**ICT203 Assignment 1**

Table of Contents

[**Requirements/Specification** 3](#_Toc169217106)

[**Design/Algorithm** 5](#_Toc169217107)

[**Limitations** 8](#_Toc169217108)

[**Simulation and Discussion** 9](#_Toc169217109)

[**User Guide** 10](#_Toc169217110)

[**Source Program Listings** 12](#_Toc169217111)

## **Requirements/Specification**

**Problem Statement**

Develop an intelligent agent to navigate a taxi in a given environment to pick up and drop off passengers using the shortest path. The environment is a 5x5 grid with specific locations for picking up and dropping off passengers. The agent will use search algorithms to determine the optimal route for each task while maximising the reward.

**Assumptions and Conditions**

1. **Environment Grid:** The environment is a 5x5 grid where each cell represents a possible location for the taxi.
2. **Passenger Locations:** The taxi can pick up passengers from four possible locations: Red (0), Yellow (1), Green (2), Blue (3). If the passenger is inside the taxi, the state is represented by 4.
3. **Drop-off Locations:** The taxi can drop off passengers at four possible locations: Red (0), Yellow (1), Green (2), Blue (3).
4. **Actions:**

* 0 = move south
* 1 = move north
* 2 = move east
* 3 = move west
* 4 = pick up passenger
* 5 = drop off passenger

1. **Rewards:**

* Each step incurs a penalty of -1 point
* Proper pick-up and drop-off actions earn a reward of 10 points.

1. **Objective:** Maximise the final reward by picking up and dropping off passengers using the shortest possible path.

**Formalisation of the Problem**

1. **State Space:** Represented by the tuple (taxi\_position, passenger\_location, destination). The taxi\_position is represented by coordinates (x,y), and the passenger\_location and destination are integers from 0 and 3.
2. **Action Space:** Action is defined as (move south, move north, move east, move west, pick up, drop off).
3. **Transition Model:** Defines how the state responds to actions. For instance, moving north increase the y-coordinate by 1, while picking up a passenger changes the passenger\_location to 4 (inside the taxi).
4. **Reward Function:** Each move action returns a reward of -1. Successful pick-up and drop-off actions return a reward of 10.
5. **Goal State:** Achieved when the passenger has been picked up and dropped off at the correct location.

**Search Algorithms**

The following search algorithms will be implemented:

1. **Breadth-First Search (BFS):** Explores the state spaces level by level
2. **Uniform Cost Search (UCS):** Explores the state space by expanding the least costly node.
3. **A\* Search (AFS):** Uses a heuristic to guide the search, aiming to find the shortest path more efficiently.

**Solution Design**

* Reading the environment
* Move to pick-up location
* Move to drop off location
* Calculate reward

**Assumptions**

* Taxi moves freely within grid boundaries
* Environment and initial state are set up correctly
* Actions are sufficient for navigation

**Expected Outputs**

* Path for each algorithm
* Total reward
* Total steps

## **Design/Algorithm**

**Solution Design Overview**

The solution revolves around navigating a taxi in a grid environment to efficiently pick up and drop off passengers using Breadth-First Search (BFS), Uniform Cost Search, A \* Search algorithms. Each algorithm’s effectiveness will be compared to demonstrate their optimisation levels in pathfinding.

**BFS (Breadth-First Search):**

The bfs method that was implemented employs Breadth-First Search (BFS) to find a path from the initial state to a goal in the “Taxi-v3” environment. It begins by initialising and deep copying the environment, then resetting it. The method starts with a queue containing the initial state and an empty path while maintaining a set of visited states. It then explores all actions from the current state, enqueueing new, unvisited states and updating steps and rewards. Once the goal is reached, it displays the path, total reward, steps, and time. If no solution is found, it prints a message, ensuring the discovery of the shortest path in an unweighted environment.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pseudocode Explanation: bfs(self) | | | | | |
| 1. | **Function** bfs(self): | | | | |
| 2. |  | Initialise **startTime** to current time | | | |
| 3. |  | Initialise **totalSteps** to 0 | | | |
| 4. |  | Copy the environment to create **copyEnv** | | | |
| 5. |  | Reset **copyEnv** to its initial state and store it as **initialState** | | | |
| 6. |  | Initialise a **queue** with the **tuple (initialState, [])** | | | |
| 7. |  | Initialise a set named **visited** and add **initialState** to it | | | |
| 8. |  | Initialise **totalReward** to 0 | | | |
| 9. |  | **While** the **queue** is **not empty**: | | | |
| 10. |  |  | **Dequeue** a **tuple (state, path)** from the **queue** | | |
| 11. |  |  | **For** each possible **action** in the **action space**: | | |
| 12. |  |  |  | Set the **environment state** to **state** | |
| 13. |  |  |  | Execute the action in **copyEnv** and obtain **newState**, **reward**, and **done** | |
| 14. |  |  |  | If **newState** has **not** been **visited**: | |
| 15. |  |  |  |  | Increment **totalSteps** by 1 |
| 16. |  |  |  |  | Add **newState** to **visited** |
| 17. |  |  |  |  | **Enqueue** a **tuple (newState, path+[action])** to **queue** |
| 18. |  |  |  |  | Add **reward** to **totalReward** |
| 19. |  |  |  | If **done** is **true**: | |
| 20. |  |  |  |  | Display the results including **path**, **totalReward**, **totalSteps**, **time taken**, and **algorithm type**. |
| 21. |  |  |  |  | **Return** |
| 22. |  | **Print** “No solution found” | | | |
| 23. | **End Function** | | | | |

