Algorithms and Data Structures 2
CS 1501

Fall 2022

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(Slides are adapted from Dr. Ramirez's and Dr. Farnan's CS1501 slides.)

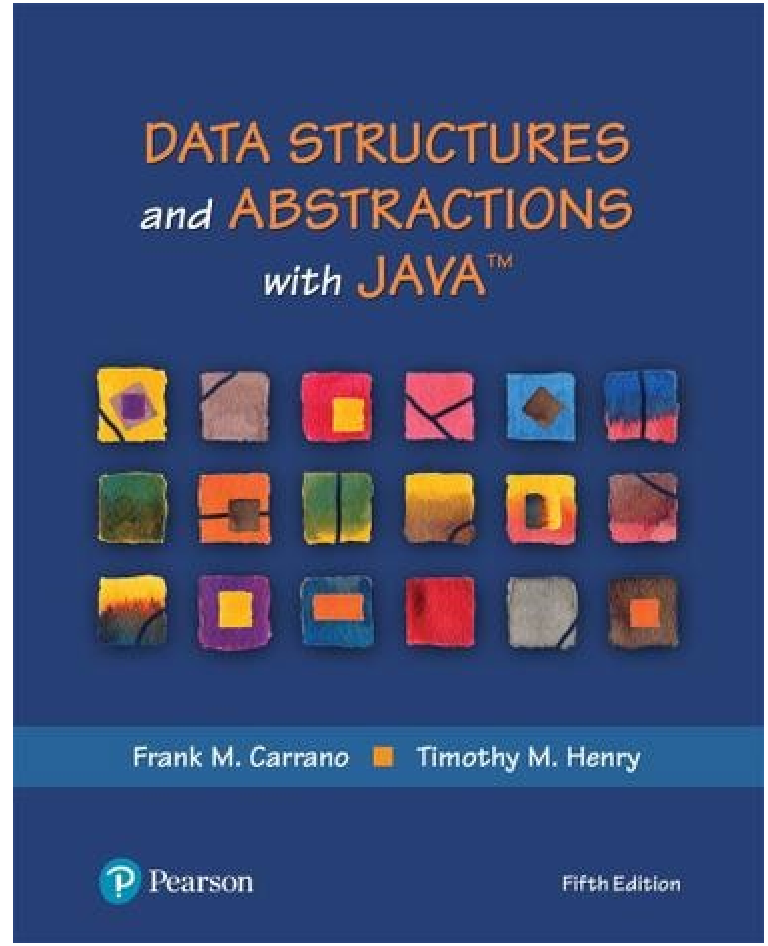
Contact Info

- **Course website:** http://www.cs.pitt.edu/~skhattab/cs1501/
- **Instructor:** Sherif Khattab ksm73@pitt.edu
- **My Student Support Hours:** https://khattab.youcanbook.me
  - MW: 10:00-12:00; TuTh: 13:00-15:00; F by appointment
  - 6307 Sennott Square, Virtual Office: https://pitt.zoom.us/my/khattab
  - Please schedule at: https://khattab.youcanbook.me/
- **Teaching Team:**
  - Junshang Jia, juj22@pitt.edu
  - Christofer Hinson, chh183@pitt.edu
  - Connor Sweeney, cps43@pitt.edu
  - More TAs to come
- No recitations this week, but you got some work to do!
- **Communication**

  Piazza (**Please expect a response within 72 hours)**

  Email not recommended!

Textbooks



Algorithms (4th Edition)

Robert Sedgewick and Kevin Wayne

Online Resources: https://algs4.cs.princeton.edu/

Data Structures and Abstractions with Java (5th Edition)

Frank M. Carrano and Timothy M. Henry

Grades

- 40% on best four out of five programming assignments; mostly autograded
  - posted on Canvas, distributed using Github, and submitted on **Gradescope** from Github
- 20% on homework assignments on Gradescope
- 20% on exams: 12% on higher grade and 8% on lower
- 10% on lab exercises; mostly autograded
- 10% on in-class Top Hat questions

Canvas Walkthrough

- Lectures posted on Tophat
  - Draft slides available on Github
- Lecture and recitation recordings
  - under Panopto Video
- RedShelf Inclusive Access for the Sedgewick Textbook
  - You can cancel before Add/Drop
- Piazza for discussion and communication
- Gradescope and autograding policies
- Academic Integrity
- NameCoach

Expectations

- Your continuous feedback is important!
  - Anonymous Qualtrics survey
  - Midterm and Final OMET
- Your engagement is valued and expected with
  - classmates
  - teaching team
  - material

Lecture structure (mostly)

Time	Description
~5 min before and after class	Informal chat
~25 min	Announcements, review of muddiest points on previous lecture, and QA on assignments/labs/homework problems
~45 min	Lecturing with Tophat questions and/or activities
~5 minutes	QA and muddiest points/reflections

Why is this class (notoriously) hard?

