VE281

Data Structures and Algorithms

Introduction and Asymptotic Algorithm Analysis

Time and Location

- Time: Monday 2:00-3:40 pm, Wednesday 4:00-5:40 pm, and Friday (even week) 2:00-3:40 pm

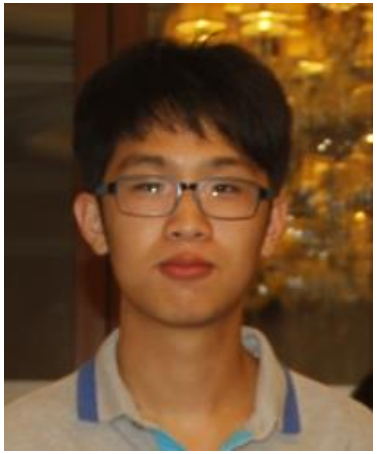
- Location: Dong Xia Yuan 100

Instructor

- Weikang Qian
- Email: qianwk@sjtu.edu.cn
- Phone: 3420-4020
- Office: Room 421, JI Building
- Office hour
  - Monday 1:00 – 2:00 pm
  - Wednesday 1:00 – 2:00 pm
  - Or *by appointment*

Teaching Assistants

- Zhou, Hongkuan
  - Email: tedzhouhk@163.com
  - Cell phone: 15021382379



- Tao, Xuyang
  - Email: tao_xuyang@163.com
  - Cell phone: 13122212391

Textbooks for Reference (Not Required)

- "Data Structures and Algorithm Analysis," by Clifford Shaffer. Online available: http://people.cs.vt.edu/~shaffer/Book/C++3e20120605.pdf
- "Data Structures and Algorithms with Object-Oriented Design Patterns in C++," by Bruno Preiss. Online available: http://www.brpreiss.com/books/opus4/html/book.html
- "Algorithms," by S. Dasgupta, C. Papadimitriou, and U. Vazirani.
- "Introduction to Algorithms, 3rd edition," by Thomas Cormen et al., MIT Press, 2009.

Grading

- Composition
  - In class quiz: 4%
  - ~4 written assignments: 16%
  - ~4 programming assignments: 30%
  - Midterm exam: 20%
  - Final exam: 30%
- We will curve the final grades, if necessary.
- Questions about the grading?
  - Must be mentioned to the instructor or the TAs within one week after receiving the item.

Programming Assignments

- We require you to develop your programs using C++ on **Linux operating systems** with the compiler g++.
- C++11 standard is allowed.
  - Compile with the option –std=c++11
- We will grade your programs in the Linux environment: they must compile and run correctly on this operating system.
- Do experiments on algorithms, e.g., sorting algorithm

Assignment Deadline

- Each written assignment must be turned in before class on each due date.
- Each programming assignment (PA) must be turned in by 11:59 pm on the due date to be accepted for full credit.
  - However, we still allow you to submit your PA within 3 days after the due date, but there is a late penalty.

Hours Late	Scaling Factor
(0, 24]	80 %
(24, 48]	60 %
(48, 72]	40 %

  - No PA will be accepted if it is more than 3 days late!

Assignment Deadline

- In **very occasional** cases, we accept deadline extension request.
  - Contact me, not TAs!
  - **ONLY** be granted for **documented** medical/personal emergencies that could not have been anticipated.
  - **NOT** granted for reasons such as accidental erasure/loss of files and outside conflicting commitments.

Some Suggestions

- Taking notes in class is a good idea.
- Start doing the homework early!
  - Don't wait until the last minute. Numerous lessons before
- Back up your code frequently in case your computer crashes.
  - Consequence: "computer crash" is NOT a reason for late submission!

Exams

- Written exams.
  - Some short questions
  - Some algorithm design problems
- Closed book and closed notes.
- No electronic devices are allowed.
  - These include laptops and cell phones.

Collaboration and Cheating

- You may discuss in oral with your classmates.
- **But** you must do all the assignments yourself.
- Some behaviors that are considered as cheating:
  - Reading another student's answer/code, including keeping a copy of another student's answer/code.
  - Copying another student's answer/code, in whole or in part.
  - Having someone else write part of your assignment.
  - Using test cases of another student.

"**Another student**" includes a student in the current semester or in the previous semester.

Collaboration and Cheating

- The previous lists of behaviors are **deliberate** cheating, but some **unintentional** actions could make you look like cheating. For example,
  - Testing your code with another one's account. Another's code may be overwritten by you. So, we see two identical copies.
  - You use another's computer to upload your code (in some cases like network/computer problems), but upload another's copy.
- We suggest you not to do those "dangerous" things.
  - If due to network/computer problem, you cannot upload, then send your code to TA's by email. By this way, you can double checked the attachment.