**UCS (Uniform Cost Search):**

The ucs method in the algo\_test class employs the Uniform Cost Search (UCS) algorithm. It begins by initialising the environment and priority queue with the initial state and cost. The algorithm then explores the state with the lowest cumulative cost, updating steps and rewards as it progresses. If a new state has a lower price than previously recorded, it updates the cost and revisits the state. Once the goal is reached, it displays the path, total reward, steps, and execution time. If no solution is found, it prints a message.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pseudocode Explanation: ucs(self) | | | | | |
| 1. | **Function** ucs(self): | | | | |
| 2. |  | Initialise **startTime** to current **time** | | | |
| 3. |  | Initialise **totalSteps** to **0** | | | |
| 4. |  | Make a deep copy of **environment** as **copyEnv** | | | |
| 5. |  | Reset **copyEnv** to its initial state and store it **as** **initialState** | | | |
| 6. |  | Initialise a **priority queue** with **tuple (cost, initialState, [])** | | | |
| 7. |  | Initialise a **set** named **visited** and add **initialState** to it | | | |
| 8. |  | Initialise a dictionary named **cost** with key **initialState** and **value** **0** | | | |
| 9. |  | Initialise **totalReward** to **0** | | | |
| 10. |  | **While** the queue **is not** empty: | | | |
| 11. |  |  | Pop the **tuple (currentCost, state, path)** from the **queue** | | |
| 12. |  |  | **Set** done **to False** | | |
| 13. |  |  | **For each** possible **action**: | | |
| 14. |  |  |  | **Set** the **environment state** to **state** | |
| 15. |  |  |  | Execute the action in **copyEnv** and obtain **newState**, **reward**, and **done** | |
| 16. |  |  |  | Calculate **newCost** as **currentCost+1** | |
| 17. |  |  |  | **If** newState **is not** visited **or** cost of newState **is** greater than newCost: | |
| 18. |  |  |  |  | Increment **totalSteps** by **1** |
| 19. |  |  |  |  | Update cost of **newState** to **newCost** |
| 20. |  |  |  |  | Add **newState** to **visited** |
| 21. |  |  |  |  | Push a **tuple (newCost, newState, path+[action])** to the **queue** |
| 22. |  |  |  |  | Update **totalReward** by adding **reward** |
| 23. |  |  |  | **If** done **is True**: | |
| 24. |  |  |  |  | Display the results including path, **totalReward**, **totalSteps**, **time taken**, and **algorithm type** |
| 25. |  |  |  |  | **Return** |
| 26. |  | **Print** “No solution found” | | | |
| 27. | **End Function** | | | | |

**A\* Search:**

The afs method in the algo\_test class implements the A\* Search (AFS) algorithm. It begins by initialising the environment and a priority queue with the initial state, cost, and an empty path. The algorithm then explores states, prioritising those with the lowest combined cost and heuristic value. The heuristic function is modified to return 0 if the goal state is reached and 1 otherwise, as the goal state is unknown. The method performs actions for each state to generate new states, updating costs and paths as necessary. If a new state is not in the visited set or has a lower cost than previously recorded, it updates the cost and revisits the state. Upon reaching the goal, the method displays the path, total reward, steps, and execution time. If no solution is found, it prints a message.

