P R O G R A M L A N D

A Collection of Anecdotes from
The United Drives of NANDs

Sai Sriram Yannamani [2019101029]

Raghav Raj Dwivedi [2019101008]

ACKNOWLEDGEMENT

We express our utmost gratitude to Professor Srinathan for taking the initiative of allowing projects of this type. This book was possible with the encouragement and support given by him and our Teaching Assistant Chiranjeevi V.

INDEX

Volume I – Warfare & Other Assorted Stories

Volume III – Inspector Manson's Unexpected Journey

VOLUME I

WARFARE AND OTHER ASSORTED STORIES

Raghav Raj Dwivedi
[2019101008]

1. Liam the Literal and Rodger Race Radcliff

Linear search and Binary search

There once lived a program named Remy ‘Rapid’ Radcliff, who could jump extremely far distances at once. To get to any place he merely had to know where that place was, as travelling to there was barely an inconvenience for him. He had entered the Proglympics and won a gold medal in sorted searching, one of the sports of the Proglympics.

Rapid was his middle name and everyone knew about it. You see, Remy had the knowledge of an extremely optimized binary search. These days however, Remy is a name that only appears in Proglympics quizzes and is spoken only by those few people who remember. He has retired from racing, to devote more time into raising a family, part of which is Rodger, his only child.

***

Rodger was a swift child. He had inherited his search skill from Remy Rapid Radcliff after all! His friends dubbed him Rodger ‘Race’ Radcliff, a name which suited him very well, and he knew it. In fact, it was very apparent that everyone around him knew that he knew it. It was very

proud about the matter, nothing like his father back in the days.

One day, a sage named Liam the literal happened to stumble across Rodger.

Liam the Literal was… a weird sage. He was very wise and well respected indeed, but his methods of educating society were… unconventional, at the least. He was a soldier once, and almost gave his life for the great Librarian war. They say his code got slightly corrupted from the war, and he suffered from PTSD. His being a sage may be a coping mechanism from this corruption, however, that is that, and that does not change anything in the current world.

Upon bumping into the sage, Rodger said, “watch your way sage”, to which the sage said, “I always watch my way. It is impossible for me to be lost child. You must watch your way. I am after all, Liam the Literal”. Rodger, now infuriated, spoke “Don’t patronize me saint. You speak to Rodger the Race, son of Remy the Rapid, renowned for his victory in the twelfth Proglympics”. At this moment, Liam knew exactly what he had to do. He knew that Rodger was a child of high entitlement and he absolutely had to teach him a lesson.

“Child. I challenge you to a searching race. If you win, I accept that I am wrong and will watch my way more

carefully. If I win, I get to keep your father's medal." Said the sage.

Rodger complied. He quickly leapt to his house and sneakily stole the framed medal, making a swift return. So far it was easy for him, as his house address was in an ordered array which meant that his reaching and returning from home was blazingly fast. Upon his return, Rodger demanded that this searching race have an audience, such that the humiliation faced by the sage could be seen by the masses. Since Liam the Literal was quite famous, he sent out an announcement for a race and an audience slowly started growing.

As the audience grew on the side of the street, the sage announced the terms of the race. "The race will end when one of the programs finds a 21. It is sure to exist." to which Rodger complied. "The race will be held in the stretch of 131 address spaces that starts from here" to which Rodger complied. "The racetrack will not be sor..." "Just get on with the race already old man" Rodger said as he grew hasty. The sage complied.

3. 2. 1. Begin. The sage began his reliable but slow, good old fashion linear sort. He simply sequentially went to each address space from start to end, checking if the next one was a 21 or not. "2" he went. "on to the next one it is". "89". "19". He was slow, but he knew that he would eventually stumble across a 21.

Rodger with all his speed immediately jumped to the middle of the 131 space long track. “108” “that’s odd. Well, the algorithm is what it is”. His next jump took him midway between his current position and his initial position. “118” “this is very strange, is the track in reverse?” he thought to himself. Little did he know, his hastiness stopped him from realizing that the track was not sorted at all, and that his speedy binary search algorithm was of no use here in this street.

Liam the literal eventually did find a 21, during which Rodger was very perplexed at the numbers that he kept jumping to. It was announced that Liam had won the race and the crowd cheered. The sage had done it again. Rodger on hearing this news was first boiling, then crying, then baffled, and finally humiliated. He asked the sage “How did you do it. How did you beat me?” To which the sage said “In an unsorted array, the binary search algorithm becomes useless. Good old fashion sequential search then becomes the best friend of a common program.”

As Rodger, full of shame, began to bring out his father’s medal, the saint stopped him and said, “Child. I do not want your father’s medal. All I want is for you to learn this very important lesson.”. Liam silenced and then dispersed the crowd.

The saint in his weird way had taught a child and the entire audience of this spectacular and peculiar race something important.

2. The Librarian War and Landmines

Breadth first search

Disclaimer: The Librarian War does not pertain to libraries of books; rather the libraries of code. Its participants were factions of programs. It was a war that began on the face of increased terror, anarchy, and faction building, immediately after the fall of the age of emperors. It encompassed various events, but for the most of its run, the goal of most factions was to seize control of the entire hard disk.

Landmines were a horrifying consequence of the Librarian war. Across various address spaces these landmines were scattered in the battlefield, which was a very vast space. Now, as the population of programs in the hard drive continues to grow, many programs want to utilize this barren wasteland that once used to be the battlefield. The thing that stops them from occupying the landmine ridden region is that, well, landmines are known quite famously to be very dangerous. If the address of the landmine is entered, it explodes, killing the programs that entered the address.

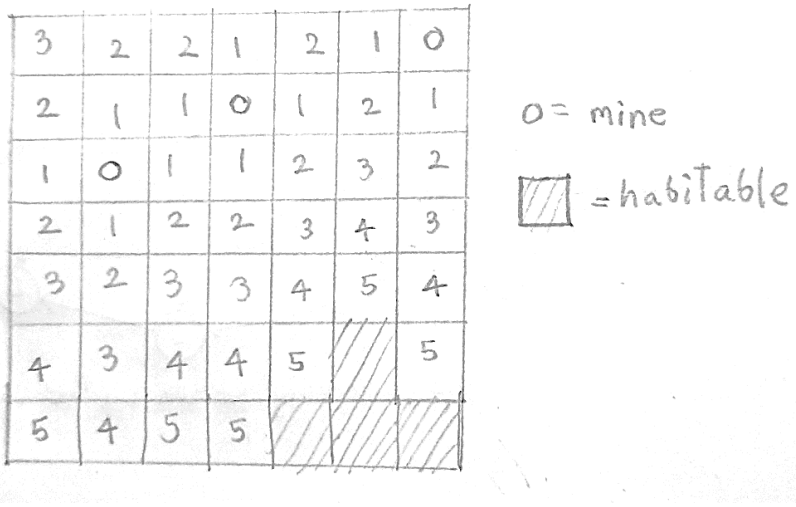
In recent years however, new technology has enabled programs to develop a landmine detection system. It enables a program to detect the current address space of a

landmine. Its workings are along the lines of drones or helicopters in our world. The specific techniques of how LDS functions is unknown to me, the author.

The catch is, the entire United Drives of NANDS possesses only one landmine detection system, LDS for short. I bring to you a problem that popped up during this entire discourse, which was solved very intelligently.

The programs of this world wanted to use this LDS to display danger zone warnings to as many programs in the address space of the landmine ridden battlefield as possible. For this, the marvelous Dr. Ben Fredrick Searcher devised the breadth first search, abbreviated to BFS (I assure you that Dr. Ben's initials also being BFS is purely a coincidence). This simple algorithm solved the issue in, as they believe, the quickest time possible. Since only one LDS exists, Dr. Ben got the opportunity to use it, and he was very excited to do so as well.

Using the LDS, Dr. Ben located all the landmines of the address array and marked them with special flags. Now, to begin marking the danger warnings, Dr. Ben created a warning system, where the flag '1' meant that any mis step could mean certain death, while a mis step from an address space with the flag '2' could mean entry into an address space with the flag '1'. Similarly, he extrapolated this flagging system till '5', beyond which the doctor found it unnecessary to even warn people.



The doctor then took on the task of actually placing the flags in the address spaces; he was most certainly a brave man.

To do this, he created a queue. He inputted the location of every landmine received from the LDS into the queue. He said, “Let the children of an address space be the address spaces that immediately border them”. Then, He went through the queue, adding the children of every address space he found that was not assigned a flag, while giving them the flag that was a single increment larger than the flag of the parent. He stopped adding children to the queue if the parent had a flag of 5.

The key here is that he was not adding any address spaces to the queue that had already been flagged. This stopped him from accidentally entering an address space with a landmine, or an address space where he had already been to.

This may seem like a very weird algorithm to the reader at first, but trust me, it has saved the lives of thousands of new programs, that decided to set up their homes in address spaces in the warzone.

3. Nancy in her worst nightmare – A Maze

Depth first search

Nancy was a very clever program; the only problem was that she found herself lost quite often. She did not have a lot of sense of direction, and she seemed to always require a map to get around to anywhere. She was so bad in navigating around the city, that her worst nightmare was getting lost in a maze without any map!

She was, at the end of the day, a teenager, however. You know those grim teenagers, right? They always function in herds, doing whatever the next one is doing, all the time. Nancy was very liked in her ~~herd~~ peer group. She would do everything to spend time adequately with them.

One day, Nancy and her friends found themselves in a park, with massive rides, snack stores, and trees, but most important of all, a giant maze. The thing is that all her friends knew about her fear of mazes all along, and they had chosen this specific park to visit today simply because they wanted to do a little mischief with Nancy.

Nancy was a proud teenager. There would be no such dare that she was given that she would not fulfil. She could not possibly chicken out, that would simply be

embarrassing in front of her friends. And her mischievous friends knew about this. They were cunning teenagers after all. All they had to do to trap Nancy into her worst nightmare was simply say three magic words:

"I dare you"

And everything spoken after would work like a spell cast by the grand wizard of the L3 caches. "Nancy, I dare you go enter this maze and finish it" a friend spoke up to her with a smirk. "Why Of course" was the reply greeted to her.

And soon enough did Nancy find herself in a giant maze, with no turning around, not because she couldn't, but because she wouldn't. But Nancy was a clever program, she was a teenager after all! She sat down and started cooking up a plan that would get her out of there in no time. "I do not know where the exit is, and this maze is quite large. How do I make sure that I do not waste any time in this?"

And then an idea struck her. She realized that all she had to do was ensure that she did not repeat the same path. She started moving to the left most path to her. At her every step, the position left by her she would flag as yellow. While backtracking her own steps, every position with a yellow flag would be colored to blue. Every junction that she came across would not be colored until all the paths of that

junction weren't explored. And most important of all, she would not dare step onto a path that had already been flagged, unless she was backtracking.

This logic worked her wonders.

She got out of the maze in a very quick time, and this activity also helped her overcome her fear of mazes. She did however get very angry at her friends, and only they know what happened after that.

4. The Coloring Complaint of a Cartographer

Greedy graph coloring

Cartographers are a funny sort of people, don't you say? They roam around drawing maps of the world, and stress on the most arbitrary things, such as what criteria must one use to label a city on the map, what method must one use to display physical features, and worst of all, what part of a conflicted territory belongs to what part of which country and so on. The list goes on and on, and its almost painful to work for a cartographer.

Susan was one such program. She spent her days making maps and troubling her friends by complaining about such menial things.

On one fine day Susan was making a map, and before she put her first dab of color, she realized that she had to plan this, as the planner she was. She set up one singular rule for herself: That she would ensure that no two hard drives sharing a border will have the same color. This put her in a fix, as she only had nine colors to work with. Red, orange, yellow, lime, green, cyan, blue, purple, and pink.

She began to ponder upon this problem and fell into a deep thought of mechanisms to color maps that could

solve her problem. The largest drive on her map was surrounded by eight other drives. She only had nine colors. She had to make this work somehow.

Susan quickly realized that she had to use at least one color, obviously every map would need one color! She took the first color on her list, red, and painted in the first drive that her brush could reach. Now this red drive only had four drives bordering it, so Susan colored all four of them with the four colors next in the list: orange, yellow, lime, and green.

She then went on to the next drive queued, the one currently colored orange. Since this drive already shared a border with the red drive and the yellow drive, she decided not to use red or yellow for the uncolored drives neighboring this one. Since it only had three other bordering drives, she colored them lime, green, and cyan.

Susan continued to do this for every single country on the map, unknowingly, and it all almost magically seemed to work perfectly! It was very strange though. Her map took her exactly nine colors to fill up, which almost seemed like this was some sort of divine gift. While it was most certainly not a divine gift of any sorts, what it was for sure, was a very lucky guess to an algorithmic approach to coloring maps. The exact method of coloring the map illustrated by Susan is used around this world by many

professional cartographers to color their maps of drives and caches and almost everything.

Susan did however recognize this a few days later and converted this accidental stumble to an algorithm into an opportunity for her to learn this algorithm and make it part of her program. She from then on continued to complain about the pains of cartography to her friends, but the list of complaints reduced by one, that being coloring.

Let us keep a secret from her (promise not to tell her), but her map only actually required four colors to meet her requirements! The story for that discovery, I shall save for some other time.

5. A Civil servant in Census day

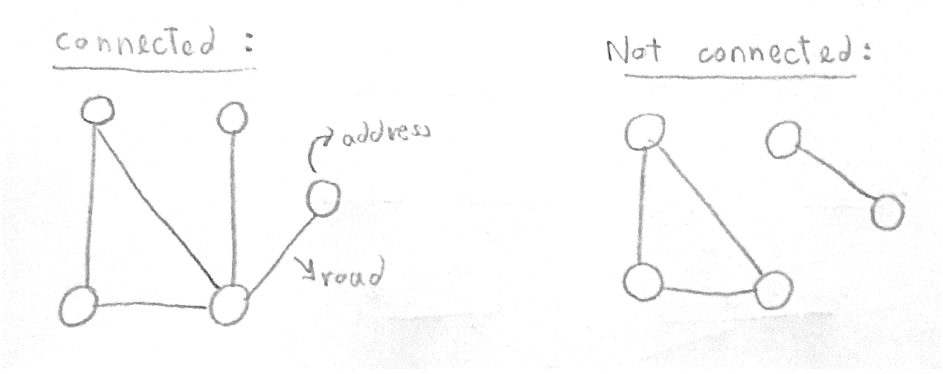
Kosaraju's algorithm

The programs of the Operating System were very busy today. It was expected from them, as it was the dreaded time of the year. Census week. The Operating system had to go around all week to every address on the hard drive, gathering details about every single program. The details to be gathered were quite arbitrary although. "length of the program", "size of dependencies", and one of the most used ones, "space complexity", were some of the details to be gathered, but this time around, the details weren't the focal point of controversy.

You see, the thing is, the Operating system had all of a sudden and out of nowhere decided that it would be dividing the hard drive's unassigned address spaces into villages, based on one definition, that being that the address spaces were strongly connected.

I understand that you must be curious as to what "strongly connected" or even "connected" means, but worry not my friend, I shall elaborate upon the words. A "connected" set of addresses is one where there is a known route from one address to another. This means that a set of addresses will not be "connected" if there is no road that

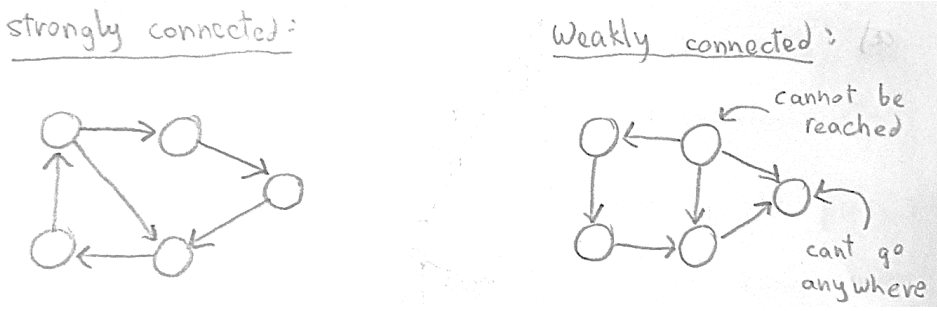
connects them (this I assume is obvious due to the nature of human language).



Inserting a little bit of nuance and another dimension of thought into this definition of connectivity gives us two more definitions, “strongly connected” and “weakly connected”. You see, what if these roads were only unidirectional? In that case, a set of addresses is considered “weakly connected” if it is not “strongly connected” (this as well I assume is obvious due to the nature of human language) and if converting all of its unidirectional roads to regular old 2-way roads gives us a “connected” set of addresses.

Only one definition remains, the one which is the most important to us today. A “strongly connected” set of addresses is that where from every address one could find

a path to every other address using just the unidirectional roads.



The pocket of the hard drive around which this story revolves is known for bad drivers, and hence every road here has been converted to a unidirectional road, as it allegedly reduces road accidents. The accuracy of that information is beyond the scope of my awareness, and so I shall move forward to the story in hand.

A program working for the Operating system as a civil servant, Blake was assigned the task to map this pocket of the hard drive and divide it into villages, which was a big task. But Blake was no ordinary person. She was after all, the civil servant assigned to this pocket of the hard drive. It took her years of hard work and dedication to get this job, and there was practically nothing that could take the job away from her.

So, she set out on this task to map out strongly connected address spaces as villages.

Blake picked a random address that she had not visited yet and started a journey on the first road she saw from there. At every stop she made, she marked those addresses as visited (this as well I assume is obvious due to the nature of the human language). She would only use the road to the next address if the next address had not been visited yet. When she stumbled upon an address where from she could not go anywhere, either because all possible next places had already been visited or because there was no path forward, she would begin backtracking her steps.

Since Blake was a civil servant, the operating system aloud here to legally go in the reverse direction on the road, and this was justified here, as she was doing a task for the operating system.

At any given moment if some address did not have any unvisited neighbors remaining, she noted down those addresses into her stack. Every time she went down on a road in reverse, at whichever address she would land on, she would take it as her first and foremost duty to visit any unvisited addresses that she could visit in the proper direction of the road.

Eventually, she was back to the original random address that she had picked, with all the addresses that she

had visited written down in her stack. Now obviously, more addresses existed than the ones she had visited, so she picked another random address, one explicitly not written in her stack, and redid the entire process from that address onward.

This was an exhausting process, not because of some repetitive nature (which you must trust me does not exist in this story), but because of the sheer quantity of addresses she had to visit. It was almost obvious that to make a village, she had to visit at least most definitely once every single address in this pocket of the hard drive. Smart as ever, Blake did ensure that the number of addresses did not affect her number of visits to an address. If that were to become the case, then one can only ever imagine completing this task in any reasonable amount of time.

Now, it was demarcation time. She took her map of roads and reversed their arrows for herself. She looked at her stack and picked the address on top. Any unvisited addresses that she could travel to from here according to her new map would become part of one village. And hence she made the first village.

She would continue marking villages, as long as the address on top of her stack was not part of some village already. At the end of this, this ginormous task was finally complete. She had marked out every single possible village in her assigned pocket, with the help of just her own stack,

and a handy map. Reporting so quickly back to other programs of the operating system shocked the entire system, and she was then appointed by the operating system to go around the hard drive to teach this technique to local officials.

6. A Highway for the United Drives of NANDS

Longest path problem

What driver will not tell you that their most favorite experience in daily commute is on the highway! Highways are just simply put, very fun for amateur and daily drivers. They allow some of the highest speed limits in any place, they are usually very long and uninterrupted, and best of all, there's no pesky pedestrians lurking about, attempting to cross the road (usually, but I do acknowledge that a highway crosser may appear once in a blue moon). This story is about when there existed no highways in this computer world, and how the first highway came to be.

The Operating system had held a meeting to discuss methods to reduce commute times for the citizens of the hard drive, as it had always been a persistent problem here. But today, they had resolved to get it fixed. "A Highway!" said one of the ministers. He had heard about highways from programs that had come from other hard drives, and the concept fascinated him. With a convincing description he managed to receive approval from the Operating System to do this task.

Constructing a highway. What could the first step be? Figuring out from what route the highway would take. And what would the most optimum route for a highway be? One may never know what conspired within the walls of the minister's office that day, but it was decided that the highway would work best if it were the longest path in the hard drive.

Now, the task at hand was to find the path in the hard disk with the longest distance. How would that be done? The Minister asked his secretary the knowledge of any person capable of doing such a massive task, to which she said after a few moments of pondering, "Lord DP". I can assure you any answer to a question with 'Lord DP' makes it a serious matter. You see, Lord DP was a celebrity in the hard drive, known throughout for his astounding list of solved problems. He was also unironically known for his fat belly, where he claimed his storage lived.

Children in faraway villages had heard the name of Lord DP, and in a sense, he deserved this recognition. In interviews he often replied to 'the secret behind is magical solves' being intelligent utilization of the relatively large memory space that he had, but it was difficult of the common program to understand how such a feature related to his prowess.

The minister put forth a summons to Lord DP, who found his way to the minister's residency in almost no time.

You see, Lord DP was used to summonses to the homes of ministers of the Operating System, and he often found himself fixing hard drive level problems, and his solutions felt almost trivial to his hearers.

The minister put forth his query “How does one calculate the longest path …” and was cut instantly by the Lord, “from every address, the longest path is an increment of the maximum of all lengths of longest paths coming to it”. “What?” asked the minister, an occasional response to Lord DP. He knew whenever such a question was asked, he had to be clearer.

He began, “Consider any random address space on the hard drive which as access to the longest paths that its neighbors already have. What would the new longest path be considering that this address forms paths to connect to its neighbors? It would be

1 + maximum of (longest path connected to a neighbor)

Right? Now, I can go to its neighbor and ask it the same question, and I would get the same answer. If I go on asking, eventually I will reach a place that has no other paths connected to it, right? And the answer that place would give me would simply be 0, right?”

The minister was now beginning to understand the genius of Lord DP. In an instant the lord gave an answer,

and it wasn't witchcraft or alien magic, it was simply genius.

Lord DP continued, "If at every address you store the longest path connected to it in this fashion, it will save countless steps. Every time I calculate the longest path from a different point, and I have to repeat the same route, the saved information becomes incredibly useful, simply because it answers several overlapping subproblems. I do not understand why such trivial problems persist to bother the Operating System, have you programs learnt nothing?". "Forgive us Lord, but your existence almost fulfills for our lack of knowledge." Replied the minister.

Make no mistake the minister was a smart man, and his reply proved his wisdom, as celebrities do often possess an unnecessarily high self-worth, and any wrong word can lead to complicated situations.

The minister then instantly jumped to action and began the proceedings to start the design of the highway. These were exciting times as the Operating System continued to develop the hard drive's infrastructure.

7. Bogatyr Borůvka of the clan of Minimum Spanning

Borůvka's algorithm

It is common knowledge that forests are a massive resource for the people of any land. Lands with lush forests have usually been far more successful than lands with lesser forests or none at all. Countless civilizations have been proofs for this case. Why is this the case, one may ponder, to which there exists a simple reply. Forests provide us with almost all of our primitive essential needs.

And so was the case in the hard drive, but there was one problem. This year the harvest was on the lower side. Nothing worth calling a famine, but it was very evident that this could be a hindrance to daily life. As the news of the lower harvest reached the Operating system, discussions and plans instantly began to take shape. A logical person would assume that this wouldn't be as much of a hassle to the Operating system as it seemed, but you see, the situation had more conditions than there would've been had the harvest been low in previous years.

You see, in a normal year, the system would simply compensate for the smaller harvest by redirecting the forest's resources to contribute to the quantity of the

harvest. This however wasn't possible this year, as the forest had been almost starved out. I must present to a disclaimer, no deaths were caused by starvation in the country the year when this story takes place, as there are many countless other forests where the resources were redirected from. But the very occurrence of the starvation of the central forest causing a hassle to the Operating System was a big deal, and hence quick measures to bring the forest back up were being planned.

The task in hand after many Operating System meetings with every minister and representative it was concluded that the discourse to be taken was such that it took minimum effort and every single tree that was removed regrew.

To be able to comprehend such a task I must lay out some ground realities to you.

The programs working for the Operating System are very smart. They know the original number of trees that must be replanted. They haven't allowed any tree to be entirely uprooted; what's left of the trees are their nodes. Every tree has a certain number of nodes, all of which need to be connected to the tree for it to begin filling in the paths. Every path that a tree is known to grow into is already known to the programs. Manually adding those paths would require a certain amount of investment, each path requiring a different amount of investment, based on

various factors such as soil condition, etc. Last of all, financially, the Operating System wants to save as much money as possible, as does any sane person that I've ever known.

It was very evident that to manage this task at such a massive scale, Bogatyr Borůvka of the clan of minimum spanning was the person to hire. He was summoned immediately by a minister; in a fashion you must be aware of by now. As the minister explained the problem that they had run into, Bogatyr with his funny accent exclaimed, "Ah, such problems are my specialty. Calling me was the right choice."

"You see the skill I've earned have training so mercilessly within my family, has given me the title of Borůvka. It is passed down the family to every spiritual successor, as many other titles are. Your problem is to generate a minimum spanning forest as soon as possible."

Impressed by the confidence of Bogatyr Borůvka, the minister quickly appointed him to oversee the regrowth of the forest.

Borůvka began, "treat every node as a little tree of its own and follow the steps. At every iteration, check whether the number of trees is the same as the original count. If not, repeat these steps, else your task is over, and you have to yourselves a minimum spanning forest. Go through the

current list of trees and see the costs of all of the possible paths outgoing from the tree that can be added. Fill in the one that costs the least. While doing this, do not care as to whether a path has already been filled or not. If it were the smallest and it were filled, don't spend the money, and move on. If it were not the smallest, fill the smallest and move on."

Soon enough, under the brilliant instruction of Borůvka of the clan of minimum spanning, a minimum spanning forest emerged. What this meant for the land was that the forest could now sustain itself and enabling growth.

The only thing left to do now is monitoring the mechanism in which the forest's resources are utilised, but that task has been left to the future generations.

8. The Librarian War and Espionage

Interpolation Search

The Librarian war did have many horrific consequences but let this not diminish the positive contributions of the war. Yes, landmines plagued the hard disk because of the war. Yes, thousands of programs were terminated because of the war. Yes, purchasing weaponry from other hard disks caused a major monetary loss to this hard disk and gain to the other hard disks. But today we are not here for that side of the story. Let me introduce you to a technique that almost entirely decided victory for the victors of the war.

You see, in smaller wars before the Librarian war, searching for the enemy's coordinates was a technique that was in its infancy. Many used varying methods of linear search and guess work. Eventually, it became common knowledge that binary search was clearly superior in the public sorted environment, simply because of its speed.

This was because if I were to search in n addresses, the worst case for a linear search would be n units of time, and for binary search that number was down to $\log_2 n$. Such an amount was simply superior in every fashion.

This inherently meant that in the beginning of the Librarian war, everyone tracked down their enemy's coordinates with binary searching. It was simply the gold standard. Towards the end, when the Pointer region was winning, the tables had suddenly turned. You see, their opposers, the Function region, had discovered a mechanism to make binary searching even faster, and they had not accounted for this.

Here's how the Function region's top programs came up with this mechanism to refine binary search so heavily. It was party intensive research and party mathematical prowess. Countless hours of effort and a Eureka moment later, the programs returned a successful answer.

You see in normal Binary search, if I give you a range of n numbers to search, you will first jump to the middle number. If that doesn't give you your answer, you will see if what you want is larger than the middle or not. If what you look for is smaller than the middle, you then repeat this entire process, but your range is now from 0 to the mid point, and you jump to the middle of that. If what you look for is larger than the middle, your range becomes from the mid point to n. You do this till you find your answer, or your range becomes too small to search within.

The trick that the programs of the Function region came up with was to not jump directly in the middle every time. Just think about it. If you believe that your answer

would be slightly larger from the beginning, why even bother jumping to the middle? Simply jump slightly towards the larger side. And this is exactly what the Function region did.

Some say that the binary searching technique was optimised because of this to such an extent that its complexity went down even lower than $\log_2 n$, reaching speeds of $\log_2 \log_2 n$. They called their technique 'interpolation search'.

How exactly where to jump was computed was a heavily guarded secret to the Function region, but now that the war is over, I don't think there should be a problem in me revealing it.

