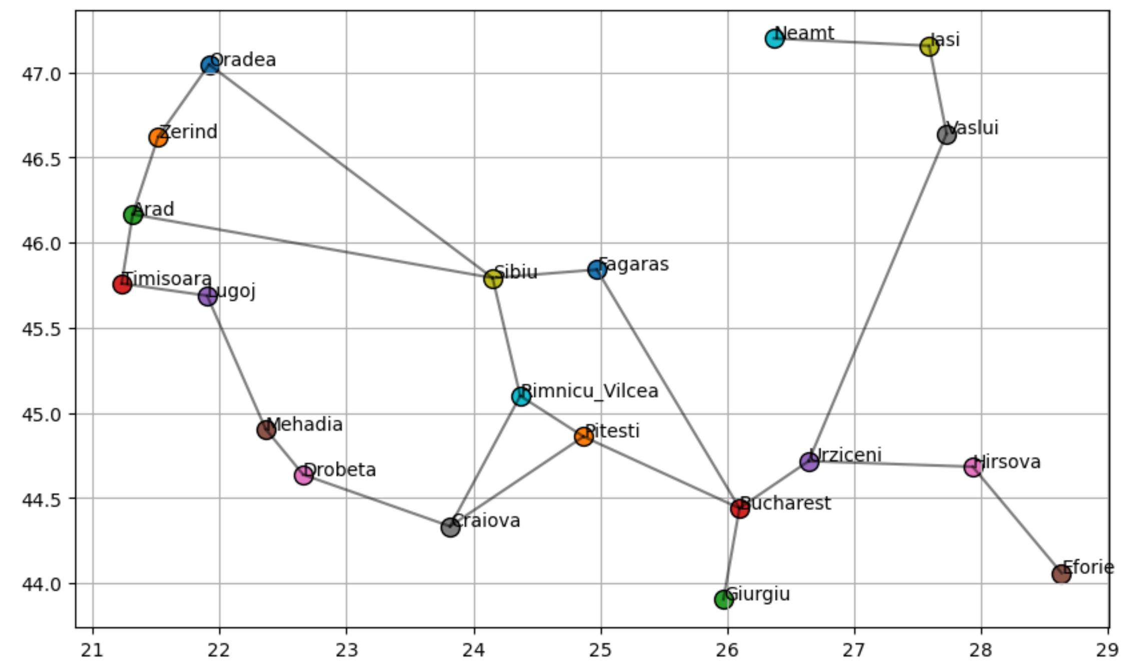
Question 1:

Introduction:

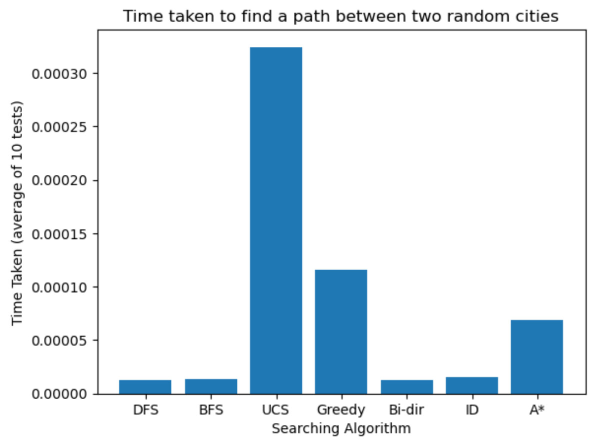
The plotted graph visualizes a geographical network of cities in Romania , showcasing the interconnectedness of urban centers within the region. Each node in the graph represents a distinct city, while edges between nodes denote direct connections between those cities. This visualization provides valuable insights into the spatial layout of the cities. Through this representation, we can better understand the geographic distribution and connectivity patterns of the cities, laying the groundwork for further analysis and exploration of the urban network's dynamics and characteristics.

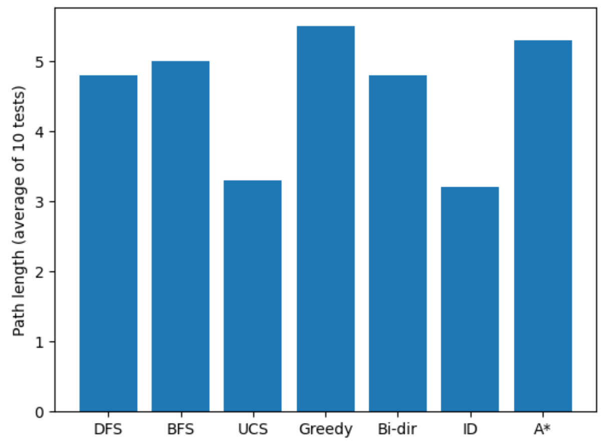


Experiment 1: Analysis of Search Algorithms for Path-finding Efficiency

Introduction:

In this experiment, we assess the efficacy of various search algorithms in finding paths between randomly chosen cities on a map. The algorithms including: DFS, BFS, UCS, Greedy Search, Bidirectional Search, ID, and A*, each with its distinct approach to exploration. By measuring the time taken and the path length for 10 repetitions of each algorithm, we aim to gain insights into their performance characteristics.
Here are the graphs plotted visualizing the results of this experiment.





Observations:

Runtime (Time Taken):

- Uniform Cost Search (UCS) demonstrates the longest average runtime due to its exhaustive search based on node costs.
- Greedy Search and A* Search follow UCS in runtime, utilizing heuristic information but requiring significant computational resources.
- BFS, Bidirectional Search, DFS, and ID exhibit comparatively lower average runtimes, known for their systematic exploration of the search space.

Path Length:

- Greedy Search returns paths with the longest average length owing to its immediate gain prioritization.
- A* Search produces paths of similar length to Greedy Search despite its informed nature.
- BFS yields shorter paths on average, reflecting its systematic exploration of all possible paths.
- Bidirectional Search and DFS demonstrate similar average path lengths, indicating comparable path optimality.
- UCS and Iterative Deepening return paths with the shortest average lengths, focusing on cost minimization and systematic deep exploration, respectively.

Question 2:

Experiment 2: Exploring Search Algorithm Performance in Randomly Generated Graphs

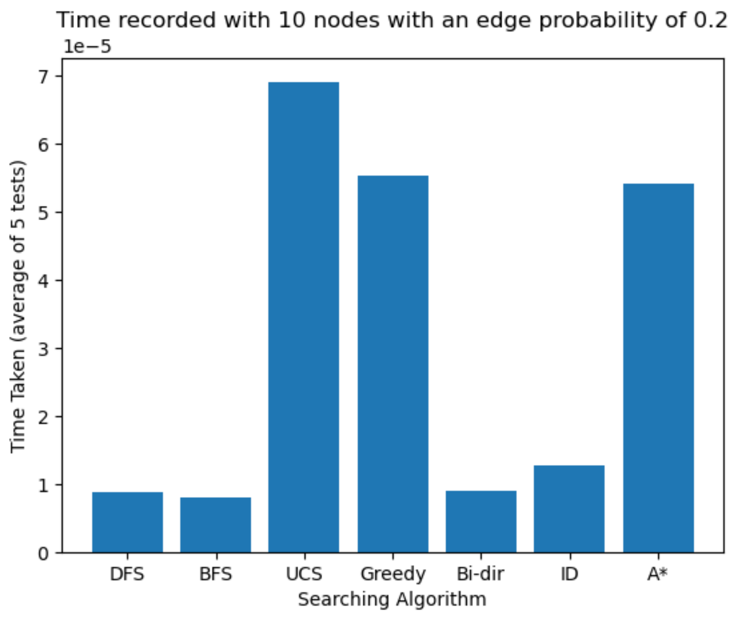
Introduction:

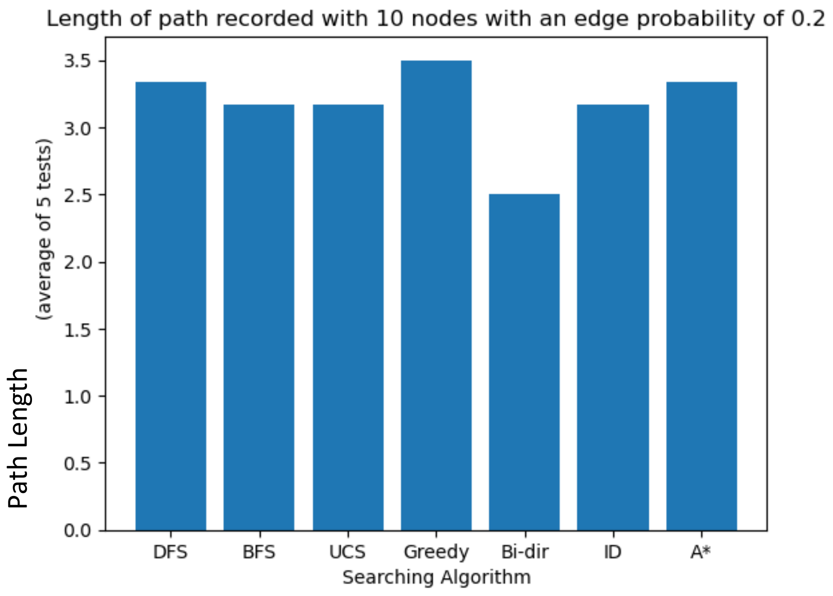
In this experiment, we explore the performance of various search algorithms in finding paths within randomly generated graphs. Each graph is created with a specified number of nodes (10, 20, 30, or 40) and varying edge probabilities (0.2, 0.4, 0.6, or 0.8), resulting in a total of 16 distinct graph configurations.

