

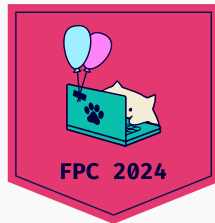
Freshmen Programming Contests 2024

Solutions presentation

By the Freshmen Programming Contests 2024 jury for:

- AAPJE in Amsterdam
- FPC in Delft
- FYPC in Eindhoven
- GAPC in Groningen

May 4, 2024



A: Annoying Alliterations

Problem author: Maciek Sidor



- **Problem:** Given n words, find a pair such that after their common prefix is removed, the sum of lengths of the two resulting words is the greatest.
- **Naive solution:** Check every pair. Runs in $\mathcal{O}(n^2)$, too slow.
- **Claim:** For a given pair s, t and a third word v such that $|v| \geq \max(|s|, |t|)$, we can always replace one of the words and the score will not decrease.

A: Annoying Alliterations

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- **Claim:** For a given pair s, t and a third word v such that $|v| \geq \max(|s|, |t|)$, we can always replace one of the words and the score will not decrease.
- **Proof:** Denote the common prefix of s, t as $p(s, t)$ and let $g(s, t) = |s| + |t| - 2|p(s, t)|$ be our goodness function.
- Suppose $g(s, t) > g(s, v)$ and $g(s, t) > g(v, t)$. Then:

$$|s| + |t| - 2|p(s, t)| > |s| + |v| - 2|p(s, v)|$$

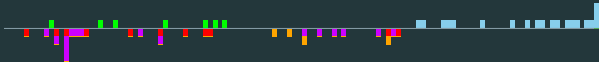
$$|t| - 2|p(s, t)| > |v| - 2|p(s, v)|$$

$$|p(s, v)| > |p(s, t)|$$

- Similarly, $|p(v, t)| > |p(s, t)|$, but these two together give us a contradiction. \square

A: Annoying Alliterations

Problem author: Maciek Sidor



- **Claim:** For a given pair s, t and a third word v such that $|v| \geq \max(|s|, |t|)$, we can always replace one of the words and the score will not decrease.
- **Therefore:** Any word of maximum length is part of a valid solution.
- **Solution:** Pick any word of maximum length and check it with every other word, take the maximum result.
- **Complexity:** $\mathcal{O}(n)$.
- **Note:** Can also be solved using a trie (also known as a prefix tree).

Statistics: 58 submissions, 7 accepted, 20 unknown

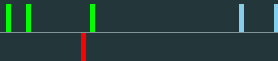
B: Building Pyramids

Problem author: Maarten Sijm



- **Problem:** Given the edge length of a tetrahedron, calculate the number of spheres in the pyramid.
- **Observation:** The pyramid consists of n equilateral triangles.
The number of spheres in triangle t is $T(t) = \sum_{i=1}^t i$.
- **Slow solution:** Calculate $P(n) = \sum_{i=1}^n T(i)$. Runs in $\mathcal{O}(n^2)$, too slow.
- **Solution:** Simplify $T(t) = \frac{t \cdot (t+1)}{2}$. Now calculating $P(n)$ runs in $\mathcal{O}(n)$, accepted!
- **Pitfall:** If t is an `int`, $t \cdot (t + 1)$ overflows. Use 64-bit integers!
- **Challenge:** The calculation of $P(n)$ can even be simplified to run in $\mathcal{O}(1)$.

Statistics: 75 submissions, 36 accepted, 1 unknown



- **Problem:** Given two types of penalty times for n teams ($1 \leq l_i < s_i \leq n$), find out over all ways of choosing the type of penalty time for each team, how many fixed points the scoreboard contains in total.
- **Observation 1:** Instead of finding fixed points for each out of 2^n options, find how many times team i is a fixed point.
- **Observation 2:** Loop over all teams, try both options l_i and s_i as potential fixed point, for team i , call this potential fixed point f .
- **Observation 3:** Other teams form 3 groups:
 - **A** Teams with $l_j < f, s_j < f$
 - **B** Teams with $l_j < f, s_j \geq f$
 - **C** Teams with $l_j \geq f, s_j \geq f$
- **Observation 4:** The number of ways to choose the other submission times, for team i to have a fixed point at rank f : $2^{|A|+|C|} \cdot \binom{|B|}{f-|A|}$
- Team j is in group **A** if $s_j < f$.
- Team j is in group **C** if $l_j \geq f$.
- Otherwise, team j is in **B**. By sorting the l_j and s_j arrays, $|A|$ and $|C|$ can be found by binary search.