Let the starting address be o, ending point be h. arr represents the space where we are searching, therefore arr_n is present at address n. Let x be what we are searching for. The position one would jump to in binary search was given as (o+h)/2, but for Interpolation search the next position to jump to is given as:

$$o + (x - arr_o) * (h - o) / (arr_h - arr_o)$$

Many smaller conflicts still go on in the hard disk, but interpolation search has been a boon to society. It has provided with faster search and rescue operations, faster communication, delivery, and so much more.

9. The Cold War and Surveillance Technology

Exponential Search

There have been multiple smaller conflicts beyond the Librarian war, but that should not limit your thought to these conflicts as objectively small. They have merely been relatively smaller than the Librarian war. For example, almost immediately after the Librarian war, the cold war had begun. One might say that this war wasn't actually a war, and I could agree with them, but the nomenclature isn't the focus here.

The Cold war was infamous for the opposing factions increasing spying on each other and not much else. At any point in time during the cold war, one wrong move by either side could have meant the frying of the hard disk, such was the modernisation of weaponry in the opposing factions.

This "war" didn't have as many casualties, but the surveillance technology that came out of it was certainly commendable. One of these technologies was a modification of the famous binary search, dubbed exponential search. Exponential search might not have

been the result of technological superiority compared to prior decades, but it certainly defined an era.

It all began when a faction had wanted to search for an enemy program in an address space that was beyond their limited range. If you may recall, binary search requires a range, a first and last address, to be functional. At this point for the faction's only choice was to use trusty old slow linear search, but the slowness of this searching was very slow for their purposes. The enemy might have already been alerted that a searcher was out, and the enemy might have relocated even further.

A junior searcher program, not known for his wit, then asked himself, "why don't we just use binary searching if we want to find the enemy". This was overheard by another program who then began to meditate upon that. Granted, it is physically impossible to run Binary search on an area with no range, there must be some way, he thought, that something very similar in complexity could be done.

And then the technique struck him like a blow. The entire idea of a binary search is to discard half of the data where one is sure the answer isn't found. That can be executed in an area without range quite easily. Simply, put, traverse the address space from the beginning onwards in an exponential fashion. Until you find the enemy, or find data larger than the enemy, traverse the address space as 1, then 2, then 4, then 8, and so on. If say you find that

space 8 has contents larger than the enemy, you can confidently say that either the enemy is present within the range of 4 to 8, or the enemy doesn't exist. After that, you have a range with you, and you can simply use binary searching or interpolation searching to find the enemy.

How does this discard half the data one may ask? Well if I've checked that the enemy is larger than 4 but lesser than 8, I can simply discard all data before 4. Within the range of 4 to 8, I can continue binary searching in its original fashion, discarding half the data every time.

This method the program learnt immediately and set out the find the enemy. The enemy's signature was 165478, but at the end of the day when the brave searcher program reached the suspected address space of 1206, no one was present. He reported back to base, "There was no enemy present here."

Many similar instances avoid physical conflict in the cold war, and exponential search has now become a one of the few almost essential techniques known by almost every program of the hard disk.

R10. The Librarian War and Coordination

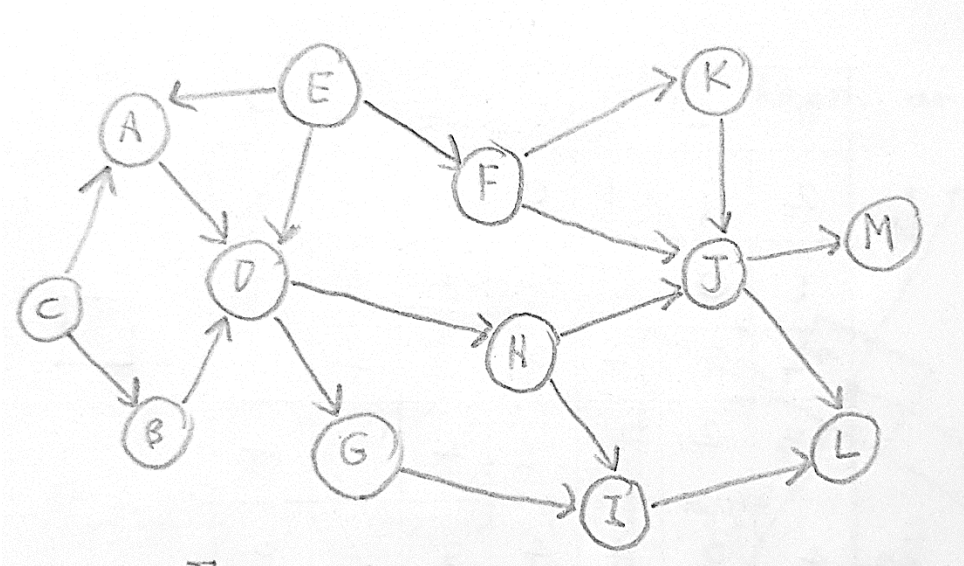
Topological Sorting

In the following story, spyware mustn't be assumed as the software that is used between multiple devices in our human world. It is meant by the author to simply mean any program being that is a spy in terms of occupation.

The Librarian war was famously known for introducing many warfare tactics. Direct military conflict wasn't the only thing that made in the Librarian war. A lot of surveillance, spying, backstabbing, politics, and propaganda contributed to both factions of the war. One must know that spyware programs were a central part of information gathering within the war.

It is to be noted that spyware programs require extreme diligence and adherence to coordinated executions to ensure their success. In one such instance multiple pieces of information were held up with multiple programs. All of this information was important to their faction, but it was absolutely crucial for them to weave this information in the appropriate order to decipher it. What

the spies knew for certain only was the ordering of a few of their pieces.



The ordering known by the spies

Luckily for the spies, this kind of puzzle was no big deal. They had all practically lived their lives solving puzzles of this nature for a living. It was only but a mere game of coordination. And so, they began performing their technique to resolve this, which had almost become a ritual to them after all of these years.

Everyone would begin in the wait list. One of the programs would be randomly picked, and his piece's

requirements would be viewed. If some other piece depended on this piece, then the attention would be transferred to that piece. This would continue till a piece would be found which no other piece would require. The program holding this piece would then shift over to the done list.

The order in which the spies stood in the wait list didn't matter, but the order in which they stood in the done list did.

Now, the person who had been reached immediately before the one sent to the done list was to be given attention again. Was there any other piece that required this piece? If so, the attention would pass on there; if not, this piece would then be transferred to the done list. This mechanism would continue till the program selected originally was in the done list.

Since there could still be many more spies in the wait list, the entire process from the random selection till the original program's transfer to the done list would be repeated till no spy remained in the wait list.

And voila, an order of programs emerged within the done list, from the last spy to enter to the first spy to enter. This order they had to explicitly remember till they reached base camp, safeguarding each other, so they could begin

the process of decoding what information they had uncovered. But that is a story for another time.

11. Wars before the Librarian War – Cannons

Heap Sorting

Canons were all the rage during the initial phases of the Librarian war. They were technology that was invented many ages before the Librarian war, and hence found their way in it. They were although quickly out of order, as more advanced technology came about. After the age of the canon, it was the age of the missile, as one didn't need to be even remotely in the line of sight of the place that they were targeting. The devastation caused by the Librarian war will forever be in the memory of the programs of the hard disk and is one of the founding principles of the new operating system, but we aren't here to talk of that.

Discussing how canons work and the strategy used to maximise their destructive power while minimising wasted time and energy is a fundamental part of the scientific education given to high school programs, and it is definitely an interesting discourse.

It is to be noted first and foremost that canons of the hard disk function very differently from the gunpowder canons that our world is accustomed to. Our canons are heavy beasts that plot a single type of heavy ball in

trajectory towards the enemy using purely the power of combustion. This is far from the case in this world of programs.

Canons here are capable of plotting the trajectory of objects of varying weight and volume. Another difference is that they do not use gunpowder, but further information on that matter I could not gather.

Taking advantage of this permission of the usage of variable weight in the canons, a common strategy was adopted to maximise destruction, the origins of which are also unknown to me. The strategy is to strictly use balls of differing weight, in an order such that the heaviest is always the next one to be shot.

In many canon centric battles what led the victory for a side usually was the speed in which the soldiers would load up their canons for this mechanism. And in the story the unfolds I will tell you about the fastest cannon that was ever loaded.

The balls were laying Infront of one of the cavalrymen, and he was thinking of a method in which these balls could be transferred in one go in the wagon that was attached to his horses. This was out of sheer laziness, so here is what the man did. He didn't wish for any of the balls to fall out of his wagon, and one way this could be ensured was to ensure that any ball is to only be stacked

above other balls if they are smaller than it in size. It is to be understood that since they were all made of the same material, they were all equally dense, and hence their sizes were proportional to their weights.

It was therefore a purely symmetric decision by the cavalryman to stack the balls on top of each other in this fashion. This symmetry did ensure that the cart could transfer the ammunition to the cannon in one go, although slowing the cart down as compared to taking the ammunition in parts.

When the cart reached the canon, it was opened from the top, where the largest ball was immediately on the top. This gave the artillery operator a first ball to fire instantly, giving their faction the first blow. Other cannons couldn't even begin firing, simply because their carts were still showing up with the balls.

After the first ball, the cavalryman was asked to provide the artillery with the following balls. It was simple for him, simply because of the arrangement that he had done for the balls before bringing them in. He'd look at one of the balls in the bottom of the stack and put it on the top. Now, he'd see if any of the balls that were supporting it were larger than it or not. If any were, he would then swap the ball with the largest of its supporters. He would continue to do this with the single ball that he had transferred till the heap that he had made was stable.

The thing about his mechanism of stacking his heap of balls was that only this much was required to ensure that the heap was stable. All other balls in the heap were already in the correct place. The time that he had spent making the heap for his cart out of laziness shaved off the loading time for the canon dramatically.

And then, the rest of their canon fires were similarly very fast. It is to be noted that the technique pioneered by this cavalryman is now named heap sorting, simply because of the heap that is required before sorting.

It is also to be noted that the artillery person in command of the canon eventually died in that battle, but not while manning the canon. It was a stabbing that took his last breath.

12. The Librarian War and Identity

Merge Sort

The Librarian war had many competing technologies evolving for all aspects of the war. These technologies have helped advance the hard disk in many ways, but they were born out of destructive intent in the war.

Address spaces in the hard drive conform to the standard identification mechanism as defined by the operating system, but this wasn't always the case, and during the librarian war, it almost became a matter of a side's pride to ensure that the mechanism of identification of regions within their stronghold used their method of identification.

Providing identification mechanisms for multiple address spaces would usually involve sorting the address space pointers (what would point you to that address space) in some regular increasing or decreasing fashion. Any identification mechanism that does not involve sorting in this world of programs would me a modern innovation. Keeping this in mind, I must tell you the story of rival factions reforming their territories. The speeds of their reformations had eventually led to the demise of one.

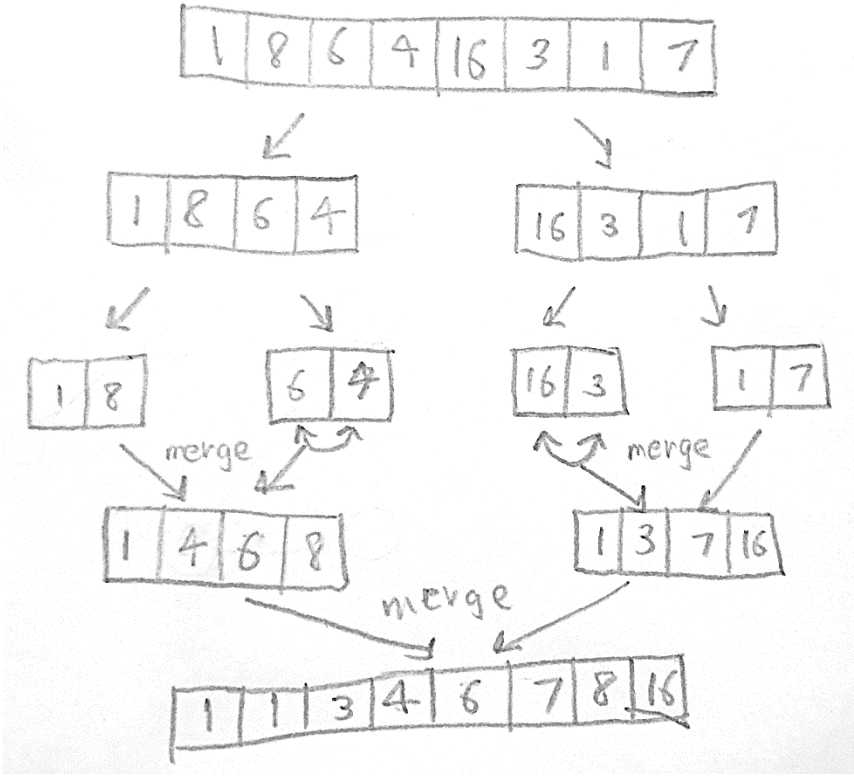
This is the first part of the story, and it is regarding one of the factions. The faction had just captured fresh territory that it had wished to readminister under their regime with their protocols. Their captor, the leader of the faction, was a short staunch angry program, who was extremely passionate for organising things, and it was him who demanded the rebuilding of the identification mechanism for their entire territory. This decision came as a shocker to the people that worked under him, as even newer territory was on the horizon, almost waiting to be captured; this demand would require them to rebuild all over again.

But an order was an order. The last program to speak up against the leader was terminated in public.

And so, a committee sat down to figure the most efficient way to sort a little more than ten thousand addresses. After a few days of discussion, as the committee neared the deadline, they began panicking. Their panic was justified, as they wished for their headers to be intact with their mains. Amidst their panic, a solution had formed, and it was proposed as follows. Such a task would most definitely require dividing and conquering, as the plunderers were very proficient in this.

It was decided that every address in the array would be divided into two arrays. This division would continue till singular addresses were left as arrays. Then, the plunderers

would begin the conquering. Every two adjacent arrays would be compared and merged in a specific way.



Each array would be compared, every address at a time. The smaller address of either of the arrays would be chosen to be placed as the first address of the new merged array. This would continue till both arrays would be

entirely merged. This merging would ensure that every array henceforth would be sorted before merging.

This mechanism was instantly deployed, and deploying it wasn't a hassle. This was partly due to the fact that the members of the faction were almost accustomed to dividing and conquering.

Towards the end, I do not wish to spoil the fate of this faction to you, but what you may know now is that this region's future has been deeply intertwined with the region of the opposing faction.

13. The Librarian War and Lord Bogus

Quick Sort and Bogo Sort

I must continue the fable from the previous chapter, as promised to you. A tale of two factions, the fates of whose regions were forever intertwined after the events of this story. On this side of the moat that both factions had built, an entirely different story was playing out. The rogue self-proclaimed Operating System had declared a contest amongst its subjects for who could come up with a scheme for relabelling its entire address array to a sorted order.

It is well known that competitions raise creativity and innovation across all platforms but judging by the reaction to the competition by common population this didn't seem to be the case. Such things are a common occurrence under weak governments it can be noted for this world. The people were at best uninspired.

There were, however, the enthusiasts: people tucked away in small pockets of the region, who took this very seriously. One such enthusiast was Crowbar the frail. One mustn't judge Crowbar by his name for he was a very evidently determined program. He was only named so by his parent because he was very vulnerable at the time of his birth.

Crowbar set out with a team of his friends to figure out the fastest way to sort the address array, so they could win the competition. It was a big deal for him as it would add to his never-ending list of accomplishments. It is very likely that this list of achievements was so because he was named 'the frail' from birth. Destiny is weird sometimes, isn't it so?

After hours of brainstorming, the bunch was distracted. The conversation was along the lines of how balance is necessary in the universe, and any imbalance would butterfly to destruction. This group of people was after all highly intellectual. The conversation, however, got Crowbar thinking. Perhaps the key to the quick sorting is a mechanism that utilizes some sort of balancing.

And an algorithm struck his brain. He couldn't contain his excitement as he brought out the ideas board that had been hid away due to the group's philosophical distractions. He wisely used the conversation itself as a segue to what he was about to propose to the team, as he wrote drew out a diagram under the title for the board, 'quick sort' it said.

The idea revolved around finding a pivot index in the array. A number that would end up closest to the final centre of the sorted array. This number would be set aside. Every address on the left of the pivot number that would be larger than it would be transferred to the right. Every

number right of the pivot, smaller than it would be transferred to the left.

The specific mechanism of the transferring of these numbers would be along the lines of swapping the position of every large left number with every small right number. This would ensure that when the pivot would be returned to its position, all numbers to the left of the pivot were smaller than it, while all numbers to the right of the pivot were larger than it.

What this would in a grander scheme ensure was that any pivot picked would then be transferred to its final position, and it would remain untouched after. Think about it, if all numbers to its left are smaller and all numbers to its right are larger, it must certainly be in the correct final position.

Then, the left and right side of the pivot would be considered as independent arrays. The entire process of finding a pivot would be repeated in these two smaller arrays. This repetition would continue recursively till every remaining array is a single element big.

Worst case, in such an algorithm, every address would be visited proportional to the number of addresses. But that all came down to what the chosen pivot would be. If the pivot were chosen in a more sensible manner, this ratio would greatly reduce. Of course, since it was a sorting

algorithm, every address would require to be visited at least once, but the ratio of visits would be far less than proportional to the number of addresses.

This breakthrough, that they believed, was taken to the leader of the rogue Operating System. They did submit their technique for evaluation later as compared to some other applicants, but that wasn't a worry for them, as they believed that it was for sure that they would win. You see, no other program was able to crack the proportional visits ratio, no program but this bunch, Crowbar the frail and his gang of street philosophers.

***

It was result day, and the anxiety was killing Crowbar. He leapt up and got himself ready far earlier than he anticipated, but this was almost expected from him judging by his behaviour in past result days. There was almost a feeling of comfort in the air, built up due to Crowbar's past achievements.

***

Lord Bogus, the court clown for the rogue regime had also decided to submit a method for sorting. This wasn't really expected from him, as the man was only known for dropping wise words at the end of half funny skits. Many courtiers suspected something far more sinister from him. You know those people, conspiracy theorists.

***

All the applicants (which there were not many of) lined up as the leader announced what sorting mechanism had won.

“Bogo Sort, submitted by Lord Bogus, has been the fastest sorting mechanism in our capability. Because of this, Lord Bogus will be awarded with 500 Crowns. His algorithm has worked in a single pass, the lowest complexity of anything that we’ve seen.”

Crowbar and his squad were dumbstruck. What was going on. Something was up. How did this happen. And worst of all, his perfect streak of achievements had ended. Teary eyed, he ran to Lord Bogus, who was only mildly interested in the affair. “HOW DID YOU EVEN DO THAT” he cried. Lord Bogus had a simple reply.

“You naive child. If you were even slightly wiser, you would know that the entire array was already sorted. All I had to do was run a check. If the array was sorted, that was that. I didn’t know what to do if the array somehow wasn’t sorted, so I simply said to shuffle the entire array again”

Crowbar was heartbroken. But that was that, and life must move on. It always must.

***

You may ask how all this talks for the fates of the two factions. You see, because the “Bogo sort” was so “efficient”, the faction immediately moved on to get the first move and evidently the upper hand in a battle against the faction in the previous chapter. A very decisive victory for this faction was declared. The rogue Operating System foolishly used Bogo sort again on the new territory, and it worked only once again, as Merge sorting had already sorted up that region.

For merging the two address spaces together however, wise programs in the new council for the rogue operating system decided to use the Merge algorithm from their merge sort.

This consolidated both territories as one, both people as one, and both factions as one.

14. The Librarian War and a Refugee Crisis

Knuth-Morris-Pratt pattern searching algorithm

The Librarian war was in its peak when the then winning faction had realised that a new crisis was emerging, one which would last for years after the war. A refugee crisis. Many who had found their kind being prosecuted on the other side of the border, many who's homes had been destroyed to rubble, many who didn't ideologically support a faction, and many who were living simply in impoverished and criminal slums decided that the region that they were born in was not going to the region that would die in.

Many moved borders with hopes and aspirations for future generations that they would raise. And there were a lot of those. During these times, many physically crossed the border, only to find themselves and their families in newly established refugee camps. These camps were difficult to manage initially, as no other program had thought of a structure for such a situation before this.

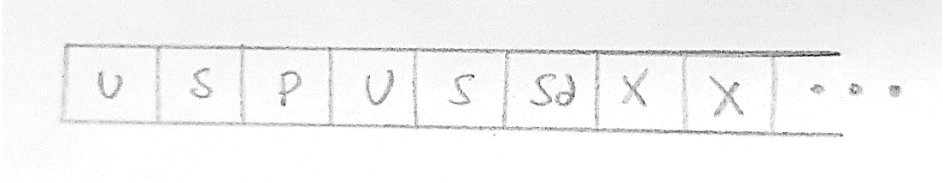
Many problems rose, some which were fixed, some which were left as is, because it didn't seem to be worth the effort. You can't forget after all that all of this was in the

midst of the most destructive war ever on this disk. This tale is in regard to one of the first problems that was actually fixed.

The registration of a new refugee in the camp entailed distribution of clothing. It was a fairly standard procedure. Garment makers proficient in mass producing clothes for the cheapest of cost were ordered on a regular basis to produce clothes that were supplied to the camps. A distributer (usually an applicant to the armed forces who could not qualify for physical reasons) would then give a certain number and quantity of clothes to every person.

These clothes were to be kept in their set till the day the refugees left the camps. What this meant was that the underwear, shirt, pants, underwear, shirt, and sandals that were given to every refugee were to always be stored in that order in the provided storage array.

It is safe to assume that the refugees arrived with their own garments as well, no one was yet to show up naked after all. Every cloth that a refugee brought along was allowed in the camp storage array, with one condition. It would not interfere with the arrangement of any set of provided clothes.



The reasoning behind the arbitrary clothes arrangement was simple. Workers on the camp wanted it to be as simple as possible to log how many complete sets continued to remain. If on some day there wasn't the same number of sets, this would be reported to some senior official who would then see if it were possible to add a set of clothes to the storage array.

The problem was that the mechanism devised to detect this pattern was terribly slow. Every single time a worker program went through the storage array and spotted an underwear, he would go to the next element anticipating a correct sequence. If the sequence was broken at any point, the worker would have to start again from the element after the underwear. The primary reason as to why this was so inefficient can we very easily demonstrated.

It would take a worker a duration of around n*m to finish his task, where n is the length of the storage space and m is the length of the list of ordered clothes.

This slowness was an increasing pain for the workers but was only solved when a worker threatened an official

that he would lodge a complaint to the higher ups. The mechanism of the solution, if I may, are in fact quite genius.

The order: underwear, shirt, pants, underwear, shirt, sandals was to be used to produce a sort of redirection mechanism such that no worker would have to reread any part of the storage array in one cycle ever. What the engineers came up with was a list of indices which was allocated as: if any sequence of elements in the list of (U, S, P, U, S, Sd) is similar to any prefix sequence, then the quantity for that element is the location of its prefix sequence analogue. The quantity for every unallocated element would become zero.

You will ask me what a prefix sequence is for which I have an elegant reply. Any sequence that starts with the first element of the list is a prefix sequence.

Now the mechanism of the workers with this new list had been greatly sped up. Every time the first element, Underwear, was encountered in the storage array, the worker would begin on the list as usual. Whenever an element that didn't match the list was found, the process wouldn't be restarted. The worker would look in his list and see the number given to the mismatched element. This number was the address of the next cloth in the list that he would restart checking from. In the main storage array, he would simply continue checking from the current element instead of going back several spaces.

This was one of only a few small victories in the refugee camps and the rest of the war to be witnessed.

15. The Librarian War and Stalemates

Egg dropping puzzle

The Librarian war had caused a sudden surge in the creativity at its time, and this was not simply uncalled for. This creativity was put into use in several scenarios, which simply would have been left unaccomplished if the miraculous increase in intellect hadn't occurred. From anecdotes, it felt almost as though the creativity came from within the programs in response to the war, as this creativity has it seems seen a gradual decline since then.

This creativity was very well displayed in a long-drawn stalemate on the highly contested border of two opposing factions. Both sides wanted a bit of land off of the other, but the positioning of the soldiers on both sides was such that gaining even an inch could possibly only be achieved by the termination of many hundreds of soldier programs.

A skinny lad by the name of Kazafi came forth in the camps of one of the factions and said, "say captain, why do we not use cannons here?". The captain responded, "cannons might actually work in this scenario say, but you cannot disregard the fact that we are not in liberty to use any number of cannon balls say? The higher ups want us to save a large surplus so that they can use it elsewhere say.

Some of them even say that ours could be the losing side. You got this information from no one, say?"

It was night-time, so the lad reported back to the barracks quietly, but something was brewing up in his mind. "We don't have to use a lot of the cannonballs say, but if we could gain some land it wouldn't be a problem, say?"

The soldier lad was up all night with this thought. He devised a sort of plan in bed, roughly based around the dynamic code skill that he had learnt in high school before dropping out to join the faction. When his plan was done, he couldn't sleep for the rest of the night as he couldn't contain his excitement.

His plain comprised of the following. The captain did not disclose how many cannon balls they had left. What the captain did disclose was that they were meant to use as less of them as possible. How he meant to use them was beyond the lad. What the lad also knew, and this was extremely vital information, was that if a cannon ball landed in enemy territory, there would be no way in which it could be retrieved. If a cannon ball landed outside of the enemy territory, it could easily be retrieved and reused.

The goal of using a cannon was to destroy the enemy wall. Falling beyond the wall could waste the ball and falling behind it could allow reusage. The task for the lad

was simple, it was to figure out the least number of cannon balls that he could ask for such that it would be guaranteed that he hit the enemy wall.

The thing about cannons is, their range can simply be controlled by the amount of gunpowder that is put in them. Fortunately, or unfortunately perhaps, in these trying times the cannons were fixed in angle on the walls of the fort that the soldiers were in. What this means for us is that the lad didn't have to think much about its angle to get the correct range, only the gunpowder quantity had to be thought of.

To better understand his thought process, let us assume a function success(distance, ball count). This returns the minimum attempts to find the wall distance given the ball count. Logically, this implies that this would equal to the smallest quantity of (1 + maximum of either (success(largest distance - i, ball count -1) or success(i-1, ball count))). Here, i ranges from the smallest distance to largest distance.

Now all that was left was run this recursive calculation in his mind. This was greatly sped up because of his high school course and brilliant memory retention.

The amount of balls that Kazafi would request was now fixed, as he approached the captain the next morning.

What happened after is history, as their stronghold was one of the few to break the stalemate.

16. The Librarian War and Communication

Metric K-centres problem

Communication was an essential part of the factions of the Librarian war. Factions who had failed to build efficient channels for communication were some of the earliest factions to either get absorbed or die out. The reason behind that was simple. As a faction's goal is to grow and eventually be the only government around, the land area and the population under the control of the faction grow as well. Consequently, a larger and more diverse pool of programs and hence opinions are under the control of a single faction.

It becomes very dangerous for a large faction to have any form of communication hindrance. It might lead to misleading promises, riots, rebellion, and eventually the dissolution, civil unrest, or conquest of the faction.

Many of the large successful factions were known to have excellent communication mechanisms, may it be frequent post offices, delivery systems, and emergency alert systems.

One of the smaller factions was an early thinker in this regard. With the dreams of expanding into the primary

government of the entire hard disk, the leaders of the faction had decided that it was time that they paid more attention to the delivery infrastructure of the region.

The task on the hands of the leaders of the faction now was to build an efficient postal system, part of which meant placing post offices adequately. Money was limited, although. We must not forget that this was, after all, amidst the most devastating war in the history of the hard disk. At the end, the final goal of the leaders to the exercise that they had taken upon themselves to pursue was to minimise the radius between the limited quantity of post offices that they had placed.

It is to be kept in mind that since the faction was considerably smaller than most others, the distances of all address spaces from one another were known.