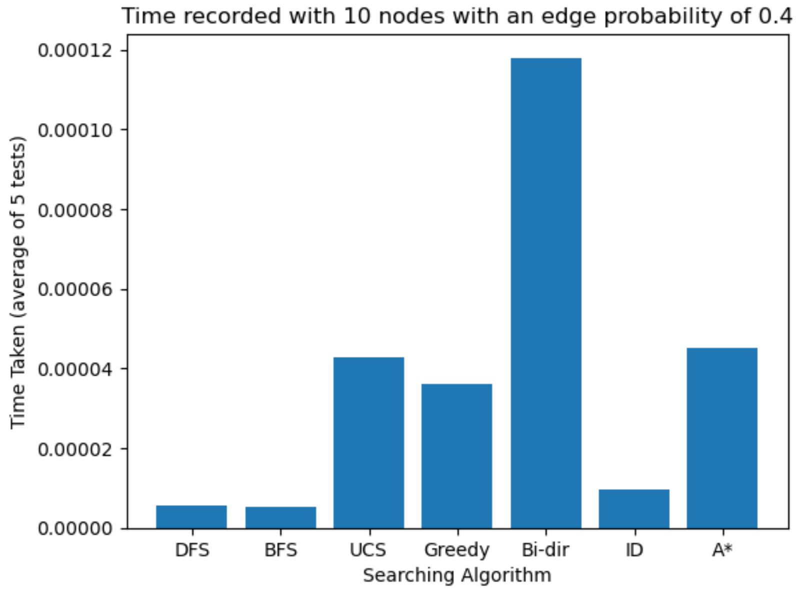
For each graph configuration, we conduct a series of tests where we randomly select 5 pairs of nodes. Then, utilizing each of the selected search algorithms - including DFS, BFS, UCS, Greedy

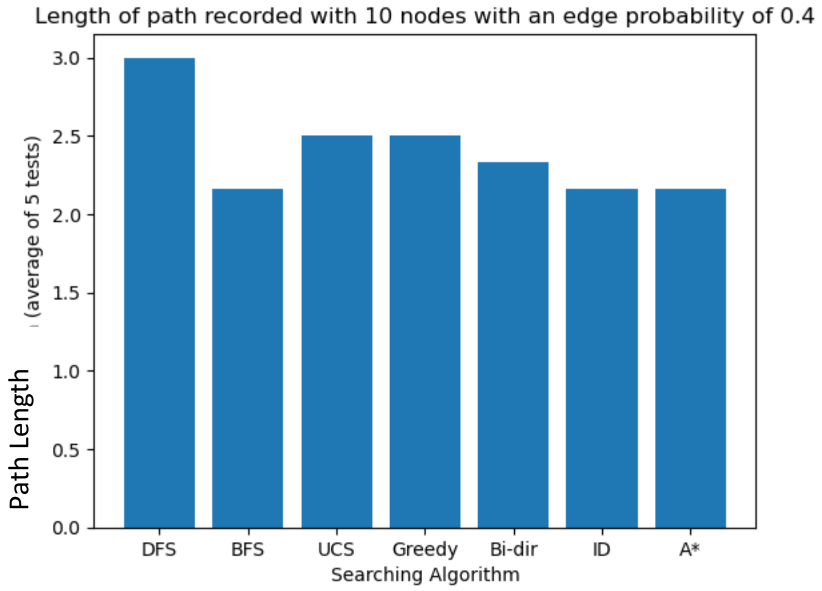
Search, Bidirectional Search, Iterative Deepening, and A* Search - we measure the time taken to find paths between the selected node pairs. Additionally, we record the lengths of the paths found by each algorithm.

Through this experiment, we aim to investigate how the size of the graph and the density of edges influence the efficiency of the search algorithms. By examining the time taken and path lengths across different graph configurations, we seek to gain insights into the scalability and performance characteristics of these algorithms in varying search spaces.

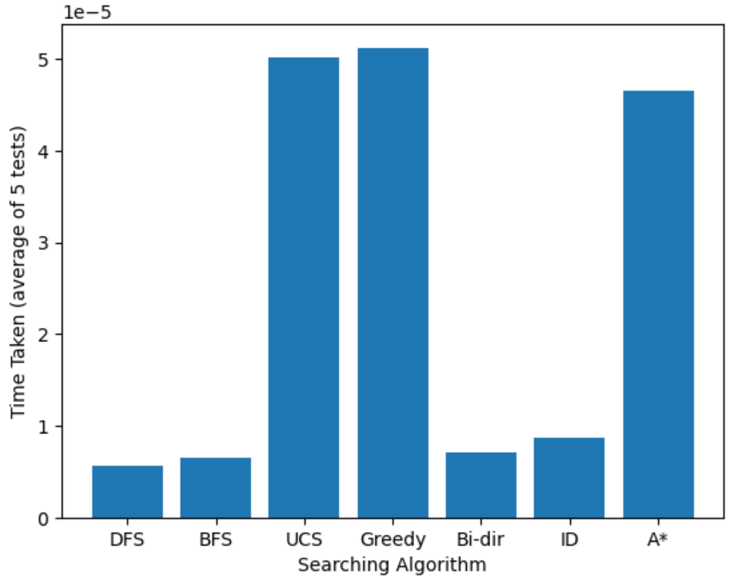




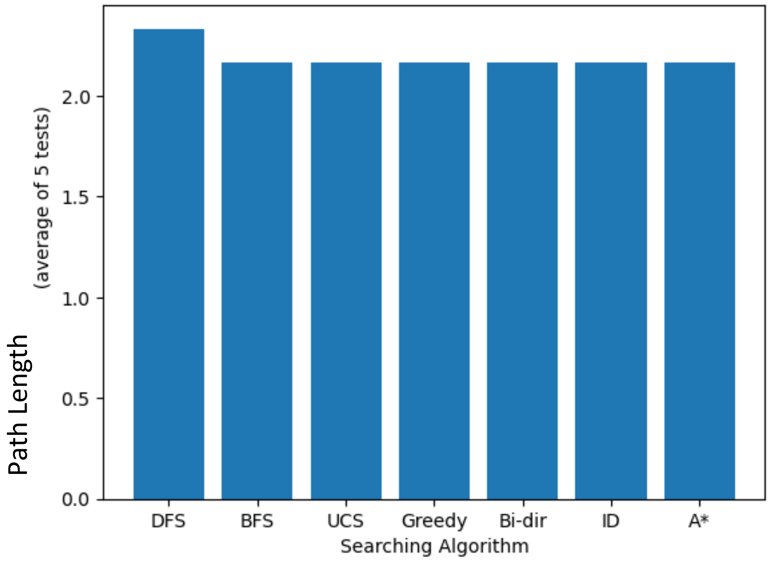

Time recorded with 10 nodes with an edge probability of 0.4
Time Taken (average of 5 tests)
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

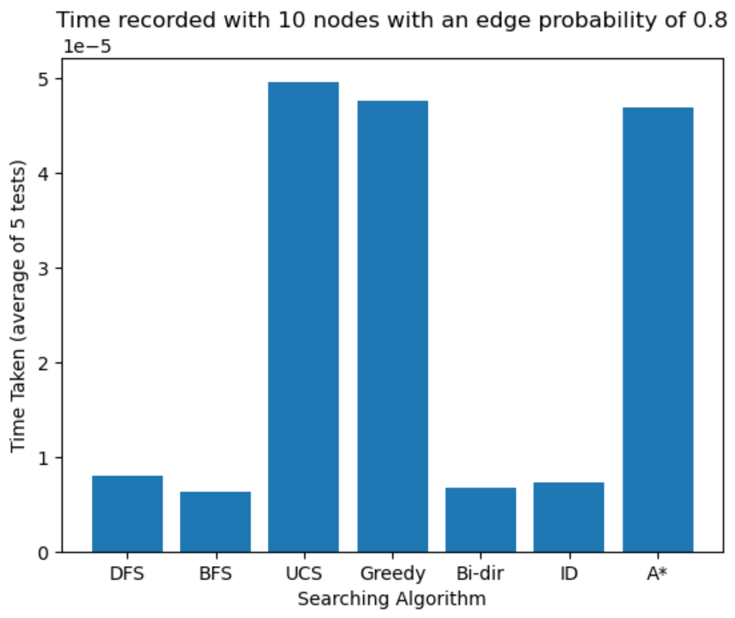

Length of path recorded with 10 nodes with an edge probability of 0.4
Path Length
(average of 5 tests)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

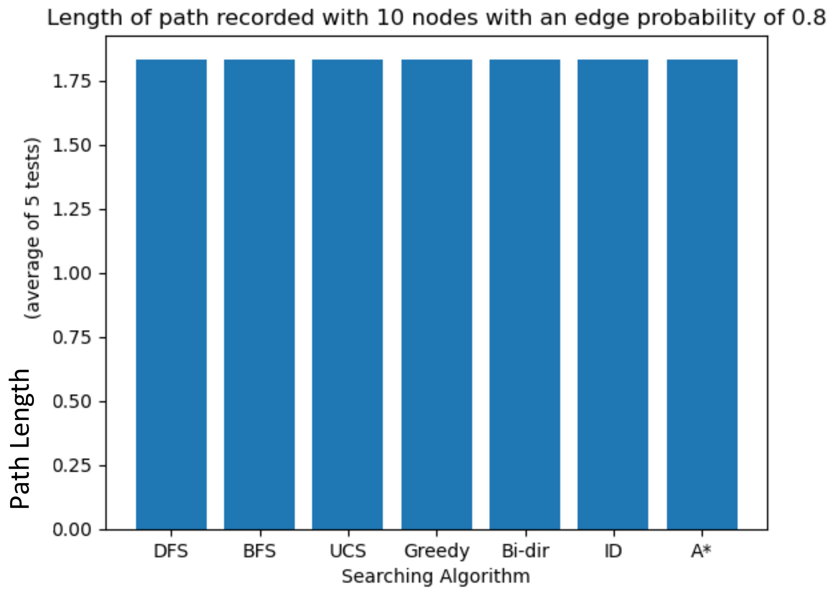
Time recorded with 10 nodes with an edge probability of 0.6