Collaboration and Cheating

- In summary, you are wholly responsible for all answers/codes you submit. If you submit a copy of another student's work (or overwrite another student's work), it is considered cheating, **no matter of the reason**!

Collaboration and Cheating

- Any suspect of cheating will be reported to **the Honor Council at JI**.
- For programming assignments, we will run an automated test to check for unusually similar programs. Those that are similar to the extent that they appear to be derived from the same code base - in whole or in part - will be reported to **the Honor Council at JI**.
- The result of confirmed cheating:
  - Reduction of the grade for that assignment to zero, **plus**
  - Reduction of the final grade for the course by one grade point, e.g., B+ → C+

Canvas

- Log into Canvas: https://sjtu-umich.instructure.com

- Check the class webpage on the Canvas regularly for
  - Announcements
  - Slides
  - Assignments

Getting Help

- If you have questions, come to see TAs and instructor during the office hour!
  - We will hardly answer your questions through email, because it is inefficient.

Prerequisite

- Ve280 Programming and Elementary Data Structures
  - Compiling and debugging on Linux operating systems
  - C++ programming, including pointers, arrays, structs, etc.
  - Recursion
  - I/O streams, including file I/O
  - Classes
  - Dynamical memory management
  - Template
  - Linked list, stack, and queue

Prerequisite

- Ve203 Discrete Mathematics
  - Computational complexity analysis
  - Some basic sorting algorithm, e.g., bubble sort, insertion sort, merge sort
  - Divide-and-conquer algorithm, master theorem
  - Graph, graph representation, depth first search, Dijkstra's algorithm (shortest path)

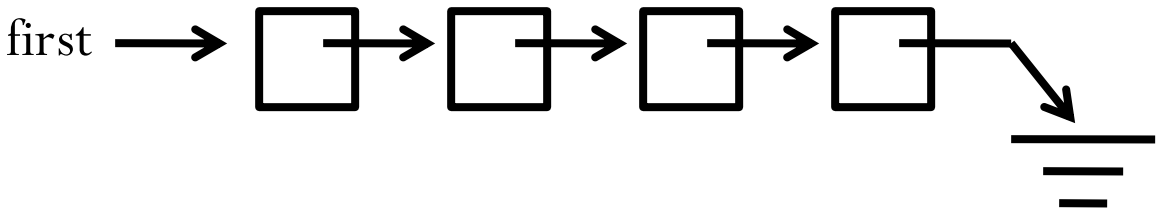
- Some important concepts will be reviewed

References and Copyright

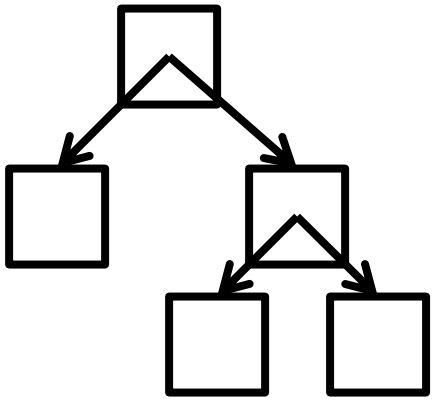
- Slides used (modified when necessary)
  - Sugih Jamin, University of Michigan
  - Sartaj Sahni, University of Florida
  - Bert Huang, Columbia University
  - Tim Roughgarden, Stanford University
  - Clifford Shaffer, Virginia Tech

Data Structures and Algorithms

- Data structure is a particular way of organizing data in a computer so that it can be used efficiently.
  - Example: linked list



- We can store a set of records as a linked list
  - or as a tree (to be talked later).

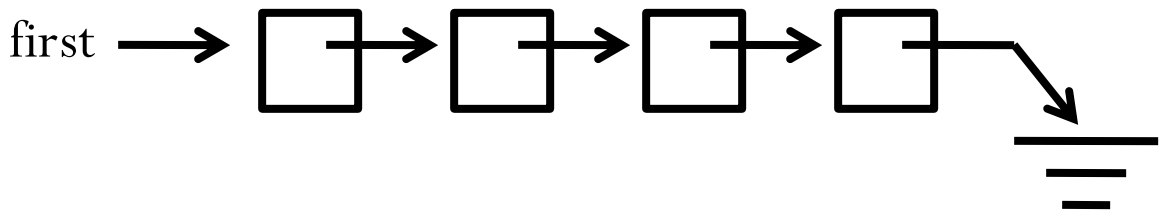


Logical versus Physical Form

- A data structure have both a **logical** and a **physical** form.
- Logical form: definition of the data structure at an abstraction level.
- Physical form: implementation of the data structure.