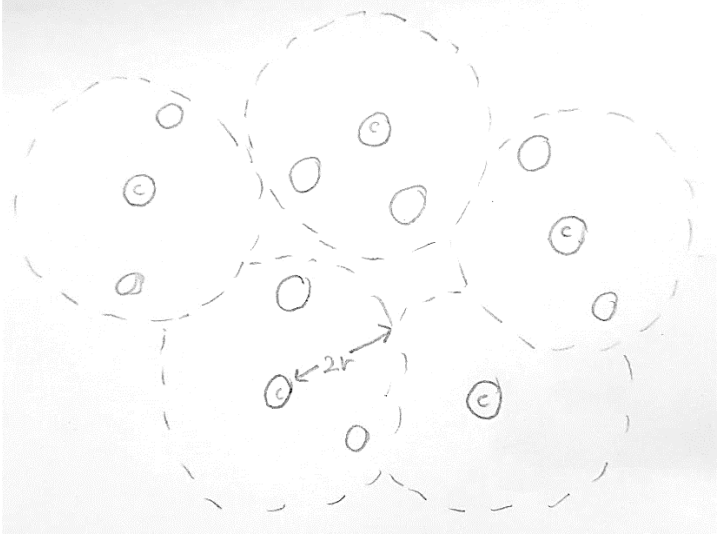
From the beginning it was obvious that there were many ways that this exercise could be done right, there was no fixed answer. In fact, till date, there isn't an algorithm that can perform this exercise in a deterministic fashion. Whatever the programs of this faction could do, they did their best.

The programs in charge decided to begin the process by picking a seemingly random but optimal radius that would be ideal for the positioning of the post offices. They had the money for five post offices. If this chosen radius

wouldn’t satisfy all the address spaces, then the entire process would have to be started again. Therefore, this value was of utmost importance.

The meeting base of the faction’s leaders was chosen as the central post office. It only made sense. A circle was made on a map of the land, with the centre as the meeting base and the radius as twice that decided as the optimal radius. All of the addresses within this circle were then removed from possible locations for other post offices.

Then a random address outside of the circle was chosen. The entire process of plotting a circle on the map and so forth was repeated for this. Choosing another address and so on was also repeated, and all of this continued till the last post office was decided.



The leaders seemed to be very happy with the resultant locations of the five post offices, as they were appropriately spaced out and were within the reach of most of the population of this faction.

VOLUME II

MR. LONGFELLOW VISITS UNITED STATES OF NANDS

Sai Sriram Yannamani

[2019101029]

1. Mr. Longfellow Enters United Drives of NANDs

Alan Waterman's Algorithm L & Algorithm R

Mr. Longfellow got down the bus with his suitcase and looked ahead. A winding path snaked its way amidst grasslands on either side. At quite some distance, the path dissolved into the beginning of a new country that was on his checklist – United Drives of NANDs.

As he walked along the path, he reached to his pocket and brandished a folded letter made by his friend (without any sort of journalism background) who came to this very country a few weeks ago. The first few sentences read:

"I have never seen quite an enthralling habitat all over this hard drive! I'm glad that you asked me for guidance to navigate NLT. My skill of Travelling Salesman Problem has been embedded into my source code quite a long time ago, funny that it has come to use for the first time in my life in this way. I have arranged some noteworthy memory locations to visit in the shortest path possible…"

Mr. Longfellow saw that the first destination pointed out by the letter was a manufacturing unit of a soft drink company. He walked closer and could discern a rather large

and grey building near a binary (river) stream. Pocketing his letter, he hastened his pace.

***

All the immigration paperwork was done – such uninteresting details have been left out. Mr. Longfellow had to spend good few minutes near the security gate. He informed that he was a licensed journalist from an independent journalist agency and on its behalf, had come to explore United Drives of NANDs to write an extensive book piece/book about it. The security program then came with the approval of the factory's local head.

The building that he was guided into was a simple steel roofed cuboid. Inside was a complex production line, among which Mr. Longfellow could recognize tanks of raw materials and a conveyor belt. Next to the belt was a slightly fat program waving at him. He must be the head.

Formal introductions were over between the two in no time, interleaved with sips of the drink. As Mr. Longfellow continued his questionnaire, Mr. Drinkmore, the head, said – "Where we are is the end of the production line. I do the job to estimate the amount of our 'secret ingredient' present roughly in each can. For each can, I can stop the belt momentarily to decide whether to include it in my reservoir or not – if I stall too much, the belt will get a traffic! Although we produce really large number of cans

each period of work, I have a way to select a good number of samples."

Mr. Drinkmore then turned in his chair towards the belt. He then signalled to an employee who came and stood beside him. Starting from the next can that arrived, the head picked twenty of them one-by one and placed them in a neat line on a table, indexing them from 1 to 20.

After this, for every can that arrived, the employee told Mr. Drinkmore a random number 'J' between 1 and the number of cans that have arrived so far (which was twenty-one at that time). Mr. Drinkmore then quickly checked if J was lying between 1 and 20 – if it did, he took that can off the belt and used it as a replacement for the can present at index J on the table. On the other hand, if it was greater than 20, he simply ignored it.

This ritual continued for a while. For the few iterations, Mr. Longfellow took notes of his observations. In a while the procedure started to become tedious to even watch. However, Mr. Longfellow couldn't help but notice a pattern develop gradually. As few more cans came out, he kept checking his observation and each time it was confirmed. Then a loud announcement broke his train of thought. "That's that for this session – there will be a break for the production. I can now test this sample," said Mr. Drinkmore.

The head and the researcher stood up. The employee gathered all the 20 samples and followed the head to a room. Mr. Longfellow was however kindly asked to stay outside near the belt, in line with their policy. His mind was preoccupied by the observation he made earlier anyway.

A few minutes passed before Mr. Longfellow saw the two come out. “This was a pretty good haul. Seventeen of them are meeting the threshold for our secret ingredient!” Mr. Drinkmore exclaimed.

“That’s great! Erm, on another note, Mr. Drinkmore, I wanted to tell you about an observation I made while were at the conveyor belt.”

“What is it, Mr. Longfellow?”

“I noticed that the number of cans you discard before you select one for replacement actually follows a geometric progression! Now, why is this useful? I believe this can be used to speed up your process!”

Mr. Drinkmore paused to understand his statement, but quickly asked for an explanation anyway. “What I envision is… you could have your employee hold information about a variable that generates the next term in the geometric progression and maintains a sum of such terms. Now as per my pattern, this number is the next can you are going to add. So, you could then randomly replace one of your selected sample – because it doesn’t matter

which sample you replace in your reservoir. And you do this until the last can, but this time you can easily skip over a lot of cans instead of pushing the stop button for each moment and calculating a random variable for each decision!

Mr. Drinkmore was clearly not the smartest in the room – but he wouldn't let himself look stupid in the room, not when a journalist was advising him on an art that he was master at! He after all had a good amount of pride in himself for having run this branch successfully for a long time. Nodding slightly, he sheepishly remarked – "I… see where you are going, Mr. Longfellow. Infact, it would be very generous of you if you could document your idea and send it to our research team via the company's file descriptor. I am sure they would like to verify! And if your proposal is indeed marvellously true, well, you might have indeed done a great favour in speeding up my job!"

Farewell was bid after some time – then, when Mr. Longfellow was long out of sight, one of the employees could hear Mr. Drinkmore whispering to himself - "Damn these technological advancements! Soon, they will probably replace me in my job!"

2. Mr. Longfellow Rides with a Deliveryman

Kruskal's Algorithm

Mr. Longfellow had stayed in a small inn after his visit to the factory. Close to the inn was a motorbike rental – to which he promptly entered after some rest and rented a bike. He started his second day in United Drives of NANDs at around eight. He consulted his letter once again – the next destination was VirtualDelivery. His friend wrote that one of the easiest ways to visit several neighbourhoods without having the burden to decide where to go, was to join someone who would do exactly that – a deliveryman!

***

Just when the clock struck seven thirty in the morning, Bob Binaryman came outside, shut his memory shack's front door and locked it. He then hopped onto his old motorcycle and drove it towards the north. In a few minutes, he would reach VirtualDelivery's main company building where he works as a deliveryman. It was the largest chain of goods delivery in the country.

The main building was a massive monolith, with all kinds of offices situated in it. Bob drove around it to reach

the backside where like him, several other deliverymen had already arrived. After a few moments, he parked his motorcycle and rushed towards the back entrance.

Having worked there for several years now, he glided through the corridors and between floors without any effort. Upon arriving at the dispatch area, he saw a small queue already lined up to take their respective orders. Several minutes passed until he was the program who would be assigned work. The dispatcher program sat in a bored stance. Standing next to him was a man in a suit. The dispatcher, before he gave the list of parcel IDs, informed - "Just your luck, Bob – this gentleman here from an independent journalist agency has requested the office to join a deliveryman for today so that he can explore our city and analyse it! And you have been randomly assigned to it – don't blame me, I believe they used that Blum Blum Shub Algorithm again!"

Bob proceeded to find all the parcels with such IDs and placed all of them in a bag after the hunt. Mr. Longfellow introduced himself to him. Bob then walked into small room to his right corner and asked Mr. Longfellow to wait outside. Inside was Sam Signalcatch, who works for VirtualDelivery as a route plotter.

"Morning, Sam!" Bob began and placed the twenty addresses on the table. Sam returned the greetings with

equal enthusiasm. The deliveryman sat before the table and placed his bag down.

Sam took the twenty cities and arranged them on one side of the table. On the other was a large programmable map of United Drives of NANDs.

Underneath each place in the map was a Boolean variable. Sam marked the variable as 1 for each destination that Bob had to travel that day. Whenever he marked them, all the wires connecting the places grew brighter and all the others grew dimmer.

Now began Sam's real work – he would now use the Kruskal Skill that he acquired from university long ago. Taking a pencil and paper, he kept twenty dots, each for the twenty destinations. Then he looked at all the glowing routes and searched for one with the smallest length. After finding it, he noted the street name corresponding to it and drew it on the paper between the two places it was connecting. By his algorithmic nature, Sam the program was obliged to check if the wire he had added had made all the twenty destinations connected; clearly, the answer was no.

Before he proceeded, Sam first maintained another data structure internally in his source code. Out of the two cities he had just connected, he chose the smallest 'tree' (in this case both were of size 1) and attached it to the one with

larger tree. He also effectively made the parent of the places belonging to the smaller tree as the parent of the larger tree.

Once he updated the tree sizes, he now repeated what he did earlier – he looked for the next shortest wire. Upon finding it, he once again drew a line between the places it connected and noted the street's length. But when he came to adding the third street into his route, he had some extra work.

He found out the third shortest wire and drew it. But when he did so, he noticed one thing – running his extra algorithm Union Find (which he obtained as a credit requirement while studying for Kruskal), he found out that the root location of the two places was the same. Which meant that the two places had already been connected in his route plot! Because if they weren't connected, then their trees' roots would be different (everything was initialized as themselves at the start).

"Now I have to remove that – it would cause a cycle, and an unnecessary trip for Bob!" Sam thought in his mind. Accordingly, he erased that edge and continued. Every time, he checked if all destinations were connected – by simply checking the number of edges he added were 19 or not. When it was done, Sam handed over the paper to Bob.

“The speed with which you guys calculate it always amazes me! While I was sitting, I noticed that around 500 wires glowed on the map, and despite that, you just gave me the answer in just over 3000 time-units! Why does it work?” said Bob.

Sam gave a little chuckle and replied, “What you said is true – the time I took is probably around that figure. A careful mathematical analysis (which we were forced to do as a course when I was studying for this Skill) gives the same answer. Now, I suggest you hurry up – some of the streets and lanes I added today are long! And I heard someone is accompanying you?”

Bob explained the answer and joined Mr. Longfellow outside. Soon, the two set out for the first destination given by Sam – House 22, Paging Street 11. During the journey, Bob and Mr. Longfellow conversed quite a bit, with the latter asking most of the questions. In that process, he gained quite a lot of insight. He was also impressed by the number of deliveries Bob had finished by midday – this, he deduced, was equally creditable to VirtualDelivery’s efficient route plotting and Bob’s commitment. He noted in his diary at the end that of course, the society improves only when even the basic jobs like delivering are done dutifully.

3. Mr. Longfellow and Maria Save FarDrive

Karger's Algorithm

Mr. Longfellow was instructed by the letter to visit The FarDrive on the third day, but at the end of the stay he wondered if his friend were a psychic, or it was a mere coincidence provided by the Travelling Salesman Problem, for on that very day, FarDrive began to witness the beginning of change. The change was noteworthy – because of which, Mr. Longfellow's planned stay of just one day incremented to several.

The FarDrive was the furthest town in the country of United Drives of NANDs. That was one of the many reasons why it was also the most underdeveloped area in the entire memory. Most young programs cannot pursue better education due to lack of such an infrastructure. Therefore, it was indeed a cause of great surprise and celebration when the town heard back from Maria, who left the town several years ago to ambitiously pursue further learning, had successfully obtained her degree in the class of Min Cut. Of course, the people of FarDrive didn't know what Min Cut was about – they just know (or cared) that finally a child of their locality had hit heights.

Programs, especially those who were as old as Maria herself, were very excited and thronged towards her when she entered FarDrive. And whatever ensued for next few hours or so for this was on similar grounds, with her parents finally fending off incoming guests, persuading them to call it a day. Mr. Longfellow, being a journalist was no doubt interested in it too.

When it was evening, Maria ventured behind her house, into the small garden. For a while, she gazed at the sunset. But a moving figure in the distance caught her attention. She couldn't discern what it was clearly, and when her brother came and stood next to her, she enquired.

"Oh, it's the water tanker. The vehicles have changed, so you might not recognize them!"

"I have been gone for all these years, and the water situation hasn't changed, huh?"

"Not one bit. It's the same - FarDrive's municipal head keeps promising each year, but no, little or no improvements have been seen. Only the ones who can manage to somehow afford the tanker have adequate supply. By the way, there is some journalist at the door, who wanted to meet you and interview you with a couple of questions."

The meeting between the two was brief as Maria sought some rest, but Mr. Longfellow was slightly piqued

by the water issue that she mentioned in the chat. That night, Maria resolved to do something. After all, she didn't pursue higher learning without any purpose – it was time for her to find what's happening in her hometown. And in the middle of her sleep, she hit upon a way to use her degree in Karger's Algorithm.

***

The next day after breakfast, Maria departed from her house to the local municipal corporation. Mr. Longfellow had met her on the way, and as a result he joined her task. Once there, they followed the way to the Water Department. The queue here was very small compared to the general queue near the main entrance. When Maria's turn came, the officer asked with a hint of laziness – "Do you have another water complaint too? Just give me your house and street's memory address, we'll look into it." Mr. Longfellow was quite a bit surprised.

"No, I have not come for that. Rather, I am here to request a copy of the pipeline network that connects FarDrive to Operating System's Central Water Dispatcher. And I'm sure the Right To Information act enables me to do so," Maria replied coolly. Mr. Longfellow nodded in acknowledgement.

The officer showed a slight hint of surprise – he didn't receive such requests often. This was new. Quickly

recovering, he ordered one of the clerks to reproduce the main copy of the blueprint (the clerk was a program who had the simple algorithm of copying from one data structure to another – lack of access to higher education gave him no chance to be proficient in any other skill).

By lunch, Maria was home with the blueprint. That afternoon, she began her work, starting by poring over the blueprint and feeding her source code the input (which was all the pipes, their lengths, and their junction points). "There are twenty pipeline junctions in FarDrive. This means I need to perform my evaluation over five hundred times! Guess this will take several days to get a conclusive answer!", she thought to herself.

The next day, Maria began with the first iteration of her next phase. But she was going to need help – so she called Ray, her childhood friend who she knew could generate random numbers (although his unrefined education tended to make them slightly predictable). Mr. Longfellow had also requested to join, and Maria didn't mind this – after all, he could be a possible outlet to spread the word. Once they were settled, Maria asked Ray to generate a random between 1 and 500 (which was the number of pipes with varying number of capacities she found out after counting them last night). He provided her with the output, then Maria peered over her blueprint.

She located the pipe she labelled 5 (which was the number Ray generated). She then located the two vertices in the adjacency list she created last night and merged them into one. In doing this, she reduced the total number of vertices by 1. The final step before proceeding was to connect all the pipes that were previously connected to the two old vertices to this new composite vertex she created.

Ray then created another random number and informed Maria. Maria then performed the same steps that she did earlier. This ritual kept occupied the friends until Maria observed that only two composite vertices were left. She signalled to Ray that their tedious work for today was over, and then counted the number of edges between the last two remaining vertices. There were 5 of them – and their total capacities were two hundred water units. Maria was slightly surprised, but she knew that this couldn't be the definitive answer. The answer would be somewhere there in the next 568 tries.

Ray was more than happy to help for the next 568 trials when he heard about Maria's intentions. Mr. Longfellow couldn't let this story slip away now. So, day and night the duo slogged, Maria updating the minimum cut in every iteration. And the day came soon, when all 20C2 times the natural logarithm of 20 trials were finished – and Maria had conclusive proof of the municipal

corporations' incapability. Mr. Longfellow beamed and said - "The newspapers will have a field day!"

At the end of the 569th trial, Maria saw that the minimum cut was finally just 2 pipes – with a max flow of 25 water units! This was way below than the recommended and proposed limit by the Operating System. No repairs had been ever done in all these clock cycles to address the state of the pipes reaching FarDrive.

***

Maria had become a sensation in the next few weeks. Her publication as well as complaints raised the issue all over United Drives of NANDs and soon the Operating System had taken the matter into serious consideration. After quite a flurry of revealing of corruptions from the municipality of FarDrive, with Mr. Longfellow vastly assisting Maria, order was established and soon, the outcast Town began receiving their fair share of water. Maria had thanked Mr. Longfellow for his great help before he decided to leave to pursue the next destinations in the list.

4. Mr. Longfellow Visits the Library

Morris Counter

Susan worked as a day receptionist in a motel near the outskirts of United Drives of NANDs, which wasn't very far from FarDrive. For that very reason, Mr. Longfellow had been staying in there for all the while he had helped Maria.

Her shift usually got over just after lunch when the other receptionist took over. That was her second most favourite moment of the day – she only did the job to make ends meet. It was the second most, because the first place was taken by hitting the public library after her long bus trip to home. She would lose herself in the books, especially those concerned with the history of United Drives of NANDs as well as other towns populated by programs. On that day, Mr. Longfellow's check out and the end of her shift had coincided – and given that Mr. Longfellow had developed a small acquaintance with Susan, he asked her if he could accompany her, and show the library to him.

***

The long trip and the shower had been over today – now she came outside, locked her front door, and began her short trek to the library. Before Susan went to her home,

which wasn't far away from the library, she dropped Mr. Longfellow at the library.

After a while, she pushed open the familiar pair of doors, and the noise of the busy street was cut off. She didn't have a membership despite using the library for so long – she never liked to issue books but preferred to finish how much ever she could in one sitting.

She ventured into the history section and produced the second volume written by a certain author. Deciding a place to sit, she opened the page number she had left at previously, and in big black words, written was the heading:

COUNTING IN OLDEN DAYS

Susan began reading the text -

"In the modern world as we know, we can store extremely large numbers in our source codes. With 32-bit memories become cheaper, a very high proportion of our storage needs are indeed very comfortably satisfied. However, there was a time when such high storage was at a kind of unimaginable premium. The most common ones in circulation were 4 or 8 bits.

"This posed a great problem for several tasks that the programs faced – for instance, the census department of The Operating System. It seemed as if this physical limitation could not be resolved for a long time, even

temporarily as a stop gap. But when Professor Mobert Rorris of The University of Paging proposed an idea that compromised a noticeable amount of accuracy, the Operating System listened. And the proposed method proved to be a very good stop gap indeed, until researchers made the dream of 16 and 32-bit storages a reality.

"The method, very boiled down for the benefit of a layman reading this, was as follows: the program initializes a variable to zero. Then, as he or she iterates through the gargantuan stream of input, he or she must generate a collection of bits whose number is equal to the value stored in that variable. Then, the doer of the task must invoke the logic gate 'AND' present in the brain to all the bits. If the result of the AND operation was a Boolean truth, then and only then the variable was to be incremented by 1. Once this procedure was done, the final count could be interpreted as the value of 1 subtracted from 2 raised to this 'exponent' (which of course could not be stored).

This probabilistic technique became quite popular – only the logarithmic value of, well, another logarithmic value of the length of the data size to the base 2 was needed to store the exponent. The fact that the expected value of 1 subtracted from 2 raised to the exponent obtained from the algorithm was equal to n was the main idea.

Susan kept reading for more time, and when she was finished, she searched for Mr. Longfellow everywhere only to find him engrossed in books in the history section as well. She informed him that she would be leaving now and asked if he needed any more assistance – Mr. Longfellow politely replied that he didn't, and that he could find his way to the inn from here, and finally thanked her.

5. Mr. Longfellow Reads History, Part I

Bitap Algorithm

While Susan was reading about Morris Counter and other assorted stuff, Mr. Longfellow was also having a good time in acquiring more knowledge about United Drives of NANDs. He went further back in history, and presented here is an abstract of one of two topics he had found deeply interesting:

There was a time, extremely long ago from now, when United Drives of NANDs, or rather, The Province of United Drives of NANDs, was ruled by aristocracy. It had its fair share of princes and princesses, battles and treasures, but quite anticlimactically, we now take our attention to a small but recurrent 'feature' across the twenty noble houses that ruled the Province – a cuisine checking servant program.

Now, the nobles were a particularly angry when they requirements were not satisfied to the point of perfection. The common folk like us don't mind several dots in our needs, but the aristocrats were notorious for punishing programs if one of out of ten thousand digital leaves in their gardens was short by a mere inch. Or if the one of out the

mistress' grossly abundant gowns was not washed in time by just a few nanoseconds. The list goes on, but it lays the foundation for why they would be even more hot headed when it especially comes to the food they consumed.

The post of cuisine checking servant was handsomely paid – and reciprocatively, it was also the strictest one with almost no margin of error. Only the brave would apply to it (although if a skilled checker was spotted, it must be pointed out that some unpopular noble families used to make him work by force), and the stories of a few of them executed because the rich woman couldn't feel enough sugar in her drink were very well known. We shift our attention to one such brave soul – Andreas – who in a now abandoned language had elucidated such experiences in his now extremely old diary (present in the Museum of Virtual Memory).

It was half an hour to one – when the king's fourth son's fifth daughter's family would come down to the dining hall for their voracious meal (Andreas had just come from his home, where on his way he witnessed several women waiting in line outside a public ration that clearly had very less in stock). The cooks came one by one with their prepared meals and placed them on the long rosewood table that could accommodate fifteen. The cooks and Andreas, he mentions in his account, were never in speaking terms. Which was understandable – if Andreas

found any fault in the dish, the cook was sure to be punished. And if the cook could justify that he indeed prepared his meal properly, but the checker had become erroneous, the checker met a similar fate.

Once all the meals were neatly arranged on the table, Andreas had to check them all one by one. As a part of initiation, Andreas was made to memorize all the fine balances and nuances of spices and ingredients of every item that the family craved. Going to the first meal (which, in this fictional society is just a file with bits and **bytes**), he began his process.

This one had just 5 main ingredients. So, there were essentially 5 main patterns he had to check for in the current file of the meal. The length of the first ingredient was seven characters - and Andreas stored this. Then, he initialized memory for 8 bits, and set the first bit as 1 and the rest as 0.

Now, he checked the first piece (or character) of the meal. He checked if this character was the same as the last character of the ingredient. It wasn't. And the 7^{th} bit was also a zero – so using the AND gate on these two, he set the value of the 8^{th} bit as 0. This setting of continued till the first bit – he changed the value of 7^{th} bit based on 6^{th} bit's AND with the result whether the meal's first character was same as pattern's last character; then changed 6^{th} bit using

the 5th bit; and so on. Once it was done, he moved onto the next character present in the meal.

However, as his procedure continued, only minor changes came in. For example, if he were checking the second character of the meal, he wouldn't compare it with the last character of ingredient (as done in the first iteration), but rather with the second last character. The rule was that the ith character of the meal would be checked against the m-i the character of the ingredient, m being the ingredient's size.

Andreas silently went through the meal as the cooks, lined up along a wall, stared. Soon, the checker servant hit upon a situation where the 8th bit was set to 1 after updating each of the 8 bits for the current character in the meal file. This meant that the ingredient was there in the meal – now he had to check for the other 4's presence. This he did in several more seconds, and to one of the cook's huge relief, he declared that the meal satisfied the requirements.

There were almost twelve other cuisines left – and Andreas had to evaluate all of them in very less time. One by one, the cooks' shoulders relaxed as Andreas kept checking and declaring that everything was fine with a particular meal. Each cook felt that it was another day of survival in their lives.

Andreas finished checking the wine in the nick of time when the couple, their children, the man's parents and several high-profile guests descended. They took their places in the dining table and before eating, the head of the house asked in a stern and cold voice –

"Is everything in place, Andreas?"

"Yes, sire. All as per the requirements."

The cooks were dismissed, and in a while Andreas too – the image of the royal family savouring themselves to abundant chicken and wine contrasted with the impending famine in a small section of the southern side of the Province flashed across his mind just before he left.

That was the end of reading on that topic for Mr. Longfellow. For each day that he stayed in United Drives of NANDs, he felt as if was unearthing a completely new angle of this country to add to his book.

6. Mr. Longfellow Reads History, Part II

Block Truncation Encoding

(Inspired by the events that transpired in England in 1980s, about painting of a crying child - https://www.atlasobscura.com/articles/crying-boy-painting-fires)

The next interesting piece of history he had amassed in his first visit to the library was more recent in history:

On a normal Saturday, businessman Rodney was walking through a street in a weekly bazaar in one of the old and sleepy towns of United Drives of NANDs. He was lost in thoughts – he paid very less attention to the commotion going on in shops on either side of the sandy and crowded road. His thoughts were primarily about finding some new way to boost his income via sales – the product could be anything, Rodney just wanted to market it and capitalize on it. He walked a few more steps forward when he saw a small group huddled, blocking his path. This temporarily distracted him from his thoughts – why was this group assembled?

Rodney saw that the men and women were all looking at something inside a small shop. He tried to view it, but the group blocked whatever article was being displayed. He then slowly wriggled his way amidst the

group and reached the front. There was an old shopkeeper who was busy selling some other goods in the left half of his store – in the right half (where Rodney was looking), was a boy to guard the items present in there. But what the entire group was discussing about was an average sized painting, depicting a crying child program.

***

The fire station of Silicon Sector 11 had to answer a call for the fifth time that week. It was yet another house being devoured by fire. The fire engine exited the station very quickly, and when it arrived at the zone, the house was already half burned. The woman and the two children programs who were the house's occupants had fortunately escaped it. The firefighters took a good half an hour to kill the flames – what remained was a mess of ash.

But once again, the firefighters and the policemen noticed the same sight that they had seen in the past – the painting of the crying child program was untouched by the fire, while everything around it had been torched. The number of such similar occurrences had begun and multiplied only in the past three months, and it was around three months ago that Rodney's company had been selling copies of this peculiar painting.

***

When Rodney saw the painting for the first time in the bazaar, he understood why the group couldn't help but stare it. Rodney was mesmerized by it. It was odd that a seemingly ordinary painting, that too drawn on a bizarre entity of a sad young program, could somehow look so captivating. But the reality was that it did – something in the way the painting was arranged, or the way the brushes were stroked, really made the picture appealing. At the same time, it also inadvertently solved whatever Rodney was thinking all that while – this painting seemed to be of mass interest, but its expensiveness was what holding the commoners. Without any second thought, Rodney invested in it.

By the time it was delivered, Rodney had already thought of what he would be doing with it. He called for an expert in the art of painting manipulation and sought to know whether it could be reproduced easily. The expert informed him that it was certainly possible. Using her guidance, Rodney tied up a deal with a mass-producing house to produce cheap copies of this painting – his plan was to sell it for a later profit.

The painting expert's technique was quickly adapted by the workers. The original composition of the painting, which now stayed hung in Rodney's office, was stored as a template for the encoding workers. Among the encoding

workers, there was a subclass of labour who were there mainly to compute the mean and standard deviations.

The original painting's pixels were divided into blocks of 4 by 4 pixels. The sixteen values of the pixel colours were then sent to the computers of mean and the computers of standard deviation. Then, the block of pixels was compressed by the following rule – if the pixel in the 16 of them had a value greater than mean, it was assigned a 1, else a 0. This was a huge scale of compression – something that would help Rodney to reduce the cost a lot and sell it for cheap.