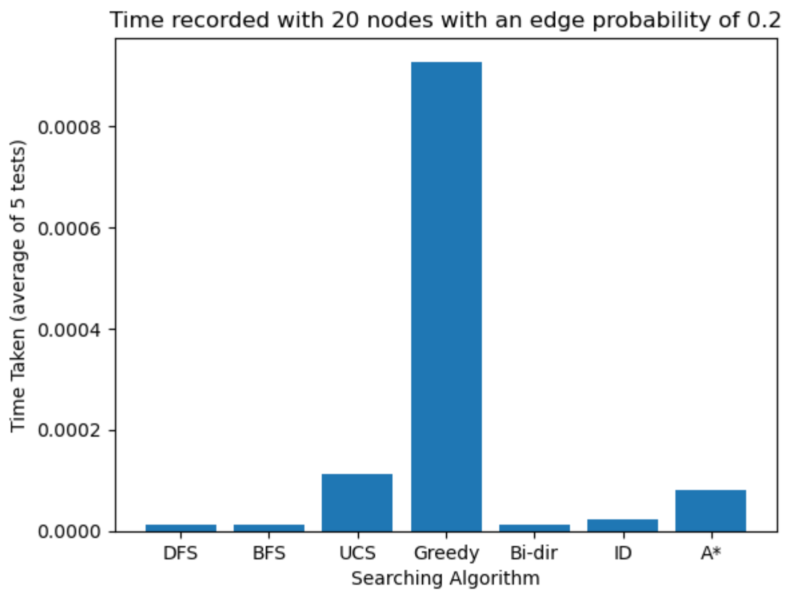


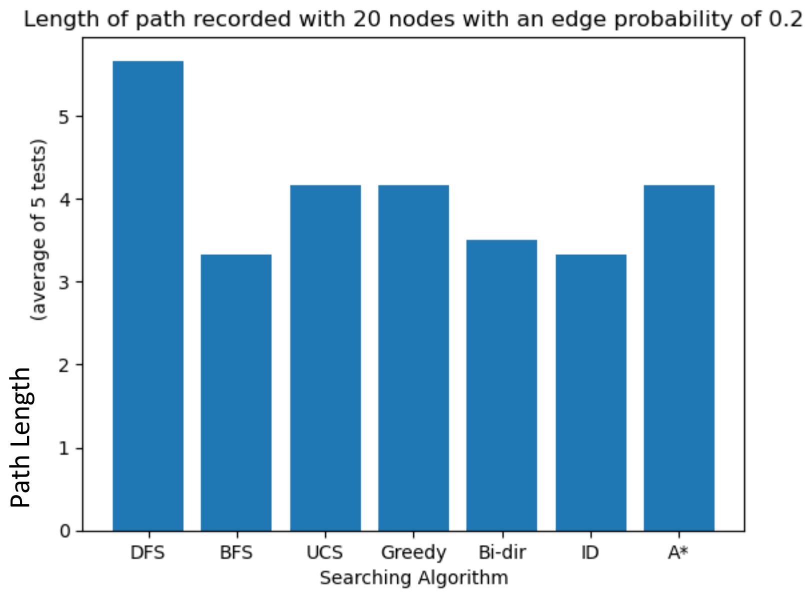
Length of path recorded with 10 nodes with an edge probability of 0.6

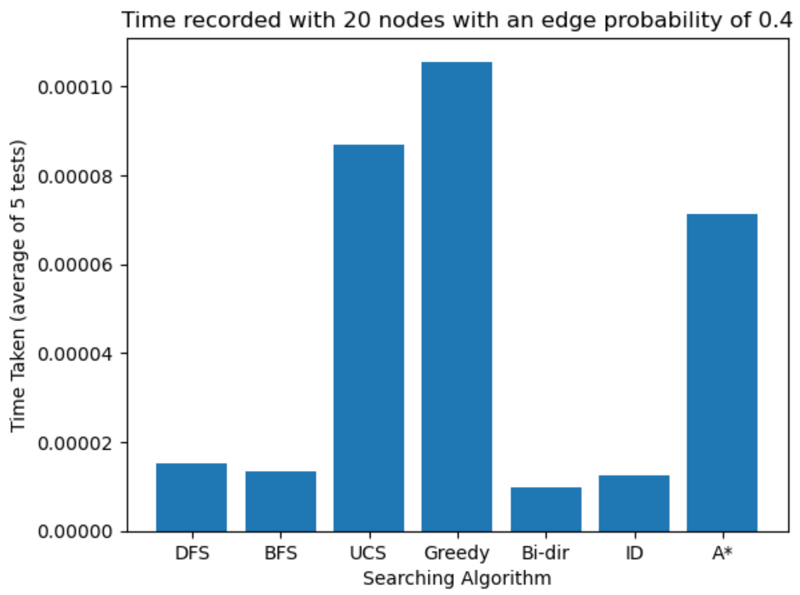


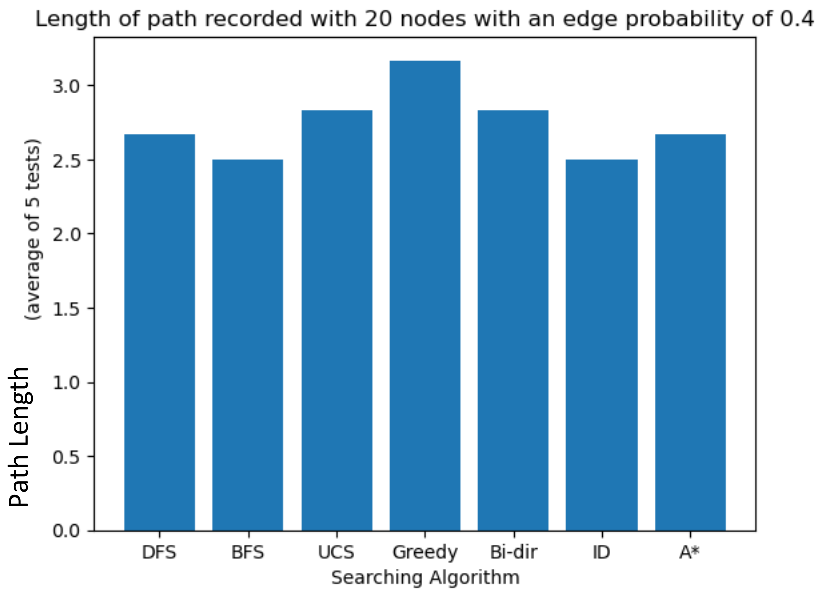

Time recorded with 10 nodes with an edge probability of 0.8
1e−5
Time Taken (average of 5 tests)
0
1
2
3
4
5
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

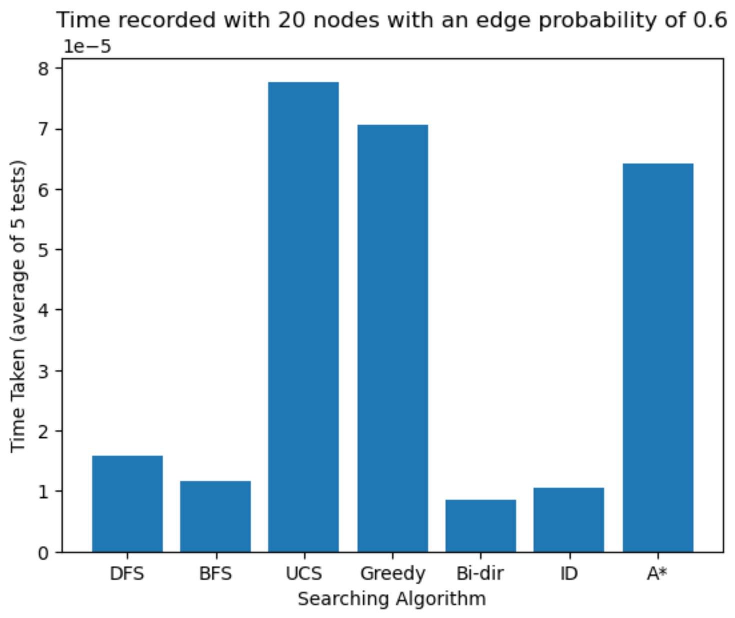

Length of path recorded with 10 nodes with an edge probability of 0.8
Path Length
(average of 5 tests)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