- **Problem:** Given two types of penalty times for n teams ($1 \leq l_i < s_i \leq n$), find out over all ways of choosing the type of penalty time for each team, how many fixed points the scoreboard contains in total.
- **Observation 4:** The number of ways to choose the other submission times, for team i to have a fixed point at rank f : $2^{|A|+|C|} \cdot \binom{|B|}{f-|A|}$
- Need to calculate $\mathcal{O}(n)$ binomial coefficients $\binom{a}{b}$, with $0 \leq a, b \leq n$: $\binom{a}{b} = \frac{a!}{b!(a-b)!}$ and 2^a for $0 \leq a \leq n$, both mod $(10^9 + 7)$
- Can precalculate factorial[k] and twopower[k] in $\mathcal{O}(n)$.
- Can find inverse of factorial[n] in $\mathcal{O}(\log(MOD))$ (or if you don't know how to calculate a modular inverse, you can brute force it on your own computer).
- Now fill the array invfactorial[k] using invfactorial[k] = invfactorial[$k+1$] · ($k+1$) in $\mathcal{O}(n)$.
- Complexity varying from $\mathcal{O}(n(\log(n) + \log(MOD)))$ to $\mathcal{O}(n + \log(MOD))$ depending on exact implementation.

Statistics: 6 submissions, 3 accepted, 2 unknown

D: Dragged-out Duel

Problem author: Wietze Koops



- **Problem:** Read two lines, comprised of 'R', 'P', and 'S', and determine who wins the most games.
- **Solution:**
 - Read the two lines character by character, increment a counter if player 1 wins and decrement it if player 2 wins.
 - Finally, print "victory" if the counter is positive, and "defeat" if it is negative.
- **Complexity:** $\mathcal{O}(n)$.

Statistics: 45 submissions, 37 accepted

E: European Election

Problem author: Veselin Mitev

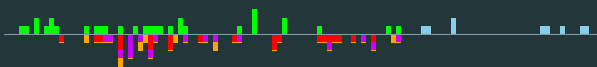


- **Problem:** Given ranked-choice ballots, determine the candidate who beats all other candidates.
- **Fun Fact:** This is also known as the *Condorcet* voting method.
- How to determine whether candidate A is better than B?
 - Go through all ballots – count how many times A appears before B, and vice-versa. Runs in $\mathcal{O}(n \cdot k)$.
- **Observation:** We can preprocess the ballots in $\mathcal{O}(n \cdot k)$, such that we can access the position that each candidate appears in each ballot in $\mathcal{O}(1)$. Thus, answering whether candidate A beats candidate B, now only takes $\mathcal{O}(n)$.
- **Solution:**
 - Pick a candidate d .
 - Go through all candidates c_i : Anytime c_i beats d : $d \leftarrow c_i$. Runs in $\mathcal{O}(n \cdot k)$.
 - **Observation:** If the election has a winner, it must be d . (This can be proven using contradiction!)
 - Check if d beats all other candidates. Runs in $\mathcal{O}(n \cdot k)$.
- **Complexity:** $\mathcal{O}(n \cdot k)$.
 - But we chose the time limit to also accept $\mathcal{O}(n \cdot k^2)$ or even $\mathcal{O}(n \cdot k^3)$.