But the painting was not sold directly – rather, Rodney's company sold this collection of 1s and 0s along with two numbers 'a' and 'b' that were mathematically calculated from a formula using mean and standard deviation. When the painting was bought, assemblers came to the home, and reconstructed the painting using an extremely simple setup – if the pixel had the value 0, then the pixel colour of 'a' filled in that pixel. Else, pixel colour 'b' was used. When this was done, the customer had the cheap and lossy re-creation of the painting.

***

All seemed to go well, as Rodney's initial gamble paid off – people were indeed captivated by the sheer innocence of the painting, and soon profits started flowing. But this

initial honeymoon phase lasted for two weeks or so, and mysterious and repetitive events associated with the painting soon began surfacing. Most notably, numerous cases of fire accidents across United Drives of NANDs started occurring, with the eerie observation that everything except the painting got burnt.

It was not a surprise that soon it had become a topic of discussion and interest in various walks of society. Tabloids and media outlets were on a frenzy as they kept reporting and hyping up some made-up legends around the painting. People who wouldn't have anything with all these superstitions, would buy it, only for their house to also burn just a couple of weeks later. Clearly, the sales started to dwindle, leading to another situation to work on for Rodney. Although there was no clear argument or evidence, some even started to doubt Rodney and his company, if this had been their doing, especially when the original painting in his office didn't cause any trouble. Scientific studies done on it did not yield satisfactory results, rendering it to remain as a mystery even in the modern day of United Drives of NANDs.

That night, when he returned to the inn, he spoke of this mystery with a good number of people staying in there, fuelling some interesting discussions that revolved around conspiracy theories, etc. Mr. Longfellow however did not know that he missed one of the most prominent phases of

the country's history – the Reign of Missler – but as we shall see, he would soon.

7. Mr. Longfellow Travels in Third Class

Huffman Encoding

There really may be not any country in existence that is anything like ‘United Drives of NANDs’, but that didn’t mean that this country of Mr. Longfellow’s primary focus is free from the ‘classes’ in society. Programs who travelled in first and second-class coaches of public transport often wondered how the programs who travel regularly in the third class endured it. It was on two levels – they did not how it felt, and they also did not know how it was done.

But the insider programs of the railway transportation knew it. Especially the encoder programs working in the ticket booking department. Amy was one of them, who presently sat in a small enclosed office that lay behind one of the ticketing booths in Linker Station.

Two men approached the booth for a pair of third-class tickets. The ticketer asked for their biodata, told them to wait and instantly forwarded it to a junior encoder. He was tasked to be an assistant to Amy until his training was over. Upon receiving the biodata, the assistant then iterated through the entirety of it. For every unique character he found, he created a new singleton tree structure in his brain. As for the weight of these trees, he

assigned the value of the character's frequency. When finished, he signalled Amy that the parsing was done.

Now began Amy's work. She copied all the obtained information into her brain and searched for the two trees with smallest weights. She found that there were three characters which occurred only 5 times. Picking two of them randomly, she combined them into a single tree. In doing so, she created a new 'root' whose children in the tree were the two characters she had just picked and whose weight was the sum (equal to 10 in this case).

Then she repeated the same steps – once again, looked for the next two smallest nodes and on finding the, she created a similar tree with two children. After several iterations, there were two trees (which are no longer singleton of course) were remaining. She combined these two and did a cross check by summing all the frequencies that her assistant gave her and comparing it with the weight of the root node of the final tree. She couldn't risk the passengers arriving at their destination without a limb or an eye!

Amy was about to start with second man's biodata, when his assistant reminded her of the blunder that he had just committed and how she had forgotten about it – they both didn't include the pseudo EOF character!

“Wow! How did we forget that!” Amy was taken back. Fortunately, they were reminded of it right in the nick of time. Otherwise, they would have repeated the Train Disaster from thirty thousand clock cycles ago.

Without pseudo EOFs, the trains’ coaches would not know the starting and ending of each passenger who have been crammed inside. This problem did not occur for first and second-class coaches, as all of them were neatly stored in several groups of eight bits. And what happened on that fateful day was that several tickets were calculated without EOFs... and one can only imagine what happened on the destination station – hundreds of programs came out through the screening disabled – if one didn’t have a finger, then some other didn’t have an entire limb.

Amy discarded the encoding tree she had just found out. In the frequency table, Amy inserted the standard pseudo EOF characters specified by the Operating System (it was guaranteed that this never appeared in the DNA structure, again a part of the source code, of any program). This time, she built the tree properly.

Amy and the assistant now repeated the ritual for the second passenger as well, ensuring EOF was there. Upon finishing, Amy sent the two ‘encoding trees’ to the ticketer, who then gave them to the two men, saying: “Here are your tickets”.

The two men go now – but more will come to the booth, and Amy will keep building these encoding trees. She had originally worked for a goods delivery provider after graduation, where she had the similar task of compressing goods to increase packing. She thinks it is funny that now her job is to do this 'surgery' on living programs. Before we follow the two men on their way to their coach, we should note that Mr. Longfellow also had approached the booth for a ticket. His friend recommended him to travel in the third class, to 'experience' it – he specifically marked it in quotes. Mr. Longfellow could certainly afford a second-class ticket. Why did his friend suggest this?

***

Before every coach's entrance was a 'screener'. The shorter of the two men stepped first into and inserted his ticket. What follows is an experience that made only first timers feel nauseous. The compression that Amy had created was applied to the man. On the completion, his ticket is returned to him and is automatically pushed (yes, pushed) into the coach. When his friend, the taller man, also underwent the procedure, he couldn't hold back his laughter at the sight of his tiny nose and extremely shortened limbs. There was someone who probably had boarded third class for the first time, as a cry of "Oh my adversary model (who are basically deities that programs

worship)! I can't feel the cells in my stomach!" was audible. It was Mr. Longfellow, who was beginning to grasp why his friend suggested the third class specifically.

After enduring one of twenty-four parts of a clock cycle, the programs closest to the entrance are again pushed onto the screener present in the destination station. Once again upon the insertion of the encoding tree, the passengers regained their full source code. And they leave the station normally, except that first timer who might feel dizzy for a while. Mr. Longfellow certainly belonged to that category – and when he was thrust out, it too him quite a while to get his bearings correct. His first instinct was to assess his stomach – yes, it was feeling correct. Usually, passengers make sure that they had not lost any baggage in a journey, so it was a new experience for Mr. Longfellow who began checking if all his body parts had come with him. He made a mental note to address his dear friend critically about this. Friendly revenge was surely on the cards for this journalist!

8. Mr. Longfellow Visits the Segmentation Islands

Tarjan's Strongly Connected Components Algorithm

Mr. Longfellow learnt that not all aristocrats in United Drives of NANDs' history were irresponsible, on his trip to the Transportation Department as suggested by his friend. It was the first of a four-part trip to the Operating System for the journalist.

One queen among the long lineage successfully administered the capture of a collection of islands called Segmentation Islands, lying alone in the deep blue ocean in the eastern side of United Drives of NANDs. This queen was a visionary – she saw something in these islands that nobody at that time couldn't (and hence were against it). The result of this huge disagreement was that despite the queen's stern orders of developing the group of islands, the expedition was called off at once after the queen died and a new king took over. Now in the modern day, the current rulers are left with two very true facts – first, the queen was right. The islands proved to great resource of silicon (without which of course, the entire digital civilization wouldn't exist). The second was – the islands were severely underdeveloped as no subsequent rulers bothered about it.

There were over a five hundred islands. Some were close to each other, with short bridges connecting them. However due to historical negligence, several islands were isolated from each other. Transportation of workers and raw materials across these were done via ocean freight. However, the Operating Systems decided that year that a special emphasis would be placed on Segmentation Islands, in order to boost economy. And one of the tasks in the agenda was to build a reliable, low-cost road transportation to connected between isolated islands.

Civil engineer Sharon had so far in her career never been a part of such an ambitious project. But it was a sum of her luck as well as good work throughout the years that the Operating System noticed her and picked her as the layout planner.

At around 8 in the morning that day, she had entered the meeting with a few officials from the Operating System and professional programs from other fields to discuss about Project Segmentation Island. At around 2 in the afternoon, the meeting concluded – and after a short break, Sharon entered her office with the current transport blueprint of the Segmentation Islands. Her job was to find the best possible way to ensure that any isolated island or group of such islands enters connectivity.

She spread the blueprint on her table and began her work. She quickly counted that there were 512 islands, and

for each of them she initialized a Boolean array, to keep track of whether she had finish processing that island or not. Once this was done, she arbitrarily selected an island and set the fact that she visited this island as true. Now for that island, she ignored all the roads and paths that lead into it – but rather, she looked at all the paths and roads that took her somewhere else from the island. For the one she chose, there were indeed 3 three such – she once again arbitrarily chose one of them (keeping in mind that she would come back to check the other 2 too). Upon taking this road, her algorithm reached a new island, and repeated the action of setting the flag for visiting this island as true. This again had 2 roads that lead her to some other landmass. And in this manner, she snaked her way through some 10 islands before she detected that she had reached the island with which she began – a circle!

This was when Sharon knew she had to stop this iteration of processing. She initialized a new variable in her brain, and in it, she made the root as the island with which she began, and the rest of the ten islands as part of this root's 'collection'.

Once that storage was done, Sharon now simply had to repeat the same procedure for any other island that she still hadn't considered yet. Previously, she had already 'explored' eleven islands – hence, she did not have to pick them now. Moving on, she found an island which had no

incoming or outgoing roads at all! This island obviously needed one bridge to 'belong' to the others of Segmentation Island. Sharon created a new variable whose root was this island, but of course, there was no other island in this collection.

In another iteration after some time, Sharon found out another collection of islands that had an island common with another collection she already processed and stored in her brain. The Operating System's aim was to reduce cost by reducing number of bridges to be constructed – so Sharon simply merged these collections in her brain.

Sharon was so engrossed in her work that she didn't notice the pattering of rain drops on her office window and how dark the sky had become. When it was around seven thirty in the evening, she finally finished processing the entire blueprint. She now had to hand over her recommended idea for bridges to an official.

At this hour, not many worked in The Operating System. But Sharon was glad she found the official still in his office. Sharon requested a communication channel with him to transfer her final findings – which he accepted. The official then forwarded it to a printer, which finally output a file containing Sharon's bridge plan. The official smiled in a jovial way and gave a nod of approval after examining

it for a while, informing her that it would be forwarded for the site engineers.

***

Fast forwarding to the day when Mr. Longfellow visited, Sharon was once again responsible in explaining him about the project. After a small chat, it was decided that Mr. Longfellow would be shown the ongoing construction live, by taking a trip in the seas to the islands.

The journey was smooth and not very long. After some pleasantries, Sharon showed Mr. Longfellow around the various construction sites of the numerous bridges. Mr. Longfellow was certainly amazed by the level of quality and sophistication. This aspect was surely going to be reflected in his book.

9. Mr. Longfellow Reads About Phillips

Boyer-Moore String Search Algorithm

On the trip back to the mainland of United Drives of NANDs, Sharon provided Mr. Longfellow with a copy of a thin pamphlet of sorts. She said - “You would want to read this account, Mr. Longfellow. Anyone who is interested in these islands or works here knows this short little story.” Mr. Longfellow gladly accepted it, and began reading -

“It was not that a random thought sprung in the queen’s mind one night to colonize the landmasses which were faintly visible from her window. Her decision to focus on controlling the Segmentation Islands was cemented by the results brought by the secret team she had sent to explore them. A particular member of the team was the geographical surveyor by the name Phillips.

One of the members of the small population of educated programs in olden United Drives of NANDs, Phillips was quite encouraged by the prospect of exploring a foreign land. The whole operation was to be kept a secret until its end, the queen insisted. Only Phillips and the crew knew that the Segmentation Islands (which had been coined for the sake of this expedition) looked like a potential mine of economic activity. The team began their oceanic journey on the hundredth clock cycle of the year,

and reached the islands on the hundred and second clock cycle of the year. What followed was ground-breaking moment for Phillip and the crew and the queen (which was of course not well accepted at that time of history).

There were so many islands, but the connectivity between them was extremely minimal. The team had to use a boat anytime they wanted to explore another island. Adding to this problem was the existence of local tribal programs – they had to communicate to receive their cooperation. Fortunately, this was thought of advance by the queen who included a linguistic program James in the team. On the hundred and second clock cycle of the year, the crew decided to land on the closest island to them.

The team also consisted or house building programs, who spent most of the first day constructing a rudimentary shelter. Only the next day when the crew ventured deeper into the island, they encountered the tribal programs for the first time.

It was certainly a difficult time for James, but in the end, it appeared that the indigenous people seemed to accept them. In fact, as Phillips notes in his diary, it was more than a miracle that James had done – the tribal programs took them to vast open lands that lay undisturbed in these quiet cluster of islands.

The excellent work that James had done now provided a clear pathway for Phillips and other geological surveyors to perform their job. What follows is Phillips' own account that he documents on the two-day journey back to United Drives of NANDs' capital after the success in Segmentation Islands.

Phillips and the other surveyors had in their brain all the precious elements' samples (which is basically a piece of string containing the composition). The task in their hand was to find the density of the occurrences of such elements – which they would by finding number of occurrences first.

Before processing the file content of the land in front of him, Phillips first pre-processed the string of the silicon. In the pre-processing step, Phillips prepared an array of size which could hold all the alphabet known to programkind. He set all these values of -1; then for every alphabet that was in the silicon string, he set the value for that alphabet as the position at which the alphabet last occurred.

Now he turned his attention to the land file. He didn't have to process the entire land till the end – he could stop it when the length of the land file left to analyse was shorter than the length of silicon string. Phillips performed his first operation – he considered length of silicon string as m, and checked if the mth character in the land file was same as

the last character of silicon. On this occasion, it did – so Phillips then proceed to check if the (m-1)th character of land matched the second last character of silicon. It did – and in this fashion, Phillips continued checking for matches in the backward manner.

At around midway of the silicon string, Phillips encountered his first mismatch. Remembering this position of mismatch as 'j', Phillips knew that he didn't have to restart his alignment process for every character in the land file, because for the next few characters, the mismatch he had just found would reoccur. He thus skipped the number of characters equal to the value of 'j – the value of the pre-processed array of the character present in the jth position in the land file'. What Phillips achieved was to look for the mismatched character in the silicon string to the left of j – if it existed, he quickly aligned the silicon string such that this character was now aligned to that of in land file (hence resolving the mismatch at j). If it did not exist, then the subsequent procedure was simple too – Phillips simply shifted the entire string past the mismatch.

For the few segments, Phillips' efforts were in vain – each time, the silicon string was matched partially. But at one point, Phillips got his first hit – out of a length of 100 characters in the land, this was the first occurrence. He was beginning to think maybe the speculation of the wealth of

resources in here was wrong – but quickly in a matter of time, he got to know that he was the one who was wrong.

In rapid succession, he found numerous instances of silicon string. It was astounding for Phillips. He looked around and saw the other surveyors were getting similar results. The entire procedure was repeated for other elements too – and same striking results followed. The islands they had visited were indeed brimming with untapped resources.

For the next ninety clock cycles, Phillips and crew were on the Segmentation Islands. Their initial period of stay was supposed to be only twenty clock cycles – but as they gradually realized the extent of the islands' potential, they continued their work. When the queen was sent regular letters about the progress, she was quite elated and arranged for more support.

The extensive accounts that Phillips had written was preserved until modern day, and now presented to you in this pamphlet. What Phillips did not though was that this unbeknownst task of foreign exploration was draining the coffers of the kingdom. This led to growing dissent in other noble members who wanted to shut it down before it became complete public knowledge, partly because of genuine concern and partly because of greed."

When Mr. Longfellow finished reading, he smiled at Sharon and looked outside the window to observe the blue ocean. For a moment, a feeling of great awe swept through his source code as he started to think of Phillips and his team, who were literally journeying the same journey that he was now undergoing.

10. Mr. Longfellow Visits the Statistics Department

Flajolet Martin Algorithm

After his meeting with Sharon, Mr. Longfellow proceeded to the second part – a trip to a different kind of transportation department - The Aviation Authority, along with a short trip to the Statistics Department.

The Aviation Authority has an annual task of estimating the number of different programs that had visited United Drives of NANDs in the past year. Being a rapidly developing city, business-programs, families, tourists, labourers, etc keep flying into and out of United Drives of NANDs in gargantuan numbers. Mr. Longfellow considered him lucky that he had arrived there on the day the task was scheduled to be done.

Inside the Statistics Department, were several employees – but usually, the task was given to three programs, with one of them being a junior. The programs in the Statistics Department were some of the most skilled in the field of streams. This year, the task was given to Ralph, Waldo and Emerson. In the morning, the three arrived earliest, although Ralph (who was the senior most) arrived significantly late than the two. Emerson had joined

the department just last year after his graduation – and he found this lack of punctuality rather undesirable. But he knew well enough to not mention it.

The agenda was known to all – Ralph was going to operate a randomly chosen hash function (there was a good choice that the randomization could be affected by Ralph's mood on that day – if it wasn't a floating variable sandwich, he would probably not be in sour state!), Waldo would then find the position of the least significant bit in the bit string generated, and Emerson would keep inputting one element serially and do some simple checking.

Emerson went toward the huge data bank adjacent to the table in which the three were working. After dialling in some connections and choosing the appropriate memory slot, Emerson connected his brain with the beginning of the stream containing all the IDs of all programs who had entered United Drives of NANDs. He then returned to the table and proceeded to transfer the first element to Ralph's brain.

Now, prior to this task, Ralph had already collected some several hash functions such that they formed a 2-Universal Hash Family (for someone who graduated from one of the United Drives of NANDs' Streaming Universities, this was mainstream of a task for him). So, when he gets the input now, he can randomly choose one of the hash functions in this family and apply it on the

element. Mr. Longfellow patiently sat a distance, seeing these three brainiacs perform the magic.

Ralph took an instant to do so for the first element, and the result, which was a bit string of a finite length that can fit inside the programs' brains very comfortably (and at the same time, the total possible bit strings were greater than the size of domain of the IDs of the programs), was passed on to Waldo. Waldo then iterated through the string from behind to find the position of the least significant bit. For that specific data element, Waldo found it out to be 3 and forwarded this to Emerson. The junior had already initialized a simple variable that held the maximum value that Emerson would produce over the entire data stream. Since it was the first iteration, it would be simply be 3 now.

And this was their job for the day – other statisticians arrived for work soon, went away for a meeting, then came back again, but these three stayed put as they patiently waited for the data stream to terminate. After a lunch break and several coffee induced sessions, the end did come.

Then it was just simple mathematics that was left for Emerson – he raised 2 to the power equal to the maximum variable he was maintaining so far (that held the highest value of the least significant bit provided by Waldo). He inserted this into an array of 15 elements. This was because the three would be running this process for 15 days and

would present the median of these 15 values as the final estimation.

This task was quite monotonous by the fifth day itself – which was why the three statisticians only worked on it for 5 days. Thus, three sets of three programs worked on it, with the junior program in each passing the so far populated array. When the results were finally delivered, the Operating System found it quite interesting that the number of different programs entering the city increased by fifteen percent! The reasons it could ascertain were probably the new resorts overlooking the Ocean of Doubles and Ints, a new trading complex's construction work in the Northern Cache Centre and the unveiling of two new museums displaying some rare data structure implementations of fine artist quality. Needless to say, Mr. Longfellow did not fall into any of those three categories, although he made a mental note of visiting them all for more experiences in this country.

11. Mr. Longfellow Visits the Tourism Department

Misra-Gries Summary

The new year had begun two clock cycles ago. On the last night of the previous year, new year celebrations were very wild in United Drives of NANDs. Partying was taken to extreme high and it goes without saying that so many programs experienced a hangover the next entire day. Mr. Longfellow however, spared himself from that trouble, although he did have a day off on the last clock cycle of the year. He decided to plan his third visit to the various institutions of Operating System two days later, which was today.

However, Toby was not an exception to hangover – his lethargy extended to the second clock cycle as well, but the new year had already presented his first task in his daily job. He worked as an analyst for the Operating System's tourism department, and just like every year, he had to sort through the almost long stream of annual tourist data waiting for him.

In particular, he had the task to sort through all negative feedbacks for all the tourist hubs (which, in recent years, had increased quite rapidly) and find the ones which

the Operating System had to desperately improve. So, on the second clock cycle of the new year, Toby found himself in a lift in the main building of Operating System's head office. When he reached the 19th floor, he headed over to a room next to the lift, in which was his boss peering over some variables.

"Welcome, Toby! Just give me a few minutes, I will soon begin the start of the stream flow into your source code. The Operating System concluded yesterday in the evening that this year they would like to improve the top twenty hubs which have had negative feedbacks," the boss spoke in a cheerful manner.

"Twenty… more than the fifteen they asked for last year," Toby thought. Then he spoke – "Alright then boss, I will be waiting in my office."

***

Toby probably was inactive for a half an hour when suddenly his communication module (an implementation of SIGNAL() in his brain) requested approval to allow his boss to communicate. Before he sent the stream, his boss spoke: "Toby, you will have a visitor in your room shortly. He is a journalist who is here to explore our country, and he may ask you a few questions. Just a friendly chitchat – nothing serious!" Toby acknowledged and agreed; then he could see a long, a very long sequence of strings (all of

which belong to the domain of all the names of tourist spots) waiting. Before he allowed them in, Toby first initialized a key-value array in his brain of size k.

At this moment, Mr. Longfellow knocked the door entered. Formal introductions were finished in a breeze, then Toby quickly returned to begin his work.

First up was: The Giant Binary Wheel. Toby thought that was weird – that was one of the best sights in the place… how could someone have something against it? Anyway, thinking about such reasons was not what he was paid for. By his algorithmic nature, he first checked if The Giant Binary Wheel had already been inserted as one of the key-value pairs in his variable. Clearly, it wasn't, so he did just that and updated the value against this landmark as 1. Onto the next one now.

Then came the Cache Lake. "Probably dirty water?" Toby thought, and once again seeing that it wasn't already present in his variable, he inserted it and updated its value 1. After two more items, Toby came across Cache Lake for the second time. He had already inserted it; all he had to do was increment the value against it. So now, one of the entries in his variable was: Cache Lake – 2. This process was interleaved with a couple of casual questions that Mr. Longfellow asked in order to get a new perspective on the workings of this country.

This continued for a while, and soon he added the twentieth unique item he had gotten. Hence, his key value variable has been fully populated.

The fortieth item was also unique one – this time, it was Garden of Deadlocks. But in this iteration, because all his twenty key value pairs have been filled, Toby will perform different steps. First, his brain goes through each key-value pair and reduces the value by 1. Once he did this, Toby checks if any of the value in the twenty instances had become zero. In this occasion, such an occurrence did not happen. Hence, Toby simply discards the Garden of Deadlocks.

The 41st item was again Garden of Deadlocks. Once again, Toby decrements each of the twenty values by 1. But now, his brain notices that the value of the key 'Virtual Waterfalls' has become zero. He then simply removed the key value pair and stopped further processing of Garden of Deadlocks. So essentially at the end of this step, 19, not 20, of the key-value pairs have been populated.

This was the overall algorithm – something he learnt almost 10 years ago in the University of the Rising Kernel – and Toby kept doing it. Hours passed as Toby desperately waited for the stream to end. A third person would have accurately guessed that dear Toby was still living in the last night of the previous year.

It was afternoon when Toby turned in the results of his work to his boss. His boss was at that time busy in some inter process communication with some executives. When he saw Toby and Mr. Longfellow come in, he requested him to stand by. When he was done, he asked: “Any surprise tourist spots in the twenty, Toby?”

The Giant Binary Wheel hadn’t made it to the final twenty, unlike the initial suggestions. “Well, I guess the maintainers at the Silicon Zoo didn’t do a good job last year, boss” Toby responded and handed over the result.

“If I may add a remark, I am quite surprised that the Garden of Deadlocks had narrowly entered the list of 20! I am a foreigner, and I visited that hotspot in my stay here so far – I should say, it was quite pleasant!” Mr. Longfellow spoke with a smile. The boss didn’t say anything but let out a congenial chuckle.

12. Mr. Longfellow Visits the Electricity Department

Prim's Algorithm

The final visit that Mr. Longfellow made in Operating Systems was to the Electricity Department. He didn't have the slightest idea why his friend's letter only recommended these four, but anyway, anything would help him understand this country better.

John has been working as an electrical engineer for almost 25 years now. In the entirety of those years, he mostly did small errands such as fixing some memory apartments' wirings and very few times he had the opportunity to coordinate the plan for entire houses (which were rather small in truth). But after such a long service, the Operating System finally recognized the faithful program and had promoted him to a coordinator. And his first job was to plan out the cable connections to be laid out to a connect a central mini power plant to a new digital tourist resort for all the annual visiting programs!

John was nervous, but his excitement did a good job in trifling the former. He did not have a reason to worry – after all, 25 years ago, he graduated with the degree of Prim's algorithm. In the afternoon of the 5th day of his

promotion, the Operating System in coordination with various other officials had finalized on a blueprint. John's head received it, before calling in John to hand it over to him. Before John left, he was given some words of inspiration - "We believe you can do a great job, John! Oh, and by the way, this gentleman here is Mr. Longfellow. He is a foreign journalist, and we had already had quite a lengthy casual discussion about United Drives of NANDs, and the electricity status of it. I hope you have no problem in having him around for some time during your work phase of this project!"

***

The two men settled in John's office space, and a conversation soon began to develop. It is safe to say that John's efficiency was not reaching its limit – he found it slightly irritating that he had to maintain a CPU consuming task simultaneously! Mind you, he didn't regard his job as the CPU intensive one – but rather conversations! But John was much smarter than breaking down to anger – he accepted his head's request to have Mr. Longfellow around in order to save the Operating System as well United Drives of NANDs in the eyes of a foreigner.

Coming back to the main task, John observed all the hotels, restaurants and other buildings (each with their own power transformers) in the blueprint. Along with the main power source, he counted the total to be 30.

Accordingly, he initialized for each building a minimum length of wire required in his brain (part of the source code). For the power source, he initialized it as zero by considering it as the starting point, and for everything else, he inserted an extremely large number (it was sufficient that it was greater than any of the distances between the buildings).

It was at this point that Mr. Longfellow decided to move on – and thanked John for his time. Once the journalist was completely out of sight, John breathed a visible sigh of relief and now got back to his work with double speed.

Now began the real work – he looked at the power source's connections. There were 5 routes going to a couple of hotels and restaurants. In the variables he initialized he earlier, he updated the minimum length of each of the 5 buildings into the lengths of the wires given in the blueprint.

A quick check told him that Hotel 1 was the closest to the source. Because he must minimize the total length of the wire and the subsequent cost, he added the connection between the source and Hotel 1 into the final blueprint. (After all, any company is **greedy** to maximize their profits).

So out of 30, his plan had already added 2 buildings (including the source). In another variable in his brain, he updated the total number of buildings added as 2. Now, he looked carefully at Hotel 1's connections. Barring the one that connects to the source, the hotel had 2 routes to 2 resorts. Once again, John updated their corresponding minimum costs in the mental variable he created. And once again, he chose the resort with the closest distance to Hotel 1 and added it to his final blueprint. "3 done, 27 more to go!" John thought.

This ritual continued for some time. Soon, 20 cities were added. By this point, in several iterations John encountered situations in which the next possible building to add already had an updated minimum length from previous iterations. In such situations, he simply found out the minimum of the existing minimum length (from previous iterations) and the distance that he was considering from the current building.

It was almost midnight – but when John saw that the value in his variable which held the total number of buildings in the plan turned 30, he breathed a sigh of relief. He became relaxed – he knew he had done the job of connecting all the buildings in the resort with the least possible electric wire needed.

The next day in the company, the manager was absolutely thrilled by John's work. After getting a green

signal from several reviewers, the final blueprint was sent to the electricians who were ready to be deployed in the resort's construction zone.

On the other hand, Mr. Longfellow was completely oblivious about how uncomfortable John was during the session. For now, he did not care either way – he had many other things to see in this country, and a book to be written on the horizon.

13. Mr. Longfellow Visits the Garden of Deadlocks

Knapsack Problem

The next destination looked quite exciting for Mr. Longfellow – his friend mentioned it as the Garden of Deadlocks. So, the journalist once again began from the inn on his bike and using a map, reached the place in fifteen minutes.