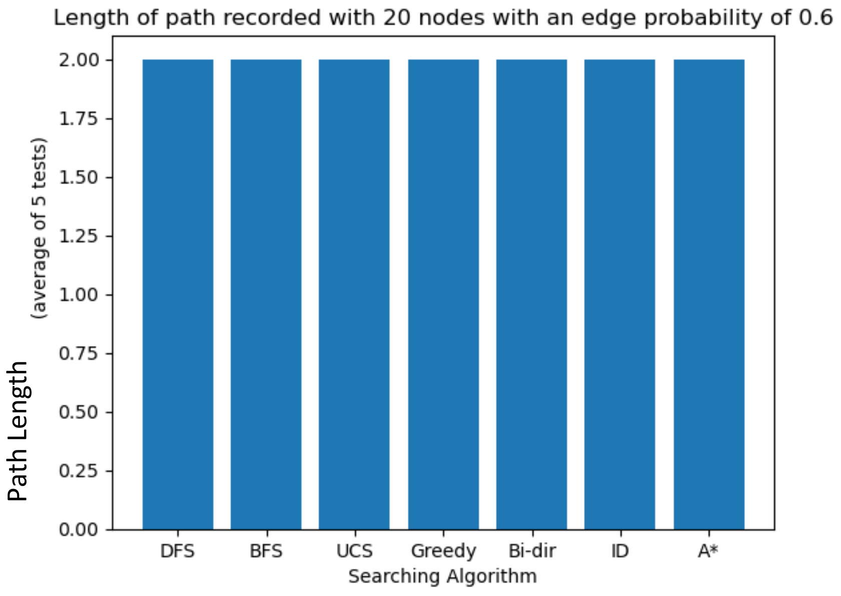

Time recorded with 20 nodes with an edge probability of 0.2
Time Taken (average of 5 tests)
0.0000
0.0002
0.0004
0.0006
0.0008
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

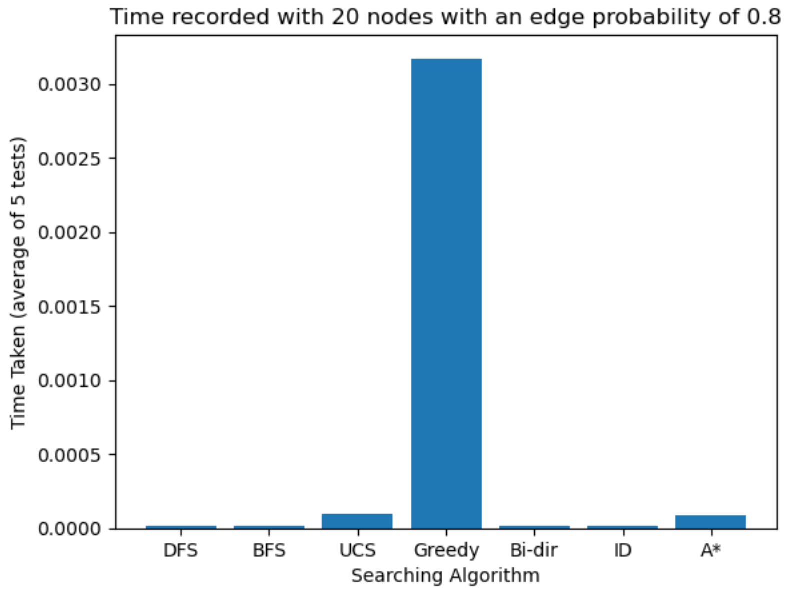

Length of path recorded with 20 nodes with an edge probability of 0.2
Path Length
(average of 5 tests)
0
1
2
3
4
5
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

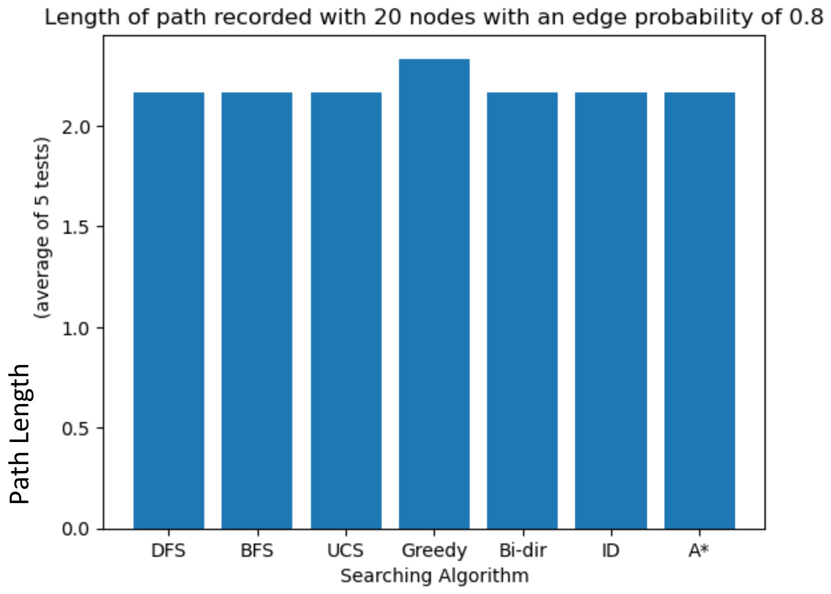

Time recorded with 20 nodes with an edge probability of 0.4
Time Taken (average of 5 tests)
0.00000
0.00002
0.00004
0.00006
0.00008
0.00010
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

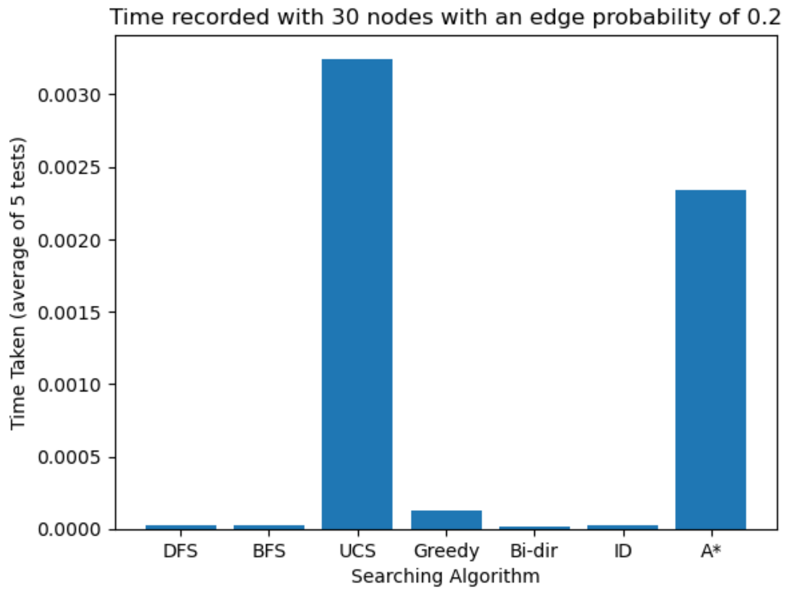

Length of path recorded with 20 nodes with an edge probability of 0.4
Path Length
(average of 5 tests)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

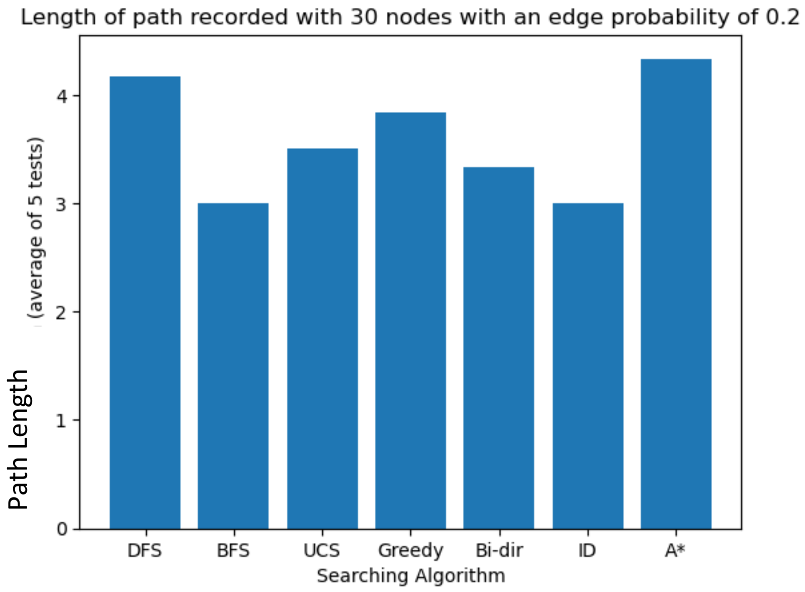

Time recorded with 20 nodes with an edge probability of 0.6
1e−5
Time Taken (average of 5 tests)
0
1
2
3
4
5
6
7
8
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

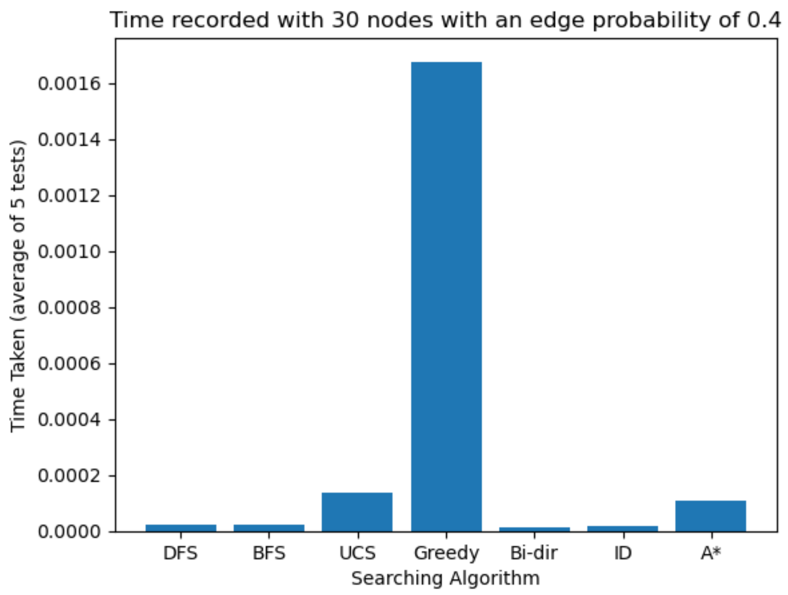

Length of path recorded with 20 nodes with an edge probability of 0.6
Path Length
(average of 5 tests)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

