Lecture 10
Contest Strategy

Jingbo Shang & Zhengkai Wu

University of Illinois at Urbana-Champaign

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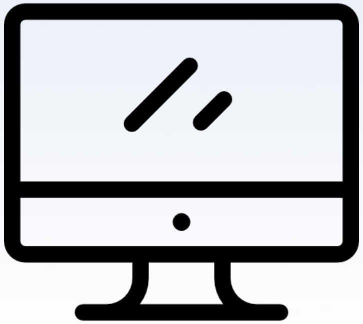
Outline

- Competing with a single computer
- Triaging a problem set
  - Complexity & input bounds analysis
- What to do during the practice contest
- Solving & debugging on paper
- Creating test cases
- Reference materials

Competing with a single computer

- During an ICPC contest, you will have one computer per team of 3 students
- **Not everyone can code at the same time!**
- How do you use the computer wisely?



Popular Strategies

- 3 DPS's
  - Take turns on the computer, based on how close you are to solving a problem.
  - "Shortest Job First" scheduling.
- 2 DPS's + 1 Support (recommended, more robust)
  - Two people take turns for coding.
  - One person focuses on thinking and debugging.
  - Used in many top world finals teams.
- 1 DPS's + 2 Support
  - Maybe too tired for 5 hours.

Tips

- One person should be coding
  - The total amount of "machine time" is fixed, i.e., 5 hours.
- Others should be solving problems/debugging on paper
  - Maximize the usage of "human time".
- Only code if you think you have already worked out the problem correctly
  - Don't waste the "machine time"!

Contest strategy

- Consider the following problems, with the given times to solve
- What is the time penalty for solving in the order:
  - **A, B, C**?

    40 + 50 + 110 = 200
  - **C, A, B**?

    60 + 100 + 110 = 270
  - **B, A, C**?

    10 + 50 + 110 = 170
- Obviously, we want to solve the easier problems first

Problem	Time to solve
A	40 minutes
B	10 minutes
C	60 minutes

Triaging a problem set

- In order to solve the easiest problems first, we need to order the problems by difficulty
- Called “triaging”
- **You should triage the problem set before coding anything!**
  - Otherwise, you might end up working on a harder problem first!
- Triaging effectively comes with practice

Components of triaging

- Need to:
  - Identify the problem type (e.g., mathematics, graph, DP)
  - Identify the intended complexity based on input bounds
  - Identify the key algorithm/technique/data structure (e.g., fast exponentiation, minimum spanning tree, hash table)
    - Be able to prove to yourself the correctness of your approach

Complexity & input bounds analysis

- Once you have identified the problem type, you must figure out what classes of algorithms will pass
  - Look to the input bounds!

- For example, if the maximum value of $n = 10^8$, an $O(n^2)$ algorithm will not pass
  - Even at 10 GHz (10^{10} operations per second), it would take over a week to complete $n^2 = 10^{16}$ operations!

Time complexity

- Rule of thumb: can perform <u>$\sim 10^8$ operations/second</u>
  - The number of operations in your solution should be at most between 10^8 and 10^9
- Asymptotically, complexity increases as follows:

$$O(1) < O(\log n) < O(n) < O(n \log n) < O(n^2) < O(n^k) < O(2^n) < O(n!)$$

  - Practically speaking, for $n \leq 10^5$, $O(\log n) \approx O(1)$
  - Remember, $2^{10} \approx 10^3$

Value of n	Worst possible complexity
$\geq 10^9$	$O(\log n)$
10^8	$O(n)$
$10^5 - 10^7$	$O(n \log n)$
$10^3 - 10^4$	$O(n^2)$
10^2	$O(n^4)$
50	$O(n^5)$
25	$O(2^n)$
20	$O(n^2 2^n)$ (TSP DP solution)
12	$O(n!)$
9	$O(n!\, 2^n)$ (TSP brute force)

Time complexity

- Time complexities for common techniques:
  - Hash table lookup: $O(1)$
  - Binary search: $O(\log n)$
  - Sort: $O(n \log n)$
  - Dynamic programming: usually polynomial (e.g., $O(n^2)$, $O(n^3)$)
  - Gaussian elimination for matrix of size $n \times n$: $O(n^3)$
  - All subsets of size k: $O\left(n^k\right)$
  - All subsets: $O(2^n)$
  - All orderings/permutations: $O(n!) \gg O(2^n)$

Space complexity

- Rule of thumb: can create array of size:
  - $\sim 10^8$ using dynamic memory allocation (e.g., `new`, `malloc`)
  - $\sim 10^6$ using static allocation (e.g., local variables in C/C++)

- Depending on n, you may need to change the data structure you use
  - E.g., adjacency list vs. adjacency matrix when $n > 10^3$

Space complexity

- Space complexities for common data structures:
  - Linear DS (list, stack, queue, heap, hash table, etc.): $O(n)$
  - Most trees (binary search tree, AVL tree, etc.): $O(n)$
  - Skip list: $O(n \log n)$
  - Segment tree: $O(n \log n)$
  - k-dimensional array: $O(n^k)$
  - Adjacency list: $O(|E|)$
  - Adjacency matrix: $O(|V|^2)$
  - Number of primes less than n: $\pi(n) \approx \frac{n}{\log n - 1}$

Triaging during a real contest

- Triaging takes time, which accumulates in your time penalties
- We want to minimize the time triaging before the first solve, but how?
- Teams have 3 students, remember?

