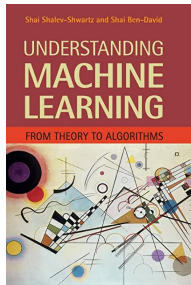
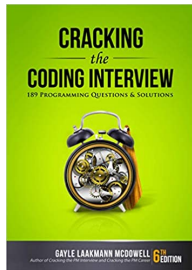
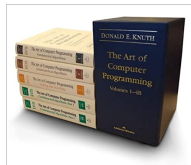
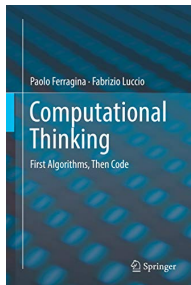
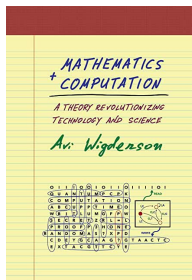
—Cormen, Leiserson, Rivest, and Stein: *Introduction to Algorithms*

Motivation (continued)

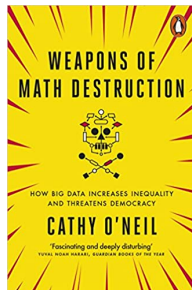
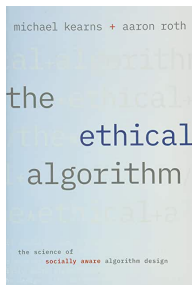
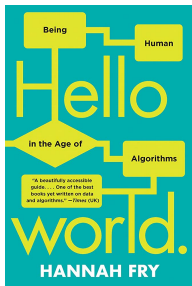
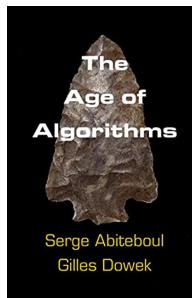
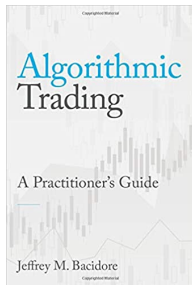
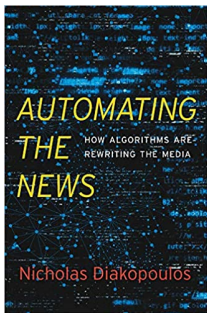
Algorithms are the heart and soul of computer science. Their applications range from network routing and computational genomics to public-key cryptography and machine learning. Studying algorithms can make you a better programmer, a clearer thinker, and a master of technical interviews.

—Tim Roughgarden, Columbia University

Motivation (continued)



Motivation (continued)



Motivation (continued)

...and that's why Advanced Algorithms is **mandatory**. Hence, you should give it the highest priority in this semester!

Contents

① Graph algorithms

- Graph search and its applications, minimum spanning trees, shortest paths, maximum flows

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③ Randomized algorithms

- Main techniques (e.g., Chernoff bounds) and applications to problems such as sorting and minimum cuts

Goals

You'll learn how to:

- Design and analyze algorithms for complex domains such as graphs
- Recognize NP-hard problems and address them using approximation algorithms
- Use the power of randomness to design fast algorithms for complex problems, and analyze them
- Analyze algorithms with respect to correctness and efficiency
- Formulate real-life problems as algorithmic problems and solve them

Prerequisites

Although there are no formal prerequisites, an undergraduate course in algorithms and a good knowledge of (discrete) probability are assumed. Specifically, you should be familiar with:

- Algorithm design techniques: divide and conquer, greedy, dynamic programming
- Data structures: lists, stacks, queues, binary trees, search trees, heaps
- Probability: basic notions, discrete random variables

Course Style

We'll discuss the intuition behind formulating an algorithmic solution and distill the core ideas that make the algorithm work. However, we'll never sacrifice rigorousness.

When you write an algorithm you need to have a proof that it's correct; an algorithm without a proof is a conjecture, it's not a theorem. And if you are proving things, well, that means mathematics.¹

—Laslie Lamport, Turing Award 2013

¹<https://www.youtube.com/watch?v=rkZzg7Vowao>

Course Style (continued)

