**Data Structures and Algorithms (CS-250)**

**Semester Project**

**Comparison of Shortest Path Searching Algorithms**

# **INTRODUCTION TO GRAPHS AND ALGORITHMS:**

If you have ever used a navigation service to find optimal route and estimate time to destination, you have used algorithms on graphs. Graphs arise in various real-world situations as there are road networks, computer networks and, most recently, social networks! If you are looking for the fastest time to get to work, cheapest way to connect set of computers into a network or efficient algorithm to automatically find communities and opinion leaders in Facebook, you're going to work with graphs and algorithms on graphs. Here we will talk about shortest paths algorithms — like Dijkstra’s, Bi-directional, Floyd Warshall which are faster algorithms used in Google Maps and other navigational services.

# **OUR LEARNING:**

In this project we wanted to actually learn and understand about different kinds of shortest path algorithms, their complexities, and benefits of one over the other rather than just simply implementing them. We wanted to take a forward engineering approach and learn the algorithms first and then fit them to best situations rather than creating applications which use these algorithms. We think that this always yields the best results and allows for problem solving as you have a strong grip on a conceptual level rather than just learning to use them in a very specific situation. The outlook of the project might yield a false opinion that our project was easy which obviously does not justify our efforts that were done under the hood. We started off with doing our research about different kinds of shortest path algorithms and choosing the best among them. We ended up choosing 4 famous unique algorithms each having their own potential. Our project than started with research phase in which we did research about these algorithms and thoroughly understood the working of each on a conceptual level. We went through different resources such as YouTube, GitHub, and Stanford university course. We than tried to dry run different inputs on each algorithm to get a deeper understanding. Once we got the major idea of each algorithm, we then moved to phase two which was checking out different implementations available online and then choosing the best one which suits our taste. We made sure that we choose the implementation that is flexible to take any number of inputs in order for flexibility and also because we wanted to do empirical time analysis too. We divided 3 algorithms among ourselves at this stage and each member was assigned an algorithm to work on. We initially took the code from our chosen code base/resource online and then started making changes in it to fit our needs. We also made sure to comment wherever necessary in order to showcase our understanding to you. Finally, we ended up running the output for a small input so that the output is easier to understand for everyone. In this process we weren’t able to actually implement the A\* algorithm ourself due to shortage of time to instead we did it’s time complexity analysis whereas its implementation was taken form online resource. However, rest assured our understanding of the code and the algorithm is complete and we would love to tell you about it in case you inquire as per your discretion. Lastly, we ended up calculating the different time complexities and finalizing the project report.

# **Dijkstra’s Algorithm:**

**Introduction:**

**Dijkstra's algorithm** (or Dijkstra's Shortest Path First algorithm, SPF algorithm) is an algorithm for finding the shortest paths between nodes in a graph. It was devised by computer scientist **Edsger W. Dijkstra** in **1956** and was published in **1959**.

The algorithm exists in many variants, but the original algorithm does not use min priority queue and runs in ‘**O(N2)**’ time where n is the number of nodes. The implementation of this algorithm based on **min priority queue** but when implemented using **Fibonacci heap** it brings down the running time by ‘**O((E+N)log N)**’, where ‘**N**’ is the number of nodes and ‘**E**’ represents number of edges. This is asymptotically the **fastest** known **single source shortest path algorithm** for **arbitrary directed graph** with unbounded **non-negative** weights.

**Time Complexity:**

1. Complexity of Dijkstra’s algorithm is: **O(N2)**
2. By using Binary Heap as min priority queue:  **O((E+N) log N)**
3. Fibonacci heap: **O(E+V log V)**

**Applications:**

1. Finding shortest route in a road network (Google Maps).
2. Finding shortest path for a packet in an internet (IP routing).
3. Telephone Networks as well as Flow network.
4. Least-cost paths to establish tracks of electricity lines or oil pipelines.

**Practically implemented:**

The algorithm has also been used to calculate optimal long-distance footpaths in Ethiopia and contrast them with the situation on the ground.

# **FLOYD WARSHALL:**

**Introduction:**

**Floyd–Warshall** algorithm (also known as Floyd's algorithm, the Roy–Warshall algorithm, the Roy–Floyd algorithm, or the WFI algorithm) is an algorithm for finding shortest paths in a directed weighted graph with positive or negative edge weights (but with no negative cycles). This algorithm was proposed by **Robert** **Floyd** in the year **1962**. The same algorithm was proposed by **Stephen Warshall** during the same year for finding the transitive closure of the graph.

**Procedure:**

As the **first step**, we initialize the **solution matrix** same as the **input graph matrix**. Then we **update** the solution matrix by considering **all** vertices as an **intermediate vertex**. The idea is to one by one pick all vertices and update all shortest paths which include the picked vertex as an intermediate vertex in the shortest path. When we pick **vertex number k** as an intermediate vertex, we **already have considered** vertices {0, 1, 2, ... k-1} as intermediate vertices. For every pair (i, j) of source and destination vertices respectively, there are **two** possible cases.