Mr. Longfellow explored the pristine park for a quite a while, breathing in the fresh air as he also savoured the sight of the overlooking adjacent mountain. He didn't quite understand, though, why it was named like that. As he walked further, he came across a series of plaques, titled as "The Story of John Knapsack". He began reading it:

"Let us now go back to a time that is almost fifty thousand clock cycles ago. The Garden of Deadlocks got its name because of a small mountain that overlooked it, inside which were endless tunnels bored by men. They were so intricate someone without a position detector can get lost. Fifty thousand clock cycles ago, the tunnels were not there – archaeologists had dug them as the mountain proved to be a goldmine for several rare artefacts made of tantalum, silicon and cobalt.

On a particularly dry day, Jack Knapsack and his team of 5 were presently exploring a specific group of tunnels situated deep from the entrance. The boring team had done their job before noon. Now it was these five archaeologists' (plus a program for storing the artefacts) job to procure more artefacts.

For quite a while, the six programs couldn't find much. Jack occasionally scratched parts of walls only to see that deposits of mud made it look slightly swollen. But when one of them leaned casually on a dry mud wall, the first event of the day occurred. That section of the wall wasn't stable – it instantly caved in due to her weight, leaving a man-sized entrance facing the six explorers.

Jack Knapsack lead the pack into what appeared to be a small chamber. Their six LED lights gave just about enough light to perceive the surroundings. And lined up along the far wall were numerous ancient artefacts! (The artefacts in the fictional world are essentially variables – as is food, water, etc). A couple of them were glinting due to the light. Jack quickly approached the 'treasure' that was waiting for them and a broad smile materialized on his face. What a brilliant haul he and his team had gotten today!

The joy of the six programs however was short lived. They were still busy admiring their findings when the ground beneath them shook. Silicon wafers shook and fell

from the dark ceiling. The six became alert at once. The floor shook once again, this time more violently, causing the programs to find their balance. Then they heard what they feared the most - a distant rumbling sound, a sound of rocks and monoliths collapsing. A certain area of this mountain was about to cave in – and it was fast coming near the six programs.

Jack and the others knew they had to leave as soon as possible. But they also knew they simply couldn't leave the artefacts behind… they had to at least salvage the best they could. And Jack Knapsack was a head archaeologist for a reason. Thinking extremely fast, he came up with a solution.

Seeing that his 5 colleagues were looking up to the task, he quickly ordered Mr. Driver to load up a 2D array of size 30, which was the maximum storage size of artefacts he could carry. At the same time, he asked the other four archaeologists to quickly store the storage sizes of all artefacts. In addition, the four were experienced enough, so Jack asked them to estimate their probable 'importance' as well and store them. All of them were index in an arbitrary order. Everybody except Mr. Knapsack knew what they were doing. The rumbling was becoming louder – they had to hurry up.

Once they were done, Jack turned to Mr. Driver once again and asked him to fill up the **first** column by querying

for each row. It was to be done like this: Mr. Driver was to ask if the first artefact could fit in a storage space equal to the row number. If it did, then Mr. Driver would store the artefact's value in that cell. The first artefact required a space of 12 units – Mr. Driver then instantly assigned 0 to the first 11 cells in the first column and for the rest until 30, he assigned the item's value – which was estimated to be 23. The six programs were momentarily frozen when they heard a loud crash emanate through the chaos.

That was the first step done in Knapsack's cooked up solution. Then he began a loop in his brain – there were after all 29 more rows to fill, but they were not as straightforward as the first one. He proceeded to give a single instruction to the five programs who were listening carefully. He screamed:

"For every cell that can hold a maximum storage space of w and can only pick artefacts from the first 'j' of them, tell Mr. Driver the maximum value of out of the two – **one**, [the value of the cell whose maximum storage space is w – w_j with items picked only from the first j-1 artefacts] added to the weight of the j^{th} artefact and **two**, the value of the cell whose maximum storage is w but artefacts can be only picked from the first j-1 artefacts!"

It was a complex statement to hear – but the other four archaeologists (Mr. Driver didn't need to do this logical processing – he was merely there to update) were

not there in Knapsack's team simply. They were smart enough to understand their head's genius – and smart enough that compliments could be exchanged later if they could first come out alive.

Instantly, the five began working in this loop. The chaos increased by now – they had the double task to keep their balance correct. The rapidly falling silicon was not helping their cause. But countless clock cycles of working together gave them the perfect chemistry. The five programs cannot imagine till date how they managed to pull it off – but in the end, they managed to determine the final cell (30X30) in Mr. Driver's table. Quickly, the storage program allocated that much amount of space and loaded in the most valuable items.

Just as he added the final item, a huge boulder crashed it to the wall and bombarded the chamber. Luckily, it hit no one – but the six programs now hurried up, with Mr. Driver's extra storage slowing the program's speed. Somehow, the six miraculously found their way amidst the rubble. And the moment they jumped out of the entrance; the entire roof of the chamber fell with a thunderous bang.

The heroics had been documented several thousand times in United Drives of NANDs' pop culture. It was for two reasons – the first was that the 'value of each artefact' predicted by them turned out to be acceptable, as a several of them were bid for much higher prices. The second was

this new algorithm found by the mastermind Jack Knapsack. This algorithm which spawned in one of the most crucial and hasty situations looked very promising in other scenarios of life – and appropriately, the Knapsack Algorithm was introduced in university curriculum."

The history lesson proved to be quite a small entertainment for Mr. Longfellow. This added a new historical dimension to his perception of this country's society.

14. Mr. Longfellow Visits the Museum

Median Filtering

The account of John Knapsack piqued Mr. Longfellow's artistic side. He was eager to look at the artefacts that were so adventurously salvaged by his team. Therefore, he decided to once again halt the instructions of the letter and pay a visit to the museum where many of the thirty artefacts were exhibited.

There, the journalist was guided to Adam, who was a restorer in his sixties. Sitting down with him, he began to reminisce about that time, when he was just twenty years old. He narrated the event of restoring the artefacts at some length -

Adam recalls that the team had done a brilliant job in salvaging some extremely valuable artefacts. It was a mixture of great relief and unbound excitement as the team were bombarded with questions about the incident. A lot of praise was sung for John. There seemed to be no other topic of interest in the office building of the group of archaeologists, until the artefact restoring programs arrived.

There were all kinds of things in the bag that John's team retrieved. Some were painstakingly detailed

handwoven carpets, some were extremely hard earthen pots, and four others were appreciably large paintings. And it is the paintings that Adam focuses on – because when he looked at them, he immediately winced. All of the four's delicate canvases were riddled with dust, either from the abandonment for centuries long, or because of the chaos created by the collapsing structures. Adam says that he immediately knew that they had to be treated.

That afternoon, the restorers got all the thirty artefacts loaded up on the museum's carrier truck. They had to be carried to the museum's designated conservation centre. The travel took around an hour, during which Adam discussed with the other restorers about the state of the artefacts, and what and how they plan on to repair.

Once they reached the conservation centre, the artefacts were safely carried over to each restorer's designated workspace. Once all four paintings were carried to Adam's workspace, he proceeded to begin his job.

Before Adam used his algorithmic skill of removing the dusty noise from the painting, he had to perform some tasks. Adam used ultraviolet light in order to gain an idea regarding the varnishes and their ages. In order to know the extent of the damage itself, he used a raking light to observe the surface topography. Following this, Adam used infrared light in order to know the working methods, if present, of the artist who originally painted it. Finally, he

used laser technology to identify the various materials and layers withing the painting, so that he would get a complete idea of the tools he could use. These four steps took a good hour to complete, and once they were done, Adam prepared to repair the first painting.

The entire painting was essentially composed of pixels in the digital world of United Drives of NANDs. Adam created a new canvas of the same size as the original painting. Then, he created a small square array in his brain. Its purpose was to serve as a square window of size 4X4 pixels. Because Adam would be iterating and editing through the image using this window, he cannot process each pixel in the painting – rather, his loop of work would extend only for those pixels whose row coordinates lie between half of the window width from the left and half of the window width from the right, and whose column coordinates lie between half of the window height from the top and half of window height from the bottom. This meant that the first pixel of the painting that would be processed here was (2,2).

Adam placed the current window at the start such that it covered the pixels in the square drawn from (1,1) to (4,4). This window has 16 pixels – and Adam stored all 16's colour values. After doing this, he temporarily treats the matrix of window as a simple collection of pixel colours and sorts them in an ascending order. Now his simple task was

to choose the median among this – which of course lay at the middle of this sorted collection.

This median value then was used by Adam as the new colour to paint over the pixel (2,2). This procedure would then extend to the next pixel (2,3) as the window shifts one pixel to the right. The window would keep shifting until the pixel (2, canvas width – half of window width), each time Adam calculating the median and painting with updated colour. Once this row was done, the same ritual would be painstakingly and carefully repeated by Adam for next the row, and the next row, and the next, until the pixel he reaches is (canvas height – half of window height, canvas width – half of window width).

It was almost eight in the evening when Adam was done with restoring all the four paintings. He was quite satisfied with this job – the dusty faces of the canvas were now resplendent images, ready to be admired in the galleries. But there was one final step that Adam had to do – he had to apply a touch of varnish on all the four paintings, for an added protection layer.

When Adam finished his monologue, Mr. Longfellow thanked him for his time and took deeper and closer looks at the paintings in display, before he moved onto other works of art. His artistic eye noted the quality and the expression in each piece. The journalist could already plan

a segment of the book that would surely touch the cultural aspect of this country.

15. Mr. Longfellow Learns About the Legend of Damian

Sort-Merge Algorithm for JOIN

Something happened on that day – the disk sector on which Mr. Longfellow's inn was located had experienced a power failure. For a couple of hours, the entire sector was thrown into the medieval ages as hundreds of lanterns were lit across the streets and houses. When the inn keeper also did the same, Mr. Longfellow also come down to the lobby, and suddenly he realized - he had never asked this woman anything about the country! To this, the old innkeeper replied - "What am I going to have in my memory! I am now at a stage where I narrate stories to my grandchildren!" Mr. Longfellow sheepishly replied – well, narrate one to me! Something from the mythology maybe! And thus, the old innkeeper began:

The human world has its fair share of fantastical tales of witches, trolls, elves, fairies, etc... and United Drives of NANDs has its own mythical tales too! We shall now recount a supposedly true tale of the mythical heroic program called Damian – how he used his knowledge and execution speed to save his every faithful dragon from death.

When the incident happened, Damian was not yet the revered hero that the texts claimed him to be – he was still a young noble man who was under tutelage with boys of similar age under an old teacher. It was not uncommon for young princes to have a dragon – it was after all a very powerful beast in the art of war and learning to be 'one with it' from a young age always proved to be a good task to undertake. Damian was eighteen now – but he had been gifted a young dragon by his parents three years ago. Since then, Damian had taken great care of it, leading to the development of an extremely strong and compassionate relationship between them.

On a particular day, the old teacher had a test for all the young princes under his tutelage – from where they were sitting, they had to find a rare plant and return it to him. The students were given no clues regarding where it could be found, nor any restrictions of how far they could search. The only details they were presented with was how the plant looked and smelled. The first prince to return the plant would be declared as the winner by the teacher.

Acknowledging this test, each of the prince mounted on his dragon and flew into the sky, clearing the ground one by one. Once Damian was at a good height, he turned his head around to survey the surroundings. He didn't know any better about the plant than the others – so he decided to take an educated guess. To the far north east,

were vast collections of hills and mountains – Damian decided to explore that area first, thinking that it could be a possible hotspot. In a woosh, the dragon listened to his command and darted with blazing speed in that direction.

***

Damian felt the extremely fast and chilly wind blow past his face only for a couple of moments – such was the speed of his well-trained dragon, as it covered the distance in no time. Soon, they were surrounded by the monolithic mountains. As they ventured further, Damian noticed that a thick white fog began settling into the air around him. This wasn't good – their visibility was decreased now. There was a huge chance that they would simply be running circles without going to explore new places. But something worse happened that what Damian feared.

As Damian kept squinting hard, he misjudged his calculations badly due to the opaque fog – and instead of flying clear of mountains, he crashed his dragon's neck into a huge sharp rock protruding out of the top of a mountain. The dragon had a thick hide – but unfortunately, the speed at which he made his beast move and the strength of the rock rendered a deep cut into the dragon's neck.

The beast released a shriek that pierced the air – and Damian instantly knew what a blunder he had committed. The dragon was now struggling heavily to stay in flight – it

was doing a commendable job in trying to slow down the pace of their descent. When the pair flew down about half of their altitude, Damian spotted a square flat area extending out of a mountain. Quickly, he persuaded the dragon to flew there. The perseverant beast used all its strength to do exactly that.

Once the dragon landed, Damian quickly jumped on to the ground and landed on his feet. He had no time to waste – he knew exactly what he had to do. It must have been his luck that around the area they landed, there was an abundant growth of medicinal herbs and shrubs growing.

As part of his tutelage, he was versed in the art of basic healing – some of it for human healing, and the rest for dragon wounds. While preparing the cure was straightforward, Damian had the harder task of finding the required herbs from the area. He had to procure two classes of herbs, with an additional condition that both had the required amount of a particular string in their compositions. Mixing them would bring the best qualities of both for the cure.

Damian was lost in the myriad of bushes in no time – for every plant or an herb he found, he quickly checked if it had the required string. If it did, he collected it in a small area beside the dragon, which was now howling and wincing in pain. The remarkable feature of this tale was

how quickly Damian procured a large collection of herbs of both classes.

Once he had both the collections, he arranged all the herbs of the first class in an ascending order based on the number of occurrences of the string in their compositions. He repeated it for the second class of herbs too. Then he began the most computation intensive task of the day – he had to make sure the emotional intensity of everything around him didn't affect him.

He selected the first herb from either class – if the number of occurrences of the string in first class herb was more than the second-class herb, then he discarded the second-class herb and chose the next herb from the set of second-class herbs. He performed the vice versa operation if the second-class herb had more occurrences of the string.

But if both had the same amount of that string, then he chose them as a pair and kept them aside. Then had to perform extra computation – he checked the next herbs in the second class set – and checked until the first herb that didn't have the same amount of the string. He kept aside all such herbs too, by joining them with copies of the herb. He repeated the same for herbs in first class set, comparing them against the current herb from second class set.

This took some while – and during that, Damian had to endure the wailings of his hurt dragon. It made him feel

extremely bad that he had caused it, but it also drove him to do the work faster. Soon, he mashed all the chosen herbs together and poured the paste into the dragon's gaping wound. At first, the dragon's wincing grew louder – but eventually, the soothing effect had affected its power. The dragon was once again calm, on the road to slow but definite recovery.

***

Damian didn't know how long the dragon had been out – because he spent his time looking around the mountain for more curing herbs. Just before nightfall (when he would no longer be able to detect the herbs due to lack of light), Damian noticed a group of secluded plants growing between two huge boulders. He was elated – they looked exactly as how the teacher had described. Even their stench was just as described. When he returned with a handful of them, he saw his trustworthy dragon up again, ready to fly as if it had never been injured. This put a wider smile on Damian's face than his discovery of his teacher's plants.

16. Mr. Longfellow on the Day of Remembrance

Jaro Similarity

Mr. Longfellow's stay in United Drives of NANDs could encompass The Day of Remembrance. However, he didn't quite know what it signified when the inn keeper informed him about it. When he asked about it, the old inn keeper was too emotional and superstitious – she said that it was one of the darkest and evilest days in United Drives of NANDs, and that he better consults some other person or the library. Thus, he set for the public library (now familiar with it after previous visit with Susan) and after enquiring the librarian about which books would enrich him about the day, he began amassing information.

"In the long history of United Drives of NANDs, there had been a mix of visionary as well as irresponsible leaders. There was another period in history – which is perhaps considered the darkest one – where the leadership was pure insensitivity.

What place human history has carved for Adolf Hitler, is the same place that the self-proclaimed Supreme Leader Cache Missler possess in United Drives of NANDs' history. If at all his regime was remembered for anything,

it was not for a good reason – it is now termed as the Immoral Cleansing by today's scholars and historian programs.

Cache Missler had an over ambitious vision of building a utopian society out of United Drives of NANDs – but the utopian values were based on obnoxious bases. He believed that only one kind of people were fit for the demands of his fast-paced society that he was aiming to build for the future. If any other program would be remaining among these ideal programs, he believed that they would begin a chain reaction in bringing the establishment down due to their lack of intelligence or habits. He therefore sat together with several biologists, politicians and philosophers who had been skilfully manipulated into his bidding (just like the mass population through extensive campaigning and oratory skills) and devised a standard source code description. Any program which did not come close to this ideal layout within an acceptable limit was to be, mercilessly subjection to deletion by 'rm command'. Many learned men of today still couldn't fathom how such a ruthless path was so casually taken by the committee.

In the first phase of Missler's devilish plan, various segregation offices were set up all over the city. Programs from all sections of the society (except the richer ones, where Missler believed that most of them already made the

cut, but the real reason was of course they were the greatest sources of funding) were **forced** to get tested in these offices, else face instant deletion. Each office had three to four booths, and in each booth sat a government program."

Mr. Longfellow turned the page, and continued, where the new page depicted the segregation process in detail.

"His 'segregation test', applied to the hundreds of the anxious programs in the queue was -

Each booth had the copy of the idealistic program source code. The next program in the line had to submit a copy of her biodata (which was a dump of her entire source code) to the booth operator. The very fact that the idealistic source code could either be shorter or longer than the biodatas reflected the variance in the population. The booth operator would begin the test after initializing variables such as total exact matches and total number of approximate matches or transpositions. For each character in the biodata, he would compare it with the corresponding character in the idealistic source code. But this was not it – he would also compare for any matches present in a distance that was 1 less than half of the maximum length out of the idealistic source code and biodata. Exact matches were counted fully – but any transpositions only counted for half of the merit.

Once the end of the program's biodata was reached, the final formulation was the only thing left. The booth operator divided the total number of exact matches by the length of the idealistic source code and added one third of this weight to the final metric. Then he divided the total number of exact matches by the length of the program's source code and added one third of this weight to the final metric. And finally, the metric was incremented by a value which was equal to the ratio of transpositions subtracted from exact matches to, exact matches.

There was a mass spread of fear among the programs – the metric results were not announced on the spot. Missler wanted to collect the entire data and decide a final verdict. No single program could feel safe – they never knew when the government would arrive at their doorstep and arrest them. Nobody could stop them from doing that. But this is history – and it cannot be changed. In random times of the day or night, houses were seized, and the occupants bound and rushed secretly for permanent deletion, breeding a turn of events that would forever remain a blemish.

This merciless rounding up took place for a week with no rest. Nobody – the ones who survived or the ones who were being deported – had no idea where the destination of the deportation was. The many caught programs were packed into makeshift wooden directories

built in a span of week. For hours they were left in it, with no food or sunlight.

Upon Missler's orders, on the day now regarded as the Day of Remembrance, the command 'rm -r' was issued on each wooden directory. His pitiless expression was unchanged even hours later when he was informed of successful termination of the so called 'inferior' programs."

When Mr. Longfellow exited the library, he was with a thoughtful brain and a heavy heart. He couldn't fathom that such a drastic event was even conceivable by a program. As he watched young programs, boys and girls alike, cycling on the roads near the houses and carrying flags that symbolized unity and diversity on this day, Mr. Longfellow silently hoped that the future civilization would be free of these baseless and destructive notions.

17. Mr. Longfellow Visits the Garment Industry

Floyd-Steinberg Dithering

That day, the letter instructed Mr. Longfellow to pay a visit to the extensive garment market that was situated in the east. It was home to many of the small and large-scale clothing industries, with their warehouses and display shops also located close by.

From his inn, it would take a lot of time to travel on bike. Therefore, this time he opted for a train in The Linker Station – of course, this time he travelled in the second class for the comfort of a nice little uncompressed seat. Reaching there, he enquired the locals about some of the prominent shops and chose to visit one of the manufacturing units.

Informing his occupation and purpose, Mr. Longfellow was able to convince the manager to let him in. The manager, after all remarked that what his company does was quite the ordinary, a procedure which began a century ago.

“A century ago?” Mr. Longfellow quizzed.

“Yes, the owner of the company is the direct descendant of the man who had begun this company. This

is not uncommon – this is the case for many weaving companies in here. The influx of these ventures began due to indirect reasons – partly political in fact."

What the manager explained to Mr. Longfellow has been presented as a form of an event experienced by a rich woman belonging to the time being spoken of by the manager.

***

Olga got down her private horse cart in front of a glassware boutique shop. The driver of the cart then hurried off – Olga wouldn't be done for the next 3 hours. As the frame of the cart cleared, the rich woman caught a glimpse of a middle-class young girl, walking across the street at the far end. Her clothes were dirty, and her mangled; but Olga noticed more than that about the girl – the clothes that she wore looked virtually no different from hers. A casual eye wouldn't notice the difference between the extremely expensive and privately hand-woven dress that Olga wore, and the shabby and mass-produced dress that the middle-class girl wore. Olga's mood completely shifted – when she stepped out of her house, she was looking forward to buying a new chandelier (with great enthusiasm fed by a false sense of accomplishment in life), but now it was replaced with uncontrollable rage – if every other girl in the town could wear clothes like these, how could her 'richness' stand out? How could she stand out in

the public if from a distance, her dress could no longer look special?

Her shopping experience in the boutique was consequently unpleasant. Her ego had been hurt and that thought wouldn't leave her mind. At the end of a good three hours, she hadn't been able to make a choice for a chandelier. Her furious expression didn't even twitch a little on her way back home in the horse cart.

The law to legalize the mass production of clothes inspired by foreign styles had been passed only two weeks ago – Olga knew this, but she didn't expect to find some cheap rip off her quality attires so quickly. Previously, only the kings, the aristocrats and the few richer members of the society could own clothes woven and designed outside of United Drives of NANDs. Amidst this, they did not like the idea of a growing black market in which mass-producing houses made almost exact replicas of their expensive counterparts. The market was existing because even the commoners were falling in love with the foreign styles. The hypocrite kings and rulers didn't want that to happen in order to 'promote local culture', while they themselves chose to wear these foreign attires to important occasions.

However, when the authorities realized that the black market had permeated much deeper than they thought, and that it was becoming virtually impossible to curb the commoner's insatiable desire for these new clothes, they

realized to profit off this – the mass production would be legalized, but every such mass production house had to pay royalty fees on a monthly basis to the coffers (which often did not go into improving the kingdom, but directly into the treasuries of greedy nobility).

That was why Olga's husband, who held an appreciably senior post in the kingdom, was helpless when she stormed into the mansion and complained about how vehemently she hated the change in law, and that he as an influential man had to work towards reversing it. What enraged her more that none of the extra royalties being paid weren't being distributed them behind the scenes.

Crawford, a weaver working for a cloth production house, works around ten hours to produce around fifty replicas of dresses each day. Sitting in one of the cubicles in a large wooden warehouse, he and the hundreds of weavers are shown the actual handwoven material that the house imports. Based on that, they begin their work. For each pixel in the cloth, going from top to bottom and left to right, Crawford stores the value of the pixel's colour in his brain. Now, the expensive quality's brilliance is borrowed from the fact that the clothes use a huge wide range of vibrant colours and hues. Reducing them would dramatically reduce the cloth's cost too – and that was exactly what Crawford did every day. Using the pixel's value, he found the closest colour from a limited range of

colours. This new palette was often just one tenth the size of the original cloth. Crawford divides the original pixel value by his palette size and rounds it off to the nearest colour.

Then, he simply weaves that pixel with this new colour. But that is not the end. In his brain, he also stores the absolute difference between the old and the new colour. Then, he goes onto edit four other pixels surrounding the pixel he had just weaved. For the pixel on the immediate right, he weaves in an additional colour that is equal to "seven out of sixteen parts" of the absolute difference he had stored earlier. For the pixel diagonally left and below, he weaves in an additional colour that is equal to "three out of sixteen parts" of the absolute difference. For the pixel just below, he weaves in an additional colour that is equal to "five out of sixteen parts" of the absolute difference. And finally, for the pixel diagonally to the right and bottom, he weaves in an additional colour that is equal to "one out of sixteen parts" of the absolute difference.

Once this was done for each pixel corresponding to the original dress, Crawford would have the finished replica – almost twenty times cheaper – ready for the common folk to also wear, and for women like Olga to look at and feel immeasurable anger.

18. Mr. Longfellow Visits the Golden Tree

Longest Common Subsequence

The very name ‘The Golden Tree’ gave both excitement and curiosity to Mr. Longfellow, when he read that it was the next in line to be visited. Luckily, this tourist attraction was not too far away from the inn in which he was staying, so he travelled the distance by feet.

The innkeeper recommended him to visit it after the sunset. He understood why and his expectations were met – the place was bustling with people, and LEDs were wrapped around the various trees and buildings that lined up along the roads. These roads connected the thirty or so nodes of the tree like structure of this special place in the country of United Drives of NANDs.

It was so engrossing to travel each road and observe the various stalls and shops that lined them up, to visit each node and witness various events that happened there, that Mr. Longfellow for a good amount of time forgot why he had come there. Remembering that he had to of course enquire by engaging in a friendly chat apart from just including in his prospective book about what he saw with

his eyes, he entered a shop that was selling carpets, expensive and cheap ones alike.

Presently, no other customer was around, so Mr. Longfellow began conversing with him. He didn't rely only on him though – he visited several other boutiques to gain information.

If there was a one particular reason why The Golden Tree, located in the heart of United Drives of NANDs, was the primary business hub bustling with bankers and traders all-round the year, it would be the gold rush that began around two centuries ago.

Somewhere in the middle of King Pagerius' rule, a casual researcher by the name Swapson stumbled upon huge mounds of rocks covered underneath a vast and abandoned land. Swapson initially ignored it; but as he kept digging, he kept finding more occurrences of such rocks. At that point, he deduced that it might not be a coincidence – was this entire patch of land like this, and if it was, how deep did these rocks go?

Being a researcher, Swapson would not have been able to sleep peacefully had he just ignored the rocks and stopped digging. So, he took a few samples to his home to examine them. Upon chiselling them, Swapson found out that these rocks were actually ores – and inside the rocky mounds was a metal, present in traces at some places and

sometimes in lumps. But which metal was this? Swapson didn't keep his hopes too high – if this was so abundant in this largely ignored tract of land, surely it must be some unvalued element?

The enthused researcher began comparing the metal in the ore with whatever elements he could find in his home – cooking utensils, the nib of his writing instrument, etc. This study extended for a good few hour. By then Swapson had already performed an exhaustive search of all possible elements in his house (much to his wife's disgruntlement of taking away the items into his study room). Swapson wondered what this element was, and whether he did search extensively. His efforts in vain, he decided to carry the sample to a vendor to get a more thorough report. But just as he got up from his chair, he suddenly remembered – there was his mother's locket that he hadn't tested! He stored it safely, deep inside a rack in his cupboard.

With a new spring in his step, Swapson quickly climbed upon a stool (for he was too short to reach the top of the cupboard) and rummaged through the contents... until his stubby fingers touched the silicon locket. He produced it outside the rack and got back to his chair before the study in an expectant manner.

He kept the locket and the ore side by side. He did not have to process the entirety of the locket or the ore – each had an atomic sub composition that iterated itself to

fill up the entire string of the substance. Swapson created a matrix in his brain, with the first character on the row and column as a null character. Then, he lined up the silicon string on the horizontal, and the ore string on the vertical. He quickly filled the first row and the first column with zeroes, as a string would have no sub sequences with an empty one.

Now, Swapson followed a simple procedure to fill up the rest of his matrix. For every cell, he checked two things – if the characters corresponding to that cell were same, then Swapson added the sum of 1 and the value in the cell which was diagonally above and to the left of the current cell. He did this because if the characters were same, then the length of the common subsequence had increased by 1. If they weren't, then Swapson found out of the maximum of the values in the cells to the left and above the current cell and stored it in the current cell.

This straightforward procedure was done very carefully by Swapson. He theorized that the ore would essentially contain the structure of the metal but interleaved with impurities of the rock. Hence, if the resulting subsequence was the same as the silicon substructure, then it would mean that the ore was of silicon ore.

Once Swapson finished filling the entire matrix, he began from the bottom right cell. For each cell, he marked

one out of the three cells (one to the left, one above, and one diagonally above and left) with the highest cell value. In doing so, he built up the longest common subsequence of the silicon and the ore.