Data Structure Example: Linked List

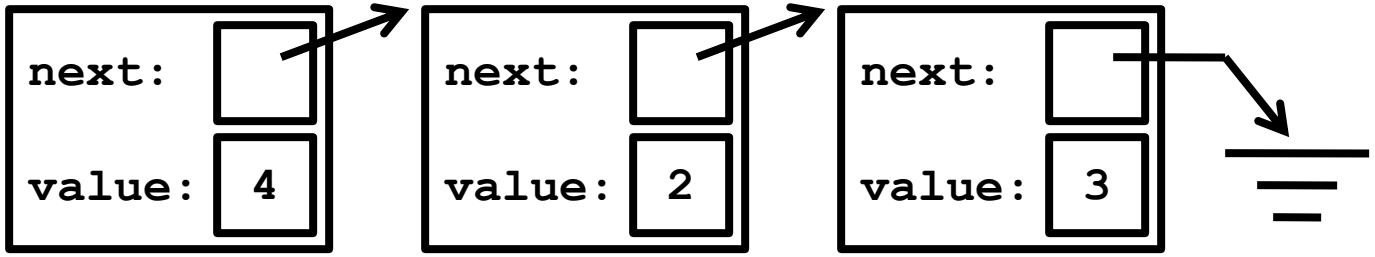
Logical Form



Physical Form

```
class IntList {
  node *first;
 public:
  ...
};
```

```
struct node {
  node *next;
  int   value;
};
```



Data Structures and Algorithms

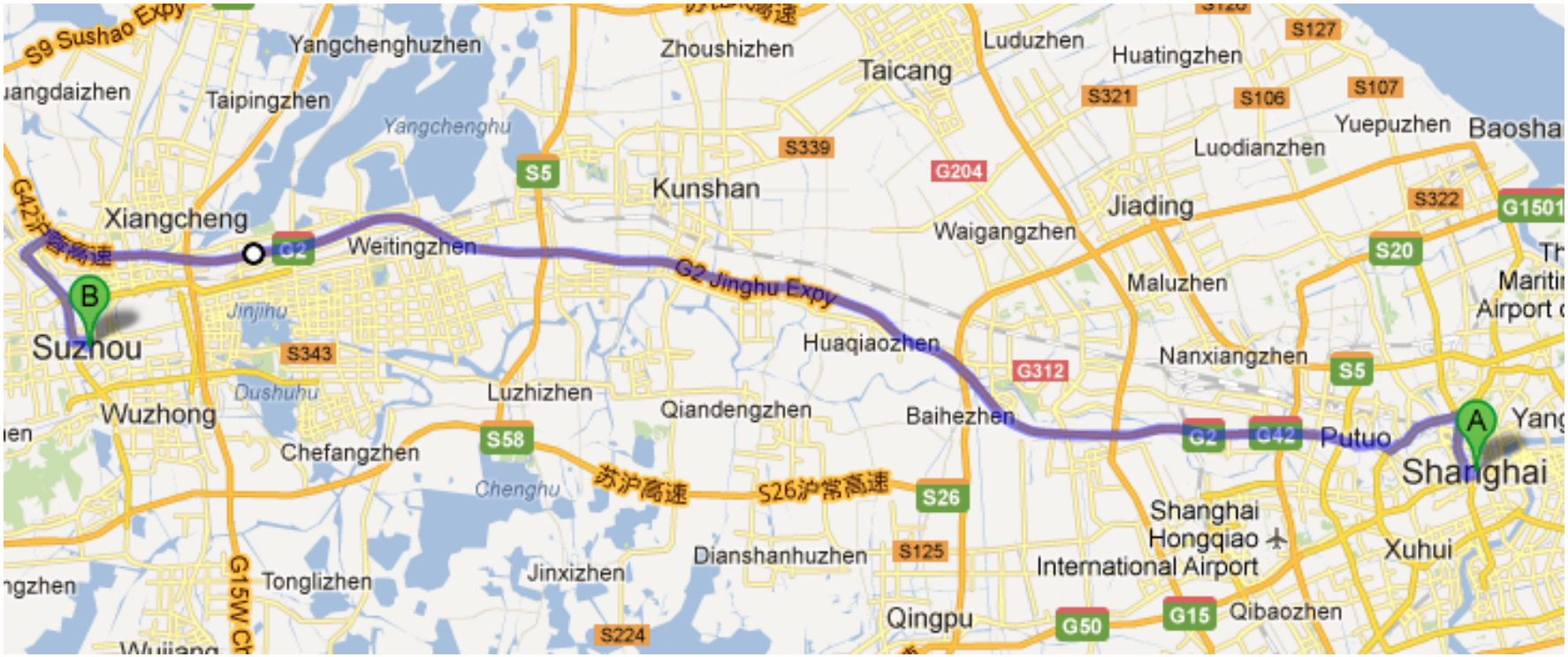
- Data manipulation requires an algorithm – a sequence of steps that solve a specific task.