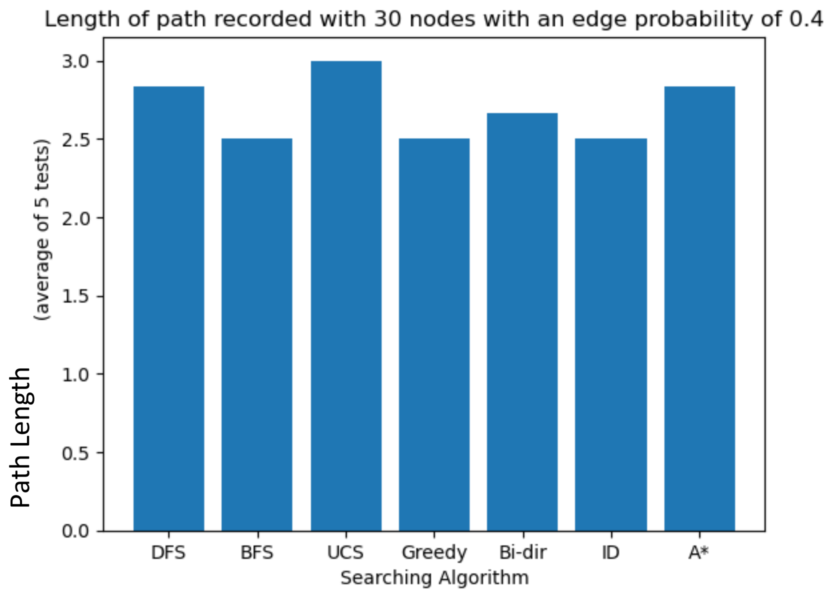

Time recorded with 20 nodes with an edge probability of 0.8
Time Taken (average of 5 tests)
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
0.0030
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

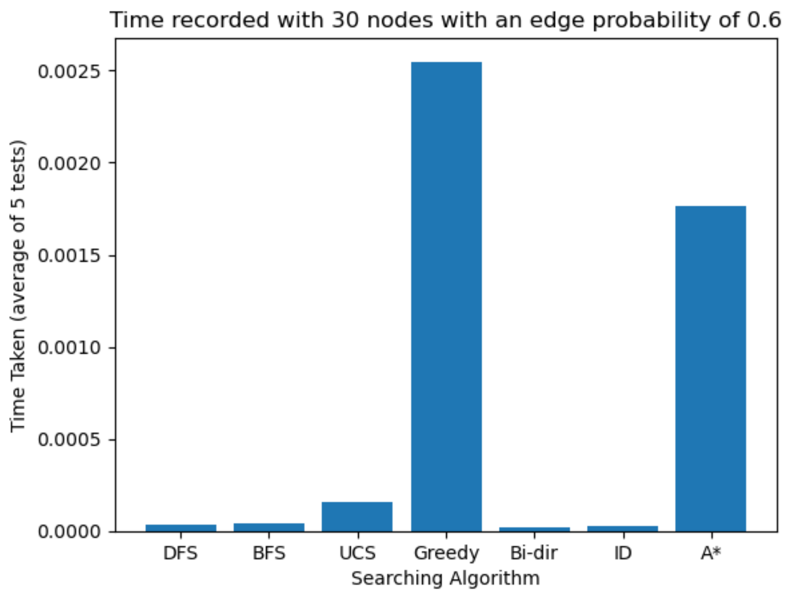

Length of path recorded with 20 nodes with an edge probability of 0.8
Path Length
(average of 5 tests)
0.0
0.5
1.0
1.5
2.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

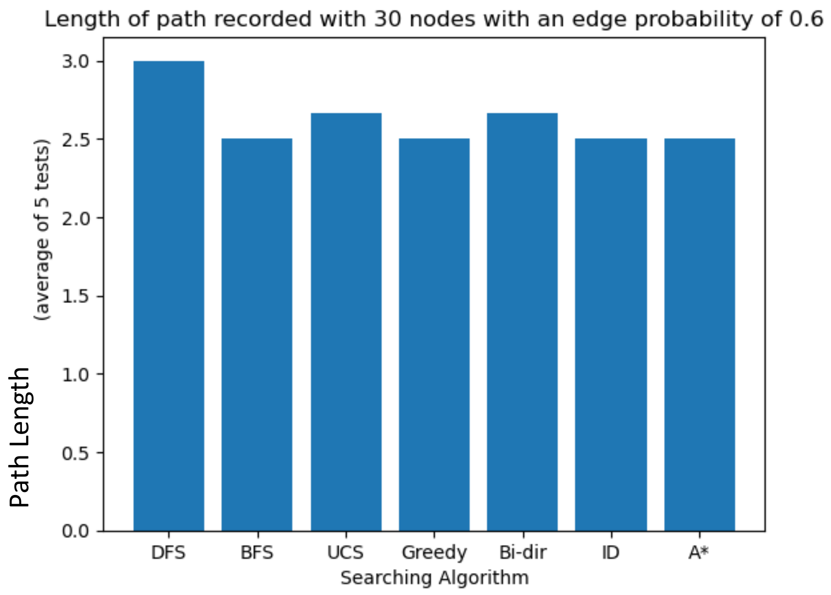

Time recorded with 30 nodes with an edge probability of 0.2
Time Taken (average of 5 tests)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

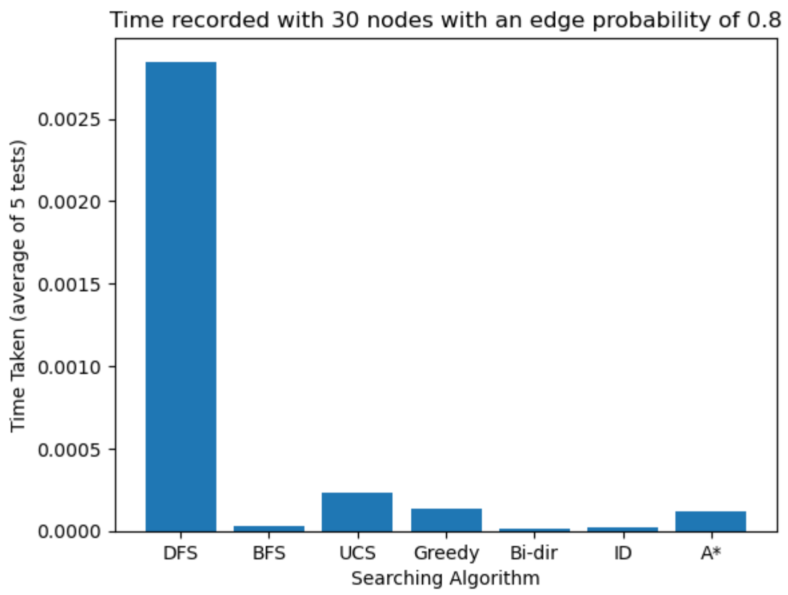

Length of path recorded with 30 nodes with an edge probability of 0.2
Path Length (average of 5 tests)
4
3
2
1
0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

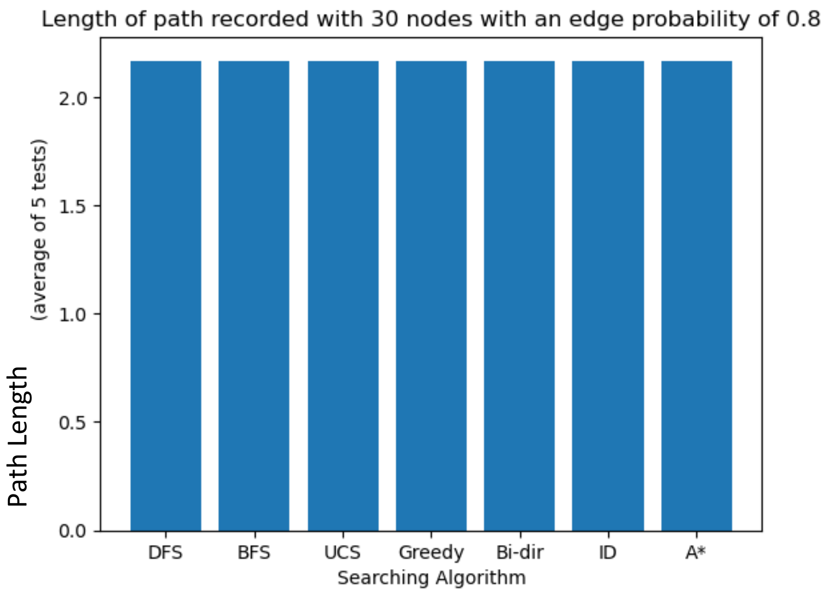

Time recorded with 30 nodes with an edge probability of 0.4
Time Taken (average of 5 tests)
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