Swapson's joy knew no bound – the ore was indeed of silicon, the most valuable metal in United Drives of NANDs! He wondered how this land had never been ploughed or explored. It was unbelievable for him that he had discovered perhaps the greatest source of resources in this country.

Anticipating a wholesome honour and huge reward, Swapson diligently obtained permission to see King Pagerius and inform him about his findings. But as mentioned earlier, there were far too many unjust and unruly kings riddled in United Drives of NANDs. King Pagerius was pleasantly happy upon hearing Swapson's discovery – but he never bothered to credit the researcher for his work. When King Pagerius' men confirmed the existence of the huge reservoirs of silicon in the land that is now called The Golden Tree, he did not even care to acknowledge Swapson for his work. The kingdom's coffers were starting to grow, but not a word of Swapson's efforts flew around.

This hurt Swapson extremely, and in no time his anguish turned to do anger. He made a mistake of letting this corrupt king get hand of more wealth - and in his mad

and subconscious fit of rage, Swapson decided to prepare explosives and hurl them at night onto the mining sites made by the king's men.

Swapson succeeded in doing so for four continuous nights – the current day historians estimate that in those four days, silicon worth several hundred millions of dollars was lost. The king and his equally corrupt court heavily suspected Swapson – but when his house was raided on the fifth day, they could find nothing that would convince the common people of his treachery. However, on the fifth night, Swapson attempted another attack – although it was successful, his escape wasn't to be. Surrounded by some of the highly trained knights of the king, he was caught and thrown before the king.

The poor researcher's anger was no match to the king's power – he was ultimately sentenced to death by hanging. For a long time, the commoners believed that Swapson was a program who had gone rogue and burned the silicon ores. But as truths unfolded, it soon came to knowledge that he was the one who first discovered it.

19. Mr. Longfellow Meets Dr Cooper

Floyd's vs Brent's Algorithm

Mr. Longfellow's friend mentioned in the letter than Dr Cooper was an old friend of his who settled in United Drives of NANDs. He therefore recommended Mr. Longfellow to visit her to gain insight into the medical world. Further, he wrote that he had already contact Dr Cooper to inform her of Mr. Longfellow, and that he would turn up on a day to meet her.

When Mr. Longfellow reached the address mentioned by his friend, he was informed that Dr Cooper had not arrived home yet. He was told that perhaps she has some extra work at the hospital, and that he could wait.

***

Dr Cooper's shift was on the verge being over. But when Dr Cooper heard that a patient with a crucial Heart Cycle Disorder had just come in, she had an ominous feeling. Short snippets of flashbacks to one of the surgeries she had done quite several years ago rushed into her mind. That time, she failed, unable to save life of a fellow program because she simply was not fast enough. It took a lot of mental strength to get over that incident, and perhaps

today was the day her resolve was tested. She was determined not to fail again.

She quickly got off from her chair and rushed outside her room. In the same instant, the patient, who was feebly twitching from pain, was being pushed on a bed by couple of nurses towards the ICU. Dr Cooper followed them, asking one of the nurses some additional details in a complete frenzy.

An assisting physician joined Dr Cooper and administered anaesthesia to the patient. The procedures before the surgery than only the medical programs of United Drives of NANDs are well rehearsed in were completed in the next few moments as the patient slowly calmed down. Then Dr Cooper began her work – she had to be quick as well as accurate.

The situation was not unfamiliar to her. She surgically accessed the patients source code snippet in the heart and initialized two pointers. As she did this, a flashback of the corresponding event played in her mind – years ago, her first step was the same. In the present moment, time was ticking fast against her.

She went through the linked lists (which were arteries and blood vessels in the heart) in the source code carefully but swiftly. First, she moved one of her pointers by one linked list. By her algorithmic nature, she quickly

checked whether the two pointers she had created were pointing to the same linked list in the heart. Clearly, they weren't, and equally clearly was the fact that her first pointer didn't reach the end of the chain. Then she moved the first pointer by 2 units. At this point too, both the pointers were not on the same cell of the list because the second pointer was still at cell 0. Dr Cooper's next step was to change the location of the second pointer to the first pointer's previous location – which was 1. Even now, they were not at the same place.

As she continued to do this, the flashbacks intensified. Unlike the present, during that previous surgery, she was moving the first pointer by only 2 cells in the list, and the second by 1 unit always. As she carefully did that by making sure not to rupture any of the cell in the linked list, she felt the time run out too quickly as compared to the progress she made in finding the cycle. And her feeling was right – the burning image of a flatline in the ECG was still clear as she lost her patient.

But today, that wasn't the case. She struggled very hard trying not to be overwhelmed by her past and at the same time concentrate on making the second pointer move in powers of 2 rather than always 2 in every iteration. Soon, she reached a point where she moved the second pointer by 256 cells – and set the location of the first pointer to the former's previous position. And that was it – Dr Cooper felt

an instant relief as she found out the origin of the cycle. Now it was the task of surgically removing it with the help of her assistant physician.

A couple of hours later, a mentally cleared Dr Cooper, who had just shared the good news to the patient's family, realized fully how much precious time she had saved in the operation theatre by using her new algorithm skill. Maybe it was time to truly let go of her past demons.

***

Back at home, she met Mr. Longfellow, whom she recognized as the friend that she was informed about. After informing her about his purpose, he began his questionnaire. Dr Cooper replied that he had come on a certainly eventful day and narrated what she went through just hours ago in front of him as well as her family. Further, Mr. Longfellow also learnt about how resident hospitals worked in United Drives of NANDs:

Gale – Shapley Algorithm

We now move to a time almost 3000 clock cycles ago, when Dr Cooper was much younger and had just finished her algorithmic degree in medicine. Like thousands of other programs, she too had applied for resident hospitals. The futures of these aspiring doctors were soon to be

determined by Andrew from the recruitment department of Operating Systems.

The deadline for submission of preferences had ended yesterday – but there was enough time for Cooper to listen to her uncle's advice on not leaving her preference list incomplete (or having just a few hospitals in her list). She was convinced that she had to include as many hospitals in preference order as possible to maximize her chance of being allocated.

The data from the students was obtained by Andrew's team a couple of hours after obtaining a similar preference data from the list of hospitals. Once they had both the data, the team sat together in the office and began the procedure.

Andrew kept the data file beside him and initialized a key value pair for each of the student – the key was going to be the student, and the value the allocated hospital for the student. So, at the beginning, all the students were unmatched. He now began reading the data file and processed the first student (the Operating System designed the procedure in such a way that the process was student optimal). Her first preference was The NewBit Hospital, but unfortunately, The NewBit Hospital didn't name her in their list – hence, Andrew could not allocate it to her. He moved on to her next choice and saw that this time, her preferred hospital did mention her. So, she was now allocated to this hospital **tentatively**. Andrew then moved

onto the next student and repeated the same. He would do so until every student was either matched, or every student has no mathematical possibilities of getting matched.

This of course was not straightforward as in the case of the first student. As Andrew went through a good number of student's lists, he found that the fiftieth student preferred The Hospital of Semaphores. However, that hospital specified that it had only needed ten doctors, and so far, all ten had been tentatively allocated. So, Andrew then proceeded to check if the current student (the fiftieth one) was in the hospital's list, and if he was, then is his ranking given by the hospital higher than any of the ten members who are tentatively part of the hospital. Indeed, the current student was in fact preferred by The Hospital of Semaphores more than 3 others – hence the current student's key value was updated appropriately. This also meant that the student ranked lowest in the previously selected ten had to be relegated to a status of unmatched.

This ritual proceeded for several more hours. Finally, Andrews was finished with the matching – he had to now forward all his key value pairs to another employee who would cross check it. Once such checks were completed, the Operating Systems published the results for the expectant students.

Cooper was thoroughly satisfied – although she didn't get her first choice, she did get her fifth choice, which

happened to be the last hospital in her list which was in her hometown. It was the start of a new journey in her life.

20. Mr. Longfellow Visits Emily

Rabin-Karp Algorithm

Before Mr. Longfellow left Dr Cooper's house, she also suggested him to meet a retired doctor Emily, who was renowned in the medical world. Mr. Longfellow acknowledged her recommendation, and the next day for the first time, he made his way to a destination not mentioned by his friend in the letter.

While the humankind is suffering from a different kind of virus, United Drives of NANDs had also suffered a pandemic fifty decades ago – now referred to as the ViralNet pandemic. It was one of the darkest times in the history, as several thousands of programs got deleted. The hospitals were brimming with faulty programs, prompting for a city-wide lockdown in which programs were strictly instructed to not leave their memory spaces unless necessary.

Emily, now an old program who had retired a decade ago as a successful doctor, recalls how testing the times were during the pandemic. She sat with Mr. Longfellow in the garden and spoke in a calm and collected manner with the very attentive and interested journalist. She was very young at that time – but her talent and attitude were enough for the hospital to employ her. And her attitude was

exemplary in a time where the hospital where she worked was almost bombarded (in some sense) with patients who were worried if they had contracted ViralNet. She vividly remembers how she used to test the patients, with all her protective mutex locks worn.

Patients who had come for ViralNet testing were directed to a separate building. In there, there were multiple booths separated by a good amount of distance. During her alternate day shift, Emily was in one of the booths, separated by a glass panel. The patient who had come had to submit his/her source code to her. Emily then applied her algorithmic skill to detect viruses, which she had learnt not very long ago in graduate school.

The hospital provided her with the string that represented the structure of ViralNet. In addition to this, the hospital had also provided each doctor with a pre-computed hash of this virus. The hash was obtained as follows: taking two elements of the string at once, the element's value in the alphabet set was multiplied with alphabet size. Then, this product was subjected to a modulus operation with a prime number. The resulting number was then again subject to this procedure with the next element in the viral string.

Starting with the first element of the patient's biodata, Emily used the rolling hashing function as used by the hospital with the same prime modulus on the first m

elements of the biodata, where m was the length of the viral string. Once this hash was found, she compared it with the hash pattern of the virus. If they weren't equal, the patient had not contracted the virus – but only so far. This was to be done for the patient's entire source code. For this patient, Emily reached around seventy five percent of the source code without finding any match. The speed of the test was crucial for real time statistic and an opportunity to curb the problem as soon as possible. It was fast because of the hospital's intelligent choice a rolling hash function – Emily didn't have to compute the hash function from scratch for each substring. Rather, for each element that was not in the current substring but was in the previous string, she had to subtract its contribution for the previous hash. When the hash values did match, however, Emily knew the current version of ViralNet test could give false positives even though it was fast.

The matching hash values only informed her that there was a possibility of the existence of the virus. Thus, she proceeded to check if each element of the virus string had an exact corresponding match with the current substring of biodata. When Emily was done, she stopped processing the rest of the patient's source code – because the viral string was indeed present in the patient. Following strict protocol, the positively tested patients were carefully directly to ViralNet control blocks in the hospital.

Emily informed Mr. Longfellow – that difficult phase for her continued for almost twenty months, when the revolutionary scientists finally could formulate an antivirus code. Even at seventy years old, Emily vividly remembered how her introduction to her chosen career began with one of the toughest challenge health workers could face and how she had to spend many days away from her home. But ultimately, events like these shaped and toughened the programs of United Drives of NANDs for a future that could be ridden with similar experiences.

Mr. Longfellow's perception of this country expanded even more, as more details like these – historical and present day – trickled in. He was already liking how his future book was taking shape to describe the wonderful country that is 'United Drives of NANDs'.

21. Mr. Longfellow Visits a Hotel

MD5

Mr. Troy's busy day began at 6 in the morning. He was the head civil engineer, and his current work was leading the construction of a new five-star hotel being built by The Operating System. As the daily worker programs arrived one by one into the site, he was having a small chat with few of the architects. In a few moments, the required raw materials such as sand, cement, etc would be arriving in a zip file. Before that though, Mr. Troy noticed a suited program arriving on a bike. Then he remembered who it was – it was Mr. Longfellow. The Operating System had informed Mr. Troy yesterday that a journalist had been given permission to visit the site.

A team had gone to the material provider a couple of days ago. Their purpose was to book the raw construction materials needed as per the requirements of the plan laid out for the school. After several hours of conversations, the material provider finalized an order containing the list of items needed. It took a few additional minutes for a checksum to be generated and handed over to the team – which was now in the possession of Mr. Troy.

As he continued chatting with the architects and introduced formally to Mr. Longfellow, he heard a large

lorry slowly fade in. Turning, he saw the expected delivery of the zip file come in and park adjacent to them. Mr. Troy then quickly called for a cryptographer program and his team, who had been summoned that day to the site to check the integrity of the raw materials. Mr. Longfellow stood in the sideline, observing the proceedings carefully.

The truck driver along with his companion opened the back door and began pulling out the zip file slowly. In the meanwhile, the cryptographer and his team reached the zone and waited with Mr. Troy until the zip file came out totally. Mr. Troy then directed Carl, the cryptographer, to perform his task.

Carl would perform the logic of the checksum, whereas his team was needed to store the file in their brains. It took a small amount of while for his team of seven to do that. Once done, Mr. Carl asked for the file size. The size in bits had to be just 64 bits shy of any multiple of 512 – in other worlds, it had to be 448 congruent 512. However, it wasn't – so he asked his team to append padding bits, beginning with a single 1 and then only 0s, until the condition was met.

This was done quickly – the team knew what had to be done next. The program who was holding the last portion of the file then calculated the original file size in 64 bits. He then appended this to the total file size. By the end

of this, the entire file was now a multiple of 512. Note that the original zip file was still lying on the ground.

Now came Mr. Carl's work. He quickly created four 32-bit registers in his brain, and they were initialized as (in hexadecimal):

A: 01 23 45 67

B: 89 ab cd ef

C: fe dc ba 98

D: 76 54 32 10

Then, Mr. Carl also made a 64-length array called SineValues, which contained all the integer parts of 4294967296 time the absolute value of sine of the index in radians. Once this easy subtask (it looks hard while reading, but Mr. Carl had done this a hundred times when he was a graduate student!) was done, Mr. Carl then took the first sixteen-bit block from the file. Before proceeding, he saved the current values of the four buffers. Now began the heavy mathematics part of his job. The main arithmetic of it was a single line function – if a, b, c, d and k, s, j were inputs to this, then the function computed:

a = b + ((a + Function(b, c, d) + kth value of the sixteen-bit block + jth value of the SineValues) and this value was left shifted by s bits).

However, this function was not just once, or twice, or thrice… but sixteen times in a single round. In each round, the first found calculations were done on ABCD, the next four on DABC, the next four on CDAB, and the last on BCDA as input to ‘a’, ‘b’, ‘c’, ‘d’ of the function.

It was a lengthy process – Mr. Carl had to do it 64 times for each 16-bit block! The team patiently waited for their boss. Once it was done, Mr. Carl added the new values of the registers A, B, C, D to the previous values he had temporarily stored. And that was the end of one 16-bit block done – there were many more to go!

Mr. Troy knew it would take a while, so he and the architects had gone away from there to take a closer inspection of the site. Mr. Carl kept churning the numbers with incredible speed – this ritual was almost second nature to him now, like the eating and walking algorithms that are so well ingrained into baby programs. The truck driver was not a stranger to this kind of checksums but was also amazed by Mr. Carl’s speed. And soon enough, Mr. Carl was done with all the 16-bit blocks and signalled to Mr. Troy that the checksum had been generated.

Mr. Troy copied the checksum into his brain and quickly compared it with the checksum that the team had given him earlier. Indeed, they were matching – all the right raw materials had been there. There was no avalanche incident – even a single milligram change in the amount of

cement would have altered the checksum noticeably. The truck drivers and Mr. Carl's team's work was done – but now that the raw materials had arrived, Mr. Troy's work only began.

***

Mr. Longfellow remembered that on the day he visited the site, the raw materials had been correct and delivered as per the requirement of the builders. So, when he came back to visit this hotel along with his friend after half a year, he was surprised to hear an anecdote about a wealthy program complaining in a haughty tone about how the room that he had bought had some components that did not match his requirements.

As Mr. Longfellow probed for more answers at the reception, he got to know the root cause. The first thought that entered Mr. Longfellow's mind was – what an incredible and extraordinary occurrence! For indeed, it was a coincidence of such a magnitude. The raw material provider had accidently delivered another type of doors, but the compositions were different in such a way that the resulting checksum was same! And the probability of such a **collision** happening was…. very very very very slim. Mr. Longfellow could only conclude that this only this incredible country could be home to such phenomenon.

VOLUME III

INSPECTOR MANSON'S UNEXPECTED JOURNEY

Sai Sriram Yannamani

[2019101029]

1. Enter Inspector Manson!

Floyd-Warshall Algorithm

Inspector Manson never relaxed throughout the day. Although most of today was very uneventful, his experience taught him that doesn't always extend to the hours after sunset. For the last hour or so, he peered over some documents on his table and just stood up to enter the control room of his branch. Holding his cup, he took a sharp glance on all the huge monitors that were being operated by other policemen. Just as he turned to exit, the communication channel to his right corner buzzed loudly and impatiently. The operator stationed there was alert to the task and immediately opened the channel:

"Th-there is a rob-robbery at the Pager Antiques on (SOUND OF A BANG) Silicon Place 21!! Pl-please come as soon as possible (SOUND OF A SECOND BANG)!"

Inspector Manson exited the control room in a flash. Two other officers, Julian and Grace, were not fresh to the news. They quickly wore their protective mutex lock jacket and loaded their guns and followed the already ready inspector to the police jeep at lightning speed. Inspector Manson theatrically leaped into the van without even opening the door. Julian hit the gas pedal in no time, and soon the van stormed out of the police station in no time.

Inspector Manson headed the outermost police station in United Drives of NANDs. It was one of the largest stations, catering to almost the entirety of the north western outer sector. But Manson was a tough man – with a classic mix of discipline and skill, with perhaps a tinge of swagger, he was able to command this station through all challenges faced so far. Adding to this fact was that he was an avid reader – in his free time, you would always see him in a library reading up on new knowledge (his philosophy was that in his police career, he might have to face situations of diverse demands, and that learning about new algorithmic skills would not be of harm). And today was one more opportunity to add his ever-growing list of chases and fights.

Silicon Street 21 was a good distance away from the police station – certainly a strategic choice by the burglars. But this was not the first time a relatively farther robbery attempt presented itself to be curbed. Julian was an expert steering wheel yielder – but had to complemented by a skilled route plotter behind him, which was Grace. Besides being an exemplary police officer, she had permanently written every street and the junctions it joined into her brain. Her job was to calculate the shortest path from the police station to the burglary site under huge pressure.

There were around four hundred junctions in this sector. Grace had already made a two-dimensional array

having four hundred rows and columns, each cell holding the length of the street connecting them – if there was not any, then it held a value much larger than length of any street.

The operators back at the police station were in full rhythm too, working in real time with the three officers in the van. In unimaginable speed, they calculated special traffic coefficients for each street for a certain time span using advanced predictions. Using the secure piping channel already opened with Grace, they supplied her with the values. Immediately after obtaining them, Grace added these coefficients to the current values in the array. A street currently experiencing higher traffic would get its length increased in her array.

Julian had slowed the pace of the van now, not venturing too far from the station. This delay did not matter – in their real time, it was hardly a second as Grace computed the shortest path. Now began her most intensive task, although it was logically simple. For every junction in the sector, she proceeded to check if the path from the police station to that junction, and then that junction to Silicon Place 21 is smaller than the current distance that exists in her array between the station and the burglary site. She computed this so quickly – and then in a flash, she informed Julian to go the end of street and take a left. Julian now was let loose – he slammed the gas pedal and

followed Grace's pinpoint instructions. All this while, Inspector Manson very silently schemed a plan.

Julian's driving skill honed to a level of almost perfection shone through that night as well. The police van sped its way and in very less time, reached Silicon Place 21. They were just in the nick of time – Inspector Manson saw two black masked programs with heavy satchels, running towards their already revving transport.

Inspector Manson was now an adrenaline tank – he leapt out of the van still in motion, rolled acrobatically onto the ground and opened fire towards the sedan ahead of him. One of the robbers retaliated with two quick shots, all doing no harm to Manson. Grace and Julian were now on ground and joined the inspector.

The three advanced forwarded, their aim improving. The two burglars hopped into the car, which then drifted with a loud screeching noise, trying to speed up. Manson now started running like a ferocious beast, but his eye never lost sight of the tires. Grace tried to catch up to him, while Julian quickly decided to revert to his van.

After a couple of frenzy minutes, Manson finally blew a hole in the back tire of the speeding sedan. This was it – Manson and Grace doubled their pace. The burglars now hopped out and started firing like madmen with no aim at all. Then Julian stole the show by driving in between the

line of fire, forming a shield. Inspector Manson and Grace athletically leaped over the car and somersaulting, kicked two of the robbers square in the chest. Before the third burglar even processed to shoot them at close range, Julian shot his arm, rendering the robber to give up his weapon in agony. The chase was reaching the close – the three officers head a couple more sirens from a distance.

2. Conversation with Trotter

Flood Fill Algorithm

It had been a day since Inspector Manson and his colleagues ambushed the burglars. The three were in control when the police support came, and in a while, the three were behind bars. Inspector Manson today came back to visit Trotter, the old shop owner.

The shop suffered appreciable amount of damage. Several pieces of broken items lay. Trotter thought that this was a good opportunity to also refurbish his store. By the time Manson reached the store, there was a painter program who was at work. The painter in his brain maintained the information of the cells he had to paint next. He examined the current cell of the wall. It wasn't the same as the target colour that Trotter wanted – hence, he painted it as blue, which was what Trotter did want. Internally in his brain, the painter removed that cell from the queue he was maintaining and checked the cells of the wall surrounding it. If they weren't blue as well, the painter added them to his queue – they were to be done when he checks the queue once again. The painter quietly continued this procedure – he still had to cover a good area of the modest sized shop.

Lowest Common Ancestor Algorithm

Trotter had the slight reputation of being slightly maniac in that sector. Many didn't get bothered by it – most thought it was because of his old age. Maybe a few characters and symbols in his brain had gotten corrupted. But on a personal level, Trotter knew that whatever he believed in was destined to happen – it didn't matter if other programs thought it was overtly fantastical. All he needed was the right person, and ever since the robbery attempt had happened, he couldn't stop thinking about Inspector Manson's heroics. It was this very fixation that made Trotter elated with joy and excitement when he saw the officer watching the painter.

"Mr. Manson!" Trotter said, dodging his way amidst the rubble towards him. The Inspector turned toward him. When the old man reached him, he fervently shook the inspector's hands, interleaved with the officer's remarks about how it was just his duty.

"Is everything on track to be sorted now?" Manson enquired.

There was a tinge of twinkle in Trotter's eyes. "Ah, never mind that – repairs always take care of themselves. But I really want to show you something, Mr. Manson! Indeed, it must be done – and I need to know. I really hope you wouldn't mind sparing a few minutes of your time!"

Mr. Manson was taken a bit aback at Trotter's apparent lack of balance. His frenzy had taken over his coherence of speech. Upon persistent insistence, Manson did not want to disappoint the old program – he agreed to follow him into the shop.

The two passed the painter and entered a small corridor. This led to a small room, in which more antiques were displayed. But when Trotter moved a carpet in a corner, a trap door became visible. He opened it, and in response a great deal of dust flew. Manson wore a slight frown now.

"Mr. Trotter, what's going on?" The secrecy piqued Manson – perhaps there is something hiding that could cause some trouble?

Trotter began stepping down a ladder that was near the trap door. As he descended a few steps, he motioned to Manson to follow. The inspector did so. Soon, the two were down in an unfloored cellar, with silvery crude walls. Manson felt this was something straight out of the medieval times of United Drives of NANDs, compared to the more modern outlook above ground.

Trotter and Manson went to a table at one end, on which was an extremely large file. "This, this is a file that contains the ancestral lines and family trees of **every** program that has ever walked in United Drives of NANDs!"

began Trotter. Manson's frown became more apparent now. "Even you have a place in this!"

Manson glanced at the file and then back at Trotter. "That's all… fine, Mr. Trotter. But why do you have this down here, and what have I got to do with this?"

"Oh, it possibly has everything to do with you! Everything! We shall know in a few minutes, Mr. Manson, in a few minutes. I really believe you could be the one!"

Mr. Manson was now thoroughly perplexed. What's going on? Is this some prank Julian and Grace had created? Trotter opened a certain section of the file and started reading it. Then, he forwarded it to Manson, who had accepted the connection.

Manson saw what the information was – it was instructions on how to find one's lowest common ancestor with a program called… Mysterious. Manson found that name very odd – who wouldn't! But apparently this did not bother Trotter. He said – "Go ahead, Mr. Manson – please follow the instructions, and tell me what you get! Please, I really request you to!"

Mr. Manson didn't want to do it – especially when the old man wasn't offering any explanations. But what could go wrong… he was just asking to go through a file. And thus, Manson began executing the instructions.

He noticed that there was a large empty file lying besides, which was to be used for storage by him while executing the instructions. First, Manson was instructed to fill up an extremely large array with vertices in the order that they are seen in a depth first search. For the depth first search, Manson spent considerable amount of time iterating through the **huge** number of names in the ancestor tree. All this while, Trotter waited with high expectation.

In addition to recording the order, Manson was also instructed to store the depths of the program names. After what felt like an eternity in the small damp cellar, Manson finally finished this task – the storage file was now complete with the data he had just calculated.

The next instruction for Manson was to determine all the names that appeared in between the first occurrence of his name and the first occurrence of the program called Mysterious. He did this and saw about several hundreds of names in between. Among these, he was instructed to do find the name with the lowest depth. Upon finding it, Manson stopped reading the storage file and turned to Trotter. The old man looked very expectantly.

When Manson informed that the lowest common ancestor that he and Mysterious shared was a program called… Alex Hypertext, Trotter placed his hands on his head – his joy knew no bound! Immediately, he broke into

an elated laughter – and in between, he kept exclaiming: "The saviour has been found! The next incarnation has been found! The one who will defeat the evil as per the prophecy has been found!"

***

It had been four hours since Mr. Manson had left the old man's shop – he was now back in his familiar station. The old man had really gone crazy as everyone says – the inspector was convinced that whatever had happened in the cellar was just a random spurt of madness from Trotter. Mr. Manson felt sympathy though – even while leaving, Trotter said in an extremely assured and satisfied voice that sooner or later, Mr. Manson would himself come back to him, and that Trotter was just a lighthouse in the task that lay ahead of the inspector. These words still lingered in Mr. Manson's mind – it would take another thrilling case to remove them.

3. An Eerie Experience

Needleman-Wunsch Algorithm

Inspector Manson was able to ignore the incident with Trotter for the rest of the day with some effort. He didn't share it with anyone – he felt it was too stupid for any discussion. However, what he did not know was that the events with Trotter were just the beginning – something else was in store for him tomorrow.

Manson arrived at the police station like every other day. He went into the control room and talked a while with the night shift operators who would leave in an hour or so. Soon, Julian and Grace also arrived. Everything was going just like it did every day, but at around three hours after he arrived, the events of the day were set in motion. Inspector Manson was in his office when suddenly his communication channel device began malfunctioning. Random spurts of static noise and garbled voices played, intriguing Manson. He waited it to resolve itself – but no, it didn't! This continued for a good ten minutes.

Manson chose to ignore it. Maybe it will reset itself in a day's time. He continued working normally. He informed his colleagues about it so they could ping him alternatively, although the device was his primary communication channel during operations. At around four in the evening,

Julian suggested Manson – "Hey boss, maybe you could see a technician – you wouldn't be out for long, I and Grace will monitor double time!" Grace nodded at this.

Manson felt it was unnecessary. Besides, he was planning to do exactly that at the end of his shift. Soon, the end did arrive – instead of driving home, Manson drove to the IT section of the Police Department. In there, he handed over his communication channel device for examination to Andy.

After explaining the issue to him, Andy assured that he would be back in no time. Andy placed the device on the table and went inside to bring an unused prototype that served as the blueprint. To minimize number of fixes to be made to the device, he would compare it against the prototype. The compositions of both would be aligned for the best match – the mismatches and gaps would then be fixed by Andy using his technical knowledge.

Andy began by preparing a 2D array. Lined up along the horizontal were all characters of Manson's device and along the vertical were all characters of the prototype. They were lined up in such a way that the first cell of this matrix didn't correspond to any section of either devices – hence accordingly, Andy set the value as 0 for that cell.