INEFFECTIVE SORTS

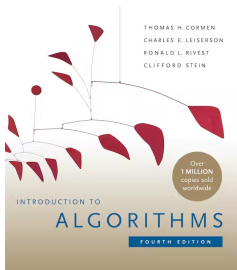
```
DEFINE HALFHEARTEDMERGESORT(LIST):  
  IF LENGTH(LIST) < 2:  
    RETURN LIST  
  PIVOT = INT(LENGTH(LIST) / 2)  
  A = HALFHEARTEDMERGESORT(LIST[:PIVOT])  
  B = HALFHEARTEDMERGESORT(LIST[PIVOT:J])  
  // UMMMMMM  
  RETURN[A, B] // HERE. SORRY.
```

```
DEFINE FASTBOGOSORT(LIST):  
  // AN OPTIMIZED BOGOSORT  
  // RUNS IN  $O(N \log N)$   
  FOR N FROM 1 TO LOG(LENGTH(LIST)):  
    SHUFFLE(LIST):  
    IF ISSORTED(LIST):  
      RETURN LIST  
  RETURN "KERNEL PAGE FAULT (ERROR CODE: 2)"
```

```
DEFINE JOBININTERVIEWQUICKSORT(LIST):  
  OK SO YOU CHOOSE A PIVOT  
  THEN DIVIDE THE LIST IN HALF  
  FOR EACH HALF:  
    CHECK TO SEE IF IT'S SORTED  
    NO, WAIT, IT DOESN'T MATTER  
    COMPARE EACH ELEMENT TO THE PIVOT  
    THE BIGGER ONES GO IN A NEW LIST  
    THE EQUAL ONES GO INTO, UH  
    THE SECOND LIST FROM BEFORE  
  HANG ON, LET ME NAME THE LISTS  
  THIS IS LIST A  
  THE NEW ONE IS LIST B  
  PUT THE BIG ONES INTO LIST B  
  NOW TAKE THE SECOND LIST  
  CALL IT LIST, UH, A2  
  WHICH ONE WAS THE PIVOT IN?  
  SCRATCH ALL THAT  
  IT JUST RECURSIVELY CALLS ITSELF  
  UNTIL BOTH LISTS ARE EMPTY  
  RIGHT?  
  NOT EMPTY, BUT YOU KNOW WHAT I MEAN  
  AM I ALLOWED TO USE THE STANDARD LIBRARIES?
```

```
DEFINE PANICSORT(LIST):  
  IF ISSORTED(LIST):  
    RETURN LIST  
  FOR N FROM 1 TO 10000:  
    PIVOT = RANDOM(0, LENGTH(LIST))  
    LIST = LIST[PIVOT:J] + LIST[:PIVOT]  
    IF ISSORTED(LIST):  
      RETURN LIST  
  IF ISSORTED(LIST):  
    RETURN LIST  
  IF ISSORTED(LIST): // THIS CAN'T BE HAPPENING  
    RETURN LIST  
  IF ISSORTED(LIST): // COME ON COME ON  
    RETURN LIST  
  // OH JEEZ  
  // I'M GONNA BE IN SO MUCH TROUBLE  
  LIST = []  
  SYSTEM("SHUTDOWN -H +5")  
  SYSTEM("RM -RF ./")  
  SYSTEM("RM -RF ~/*")  
  SYSTEM("RM -RF /")  
  SYSTEM("RD /S /Q C:\*") // PORTABILITY  
  RETURN [1, 2, 3, 4, 5]
```

Textbooks

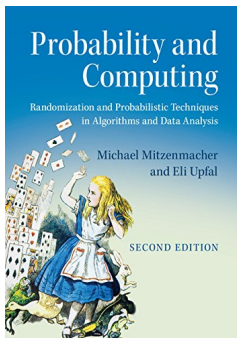


Cormen, Leiserson, Rivest, and Stein
Introduction to Algorithms

4th edition

MIT Press, 2022

- The leading algorithms textbook
- 1.000.000+ copies sold worldwide
- Translated into more than a dozen languages



Mitzenmacher and Upfal
Probability and Computing

2nd edition

Cambridge University Press, 2017

- Standard reference for randomized algorithms and probabilistic analysis

Lecture Time & Place

24 lectures:

- Mondays 12:30–14:10, room 1A150
- Thursdays 12:30–14:10, room 1A150

Moodle

The only source of course information. You'll find:

- Announcements
- Log of lectures
- Lecture notes
- Examples of exam exercises
- Further readings

Exam

Written test, 2 hours. It comprises:

- 2-3 theory questions: questions on the topics presented in class
- 2 problems: exercises aimed at verifying the student's ability to use notions learned during the course to solve new problems

Instructor

Michele Scquizzato

- <https://www.math.unipd.it/~scquizza/>
- scquizza@math.unipd.it
- Room 4BC2, 4th floor
- Office hours: by appointment
- Research area: algorithms