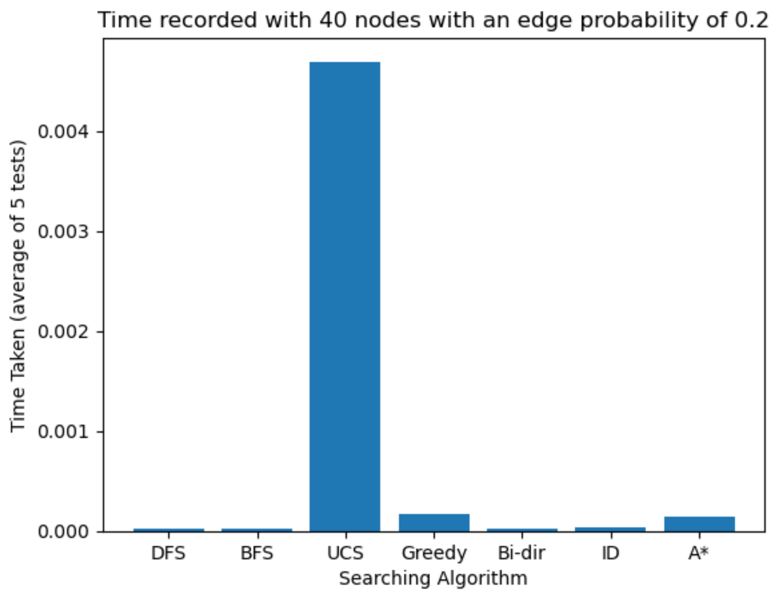

Length of path recorded with 30 nodes with an edge probability of 0.4
Path Length
(average of 5 tests)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

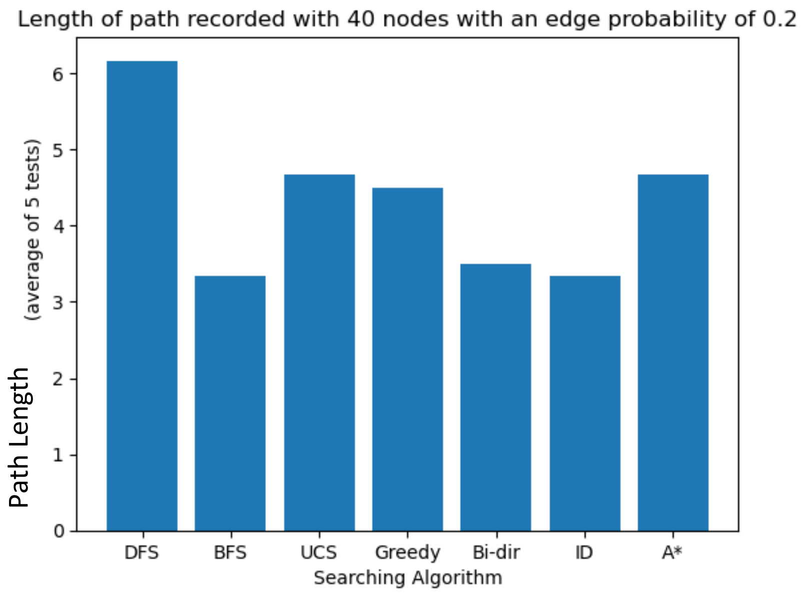

Time recorded with 30 nodes with an edge probability of 0.6
Time Taken (average of 5 tests)
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

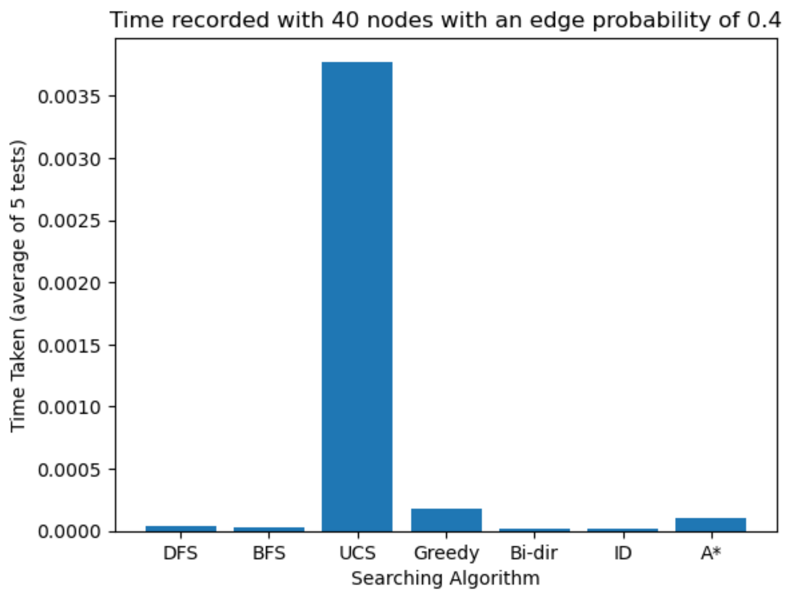

Length of path recorded with 30 nodes with an edge probability of 0.6
Path Length
(average of 5 tests)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm


Time recorded with 30 nodes with an edge probability of 0.8
Time Taken (average of 5 tests)
0.0000
0.0005
0.0010
0.0015
0.0020
0.0025
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

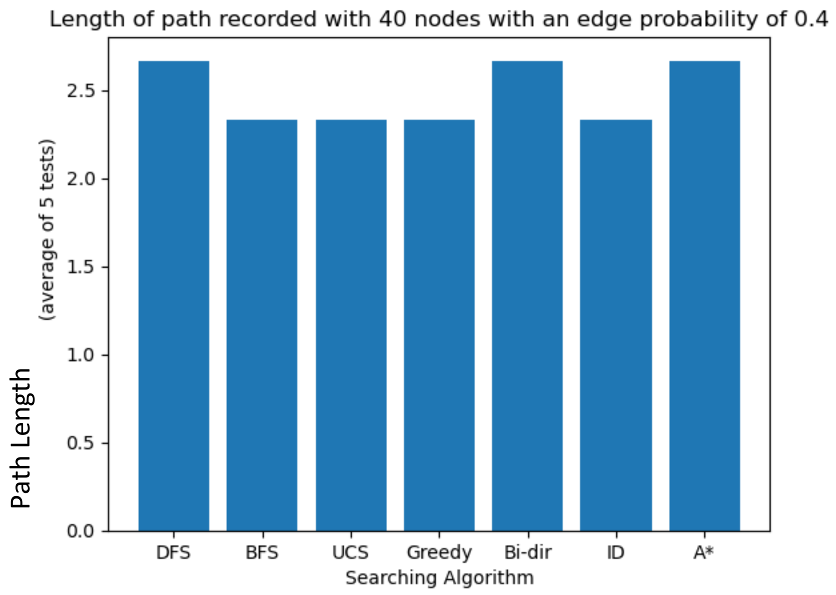

Length of path recorded with 30 nodes with an edge probability of 0.8
Path Length
(average of 5 tests)
0.0
0.5
1.0
1.5
2.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm


Time recorded with 40 nodes with an edge probability of 0.2
Time Taken (average of 5 tests)
0.000
0.001
0.002
0.003
0.004
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

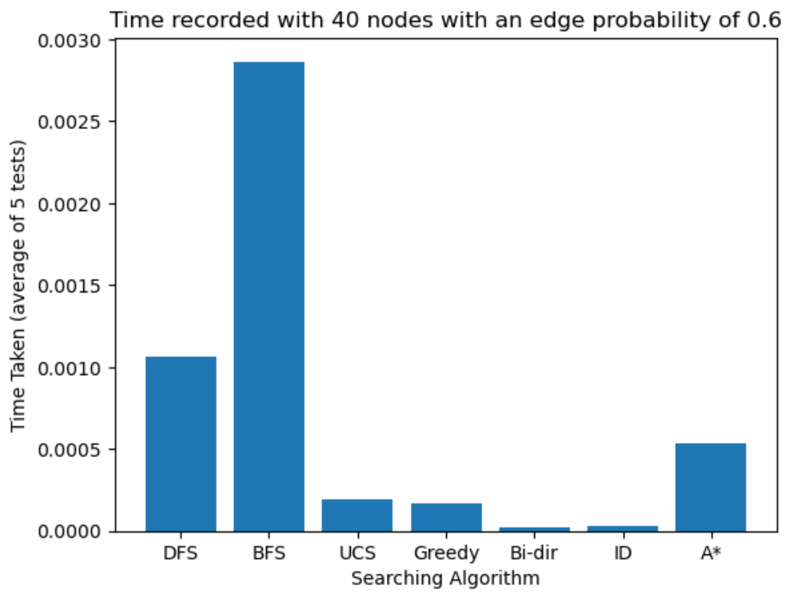

Length of path recorded with 40 nodes with an edge probability of 0.2
Path Length
(average of 5 tests)
0
1
2
3
4
5
6
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