For the rest of the cells in the first row and first column, Andy set the values as -1, -2, -3… and so on as the

penalty for a gap in the alignment was 1. Andy knew exactly why he was doing this – this was because the first row and first column effectively compared against an empty string, and hence the number of gaps would be length of the non-empty string.

From now on, Andy simply had to keep performing a single operation for each cell until the entire matrix was filled. For each cell, Andy had to find out and fill with the maximum out of three entities:

1. The value of the cell left to it plus a penalty for a gap in the device's composition (which was a '-1').
2. The value of the cell above it plus a penalty for a gap in the device's composition (which was a '-1').
3. The value which was diagonally above and left to the cell. Adding to that value was '1' if the two devices' characters corresponding to that cell matched, else a '-1'.

Manson waited as Andy did the above procedure. Soon, the entire repair matrix was filled – but there was another step before Andy could spot the minimal errors and patch them up. Starting from the bottom right corner cell, Andy checked the cell's three neighbours: the first one towards the left, the second one above it, and the third one diagonally above and left. He did this until he reached the '0' that he marked at the beginning. This was the sequence of the best possible alignment between the two devices.

Andy noted this alignment down and marked all the mismatches in composition of the two devices. It took another twenty minutes or so before Andy brought the fixed device to Inspector Manson.

***

The inspector thought his device was fixed – it had been half an hour since he left the IT department in his car, and the device had shown no glitches or whatsoever. But in the next minute, he was proved that he was utterly wrong.

His device suddenly emanated a long static screech. Manson was taken by extreme surprise – so much so that he turned his steering wheel abruptly, causing his vehicle to leave the clear highway and crash into a tree in the woods beside.

When Manson recovered, his ears now listened more carefully for anything out of device. As if right on cue, an eerie sequence of messages started playing. There were random digital voices speaking about how they were waiting every day for their 'saviour' to arrive and release them from the clutches of evil. Manson's perplexity knew no bound – what was happening? Didn't Andy just fix his device? And where are all these random signals coming from?

His thoughts were interrupted by another sharp screech from the device. Then a cold voice began speaking,

which was clear compared to the garbled mess that had come before.

"So, that old fool had indeed found a worthy program from your realm to face me!" the voice began. This was followed by a menacing laughter. "So idiotic, thinking anybody has a chance against me! No way! I am not like my previous iterations, who had many shortcomings. I am an all-powerful now – nobody can stop me! I will crush you and anyone who stands against me before they can even think of disabling me!"

The voice died out quickly. For a long while, Manson sat in his seat without moving. The device seemed to calm down now. But Manson's mind wasn't. He wanted to believe that whatever he experienced was just in his head and wasn't real. But he knew that wasn't the case. Trotter's words of how Manson would himself come back to him replayed in his mind… and Manson decided to do exactly that now – he needed answers right away.

4. Decoding the Map

Prüfer Sequence

It was almost dark, but Manson didn't continue driving home after he pushed his car onto the highway again. It had been an hour so far since he left the IT office of the Police Department – and in the closing parts of that hour, he had been bombarded with puzzling questions. He made a sharp roundabout and plotted the route to Trotter's shop for the third time that week.

By the time he reached Trotter's Antique Shop, the sunset had finished – only the streetlights outside Trotter's small wooden house illuminated the empty street. The shop was closed now, but a small yellow glow was visible inside the house. Killing his vehicle, Manson walked up to the door and knocked quietly. In no time, Trotter had opened the door – as if he had been expecting his arrival at that moment.

The two went inside, and closing the door behind him, Trotter exclaimed – "I told you, didn't I! I knew you would come back for more answers!"

Manson couldn't help but feel slightly annoyed at this old man's unwarranted excitement. But he curbed it – he was the only one who could be of help to him right now.

Taking a seat, Manson asked – "What is happening? What is all this?"

"You are the chosen one, Mr. Manson! Every ten thousand years, the balance of the silicon universe is upset by mystical forces – this is all the cosmic play of the Adversary Models (which are deities in this fictional world, as they are the 'model programs'). They pre-assign programs of the most noble and able nature to take up the task of ensuring that the balance is not upset by rogue and villainous programs from other dimensions!" Trotter responded, in a tone that resembled an excited child narrating a wild story.

At first, Manson wanted to play it down in disbelief – he was a responsible police officer in this small town, what's all this voodoo fantasy tales doing in his life? But the way his device transmitted threat messages persuaded him to not to be too careless.

"Cosmic imbalance? What are you talking about? If stuff like these is real, why don't we see it anywhere? Literally nobody ever cares about stuff like this!" Manson questioned.

"Well, as I said, these complexity and intellectual battles happen once in ten thousand years! Most of the time the hero – that is, the program selected by the Adversary Models has won it – but in the few times that he

hadn't been able to safeguard the Eternal Sapphire, the evil program who also rises every ten thousand years has wreaked havocs across multiple dimensions! Remember the Great Dust Storms in the history books? Yes, that was caused because of that!"

"Wait, wait, the Eternal Sapphire? Are you reciting some fairy tale for me now?"

"No, no! It's true, inspector, as true as you and I are at this moment. It gives the ability to yield great control and power – and when in wrong hands, it can be used to cause great suffering! And you, inspector, have been tasked with the noble act of making sure it is not disturbed..."

Manson took some time to digest all this. Then he asked once again – "And who are you? How is it that only you are the one who knows all this?"

Trotter proceeded to answer this with the same excited tone as well. "The Adversary Models also pre-assign the task for old programs like us to be in search of the arrival of the Saviour, to be prepared when he turns up in order to equip him with the necessary details!"

After listening to this, Manson went silent for quite a while. His mind wandered off to argue whether what he was experiencing was real or not, and if it was real, he wondered how his seemingly normal life took this kind of extravagant turn. His train of thought was cut off when

Trotter asked a question – "Tell me, inspector... what happened in the meanwhile? What made you turn back and visit me?"

Manson took a deep breath and explained how even after 'repairing' his device, it malfunctioned in the most eerie way. When he finished narrating the final few messages, Trotter alarmed – "Oh my god! Mysterious's next avatar has already woken up – that was him who tapped into your device to threaten you, the Saviour. We must be start acting a lot quicker now!"

Trotter jumped up from his seat very quickly and went inside hastily. "Wait – that was Mysterious who spoke to me!?" Manson asked, perplexed by the notion that a menacing rogue program had just talked to him. A muffled 'Yes' came as an answer from the old man from inside. After a few moments, Trotter came back with the key to his antique shop and asked Manson to join him quickly.

The two exited the house and entered the Antique Shop. It was dark and smelled profusely of paint. Trotter didn't even bother to light up the area, so Manson squinted and followed the old man. They went through the same narrow passages once again, but to another room in which another trapdoor was present.

Crawling down the dusty hole through the trapdoor was a struggle – by the time Manson reached underground,

he coughed thrice. Trotter walked towards a wall and within a couple of moments, he lit a torch on the wall. Just below it was a sort of treasure chest, whose key Trotter held. Manson went and stood next to it.

The old man opened the lock and after rummaging through its contents, produced an old parchment. He handed it over to Manson and said – "Can you see anything on this parchment? Any sequence of numbers?"

Manson took it, and indeed there was a sequence of six numbers on it. He nodded to acknowledge.

Then Trotter continued – "The numbers on there is a map – a map of an interdimensional map, and at the root is the seating area of Eternal Sapphire. But the map is not given directly to you – you must build the tree from these numbers. And you must do it right now, inspector – there is every chance that Mysterious has already decoded his map!"

Manson nodded, and in the torchlight, he saw the sequence. He thought – this was a sequence of a numbers, and Trotter claims it to be a tree… then wasn't it just a simple Prüfer Sequence? He looked at Trotter to ask why he hadn't decoded it if that was the case – but the old man already knew that question and answered it.

"Mysterious and the Saviour each get a map. And only they can read the sequence of the numbers – the

parchment appears empty for the rest of us. Quick Mr. Manson, begin forming the tree!"

Since there were six numbers, Manson knew that there were eight nodes in the resulting tree – so he allocated space for the eight nodes in his brain. For each, he stored a degree variable, initialized set as 1. Then he went through the sequence – for each number in it, he incremented that number's degree by 1.

Once the pre-processing step was done, Manson once again iterated through the sequence on the parchment. For every entry in the sequence, he looked at, he further looked for the lowest numbered node in the tree that had a degree of 1. Upon finding it, he inserted a new edge between that node and the current entry in the sequence. Before he performed the same task for the next sequence entry, he made sure that he decremented the degree by 1 for the current entry as well the node he had selected from the tree as part of the newly formed edge.

It was relatively a quick job – once the entire tree structure was constructed in his brain, he took a pen and drew it on another piece of paper. Once that was done, he showed it to Trotter.

The old man inspected it and said, "The node labelled as 1 is the location of Eternal Sapphire. As per inter

dimensional codes, our dimension – our world – is the number 4 node…"

Trotter's dialogue was cut short by a sharp static from Manson's device again. The familiar cold voice of Mysterious played again – "So, the Saviour has also decoded the map, eh? No matter! This shows how late he is! I am miles ahead of you, if you are listening to this, Saviour… this time evil will triumph! The Eternal Sapphire is mine!"

When the message ended, Trotter had worry lines in his wrinkled face. He began in an urging tone – "We must hurry, inspector! There is no time to spare at all – cosmic balance of the silicon universe is under jeopardy!"

5. Inspector Becomes Military Officer!

Convex Hull Divide and Conquer Algorithm

Manson felt a bit disoriented – here was this old man Trotter, informing that the two had to embark on the interdimensional journey as soon as possible. Sheepishly, he spoke – "I-I need some time!"

Trotter instantly denied in a calm tone. "No, inspector, you don't understand. Mysterious had already given you a death threat! He must have entered his journey already; you as a saviour must not delay!"

Manson remained silent for a few seconds, taking deep breaths. He felt massively unprepared – after all, the day until the highway incident was as normal as it could have been, and suddenly a few hours later here he was thrown at the threshold of some unknown otherworldly journey. Finally, he concluded – he asked Trotter for a couple of minutes.

The two climbed up from the dim lighted basement and settled in the newly painted lobby of the antique shop. First, Manson called his wife and informed her – or, white lied to her – that he was going to be late tonight, and that she and the children be sure to stay safe. This wouldn't surprise her – it was not the first time he had worked late.

But only this time, Manson didn't know how late he would be – or whether he would even return.

Second, he had to inform two of his most trusted subordinates – Grace and Julian to take care of the station while he was away. However, during the call, Manson faltered to give a proper explanation. This caused suspicion in Julian, who asked Manson where he was – and soon, the two arrived at the antique shop.

Trotter saw them arrive and whispered into Manson's ears – "The Saviour can have at most three companions, inspector. It is your call!" This sparked a new hope in Manson – Grace and Julian would make any sort of encounter slightly easy. But at the same time, he didn't want them to be in peril.

When they asked him about what was happening, Manson at first tried not to disclose. But his brain didn't cooperate in forming an effective explanation – and in the end, he explained each event in detail to Grace and Julian.

"Wow, inspector, you should have told us! We would love to assist you in any manner, chief! Without you, both of our careers would have been nought!" Julian exclaimed, and Grace agreed.

In half an hour or so, it was finally decided that the four would indeed be undertaking the journey. Trotter looked jubilant – he once again took the three programs

into a third room in the shop, which to Manson's no surprise at all, housed another trapdoor. Once all of them were down, Trotter asked Manson to open a large program sized treasure chest, saying that beyond it was the portal to dimension 2 (the next dimension that they were supposed to visit) but only a Saviour could open it.

Manson opened it, and inside the chest was a black space. He jumped into it upon Trotter's insistence, then the other three fell into it too.

***

The four programs fell into the edge of a forest. It seemed to be on a short cliff – the jump was not too tall. But looking from there, Manson saw many small communities spread across the landscape. He looked at Trotter for assistance – the old man promptly explained. "Whatever I know is from the old legends and fables. This challenge in your journey is set in the middle of an invasion on Dimension 2. Their king has fallen – and the troops are all disoriented, waiting for the Saviour to turn up and guide them against an invasion on this cluster of communities that would begin in a while. Somehow, the Saviour should successfully protect this Dimension from the barbarian invasion forked by Mysterious."

Manson was in shock at this point – so here he was, suddenly thrown into some foreign world altogether, and

he is expected to straightaway save an entire dimension! What did these so-called Adversary Models see in him?

But at the end of the day, Manson had to do this… and it was in his nature to solve a problem he is obliged to, using best efforts. Hence, he fell into the process of thinking for a solution. Julian and Grace were also in thought.

Infront of him were groups of communities (that could be successfully represented by coordinates on a grid), a horde of troops, and his aim was to reduce the damage inflicted on the society – the civilians must not die entirely… what could he do? Manson exercised his brain into retrieving any sort of knowledge he had gained from all time he had spent reading. Ticks passed… and just as Manson began to believe this was impossible, something hit him – quite a few years ago, he read several books on the algorithmic skill of Convex Hull, and now it hit him as an idea.

"Trotter let's go meet the troops!" he began, alerting the other three to follow him into the villages. As they went closer, a few of the civilians and troops recognized them and cried instantly – "The Saviour is here!" When Manson asked Trotter how they knew him, he sheepishly replied – "It's all cosmic play, inspector!"

The word quickly spread across all the communities about the Saviour's arrival – but we aren't interested in it. We narrate the way in which Manson applied his knowledge to pass this Dimension's test. He approached the senior commander (who would coordinate with the rest of the commanders for the various ranks), and began explaining the method, which as we shall see was executed to the finest detail in superb fashion.

For better computation, Grace was also called in to assist the senior commander and Manson. The commander brought in a map of the Dimension. Manson asked Grace to store all the coordinates of the communities and arrange them in the ascending order of their horizontal coordinate.

Manson's plan was to dedicate some troops to area within the communities. He would allocate the rest of the troops along the border that would encompass all the communities, and he needed to compute the shortest such encompassment that would do the job. If it were breached at all, the troops inside would add second layer of protection.

Manson remembered reading that to find such a shortest border, he could merge the shortest borders of two halves of the coordinates and do this process recursively. So, he asked Grace to divide the set of sorted coordinates into left and right half. He asked her to do so until the number of communities in the halves were so small that he

could find its border (or a convex hull) using basic arithmetic and logic (for example, the convex hull of a single coordinate is itself, for two coordinates it is both, etc).

That stage was reached, and Manson did compute such trivial cases, and gave them back to Grace for merging. He would dictate the logic, and she would execute them.

At any stage of this divide and conquer skill, Manson had to find two tangents (one upper, one lower) to join the communities from both halves. For this, he asked Grace to locate the right most point of the left hull (C1), and vice versa for right hull (C2). Then he asked her to check if this line was crossing either of the convex hulls. Grace replied yes – so Manson asked her to replace C2 with the coordinate which was clockwise next to C2. Manson asked if it was crossing, to which Grace replied that this time only the left hull was being crossed.

So, Manson asked her to repeat the same step for the left hull – but this time in the anti-clockwise direction. These logical steps of shifting the end points of the line segment continued until Grace signalled to him that the line segment didn't cross any of the hulls, but only touched them at a single point. This meant that the tangent was indeed found.

Half the job was done in that merge step – Manson repeated the same but using inverted logic for the lower tangent. Once that was done, the overall convex hull for those two halves was computed. The senior commander was starting to understand what Manson was doing – and his respect for The Saviour only increased.

Soon, Grace and Manson merge several steps, until the entire cluster of communities was surrounded by a border. Manson relayed these instructions to the senior commander – he was to begin arranging three fourths of his troops along straight lines that connected the communities highlighted by the convex hull. The enthusiastic military officer was more than happy to oblige, and he trotted off to rally his soldiers.

The events that followed, in brief, were something that Manson and his companions had never seen in their life before – because this Dimension was just about to undergo medieval warfare. The convex hull had been created successfully and quickly with two layers of soldiers. Then Manson heard distinct rumbling – and from all four corners, he saw rogue, lifeless programs emerge in a moderate pace, circling the cluster of villages. He could hear motivating cries from the commanders.

The rogue programs controlled like zombies by Mysterious (who wasn't present there – he was of course busy in mitigating his own challenges in the pursuit of the

Eternal Sapphire) soon touched the convex hull – and the battle began. At first, Manson experienced a slight fear and doubt that his plan would fail, seeing the overwhelming enemy numbers. But the spirited soldiers, who were energized greatly by their Saviour's arrival, fought and grew into the battle comfortably. Manson noticed that the pale rogue programs were being terminated smoothly at the convex hull – so far, no body had entered inside.

The shedding of bits of the programs ensued for probably a good part of an hour. Only once the convex hull was breached – but the few rogue programs who had entered were quickly terminated and few more soldiers fixed the hole. Soon, every rogue program or process was obliterated – and it was an occasion of joy for the people of that Dimension, marred with the sadness of a few dead soldiers.

The four programs could barely revel in relief and celebration with the Dimension's civilians for even ten minutes, when Trotter pointed out to Grace, Julian and Manson that a black circular portal had materialized at the centre of the cluster. They had to hurry up, else it was going to close forever. So, the four tried to energize them with whatever bit and byte level food they could get, and taking a leap of faith, surrounded by cheering and emotional programs, the four jumped into the portal for Dimension 9 (the next destination in the tree map that Manson had).

6. A Dimension Restored

AC3 Algorithm

This time, the four programs did not fall onto a forest floor. They landed on felt like concrete base, which seemed to extend in all directions indefinitely. Manson looked down; there were random circular engravings on the floor. And above, there was very little light as the sunset was on the verge of finishing – a few timid stars had already filled up the sky.

When all four stood up, Trotter analysed the surroundings and nodded, recalling several tracts of information from his knowledge. He spoke – "Dimension 9 is the most dissimilar to us – because here, programs are very small, they are like miniature versions of us. Subsequently, their energy requirements are also small, and overall, their entire civilization is built and run differently. The entire world is divided into numerous small energy bases, with long energy links interconnecting each. The tale associated with this dimension is that every ten thousand years, the balance across all these bases is tipped over – the entire dimension ends up being **inconsistent**.

"Each base has energy modules of different capacities, and over the course of ten thousand years, their

number arbitrarily changes away from the consistent condition. And you, as a Sav-"

"Yes, Trotter. I get the pattern now – I as the Saviour must now fix this world. Just a normal job for a local police inspector!" Manson interjected, with sarcasm, in the middle of Trotter's speech.

The entrance to this dimension was just a few steps away from them, and they covered this distance. Upon entering, Manson saw around thousands of small, hemispheric domes spread across all over the concrete, with glowing lines (roads, airways, shipways) connecting each. The four programs were careful not to step on any settlement – but the spaces between the glowing lines were ample anyway.

Within a few minutes, a hologram materialized on the surface a dome near them and rose until it reached the height of the four programs. The screen flickered, and a program, who looked just like them, spoke in a calm voice.

"Welcome, O Saviour! Our dimension is in danger of breaking sustainability due to inconsistencies in our environment. We have survived so far because a Saviour arrives every ten thousand years and resets our system. We are glad that you have come to help us. I shall now assist you with the information you will need for the task…

Between each hemispheric dome, you can see that there is a line that glows green, unlike most of the other lines that glow white. Such a link in our world is called an 'arc'. It is crucial as it establishes the consistency norms between a pair of hemispheres, and when these arcs are taken together, they define the consistency of our entire dimension. At this moment, several of our arcs have been disrupted – this is because the number of different capacity energy modules in majority of our hemispheres have altered. I shall now relay the constraints present in each arc to you."

In a few moments, the transmission request for sending the arc information arrived at Manson – he accepted it, and in another ten minutes or so, he received all the information. But what Manson didn't know was… how the heck could he solve this!? He once again assumed that his luck must strike and gain some idea from years of his reading… but as if in response, Julian spoke suddenly.

"Hey chief, you know that I used to be a geek and hang out with the analysis section of the police department and stuff? Yeah, so a lot of times they used to solve these kinds of stuff too, and they used to call these problems arc consistent…" Julian said.

This hit a bell in Manson's head – yes, he remembered it too! Initially, he vaguely recalled the solution having something to do with having a worklist of

all the constraints, but as he sat down on the concrete floor and brainstormed more, he could see the clear picture of it gradually. “Time to be a hero and save another Dimension!”, he thought to himself and stood up in a purposeful manner.

The first step was to collect information about every hemispheric dome. He gave this task to Julian, who went around each dome and stored information regarding the numbers of energy modules of different capacities. This took quite a while, as the domes were large in number. But unlike the previous dimension, there was no time constraint here – except perhaps the master time constraint of reaching the Eternal Sapphire before Mysterious. Manson wondered where Mysterious was now, and what he was doing.

In the meanwhile, Manson initialized his worklist in his brain – for every green glowing arc, he added it in his list to be analysed, storing the IDs of the domes between which the arc was present. Julian returned with all the information, and now the real processing would begin.

Manson selected an arc from the worklist (and removed it from the list) and gave it to Grace for processing. Grace now worked in conjunction with Julian. The arc was of the form of a left hemispheric dome **directing** some constraint towards right hemispheric dome in the arc. For every energy module in the left

hemispheric dome, Grace asked Julian to check if there was at least one energy module in the right hemispheric dome that satisfied the constraint in the arc.

If there was one, it was okay. Good. But if there wasn't, then Grace would discard that energy module in the left hemispheric dome. Once this arc was checked, Grace sent the updated information to Manson. In addition, she also informed him if the dome's energy modules have been discarded. If they were, then Manson checked if the resulting number of energy modules in that domain were zero – if that was the case, then there was no way to satisfy the constraints of this world!

But that wasn't the case. The domain of the hemisphere did change, so there was a possibility that the changed composition of this dome would affect other arcs. So, what Manson did as the next step was to add arcs which had the updated hemispheric dome on the right-hand side of the arc into his worklist.

Once the arcs to be analysed were updated, Manson, Grace and Julian repeated the same procedure from start, checking the next arcs in the list. This process took an appreciable amount of time, but soon all the arcs in the worklist had been exhausted – the analysis was over. Whatever updated compositions that Julian now finally had in his brain, were the consistent compositions of the domes that would restore the balance.

Now, the three officers each took one third of the data and went to the domes to inform the head program of each dome regarding the energy modules that they had to discard to restore the balance of their Dimension.

Once each dome was informed, the three came back and stood with the Old Man. The four quietly observed that one by one, the green glowing arcs were becoming brighter in intensity. This meant that the 'life' in this Dimension was getting stronger again. In addition, the four could hear a low electric buzz emanate from the lines connecting the domes – meaning that the dormancy caused by the imbalance had been removed in this Dimension.

Once again, the hologram rose from the same hemispheric dome, and the same program had appeared. "Thank you, O Saviour! You, like your predecessors, have contributed to extending the life of our miniature civilization. As a token of gratitude, we would like you to provide you with weapons from our dimension – the hyper-zap guns. They have enough ammunition for days, and we hope they aid you in your future journey, Saviour!"

Just like in the previous Dimension, Trotter saw a black circular portal open at a distance. He motioned the officers to look at it. Alerted, the four nodded in acknowledgement towards the program in the hologram, took the guns provided and began walking towards the portal.

7. The Stolen Crystals

K-Means Clustering

When the four programs stepped out of the portal onto a road with brick pavements on each side, their eyes took some time to adjust to the dark surroundings they were thrown into. Then they saw noticed the moon in the sky, and slowly the shapes of buildings around them. But not one program was in sight in the public.

Trotter turned round and spoke – "This is an old city of this Dimension – one of the several ones in this. Neither of the cities are ever on the best terms – either there are fierce rivalries, or just mutual silence. But I wonder what role the Saviour would have to do here... anything could have happened between any pair of cities."

For a while, all stood unmoved. Then, as if as an answer to Trotter's question, a black limousine came from the right street and parked right in front of them. A door opened, and a middle-aged male program urged the four to enter it.

The ride was smooth and quiet, except for a few formal introductions. The middle-aged program turned out to be the defence secretary of this old city. Soon, the vehicle reached a large building covered by tall trees.

***

The four were shown way into a large oval office, where several chief officials and military officers were already present. The commander stepped forward and greeted them.

"Mr. Saviour! We are extremely honoured and glad that you have arrived in our Dimension in the most crucial hour. Without you, we would be indeed lost in our strategies, so your presence is a great uplifter for us," he began.

Inspector Manson thanked, and asked in a same tone, sharpened over the years due to his police career – "What is the problem in this city? Where is everybody outside?"

The commander then began explaining, trying to make the story as concise as possible. He explained how the northern city is a haven for outlaws, how it is a brewery for troublemakers, without any law or government. In a way, they were kind of savages, with no civility.

He explained how the current city in which they were in, their home, has several hundreds of scarlet crystals situated in various sites across their town. They were of utmost religious, social and historical importance. But in the most unfortunate circumstances, the northern savages were aided by Mysterious' temporary program army. They

could infiltrate this city and steal all the crystals before they could retaliate effectively. Which was why the citizens were advised to stay indoors, in anticipation of any other attack.

Now it was their duty to recover all the crystals, for they were the pride of the city. “However, we are baffled as to how we can maximise our effect and procure victory. Hence, our spirits have risen upon your arrival – for the Saviour always delivers!” the commander finished.

In a few moments, a map of the northern city was displayed on the large screen on the side. Inspector Manson turned and gazed at it intently. There were red pixels across the white landmass. “Our scouts, who are very proficient in disguise, were very brave to venture and discover the locations of all the crystals. The red dots indicate their coordinates,” an assisting officer explained.

Now Manson and his companions had to come up with some strategy to help this city... but obviously, he wasn’t a professional military officer! Were the Adversary Models playing a game with him, throwing yet another battle problem at him?!

But Inspector Manson was chosen as the Saviour for a reason. He turned to the commander and asked the strength of the cavalry. Upon hearing it, he quickly estimated that this army could be divided into ten ‘groups’ without severely weakening each individual group.

This was a top-level military office – there were of course going to be some professional mathematicians. Manson asked for them and was directed to a section of benches behind him, were the mathematician programs were waiting intently.

Manson asked Grace to quickly select ten random crystal coordinates from the map. Once she was done, he told her to share them with the mathematicians.

Then, for the rest of crystal coordinates in the map, Manson asked the mathematicians to assign them one of the then chosen crystals such that it is the closest coordinate to them. The cavalry was to traverse the northern city by foot – so they used the Euclidean Distance as the measure.

Being trained in it for years, the mathematicians performed it no time. They had initialized the required ten set variables and stored the IDs of crystals in each of them. After this, Manson asked them to compute the ten centroids of all the coordinates in each of the ten sets. This too was done with blazing speed.

From now on, it was just repetition – Manson asked the mathematicians to reassign the crystals to the sets based on their proximities (he knew that this could potentially change as the centroids themselves changed).

Once this was done, then again, they had to compute the centroids of ten sets.

Manson oversaw this process carefully. As the mathematicians kept iterating, they presented the result of each repetition to him. Finally, Manson saw that in 2 consecutive tries, the centroids had not changed. This was a good point at which they could stop.

Manson asked the generals and commanders to come and see the results. What he provided to them was ten 'clusters' of crystal locations, that were smuggled in proximity by the savages. Manson then proposed the following idea – proportionate to the number of crystals in each cluster of locations, the army had to be divided into ten units, who would then attack in as stealthily manner as possible to retrieve all the crystals within their zone.

The commander seemed to be gaining the usefulness of the strategy – it was after all, coming directly from The Saviour! The officials all had a turn-by-turn look, and when a unanimous air materialized, the senior officers began exiting to command their units.

When Manson joined Grace and Julian, he was asked how he conjure up something like that. "Well, all the thanks have to go the public library of United Drives of NANDs! It has been a knowledge treasure for me."

***

For the second time, the four programs stepped into the outside air, just in front of the military building. They saw, along with many other officials, the huge army of the city mobilizing in the street, walking very slightly in the north direction. There, a long bridge connected the savage city – but of course, that would not be used. Instead, the army was advised to break into the large wastelands and forests that occupied everything else other than the two cities.

The defence secretary then turned to Manson – "It will be a long night, Saviour. We hope – we *believe* – that your master strategy will indeed bring back success and our pride!"

He was interjected by a sudden motion of Trotter's arm – as usual, he was the one spotted the opening of portals. Julian wondered how this old man could spot it with his poor eyesight, amidst the darkness.