Statistics: 50 submissions, 15 accepted, 21 unknown

F: Flag Rotation

Problem author: Jeroen Op de Beek



- **Problem:** Count how many cells will change when painting the flag rotated.
- **Observation:** Since each column has to be repainted to one color, we will change $n - cnt_c$ cells in it (where c is the final color).
- **Solution:** Count how many cells won't change.
 - First sort the array, then check for segments made of identical elements, this way we find the count of each cell color.
 - $$\text{answer} = n^2 - \sum_c cnt_c^2$$
- **Complexity:** $\mathcal{O}(n \log n)$.
- **Note:** this can also be done using a (hash) map.

Statistics: 85 submissions, 31 accepted, 9 unknown

G: Galactic Expedition

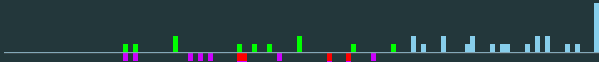
Problem author: Veselin Mitev

- **Problem:** Navigate between wormholes to find the ancient relic, without running out of fuel.
- **Observation:** You can refuel more than enough times to simply explore all wormholes, until you find a way to reach the relic.
- **Solution:** Perform a “live” search – explore the wormholes while always keeping enough fuel ($\frac{d}{2}$) to go back to home base:
 - If you can reach the relic within the fuel limit, do that.
 - Find the closest unexplored wormhole:
 - You can do that using **Dijkstra**, or **Floyd-Warshall**.
 - Can we reach it while still having enough fuel to go back to home base?
 - If yes: Go to that wormhole and update the distances between the points.
 - If no: Go back to home base and refuel.
 - Repeat.
- Worst case: We can explore all wormholes in $\frac{n}{2}$ runs.
- If we know all wormholes, it is guaranteed that we can reach the relic, if we follow an optimal path.
- **Time Complexity:** $\mathcal{O}(n^3)$ or $\mathcal{O}(n^3 \log n)$. Or if you're clever about how you cache the results from the Dijkstra search algorithm you can do it in $\mathcal{O}(n^2)$ or $\mathcal{O}(n^2 \log n)$.

Statistics: 3 submissions, 0 accepted, 3 unknown

H: Horrendous Mistake

Problem author: Jeroen Op de Beek

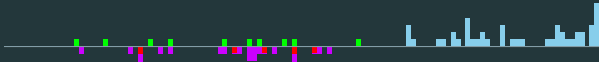


- **Problem:** Calculate the value of the function `sum`, which uses values instead of indices.
- **Naive solution:** Simply run the function after every update. This takes $\mathcal{O}(n \cdot q)$ time, too slow!
- **Observation:** To be fast enough, every query must be processed in $\mathcal{O}(1)$.
- **Solution:** Do some extra bookkeeping:
 - Count how often every value occurs in the initial array ($= c_x$ for every $0 \leq x < n$).
 - Calculate the value of `sum` for the initial array and store this.
 - For every update (x, v) (let the old value in the array be v_{old}):
 - Decrement $c_{v_{old}}$.
 - Subtract $c_x \cdot v_{old} + a_{v_{old}}$ and add $c_x \cdot v + a_v$ to the stored value of `sum`.
 - Increment c_v .
 - Update the value in the array.
- **Complexity:** $\mathcal{O}(n + q)$.
- **Pitfall:** Beware of `int` overflow, be sure to use 64-bit integers!

Statistics: 46 submissions, 11 accepted, 24 unknown

I: Intelligence Exploration

Problem author: Makar Kuleshov



- **Problem:** Calculate the value of the implication $a_l \rightarrow a_{l+1} \rightarrow \dots \rightarrow a_r$ for many subarrays.
- **Naive solution:** Go through the whole subarray to calculate the result. Runs in $\mathcal{O}(n \cdot q)$, too slow!
- **Observation:** When the right argument of an implication is 1, the result is always equal to 1.