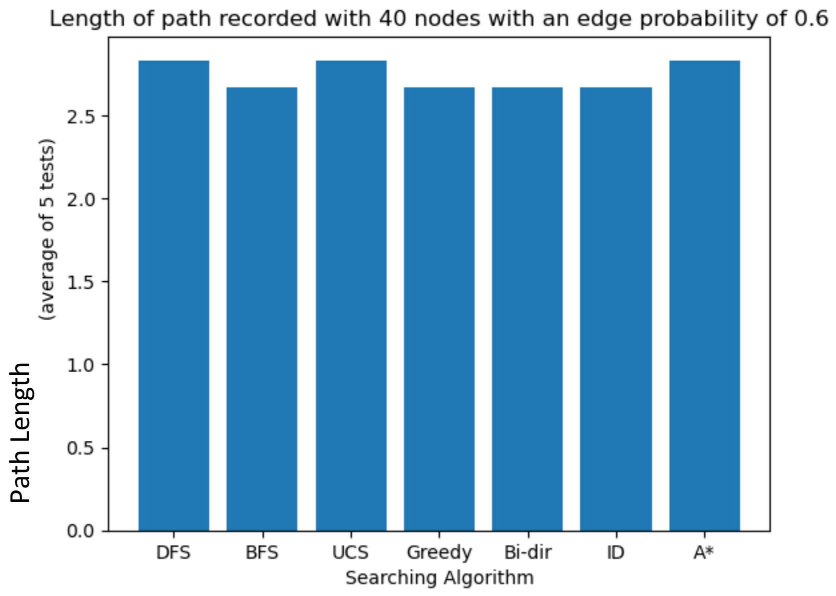


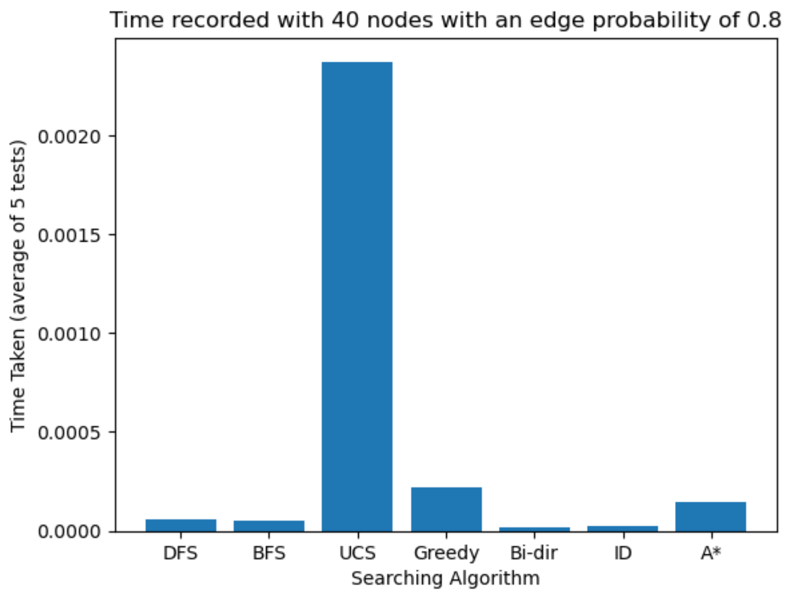
Time recorded with 40 nodes with an edge probability of 0.4
Time Taken (average of 5 tests)
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

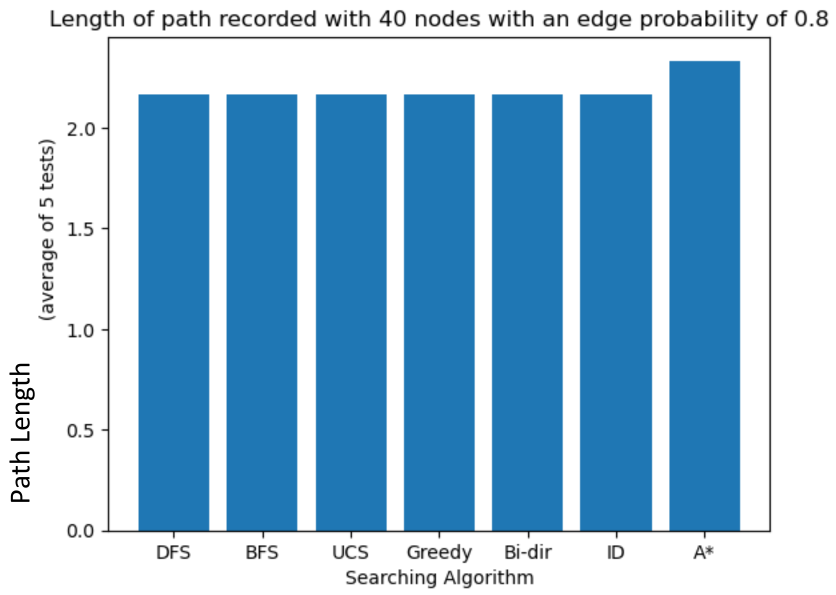


Length of path recorded with 40 nodes with an edge probability of 0.4
Path Length
(average of 5 tests)
2.5
2.0
1.5
1.0
0.5
0.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

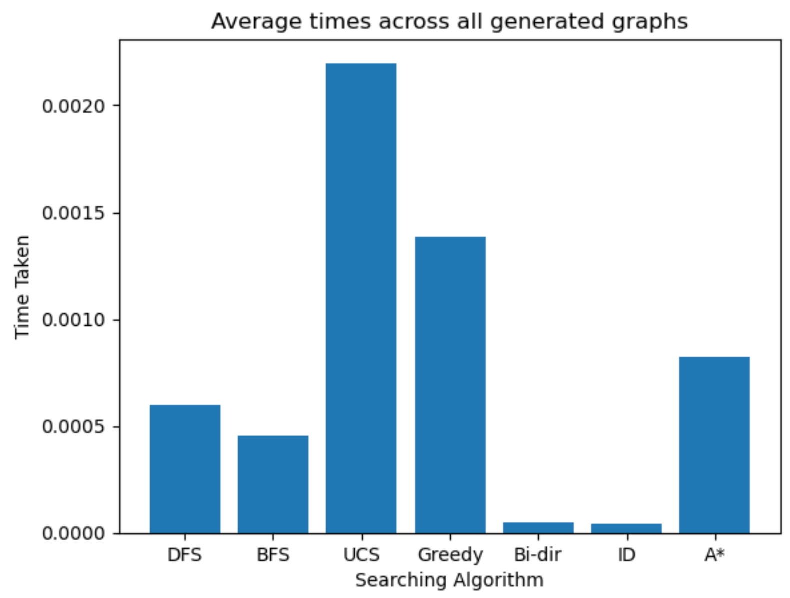

Time recorded with 40 nodes with an edge probability of 0.6
Time Taken (average of 5 tests)
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

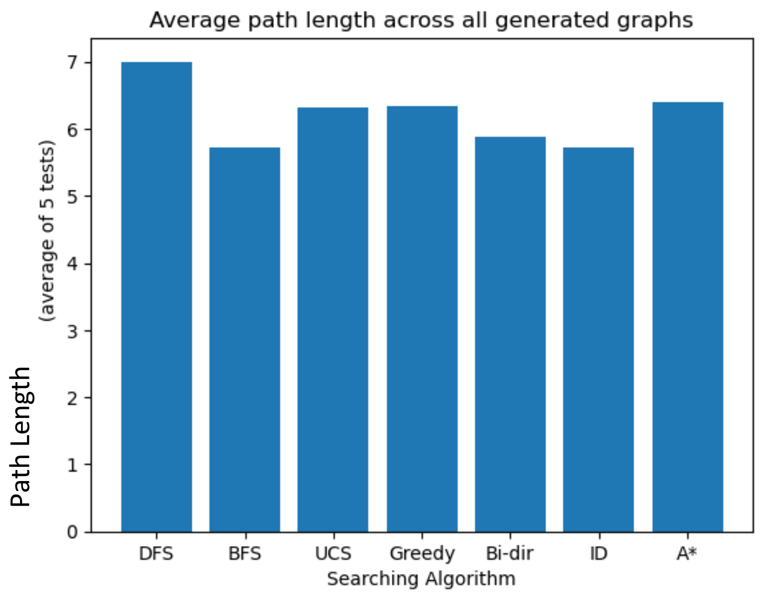

Length of path recorded with 40 nodes with an edge probability of 0.6
Path Length
(average of 5 tests)
2.5
2.0
1.5
1.0
0.5
0.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm


Time recorded with 40 nodes with an edge probability of 0.8
Time Taken (average of 5 tests)
0.0020
0.0015
0.0010
0.0005
0.0000
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

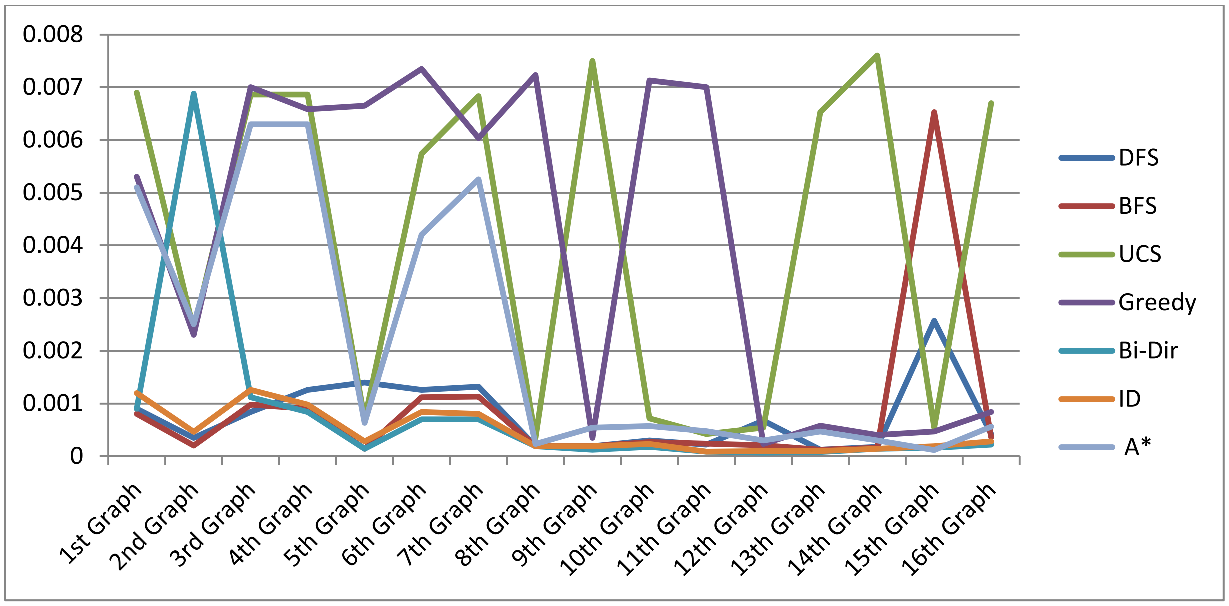

Length of path recorded with 40 nodes with an edge probability of 0.8
Path Length
(average of 5 tests)
2.0
1.5
1.0
0.5
0.0
DFS
BFS
UCS
Greedy
Bi-dir
ID
A*
Searching Algorithm