- Data structures + Algorithms = Programs

- The study of data structures and algorithms is fundamental to Computer Science.
  - Database related to balanced binary search tree.
  - Computer networks related to shortest path algorithm.
  - …

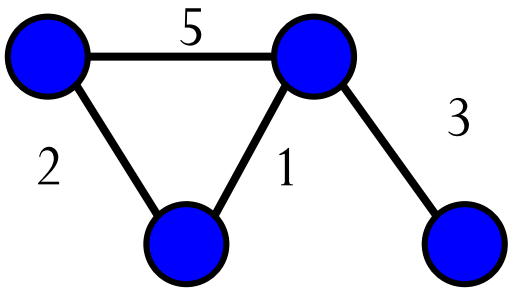
Real World Problem: Navigation

- Finding the shortest route from Shanghai to Suzhou



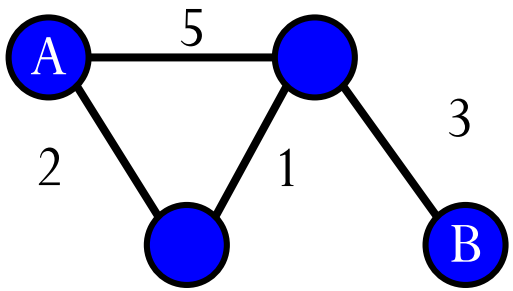
Real World Problem: Navigation

- What information do we need?
  - Streets.
  - Intersections of streets. (We assume that our departure place and destination are at certain intersections.)
- How do we store the information in computer?
  - Graph: consisting of "nodes" and "edges".
  - Each edge has a weight to denote the distance between two nodes.



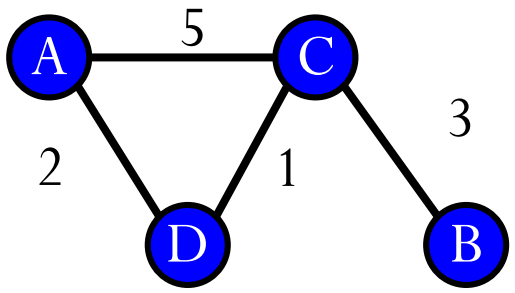
Real World Problem: Navigation

- The algorithm: finding the shortest path from a source node (A) to a sink node (B).



Challenges: Efficiency

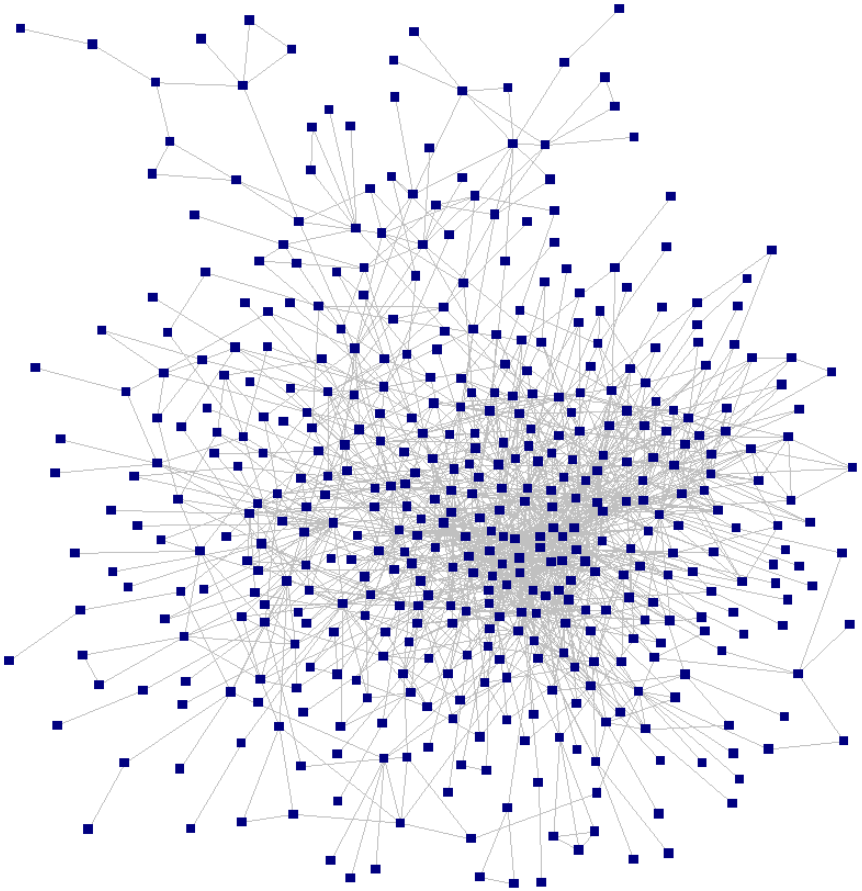
- For a small number of nodes, we can enumerate all the possible paths.