So, we can look only at the last 1 in the subarray and the following zeros.

$$a_l \rightarrow \dots \rightarrow 1 = 1 \quad \underbrace{a_l \rightarrow \dots \rightarrow 1}_{1} \rightarrow 0 = 0 \quad \underbrace{a_l \rightarrow \dots \rightarrow 1 \rightarrow 0}_{0} \rightarrow 0 = 1$$

$$\underbrace{a_l \rightarrow \dots \rightarrow 1 \rightarrow 0 \rightarrow 0}_{1} \rightarrow 0 = 0 \quad a_l \rightarrow \dots \rightarrow 1 \rightarrow \underbrace{0 \rightarrow \dots \rightarrow 0}_{k \text{ zeros}}$$

If k is even then the result equals 1.

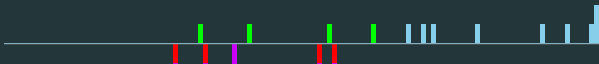
If k is odd then the result equals 0.

- **Solution:** For each position precompute the index of the last 1 appearing not after it. This way you can determine the number of zeros in the end of a subarray in $\mathcal{O}(1)$.
- **Complexity:** $\mathcal{O}(n + q)$

Statistics: 78 submissions, 10 accepted, 46 unknown

J: Jailbreak

Problem author: Wietze Koops



- **Problem:** Escape from a $w \times h$ grid jail where you can go up only if you have a ladder. Ladders can be carried to a different place on the same storey.
- **Observation:** If we know to which holes a ladder can be carried, then for each cell, we know which cell we can move to.
- **Solution:**
 - Using a for loop in both directions, determine which cells can access a ladder.
 - Then we know for each cell to which cell we can move.
 - Hence, we can define a graph representing the grid.
 - Determining whether a path exists from the starting cell to an exit can be done using $\mathcal{O}(wh)$ BFS/DFS.

Statistics: 18 submissions, 4 accepted, 9 unknown

K: Kangaroo Race

Problem author: Leon van der Waal



- **Problem:** A kangaroo jumps from x to $x + x(x - 1) = x^2$ in one step. How many steps until it reaches 1?
- Notice that when a kangaroo jumps over the n -th segment, it jumps to $x^2 \bmod n$.
- So after i jumps, the kangaroo is in segment $x^{2^i} \bmod n$.
- Therefore we need to determine the first i such that $x^{2^i} \equiv 1 \bmod n$.

K: Kangaroo Race

Problem author: Leon van der Waal



- **Problem:** Determine the first i such that $x^{2^i} \equiv 1 \pmod n$.
- **Observation:** If $\gcd(x, n) \neq 1$, then $\gcd(x, n) \mid x^{2^i} \pmod n$, so the kangaroo will never reach 1.
- Otherwise, $x^r \equiv 1 \pmod n$ for some r . We call the smallest such r the *order* of $x \pmod n$.
- Notice that the powers of x repeat every r -th power:

$$1, x, x^2, x^3, \dots, x^{r-1}, x^r = 1, x^{r+1} = x, x^2, x^3, \dots$$

K: Kangaroo Race

Problem author: Leon van der Waal



- **Problem:** What is the first i such that $x^{2^i} \equiv 1 \pmod{n}$.
- Therefore, any i that satisfies $x^{2^i} \equiv 1 \pmod{n}$ also satisfies $2^i \equiv 0 \pmod{r}$.
- **Observation:** This means that r is a divisor of 2^i , and thus $r = 2^k$ for some k .
- Therefore, the answer to the problem is k .
- **Observation:** $r \leq n$, so $k \leq \log_2(n)$

K: Kangaroo Race

Problem author: Leon van der Waal



- **Problem:** What is the first i such that $x^{2^i} \equiv 1 \pmod n$.
- **Observation:** $r \leq n$, so $k \leq \log_2(n)$
- **Solution:** It therefore suffices to check the first $\log_2(n) < 60$ jumps. If the kangaroo has not reached segment 1 by then, it never will.
- **Complexity:** $\mathcal{O}(q \log n)$