Average Time and Path length across all graphs

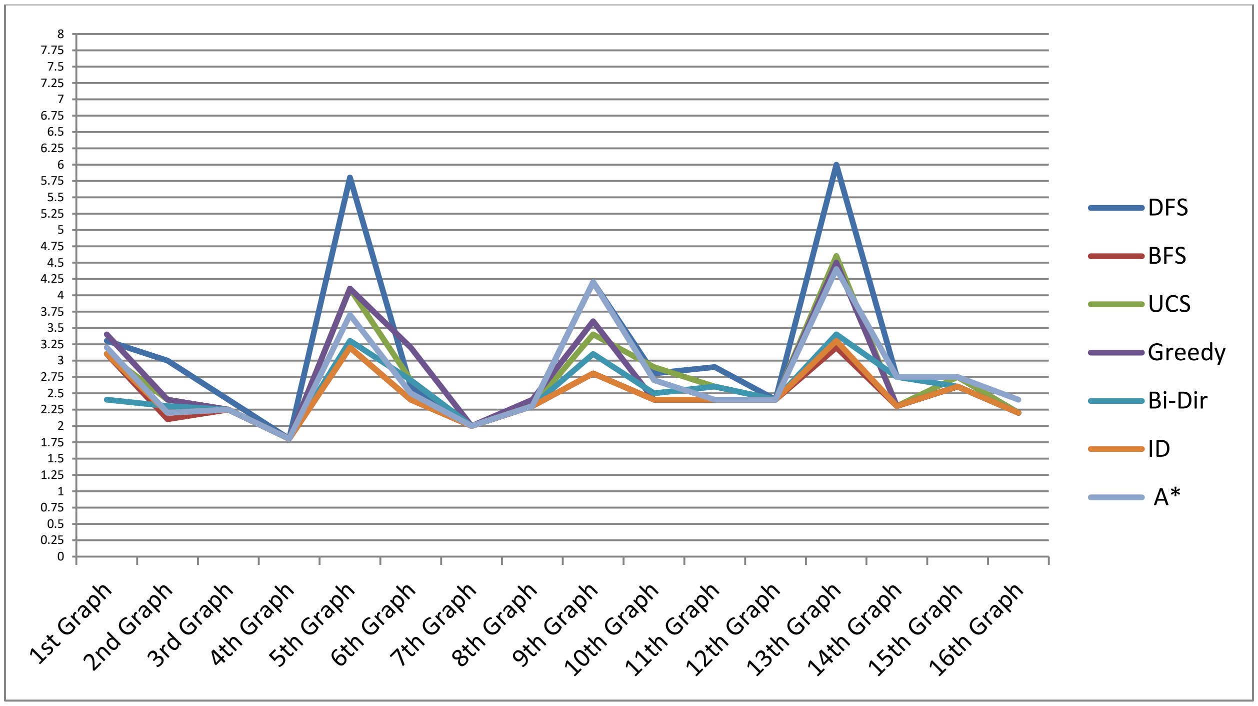




Average Time for various search algorithms across different graphs



Average path for various search algorithms across different graphs



Observations:

1. **Effect of Edge Probability on Time and Path Length**:
    - As the edge probability increases, the time taken for most algorithms tends to increase, indicating that the algorithms take longer to search for paths in denser graphs.
    - Conversely, the length of the paths tends to decrease as the edge probability increases, which makes sense as denser graphs offer more direct routes between nodes.
2. **Performance of Algorithms**:
    - **Uninformed vs. Informed**: Uninformed search algorithms like DFS and BFS generally perform better in terms of path length compared to informed algorithms like A* and greedy search, especially in denser graphs. However, informed algorithms often exhibit faster execution times, particularly in sparser graphs.
    - **Greedy Search**: Greedy search consistently shows high path lengths across different graph densities, indicating that it tends to find suboptimal paths. However, it often performs well in terms of execution time, especially in sparser graphs.
    - **UCS and A***: Uniform Cost Search (UCS) and A* consistently exhibit competitive performance in both time and path length across different graph densities, showcasing their effectiveness in finding optimal paths efficiently.
    - **Bidirectional Search**: Bidirectional search generally performs well in terms of time but may exhibit higher path lengths, especially in denser graphs.
    - **Iterative Deepening (ID)**: ID shows mixed performance, sometimes being comparable to informed algorithms like A* and sometimes falling behind.
3. **Graph Density Impact**:
    - In sparser graphs (lower edge probabilities), informed algorithms like A* and UCS tend to have better performance in terms of time, while in denser graphs, their performance becomes comparable to or even worse than some uninformed algorithms.

- Uninformed algorithms like DFS and BFS tend to perform relatively better in terms of path length in denser graphs, possibly due to their systematic exploration of the graph structure.

4. **Trade-offs**:

   - There seems to be a trade-off between time and path length for different algorithms. Greedy algorithms prioritize speed over optimality, leading to shorter execution times but potentially longer paths. Informed algorithms, on the other hand, focus on finding optimal paths, which may require more time, especially in denser graphs.

Question 3:

Experiment 3: Measures Of Centrality

Introduction:

In this experiment, we analyze various measures of centrality for the given graph, including Degree, Closeness, Betweenness, Katz, and Eigen-Vector centrality. Each centrality measure provides insights into the importance or influence of nodes within the graph based on different criteria, such as their connectivity, proximity, or role in facilitating communication. By examining these centrality measures, we gain a deeper understanding of the structural properties and dynamics of the network under study.

The table provided contains the rankings of each city under different centrality measures.

	Degree Centrality	Closeness Centrality	Betweenness Centrality	Katz Centrality	Eigen-Vector Centrality
1	Sibiu	Pitesti	Bucharest	Sibiu	Sibiu
2	Bucharest	Rimnicu_Vilcea	Urziceni	Oradea	Arad
3	Arad	Bucharest	Sibiu	Drobeta	Oradea
4	Craiova	Sibiu	Pitesti	Urziceni	Fagaras
5	Rimnicu_Vilcea	Craiova	Craiova	Vaslui	Rimnicu_Vilcea
6	Pitesti	Fagaras	Fagaras	Zerind	Zerind
7	Urziceni	Urziceni	Vaslui	Neamt	Bucharest
8	Oradea	Giurgiu	Drobeta	Giurgiu	Pitesti

9	Zerind	Drobeta	Mehadia	Pitesti	Craiova
10	Timisoara	Mehadia	Arad	Hirsova	Timisoara
11	Lugoj	Lugoj	Hirsova	Rimnicu_Vilcea	Urziceni
12	Mehadia	Arad	Iasi	Arad	Drobeta
13	Drobeta	Hirsova	Lugoj	Bucharest	Vaslui
14	Fagaras	Oradea	Rimnicu_Vilcea	Fagaras	Giurgiu
15	Hirsova	Timisoara	Timisoara	Eforie	Lugoj
16	Vaslui	Zerind	Oradea	Mehadia	Hirsova
17	Iasi	Vaslui	Zerind	Lugoj	Mehadia
18	Giurgiu	Eforie	Giurgiu	Iasi	Iasi
19	Eforie	Iasi	Eforie	Craiova	Eforie
20	Neamt	Neamt	Neamt	Timisoara	Neamt

Observations:

❖ **Consistent Top-Ranking Cities:**

- Cities like Bucharest, Sibiu, and Pitesti consistently rank high across multiple centrality measures.
- This suggests their pivotal roles in facilitating communication, information flow, and overall connectivity within the network.

❖ **Peripheral or Less Influential Nodes:**

- Conversely, cities with lower centrality rankings may represent peripheral or less influential nodes within the network.
- This may indicate their relative isolation or limited interactions with other cities.
- Some cities with lower centrality rankings include: Giurgiu, Eforie, Neamt, Iasi, Timisoara, Lugoj, Mehadia, Drobeta and Vaslui.

❖ **Diverse Characteristics Across Measures:**

- Comparing rankings across different centrality measures reveals cities with diverse characteristics in their centrality profiles.
- For instance, Arad ranks significantly high in Degree Centrality (#3), indicating it has many direct connections, but it ranks lower in Betweenness Centrality (#10), suggesting it may not serve as a crucial bridge between other cities.
- This implies that while Arad is well-connected locally, it may not play a pivotal role in facilitating communication and information flow between other cities, potentially limiting its influence in the overall network dynamics.

Question 4:

The following tables show the time and space complexities of various operations under multiple graph representations. Note that ‘V’ and ‘E’ represent the number of vertices and edges for a graph respectively.

Time complexity for operations

Operations	**Graph Representations**		
	Adjacency Matrix	**Adjacency List**	**Edge List**
Insertion of vertices	**O(V^2)**	**O(1)**	**-**
Insertion of Edges	**O(1)**	**O(1)**	**O(1)**
Deletion of vertices	**O(V^2)**	**O(|V| +|E|)**	**O(E)**
Deletion of Edges	**O(1)**	**O(|E|)**	**O(E)**
Checking for the existence of an edge	**O(1)**	**O(E)**	**O(E)**
Finding the neighbors of a vertex	**O(V)**	**O(1)**	**O(E)**

Space complexity for different graph representations:

	Graph Representations		
	Adjacency Matrix	**Adjacency List**	**Edge List**
Space complexities	**O(V^2)**	**O(|V| +|E|)**	**O(E)**