- Lots of concepts
  - Attend lectures and recitations (if you absolutely cannot attend, watch the video recordings)
  - Study often!
  - Put effort into the weekly homework assignments
- Programming Assignments are relatively hard
  - Refresh your Java programming (CS 0445) and **debugging skills**
  - Start early and show up to student support hours!

Goals of the course

- To convert non-trivial *algorithms* and data structures into *programs*
  - Various issues will always pop-up during *implementation*
    - Such as?...
- To analyze algorithms and how they affect the run-times of the associated programs
  - Different solutions can be compared using many metrics

Announcements

- Lab 0 is due this Friday (not graded)
- Recitations start next week
- Homework 1 will be assigned this Friday
- JDB Example will be available on Canvas
- Draft slides and handouts available on Canvas

Today's Agenda

- A technique for modeling runtime of algorithms
  - $\sum_{all\ statements} Cost * frequency$
- Determining the order of growth of a function
  - Ignoring lower-order terms and multiplicative constants
  - The Big O family

Let's consider the ThreeSum problem

- 3-sum Problem
  - Given a set of arbitrary integers find out how many **distinct** triples sum to exactly zero
  - do you have questions on the problem specification?
- Example input:
  - 5, -1, 2, -3, -2, 1, 0
  - what should the output be?

Brute-force solution

Enumerate all possible distinct triples and check their sums

```
cnt = 0
for each distinct triple
    if sum of triple equals zero
        increment cnt
```

- How would you enumerate all distinct triples?
- What if all the input integers are unique?

Brute-force solution

```
public static int count(int[] a) {
    int n = a.length;
    int cnt = 0;
    for (int i = 0; i < n; i++) {
        for (int j = i+1; j < n; j++) {
            for (int k = j+1; k < n; k++) {
                if (a[i] + a[j] + a[k] == 0) {
                    cnt++;
                }
            }
        }
    }
    return cnt;
}
```

- Why is it correct to start the j loop from i+1?
  - Would we miss a triple if we do so?
  - Is it correct to start the j loop from 0?

ThreeSum: brute-force, 3-loop solution

```
public static int count(int[] a) {
    int n = a.length;
    int cnt = 0;
    for (int i = 0; i < n; i++) {
        for (int j = i+1; j < n; j++) {
            for (int k = j+1; k < n; k++) {
                if (a[i] + a[j] + a[k] == 0) {
                    cnt++;
                }
            }
        }
    }
    return cnt;
}
```

Would that solution be correct if the input integers are not distinct?

Mathematically modelling runtime

- Runtime primarily determined by two factors:
  - **Cost** of executing each statement
    - Determined by machine used, environment running on the machine, etc.
  - **Frequency** of execution of each statement
    - Determined by program and input

What is the runtime?

A technique for modeling runtime of algorithms

- $\sum_{all\ statements} Cost * frequency$

- Split the algorithm into blocks such that
  - the code statements in each block have the same frequency
- $\sum_{all\ blocks} Cost * frequency$

Algorithm Analysis Example 1

$$\text{for}\,(\overset{1}{\boxed{i=0}};\ \overset{n+1}{\boxed{i<n}};\ \overset{n}{i{+}{+}})$$

$$a[i] = i;$$

Algorithm Analysis Example 2

1

0 or 1

0 or n

```
if( x >0 ){
  for( i=0 ; i<n ; i++ )
    a[i] = i;
```

Algorithm Analysis Example 3

1

```
for (i = n; i >= 1; i = i/2)
    a[i] = i;
```

log n

A faster algorithm for 3-sum

- What if we sorted the array first?
  - Pick two numbers, then binary search for the third one that will make a sum of zero
    - e.g., a[i] = 10, a[j] = -7, binary search for -3
    - Still have two for-loops, but we replace the third with a binary search
      - Runtime now?

$$\underbrace{n^2}_{\text{all pairs}} \underbrace{\log n}_{\text{Binary Search}} + \cancel{\underbrace{n \log n}_{\text{Sorting}}}$$

    - What if the input data isn't sorted?
  - What about the sorting time?

The 3-sum problem: can we do better?

- There is an O(n^2) algorithm
- There is also an O(n log n) algorithm under special cases
- **Unsolved problem**: Is there an O($n^{2-\varepsilon}$) algorithm for some $\varepsilon > 0$?