CMSC 420 – 0201 – Fall 2019
Lecture 01

Course Introduction & Background

CMSC 420 – Course Overview

- Fundamental data structures and the algorithms for building and maintaining them
- Mathematical methods for analyzing their efficiencies
- Applications and implementation
- See the course syllabus:

  http://www.cs.umd.edu/class/fall2019/cmsc420-0201/syllabus.html

Elements of Data Structures

- How to store, access, and manipulate data
- Fundamental to Computer Science

Examples:

Information Retrieval: Web search, forensic search, image search

Geographic Information Systems: Proximity searching (How many people live within 25 miles of the Mississippi river?)

Text/String Search: Symbol tables in a compiler, document search

Networking: Shortest paths/distances in a graph

Computer Graphics/VR: Visibility culling – What can be seen from a given vantage point?

Elements of Data Structures

- Basic aspects of a data structure:
  - Modeling: How real-world objects presented as abstract mathematical entities
  - Operations: The allowed functions to store, access, and manipulate these entities and their formal meanings
  - Representation: Concrete representations in memory (e.g., array vs. linked list)
  - Algorithms: Computational approaches to execute these operations
- What we will teach:
  - Tools: Common techniques in the design of data structures
  - Design principles: Methods that can be widely applied in data structure design
  - Overall: How to design data structures, how to implement these designs, and how to evaluate them

Two Angles Towards a Common Goal

- Theoretical:
  - Mathematical description of the resources needed by a data structure
  - Criteria:
    - Query time
    - Construction time
    - Update time
    - Memory requirements (and possible tradeoffs with query time)
- Practical/Empirical:
  - Ease of implementation
  - Efficiency on actual data sets

Review: Asymptotic Analysis

- Principles of Asymptotic Analysis:
  - Running time as function of basic parameters (input size, number of vertices/edge in a graph, basic properties of the input set, dimension of the space)
  - Worst-case or average-case?
    - Worst-case: Maximum running time for a given input size
    - Average-case: Expected running time over a given probability distribution of inputs
    - Randomized: When algorithms use randomization, it is common to express running time in the worst-case over inputs, but in the expected-case over randomized choices
    - Amortized: Running time averaged over a long sequence of operations
- Asymptotic notation ("big-O") to focus on growth rate:

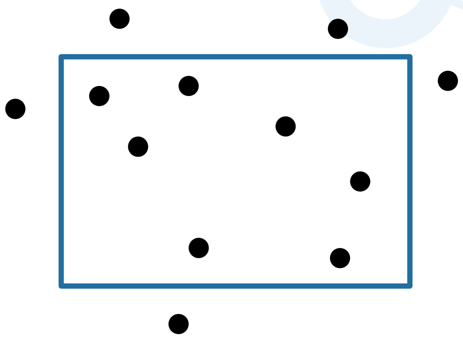
$$T(n) = 22n^2 + 7n \log n + 5n^3 = O(n^3)$$

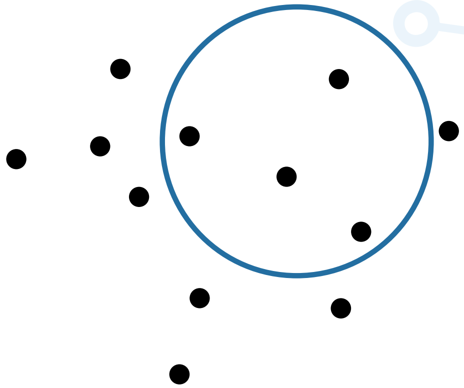
Review: Asymptotic Analysis

- Examples:
  - $O(1)$ (Constant time): Can’t beat this!
    - Examples: Stack push/pop, hashing (expected case)
  - $O(\alpha(n))$ (Inverse of Ackermann’s function):
    - Insanely slow-growing, but not constant. $\alpha(n) \leq 5$ if $n \leq$ number of atoms in universe
    - Example: Disjoint-set union/find (used in Kruskal’s MST algorithm)
  - $O(\log\log n)$
    - Example: Van Emde Boas Trees - For storing small integers
  - $O(\log n)$ (Logarithmic time): “Gold standard” for comparison-based structures
    - Examples: AVL tree, Red-Black tree, 2-3 tree, …

Review: Asymptotic Analysis

- More Examples:
  - $O((\log n)^c)$ (Polylogarithmic time):
    - Example: Orthogonal range searching in 3-dimensions and higher
  - $O(n^p)$, where $0 < p < 1$(Sublinear polynomial time):
    - Examples: Nearest neighbor searching, spherical range searching
  - $O(n)$ (Linear time)
  - $O(n \log n)$
    - Standard for any algorithm based on comparison-based sorting
  - $O(n^p)$, where p is any constant (Polynomial time)
  - $O(p^n)$, where $p > 1$ is any constant (Exponential time)





Summary

- Course Overview
- Basic elements of Data Structure Design
- Review of Asymptotic Analysis