1. k is **not an intermediate vertex** in shortest path from i to j. We **keep** the value of p[i][j] as it is.
2. k is **an intermediate vertex** in shortest path from i to j. We **update** the value of p[i][j] as p[i][k] + p[k][j].

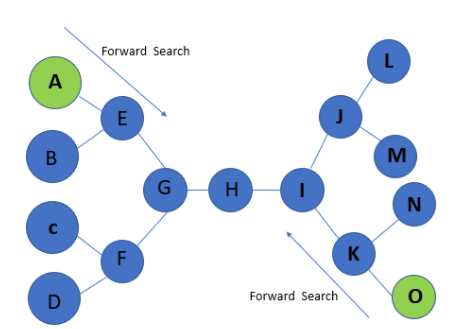
**Time complexity:**

The complexity of Floyd–Warshall algorithmis **O(n3)**

**Applications:**

1. Finding a regular expression denoting the regular language accepted by a finite automaton (Kleene’s algorithm)
2. Inversion of real matrices (Gauss–Jordan algorithm).
3. Optimal routing.
4. Finding a regular expression denoting the regular language accepted by a finite automaton
5. Computing the similarity between graphs

# **Bidirectional Search Algorithm:**

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**Introduction:**

**Ira Pohl** (**1971**) was the first one to **design** and **implement** a bi-directional heuristic search algorithm. Bidirectional search is a graph search algorithm that finds a shortest path from an **initial** **vertex** to a **goal** **vertex** in a directed graph. In this algorithm we start from both the **source**(initial vertex) and the **destination**(final vertex) and we **end** the **search** when both the set of visited edges **intersect**. This will give us the shortest path.

Suppose if branching factor of tree is ‘**b’** and distance of goal vertex from source is ‘**d’**, then the **normal** **BFS/DFS** searching **complexity** would be **O(bd)**. On the other hand, if we execute **two** **search** **operations** then the **complexity** would be **O(bd/2)** for each search and total complexity would be **O(bd/2).**

This algorithm can be used when:

1. Both initial and final goals are **unique** and **completely** **defined**.
2. The **branching** **factor** is exactly the **same** in **both** directions.

**Time Complexity:**

Time and Space Complexity O(bd/2).

# **A\* Search Algorithm (Not Implemented):**

**Introduction:**

**A\* Search** is a computer algorithm that is widely used in pathfinding and graph traversal. It enjoys widespread use due to its performance and accuracy. Peter Hart, Nils Nilsson and Bertram Raphael of Stanford Research Institute first described the algorithm in 1968. It is an extension of Edsger Dijkstra's 1959 algorithm. A\* achieves better performance by using heuristics to guide its search.

A\* selects the path that minimizes :  **f(n) = g(n) + h(n)**

where n is the last node on the path, g(n) is the cost of the path from the start node to n, and h(n) is a heuristic that estimates the cost of the cheapest path from n to the goal. The heuristic is problem-specific.

**Applications:**

A\* is commonly used for the common pathfinding problem in applications such as games. It also helps in general artificial intelligence engines like chess, Sudoku etc. It finds applications to diverse problems, including the problem of parsing using stochastic grammars in NLP.

**Complexity:**

The [time complexity](https://en.wikipedia.org/wiki/Computational_complexity_theory) of A\* depends on the heuristic. In the worst case of an unbounded search space, the number of nodes expanded is [exponential](https://en.wikipedia.org/wiki/Exponential_time) in the depth of the solution (the shortest path) *d*: *O*(*bd*), where *b* is the [branching factor](https://en.wikipedia.org/wiki/Branching_factor) (the average number of successors per state)

**Worst-case performance :** O(|E|) = O(bd)

**Worst-case space complexity :** O(|V|) = O(bd)

# ***Performance:***

Calculated on a Peer to Peer Network graph having 16 vertices and 58 edges.

|  |  |  |
| --- | --- | --- |
| **S. No.** | **Algorithm** | **Time** |
| 1. | Dijkstra’s Algorithm | 0.025s |
| 2. | Floyd Warshall Algorithm | 0.027s |
| 3. | Bidirectional Search Algorithm | 0.028s |
| 4. | A\* Search Algorithm | 0.035s |

# ***Sample output:***

# **Dijkstra’s Algorithm:**

(Implemented by Muhammad Afnan Shakeel)

Text

Description automatically generated

# **Floyd Warshall Algorithm:**

(Implemented by Moiz Zubair)

Text

Description automatically generated

# **Bidirectional Search Algorithm:**

(Implemented by Sheroz Khan)

![Text

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generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAeAB4AAD/4RDuRXhpZgAATU0AKgAAAAgABAE7AAIAAAAMAAAISodpAAQAAAABAAAIVpydAAEAAAAYAAAQzuocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAFNoZXJveiBLaGFuAAAFkAMAAgAAABQAABCkkAQAAgAAABQAABC4kpEAAgAAAAMyOQAAkpIAAgAAAAMyOQAA6hwABwAACAwAAAiYAAAAABzqAAAACAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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