- Path A → C → B: 8;
- Path A → D → C → B: 6;
- The minimum is 6.

Challenges: Efficiency

- However, in real world, the graph is much more complicated.
- It is impossible to enumerate all the possible paths!
- How can we solve the problem?
  - Dijkstra's algorithm



More about Efficiency

- Choice of data structures or algorithms can make the difference between a program running in a few seconds or many days.
- Example: Number of comparisons for **linear search** and **binary search** (Worst Case)

Input Size	Linear	Binary	Ratio (L/B)
64	64	6	10.7
128	128	7	18.3
256	256	8	32
512	512	9	56.9
1024	1024	10	102.4

More about Efficiency

- A solution is said to be efficient if it solves the problem within its resource constraints.
  - Space, i.e. memory consumption
  - Time ✓ **Our major concern**

- The cost of a solution is the amount of resources that the solution consumes.

- We value efficiency of the data structures and algorithms!
- We will learn how to analyze their efficiency.

Course Objectives

- Learn the tool:
  - Common data structures and algorithms
  - And their efficiency

- Apply the tool
  - Solve a problem using existing data structures and algorithms.
  - Choose the right tool: some tools are better for certain tasks than other tools. Do performance analysis.

Topics

- Asymptotic Algorithm Analysis
- Data structures
  - Trees, including binary search tree, balanced binary search tree
  - Hash table
  - Heaps
  - Graphs
- Algorithms
  - Sorting and searching
  - Graph-related algorithms, such as minimum spanning tree, topological sorting
  - Dynamic programming
  - Branch-and-bound

Questions?

Asymptotic Algorithm Analysis

How to Measure Efficiency?

- Empirical comparison: run programs
  - Use the wall-clock time to measure the runtime
  - Empirical comparison could be tricky. It depends on
    - Compiler
    - Machine (CPU speed, memory, etc.)
    - CPU load

- Asymptotic Algorithm Analysis
  - For most algorithms, running time depends on the "size" of the input.
  - Running time is expressed as $T(n)$ for some function T on input size n.

Input Dependency: Example

- Summing an array of n elements

```
// REQUIRES: a is an array of size n
// EFFECTS: return the sum
int sum(int a[], unsigned int n) {
  int result = 0;
  for(unsigned int i = 0; i < n; i++)
    result += a[i];
  return result;
}
```

- The runtime is roughly cn, where c is some constant.
- With n fixed, any array has roughly the **same** runtime.

Best, Worst, Average Cases

- In the example of summing an array, all inputs of a given size take the same time to run.
- However, in some other cases, this is not true, i.e., not all inputs of a given size take the same time to run.
- Example: linear search

```
// REQUIRES: a is an array of size n
// EFFECTS: return the index of the element
// equals key. If no such element, return n.
int search(int a[], unsigned int n, int key) {
  for(unsigned int i = 0; i < n; i++)
    if(a[i] == key) return i;
  return n;
}
```

Exercises

- What is the best case for linear search?
  - Data is found in the first place you look.
- What is the worst case?
  - Data is found in the last place.
  - Or data is not found.
- What is the average case?
  - Average performed over all possible inputs of a given size.

Best, Worst, Average Cases

- Best case: least number of steps required, corresponding to the ideal input
- Worst case: most number of steps required, corresponding to the most difficult input.
- Average case: average number of steps required, given any input.

A Common Misunderstanding

"The best case for my algorithm is $n = 1$ because that is the fastest."

- Wrong!
- Best case is a **special input** case of size n that is **cheapest** among all input cases of size n.

Which Case to Use?

- Average case or worst case is common.

- While average time appears to be the fairest measure, it may be difficult to determine.
  - Sometime, it requires domain knowledge, e.g., the distribution of inputs.

- Worst case is pessimistic, but it gives an upper bound.
  - Bonus: worst case usually easier to analyze.