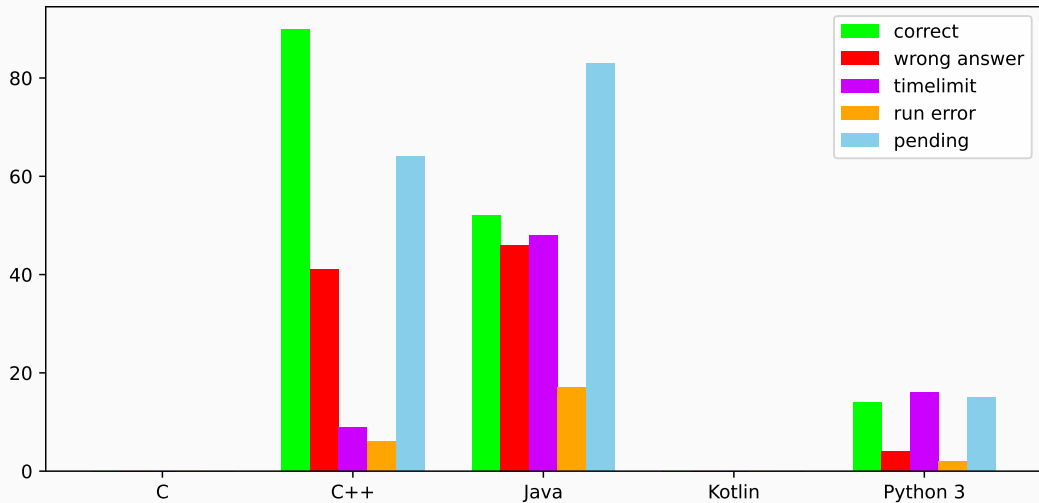
Statistics: 44 submissions, 2 accepted, 27 unknown

Want to solve the problems you could not finish?
Or have friends that like to solve algorithmic problems?

<https://fpcs2024.bapc.eu/>

Friday 10 May 2024 13:00–17:00

Language stats



Random facts

Jury work

- 447 commits (last year: 361)
- 357 secret test cases (last year: 339)
- 120 accepted jury/proofreader solutions (last year: 96)
- The minimum¹ number of lines the jury needed to solve all problems is

$$2 + 1 + 11 + 1 + 5 + 1 + 22 + 5 + 3 + 11 + 4 = 66$$

On average 6.0 lines per problem, down from 6.4 last year

¹After codegolfing

Thanks to the proofreaders:

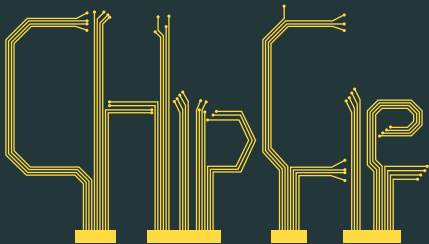
- Arnoud van der Leer (TU Delft)
- Daniel Cortild (RU Groningen)
- Davina van Meer (Delft)
- Henk van der Laan (TU Eindhoven)
- Matei Tinca (VU Amsterdam, 📍)
- Michael Vasseur
(VU Amsterdam / DOMjudge)
- Mylène Martodihardjo (VU Amsterdam)
- Nicky Gerritsen
(TU Eindhoven / DOMjudge)
- Pavel Kunyavskiy
(JetBrains Amsterdam, 📍 Kotlin Hero 📍)
- Ragnar Groot Koerkamp
(ETH Zürich / NWERC jury)
- Rick Wouters (TU Eindhoven)
- Sièna van Schaick (Radboud Nijmegen)
- Thomas Verwoerd
(TU Delft, 📍 Kotlin Hero 📍)
- Yoshi van den Akker (TU Delft)

Thanks to the Jury for the Freshmen Programming Contests:

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- Mansur Nurmukhambetov (RU Groningen)
- Tymon Cichocki (TU Delft)
- Veselin Mitev (TU Delft)
- Vitor Greati (RU Groningen)
- Wietze Koops (Radboud Nijmegen / RU Groningen)
- Wiktor Cupiał (TU Delft)



Want to help out with future contests?



<https://wisv.ch/chipcie-interest>

<https://wisv.ch/runner>