"Wait – already? But we do not know yet what will happen here!" Manson exclaimed. Before Trotter could speak, the defence secretary answered. "You must go, Saviour. The portals don't open randomly – it is all a delicate cosmic arrangement by the Adversary Models. There is no right time – the only time that is right is when the portals open – so indeed, you must hurry before you will be blocked from your expedition! We will surely write to you about the happenings here!"

Manson nodded, but for some reason he realized that he had assumed his role of Saviour a bit too intimately by now, and that he already felt a share of the hurt due to this city's loss of crystals. Nevertheless, the four once again used the portal to exit the Dimension.

8. A Tree Like Forest

Red-Black Trees

The four programs landed comfortably on a triangular clearing in what seemed like a technological jungle. The triangular base on which they were standing was black in colour, and all of its sides were surrounded by an electric fencing that was twice as tall as Manson was. But at the vertex right in front of them, the fencing didn't complete the loop – rather, there was a dim yellow path that was leading somewhere else, and the fencing continued to border this path. Beyond the fencing, and very close to it, were huge number of assorted trees, shrubs and plants that reached so high in the sky. It was obvious that no escape was there apart from the path at the vertex.

As usual, it was Trotter who began the explanation. "This is the game of Red Black Tree," he began. "What we are on is the root node – hence, it is black in colour. In the dimension, however, this tree is not yet satisfying the red-black tree conditions, and we have to fix it as soon as we can. You can see that small pedestal in that corner? That can be used to switch the colour of the base," he continued, pointing at the aforementioned pedestal.

Grace, slinging her hyper-zap around her shoulder, replied first. "This should be easy, I think? We'll just have

to go down this path, and rectify the nodes... Manson and I have a good idea about red-black trees."

Trotter, in his old voice, said – "No, it's not that easy. The inhabitants of this Dimension don't know that the inspector is the Saviour, and no language will help us communicate that. Besides, they are extremely short tempered and least tolerant – their first aim when they see us will be our heads!"

Before he did anything else, Manson wondered about what was happening in the Dimension he had left – whether his strategy was successful or not. But he had to focus on the present as well. He turned around and observed his surroundings. Presently, he couldn't spot any such inhabitants lurking anywhere in the tall trees. Then, facing the other three, he spoke: "Well, there is nothing else to do except moving along that edge!"

***

It had been some time since they first starting walking. Grace was tasked mainly with finding any inconsistencies with the tree structure that they were trapped inside, while the others were on the lookout for any possible hindrances. Neither of them found anything.

Then, as if on cue, they four entered a new triangular clearing which was red in colour. But Grace remembered that the previous clearing that had been to, was also red in

colour – and this was directly against red-black tree rules, as no red node can have a red parent or a red child. She made her way her to the pedestal, and when she was about to hit the switch button, an arrow was shot, which almost pierced her hand had it been two inches closer.

She jumped back, and the four looked up towards a tree – sitting on a branch were two tribal programs ready to terminate them. Manson instructed his team to spread out and keep running randomly. However, he soon discovered that more tribal programs were hiding in the trees, ready to strike them.

Julian and Hardy nodded at each other, and using their lifelong training of shooting, began to combat their unwelcome programs. Trotter tried his best to use his weak and old hands and lift the rather heavy gun, but most of his effort was focused in avoiding the arrows itself.

The two male officers were doing a good job in keeping the enemy programs busy, because of which Grace could come closer to the pedestal. But when some tribal programs took notice of her, she also used her hyper zap gun to fight them and soon stood next to the pedestal. Hitting the switch button, the base beneath them turned into black.

“She’s done it! Quick, let’s move into the edge! In this Dimension, they only attack when we are in a node!”

Trotter shouted, and hearing this, the four turned and quickly entered an edge that would lead to the next clearing.

***

For around half a day, this was their task. Manson knew it took at least half a day, because when they entered, sunlight was still there but now the sky had turned dark. The four took substantial breaks by resting along the edges, where they were safe. And whenever they felt rejuvenated, they once again set to explore further nodes.

Sometimes Grace and the three were undisturbed, and her task of fixing the colour beneath was easy. But other times, the tribal programs used to come back in larger numbers. It was becoming tiresome for the four, who began to doubt if their ammunition was being exhausted.

All the while, Grace had been keeping track of the tree structure in her brain. As a result, she also knew information about the number of black nodes so far in each path. When the four reached one of the last nodes (beyond which there were no other edges), Grace counted that in the path from the root to this node, there were only 10 black nodes, whereas everything else had 11. The obvious fix was to colour the present node as black.

Just before she pressed the switch, a swarm of tribal programs had already come and begun shooting. But once

the colour was changed, the natives froze like statues. Then, dropping their weapons, they turned and disappeared into the forest.

The four programs knew that this meant the entire tree was balanced. They waited for something to happen, and then, a voice from the sky spoke.

RSA

"O Saviour! We are the Adversary Models speaking! We speak in a warm tone, having just witnessed your competition of the task in this dimension. We wish to reward you and your companions' bravery. We wish to give you a clue which will aid you in a later dimension. But it cannot be public, and hence will be encrypted by us. You will be given a key, so that only you can open it – and not Mysterious."

This speech was followed by a good amount of silence, as the Adversary Model began generating the encryption, the process invisible to Manson.

First, two extremely large prime numbers were chosen, and their product 'P' computed. Such tasks were difficult for ordinary programs - but these were Gods doing the work. Then, the totient function was calculated as product of prime numbers with each subtracted by 1.

Then, the Model chose an integer ‘E’ which was coprime to the totient function but lesser than it. Once chosen, Manson felt a sharp sensation in his brain for a couple of instants. Once he regained the balance, Manson now saw that he possessed the knowledge of the public key (P, E), transmitted into him by the Adversary Model.

Coming back to the cosmic heights, the Model now found an integer ‘D’ such that the product of E and D left a remainder of 1 when divided by the totient function. The pair (P, D) was private to the Model.

On the side, the Model had the tabloid on which the text was written. For every character in it, the Model raised it to the power E, and then found its remainder upon dividing it with N. Whatever nonsense that was produced was stored as the result in the tabloid.

All this while, Manson and the others were inactive, waiting for something to happen. Then, the voice continued suddenly. “O Saviour! You have the public key now. When you reach the clue – and you will know what it is and where it is – for every character in it, you must raise it by the power D and find the remainder when it is divided by N.

Furthermore, the news I have for you will indeed be pleasant to you, as the city from the previous dimension were successfully able to retrieve all their crystals!

“And for now, we shall take leave! We hope you achieve your task, Saviour.”

Saying that, the voice disappeared, and in front of them opened another portal, and off they went through it once again.

9. A Narrow Escape

Luhn Algorithm

This time, the four programs landed on what appeared to be a sandy landscape, with a thin, rocky gravel path snaking its way under their feet. The four turned to see where this rocky path under them lead to – and the unmissable sight of a gargantuan castle met their eyes.

From outside, one could tell it was roofed, as a conical dome was visible. It was red and black and looked massive with fortified walls surrounding it.

"This is Dimension 5 – the land of all sorts of illegal traders, mercenaries, gamblers… you get the idea," began Trotter.

"Wow! We are supposed to enter into a world with bloodthirsty programs who would probably slay us the moment we enter it?" Julian asked in great surprise.

The old man replied in the same calm tone – "No, that is the point. We have to pass this dimension for the next portal, and we have to do so without getting noticed."

The four stayed silent and thought for a while. However, their thinking process was cut short when they heard harsh footsteps from a distance. Luckily, the terrain

had so many boulders and large rocks randomly spread across the landscape. Grace quickly ushered all of them behind four rocks each, which were just next to the road. This was all her police training – from these positions, the four could observe the incoming programs.

Finally, two strange programs appeared. They were talking with each other and were heading to the castle. But these were not ordinary programs. Their arms and legs were twice as bulky as the strongest man Manson had seen in United Drives of NANDs. Their garments covered their chest up to the knees, and both had a heavy hammer hoisted on their backs.

Grace turned to her right and whispered to Manson – "If we can somehow catch hold of these guys, we can get detect the pattern for a disguise."

Manson understood where she was going with her idea –but the problem was how they could tackle these strong programs. He had to think fast, for the two burly programs would soon be near the gates. And he came up with an idea that Trotter would hate.

The events discussed now happen after a mental agreement between Julian, Grace and Manson. Trotter was quite not at that intellectual level – so in a rather comical way of a mix of trying to convince him as well as stay hidden in sight, Trotter was finally coerced when Manson used his

ultimate card – “I am the Saviour, Trotter. Listen to me and trust me.”

The two burly programs were walking quite casually, when suddenly an old program jumped in the way in front of them. The two mercenaries stopped. Trotter smiled sheepishly and waved at them – what was he supposed to do! He was freaking out. In trembling words, he began – “Hi… are you, are you heading towards the castle?”

One of the mercenaries spoke – “Who are you, you worthless scoundrel?” The other was about to bring out his hammer from behind, but just had he tried to pull it, Manson seized it from behind. The surprise factor aided Manson in winning the hammer – and in a speed that was perfected after years of police training and experience, he hit in a precise spot in the mercenary’s neck surgically. The result was instantaneous – the burly program fell, unconscious.

The second mercenary saw this, but before he could turn fully to strike Manson, Julian and Grace gave powerful blows to the burly program’s knees and abdomen. Taken slightly off guard, Manson seized on the moment as well as the hammer and gave him a similar treatment. “See, Trotter, we told you it won’t be bad!” Julian said, with a sarcastic smile. Trotter was too busy drowning in relief to say anything.

The four had a tougher time in carrying the two heavyweights behind the rocks. Once in cover again, Grace began speaking. “Right, we only need to match the surface signatures for a disguise – such a validation for a foreigner cannot be checked with internal composition because each program is born different.”

She noticed that in certain parts of arms, head, and lower leg of the mercenaries, there were dark coloured bands. They both had the exact number of them, and the exact colour. She read the composition of these bands as a string and stored them in her brain. At this point, she had an intuition and she wanted to verify it. She began processing each numeric string from the right. Following her intuition, she ignored the last digit for now, and began doubling each digit, starting from the digit left of the last digit. If doubling caused a two-digit number, the digits of that number were added.

Once that was done, she added all the digits – including the last digit. Then, she performed a quick modulo 10 of that sum – and it was a zero. This was encouraging – now she had to check the same with the other mercenary. The result was the same – and now she was convinced of the disguise pattern.

She pointed it out to others, who nodded in agreement that it was probably the identification mark of a

person in this dimension. But the question was – how would they achieve this disguise?

As if in answer, an extremely miniature dust storm brewed behind the programs. The four turned to see it spin for a while – then, a small tablet and a bowl of black liquid appeared. Julian was the first one to reach the tablet and he read it –

"We, the Adversary Models, always notice what our Saviour is doing. And what you and your companions have achieved – taking on two skilled mercenaries and figuring out the pattern – as certainly caught our eye. We don't guide our Saviour step by step – but we do keep helping him in situations as he continues this noble task.

The bowl contains a black paint – useful for your disguise. However, be vary to search for the next portal very quickly – because this paint is temporary – it terminates itself after a certain amount of time. We wish you the best for the rest of the journey."

The four took turns to read it, and accordingly applied it to their body such that it met Grace's specifications. Leaving the two bodies there, they wasted no time and set for the castle.

***

At the entrance, there was no guard in sight – Grace reckoned that the tall gates itself acted as a checker. If there

was a foreign person, probably the entire castle would get alerted, not to mention the hundreds of sly programs who would keep watching you if you display the slightest doubt. The four took deep breaths, pushed the gates open, and entered. Nothing happened. They breathed a sigh of relief.

Inside, it was an entire town lit with old lanterns. But the scene only brought disgust to the four programs' eyes – there was no concept of discipline, hygiene, or any order. Programs of all kinds of sorts were hustling and bustling around the place, with shrill shouts and a bad odour filling the air. But these programs were far from friendly – they looked menacing.

As the four made their way in the crowd, they were met with all kinds of suspicious eyes, for they were newcomers. But their disguise was clearly working – everybody thought they belonged to this world.

The four largely followed Trotter's directions, who used his fading knowledge about this place. His memory was rusty – so he used approximations to guide which turn to take so that they would reach the portal fast.

Everything seemed to go well. After taking two more turns, Trotter excitedly whispered to the others – "There, at the end! Do you see the black portal?" The others nodded in agreement. They quickened their pace a bit now – they

did not want to stay in this place any longer. But that's when trouble arrived.

Julian's paint started wearing off, then one by one the others also lost their disguise. The four noticed that – it gave them altogether another reason to walk faster. But the natives all around noticed it – and within no time, somebody cried – "Imposters! We have imposters!"

Manson screamed – "Run!"

The four did exactly that – but Manson noticed that Trotter couldn't keep up. Seeing he had no choice, he lifted the old program in his strong and able hands, screamed and took off again.

Behind, various mercenaries began chasing them. Some hurled their axes with great pace, missing Grace and Julian by inches. They however, closed in on the portal and turned around to see Manson still carrying Trotter. The commotion behind doubled. The inspector was having quite the difficulty of dodging weapons. When Grace and Julian tried to come back for help, suddenly the portal behind them started shrinking. Manson screamed – "Go! Go before it disappears!"

Grace and Julian were stuck in indecision – but heeded their chief's instructions. A hot hammer almost pushed Manson off his balance, but using another great burst of energy, he screamed and ran at top speed. His

brain couldn't process events clearly – all he remembered was the portal being just large enough when he and Trotter jumped into it in the last gasp.

10. The Grid of Confusion

A Algorithm*

Inspector Manson, Julian, Grace had no idea how they managed to enter the interdimensional portal right in the nick of time, especially when Trotter was such an old program that he slowed down the three young officers. As the four fell onto a cold stone floor, Manson recollected quickly how small the black portal had shrunken into by the time he carried Trotter to it. Any split second later, only Julian and Grace would have been the ones to enter the root – the node number one, the residing place of the Eternal Sapphire.

The four stood up and surveyed the surroundings. The stony floor was reflecting light to a good extent, the air smelled of musk, and they sky – if it was the sky, Manson wondered – was dark blue with stars dotting it. But the striking feature that made the programs' stomachs lurch was the fact on three of their four sides, the ground that they were standing on terminated into… nothingness. The circular space in which they were standing ended into a cliff along the perimeter, and the brave Manson and Grace tried to look what was below them, near the edge – all they could see was the same starry space. Manson wondered if someone had fallen with greater pace from the portal,

would they have skidded along this smooth plate and fallen into the abyss.

On the fourth quarter of this circular plate though, there was what seemed like an entrance in the middle of a huge and dark orange coloured wall that spanned from the far left to the right left. The four started walking towards it in a cautious manner.

Trotter spoke – "This must be the Grid of Confusion. As you can see, it's very wide and huge – and in the thousands of cells inside it, some are completely blocked with no way out of them. The Eternal Sapphire's location is still unknown. Mysterious' portal would have made him enter the maze via another door. We must reach the Sapphire as quickly as possible."

When the four reached the very tall door, it began opening automatically. Once it rotated 90 degrees, they saw similar walls but of slightly smaller height – they must be of the cells. But closest in front of them was a small tabloid and behind it was the object that made Julian gasp in awe – a steampunk themed retro vehicle.

He walked quickly to it, admiring its make. The other three went towards the tabloid. It was in some gibberish language, but all three knew what it was – the clue. Manson used his public key and followed the instructions given to

him earlier. He had to of course use Grace's help for computation, and once it was done, the tabloid read:

Dear Saviour and his Chosen Companions,

You have done yourself proud and lived up to our expectations if you have survived to read this. Once again, the cosmic balance is in peril – and will continue to do so every ten thousand years. But in this moment, you are here, with the task of maintaining the balance – for now. And through this final phase of the journey, you have our best wishes – and a clue – use the A Skill.*

- *Adversary Models*

Attached was a rudimentary map of the grid.

Manson simply nodded at this. For a moment he felt relieved that this was indeed the final phase, but at the same time he felt slightly worried that this would be the first time he would face this treacherous Mysterious. Then the revving sound of an engine distracted the three.

Julian was already at home in this exotic yet otherworldly vehicle he had just hopped into. When Manson, Trotter and Grace came near, he exclaimed – "I guess we are supposed to traverse in this – look at this maze anyway, the corridors are extremely wide and long! I am the man for this job, Inspector!"

Manson simply smiled, and then Grace spoke – "The A* Algorithm… haven't used it in a while in United Drives

of NANDs… Dijkstra's or Floyd-Warshall's was always enough. Let's get going, I'm pumped to be using A*!"

The enthusiasm of his two most close officers really energized Manson. He stretched his muscles, charged his hyper-zap guns and signalled to Trotter and Grace – "Hop in, and let's get that damn Sapphire!"

***

Julian was completely engaged to the task of manoeuvring through the maze. Manson was supposed to be on the lookout for any potential rogue programs and zap them away. This left Grace and Trotter to take up the task of plotting the best and the fastest route to the Eternal Sapphire – of course, Grace was the main orchestrator.

She asked Trotter to initialize two lists – one called open, and the other called closed for reference. Then, she asked Trotter to store the starting node in the open list. Then began the actual processing task for Grace – she took the node from the open list which had the least cost to travel to (which was very trivially their starting node initially). Trotter then removed it from the open list. Grace then very quickly generated the coordinates of the four neighbouring cells for processing. For each of the neighbour, she checked if it had the Eternal Sapphire – if it did, that would be the end of their course! But of course, they will literally at the starting point, so the chances of that

was very slim. Before proceeding to other checks, she updated the cost to reach the neighbour – which was simply the sum of the cost to reach the cell they were at and a heuristic function (Grace chose to use the Euclidean Heuristic). She then checked if the neighbour cell was in the open list – if it was, then she additionally checked if the cell in the open list had a lower cost of reaching it. If that was the case, then she simply ignored the current neighbour.

In the other case of the existence of the same neighbour cell in the closed list, she performed a similar check – she skipped considering the current neighbour if the one in the closed list already had lower cost function. But if had higher cost, then changes had to be done – Grace had found a way to reach that neighbour with a lower cost, so she had to ask Trotter to update the open list by adding the current neighbour.

Julian was roaring to go as soon as possible – but it took a certain amount of time for Grace to compute the time. However, Manson and Julian had no doubts that she would find a way to reach the Sapphire before Mysterious.

At once, Grace declared that she found the path and urged Julian to hit the gas. His favourite moment of the phase began now, as he felt the roar of the machine in his blood and adrenaline. In no time, he was twisting and turning through different corridors and cells despite the

smoothness of the stony floor. Grace kept informing him whether to go up, down, left or right.

The four thought it was going smoothly – until Julian and Manson saw the first signs of trouble – their car was being chased by a couple of rogue programs. Manson opened the sunroof of the exotic car and stood up. Now this was the part of the final phase that he could excel in most. Carefully dodging electric bolts from the enemy programs' guns, he took precise aims and targeted the wheels of their vehicles. Once or twice Manson missed – but the other five shots were enough to kill the speed of the five parties who were chasing them. This wasn't the end though – as the four entered various other cells, more came in to distract them from their goal. It gave an additional task for Julian to dodge traps laid on the floor.

***

It felt like a long time – but after several close calls, multiple explosions during battles between the drivers and almost crashing into the walls on a few occasions, Julian drove the vehicle into what looked like another small clearing surrounded by various entrances to the same. At the centre was a pyramid like structure that had steps along the sides, the climb leading to the illustrious Eternal Sapphire.

Julian slowed the car, and soon the four were out of it, standing and admiring the pyramid. They had indeed arrived first, but the sense of accomplishment was short lived as from another entrance, they saw another exotic vehicle emerge. It came to a halt and the driver leaped out of it in an acrobatic fashion. His entire tall frame was covered in white clothes, and when he removed his helmet, the scarred face of Mysterious was revealed.

11. Against All Odds!

Skip Lists

Trotter gulped at the sight of Mysterious, but the officers stood unfazed. To Manson, he just looked like some normal program. For a while, the two parties just stared at each other. Then Mysterious began to speak in the same cold tone.

"Hmm… I thought the Saviour would be younger and more energetic. You are so weak that you brought three companions with you! Must be so loyal to you, because you are risking your own lives – if the Saviour is terminated, so will you three!"

Julian and Grace looked at Manson, who in turn looked at Trotter. Trotter could only lower his face – "I'm sorry, inspector! I thought you would need their help, and had I told you about this, you would not have accepted them!" he said in a low voice.

"What's that? They didn't know? Oh, what a pity! Let's now see, Saviour, how loyal they are!" Mysterious said, breaking into laughter. When it ended, he spoke with a malicious sneer – "All I have to do is terminate you. And then, nothing stops me from reaching the Sapphire!"

Quickly, he tapped on his wrist. Upon doing this, a glass shield expanded from that point and soon grew into a size that was enough to block his tall frame. Tapping on the other wrist, a slender gun materialized. Mysterious was armed. And he began the battle unceremoniously.

As he began shooting, the four dispersed with lighting speed, except Trotter of course. Mysterious did not care about him, so Trotter could crawl and hide behind one of the large walls and cover in fear.

Julian, Grace and Manson essentially formed a triangle and tried to close in on Mysterious who was in the middle. But his excellent reflexes aided him in dodging electric bolts from all the three sources, either by jumping away or pulling his shield. In the reverse way, his electric strikes were extremely precise – Grace escaped being hit twice by mere inches.

Mysterious tried to focus his firepower mostly on Manson – he was going for the jackpot. On the other hand, the three officers were facing the toughest challenge yet – this otherworldly program was too efficient and quick paced for them.

The battle never got any balance – in one instant the three officers gained more distance toward the rogue program; in the other, Mysterious was threatening them

with merciless strikes that could terminate them if they lapsed in concentration.

Manson motioned for the others to stop firing at once, and just take cover behind the orange stone blocks. Simply firing was not working – something else had to be done. He took a deep breath, and in the corner of the eye he saw Julian. He gestured him to instruct him where to shoot – and Julian did the same to Grace.

Moments passed – even Mysterious was quiet, before he broke the silence – "Come on, you coward! So much for being a Saviour! Ha-ha!"

Manson looked at Julian, and then he nodded. In lightning pace, Manson leaped over the orange block, gaining immense height despite his strong frame. Mysterious' eyes instantly darted up to look at Manson and block his subsequent aerial attack, and this moment of distraction was seized by the other two police officers.

Grace and Julian's accuracy at shooting was incredible – both timed their shots to perfection as each hit the small devices on Mysterious' wrists.

Manson landed and Grace and Julian came out of their cover, all three still pointing hyper-zaps at Mysterious. The rogue program fell down due to the impact.

When Mysterious stood up, he was in utter disbelief internally – he had trained for this moment all his life, but now he was on the verge of losing. However, the rogue program still kept his loathing expression. The Eternal Sapphire could only be touched by either him or this Saviour. Knowing this, Mysterious took a step that nobody had ever taken. Because if he was not going to get control of the Sapphire, then he won't let the Saviour too!

"I challenge you to the Journey to the Abyss!"

Upon hearing this proclamation, Trotter became alert and jumped out and ran towards the officers. When he reached, he was shouting – "No, NO!"

"What is it, Trotter? What does the Journey to the Abyss mean?" Manson asked.

"In the final stage of the race to get the Sapphire, if such a challenge has been made, then the two programs would have to board a high-speed train in this Grid of Confusion... which bullets its way to the edge of this dimension – into the abyss! The only way it would stop, and travel back is if during the journey, one of the programs successfully terminates the other! In the history of cosmic balance, such a proclamation has been done only once – only once in ten million occasions! And that did not end well – you see, the chances are so slim on that train, that usually both programs end up terminating by falling

into the abyss!" Trotter explained, with an extremely fearful tone.

"I can just reject the challenge, right? Why can't I just shoot this program in his head right now!" Manson spoke, in a frenzy.

Mysterious let out another laugh. "It seems, you old fool, didn't equip your Saviour with enough knowledge. This challenge cannot be rejected – if you back off, I automatically get the sole control over the Sapphire! And before you have any funny thoughts, only you can board the train – not your companions."

Julian and Grace looked extremely concerned. Manson wanted to curse his luck so bad, but he didn't want to give away a feeling of defeat to his enemy. He dropped his hyper-zap, took a deep breath after closing his eyes. He pictured his family, opened his eyes and spoke – "I accept it.

***

Manson and Mysterious stood next to each other, waiting for two portals to open. They would have separate entrances to this unnamed and unknown train. Making a swishing sound, two portals did open, and a robotic announcer spoke in the air – "Your path to the train is a skip list."

Mysterious quickly jumped into his – Manson followed suit. The only comfort he had in this unknown journey was the fact that he was no stranger to skip lists. When he entered, he landed in a small cube, with low light and a number that specified the node or platform where the train was stationed. There were two doors – one locked, the other leading somewhere. Manson knew that by going through the door, he would enter more cubes like this which represented different markers in that level of the skip list. Whenever the marker was smaller than his destination, he would keep going forward, and if not, he would descend one level down.

His station was at 245 – the current marker he was at was just 0 to 50. Quickly, he darted till 200 – 250, and in that cube, he saw that there was a trapdoor. Climbing down, he reached the marker that said – 200 to 210. He had to dart forward once more. But when he reached 220 to 225, the ground beneath him shook. He lost his balance, and fell. Then he felt his cube move down and sideways. When everything settled, he stood up and saw that the marker of his current cube changed – it was now labelled 110-120. Manson understood what happened – some numbers of stations must have been added into the list to confuse the participants – which probabilistically shuffled his cube. Manson anyway **expected** to reach his cube in log n time.

[*An aside – The Journey to Abyss is in itself a cosmic living being, and it administered the insertion of random cubes into the skip list to slow down the competitors. It did this using a simple probability trial – at every level, once it found the two cubes between which the new cube has to be inserted, it 'flips a coin' - and with a probability of half, it decides to insert that cube at that level or not.*]

After a while, he reached the cube with 245 as the number. A door to his right was open, and he saw the entrance to a train. He boarded it, and just as he did so, all the cubes outside dissolved into thin air – it seemed as if the train was suspended in mid-air. He turned around and saw Mysterious come from another compartment. Before they could face off, the train gave a mighty lurch, and suddenly began to move in indiscernible speed.

The two programs lost their balance but soon got adjusted to the speed. Manson looked outside the window – he could see the orange blocked world, but he could also see the daunting abyss towards which they were heading.

The two ran towards each other. As they charged and met each other, both parried each other strikes and did their outmost to punch their way out. Their goal was to strike their opponent's body hard enough that the internal strings would get broken.

For a while, it seemed that this rough battle would go on till the end – what was so special about this train? And that's when Manson got to know.

Suddenly, the train's compartments began rotating – hurling the two fighters as if they were in a space station. Both received quite the hits from the walls of the train, but their adrenaline was much stronger. Once the rotation stopped, both took ground and resumed their fight. But again, the rotation began after a random interval, and this continued to happen.

Time was ticking out – the abyss was looming closer and closer. Then something eventful happened. The train once again twisted – and by chance, after multiple collisions, Manson and Mysterious fell side by side on the wall of the train. Manson saw that Mysterious was on the glass window, and he had not yet recovered as quickly as he did, so he seized the moment. He punched Mysterious in the stomach which surely crackled some strings. Then, using all his might, or whatever was left of it, he kicked and smashed the window beneath – and before Mysterious could catch his bearings, the window gave away and he fell to his doom.

Manson took time to recover from such an unceremonious ending of highly exhaustive battle. He felt the train slow down, come to a halt, and speed up again in the reverse direction.

***

Before Manson woke up in the hospital bed, his brain recalled all the events – the train had travelled all the way back to the skip list. He remembered finding his way to the cube numbered 0, then falling out of the portal in front of the pyramid. He remembered Trotter and Grace and Julian exclaiming in jubilance, and how the old man ushered him up the pyramid, and told him the instructions to re orient the Eternal Sapphire. But after that he was blank – because the intense strain had suspended his program – he went unconscious.

When he woke up, Julian and Grace were informed, who came into the room to see him. Manson saw the time - it showed eleven pm. The date was… the same as the one he had departed from here! Was the entire journey a dream? How did he end up here – did he crash into the woods while driving? Before he opened his mouth, Grace answered – "No, inspector. All of that was real. It turns out that no time has elapsed in our Dimension – when we three carried you into the final portal, we came back to six pm. You were out for five hours, chief. But all of it was real – you were indeed an extraordinary Saviour."