Triaging during a real contest

- Every problem set has a ridiculously easy problem
- Everyone should first find that problem, then have the fastest coder solve it while the other 2 continue triaging

- Problems should then be solved *on paper* in order of difficulty until the computer is free
  - Switch off as soon as a person solves a problem or gets stuck
- The computer should rarely be idle!

Tips

- Use a sheet to record all (partially) known problem types
  - Who to do this? The support guy.
- Check whether your teammates have read/thought the problem before you read/think it.
  - Avoid double work.

How to practice triaging

- Problem sets from previous contests have already been triaged for you!
  - Just look at the number of solves on the final scoreboard ☺
  - Some contests release difficulty rankings in judging notes
    - E.g., our regionals, North American Qualification Contest
- Attempt to triage yourself, then compare with the actual difficulties
- Everyone's triage ranking may be different, but likely fairly similar

Questions so far?

Exercise

Triage the provided problem set

Before the contest starts…

- You want to:
  - Know the efficiency of the judge machine
    - How many addition operations can you run within a second?
  - Know the memory limits
    - Maximum size of integer array you can allocate on the heap
  - Know the stack size
    - Is tail recursion optimized by the compiler?
    - Maximum size of integer array you can allocate on the stack
    - Maximum depth of head recursive calls you can make
  - Know the priority of judging results
    - If you have a Runtime Error and Wrong Answer, which will you see?
  - Know the maximum size of code you can submit

What to do during the practice contest

- In some cases, the judges will specify all of the information on the previous slide
  - Read it carefully!
- However, if any of it is not provided, **use the practice contest** to test the judge environment!

While the contest is running…

- You will need to:
  - Solve problems *on paper*
  - Code them up correctly
  - *Make your own test cases* and test your solution
  - Debug, potentially *on paper*
  - Get AC!

Solving on paper

- Write pseudocode
  - At least the framework
- Identify the key algorithm/technique
  - E.g., dynamic programming, math, simulation
  - Write down the meanings of the important variables
- Think about techniques to make your coding faster
  - How to efficiently cover corner cases
  - How to arrange functions and methods

Debugging your own code

- On the computer
  - Write down the meanings of the important variables
  - Check whether those variables work properly as expected by printing some intermediate results
  - Scan the code *thoroughly* before submission to make sure there are no typos (e.g., i → j)
- On paper
  - Follow the same procedures as for debugging on the computer
  - Run through corner cases and tricky test cases by hand, stepping through the code and keeping track of variable values

Debugging your teammates' code

- Think about how will you implement the solution to the problem ***before*** looking at others' code!
- Figure out whether your overall approach and framework are the same or similar
- <u>Pay more attention to the differences</u>
  - More likely that errors appear at those points

- In general, follow the same techniques as for debugging on paper

Creating test cases: Corner cases

- Often the cause of Wrong Answer (WA)
  - Let n be the input
  - Smaller n's, such as 0, 1, 2, 3, might be corner cases

- Example: Suppose in your algorithm, you are going to enumerate 3 different points out of n points.

```
answer = 0;
for (int i = 0; i < n; ++ i) {
    for (int j = 0; j < i; ++ j) {
        for (int k = 0; k < j; ++ k) {
            // Update answer
        }
    }
}
printf("%d\n", answer);
```

In this case, you should be careful when $n = 1, 2$.

Creating test cases: Extreme cases

- Often the cause of Time Limit Exceeded (TLE)/Runtime Error (Segmentation Fault)

- Two types:
  1. Write code to generate a *large case* based on the *limits* in the problem
  2. Based on your algorithm, figure out the *worst-case input* (on which your algorithm is most *inefficient*), which might be different from the large test case

Questions so far?

A note on reference materials

- You should take ***tested*** implementations of common and useful algorithms & data structures
- Should also include miscellaneous like trigonometry identities, common integer sequences, number theory relationships, etc.

- Reference materials are for *reference*, **not reading**
  - You should be able to flip to the page and apply it immediately, not search through your materials for the right information
- Make sure you are familiar with your references!
  - Indexing helps!

Questions?

Problem set

- This week's problem set will be special
- Triage the 1 problem set we provide

Resources

- **Chapter 1** of Competitive Programming by Steven Halim
  - **We highly encourage you to read the entire chapter!!!**
- **Chapter 1-2** of Art of Programming Contest by Ahmed Shamsul Arefin