|  |  |  |  |
| --- | --- | --- | --- |
| Pseudocode Explanation: heuristic(self, done) | | | |
| 1. | **Function** Heuristic(self, done): | | |
| 2. |  | **If** done **is True**: | |
| 3. |  |  | **Return 0** |
| 4. |  | **Else**: | |
| 5. |  |  | **Return 1** |
| 6. | **End Function** | | |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Pseudocode Explanation: afs(self) | | | | | |
| 1. | **Function** afs(self): | | | | |
| 2. |  | Initialise **startTime** to current **time** | | | |
| 3. |  | Initialise **totalSteps** to **0** | | | |
| 4. |  | Make a deep copy of the **environment** as **copyEnv** | | | |
| 5. |  | Reset copyEnv to its **initial state** and store it as **initialState** | | | |
| 6. |  | Initialise a **priority queue** with **tuple (cost, initialState, [])** | | | |
| 7. |  | Initialise a set named **visited** and add **initialState** to it | | | |
| 8. |  | Initialise a dictionary named **cost** with key **initialState** and value **0** | | | |
| 9. |  | Initialise **totalReward** to **0** | | | |
| 10. |  | **While** the queue **is not** empty: | | | |
| 11. |  |  | Pop the **tuple (\_, state, path)** from the **queue** | | |
| 12. |  |  | **Set** done **to False** | | |
| 13. |  |  | **For each** possible action: | | |
| 14. |  |  |  | **Set** the **environment state** to **state** | |
| 15. |  |  |  | Execute the action in **copyEnv** and obtain **newState**, **reward**, and **done** | |
| 16. |  |  |  | Calculate the **newCost** as **cost** of **state+1** | |
| 17. |  |  |  | **If** newState **is not** visited **or** cost of newState **is** greater than newCost: | |
| 18. |  |  |  |  | Increment **totalSteps** by **1** |
| 19. |  |  |  |  | Update cost of **newState** to **newCost** |
| 20. |  |  |  |  | Add **newState** to **visited** |
| 21. |  |  |  |  | Calculate priority as **newCost+heuristic** of **done** |
| 22. |  |  |  |  | Push a **tuple (priority, newState, path+[action])** to the **queue** |
| 23. |  |  |  |  | Update **totalReward** by adding **reward** |
| 24. |  |  |  | **If** done **is True**: | |
| 25. |  |  |  |  | **Display** the results including path, **totalReward**, **totalSteps**, **time taken**, and **algorithm type** |
| 26. |  |  |  |  | **Return** |
| 27. |  | **Print** “No solution found” | | | |
| 28. | **End Function** | | | | |

## **Limitations**

A limitation of the provided solution stems from the inherent uncertainty surrounding the goal state in the program. Since the goal state is unknown, the A\* search (AFS) and Uniform Cost Search (UCS) algorithms must operate without complete information, relying instead on a modified heuristic function. This simplified heuristic, which returns 0 when the goal state is reached and 1 otherwise, may not accurately estimate the distance to the goal. Consequently, AFS and UCS may yield comparable rewards and paths due to their optimal nature, but their performance in reaching the goal may vary considerably. This discrepancy highlights the challenge of navigating the state space effectively without precise knowledge of the goal state.

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## **Simulation and discussion**

The simulation results offer valuable insights into the performance of Breadth-First Search (BFS), Uniform Cost Search (UCS), and the A\* Search algorithms in the Taxi-v3 environment. Despite all three algorithms successfully reaching the goal state with identical paths and rewards, their execution times vary noticeably.

BFS, known for its simplicity, completed the task in approximately 0.016 milliseconds. However, its exhaustive exploration strategy led to a higher step count of 56, reflecting its thoroughness in traversing the state space.

In contrast, UCS and A\* Search, levering cost information, exhibited slightly longer execution times of around 0.018 and 0.028 milliseconds, respectively. Yet, they achieved this with fewer steps, indicating their efficiency in navigating the state space by prioritising lower-cost paths.

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These findings emphasise the critical role of algorithm selection, balancing completeness, optimality, and computational efficiency. While BFS ensures completeness, UCS and A\* search prioritise solution quality and reduce exploration, resulting in quicker execution times without compromising the solution's optimality.

## **User Guide**

1. **Version:** Python 3.12.3

2. **IDE Used:** Visual Studio Code was utilised for creating this program. However, any IDE of your choice can be used.

3. **Folder Structure:**

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4. **Prerequisites:** To set up the environment for running the program, start by opening the folder with your preferred IDE. This is followed by creating a virtual environment using the command **‘python -m venv <venv\_name>’**. You can name it anything you prefer. However, I chose to name it **assess1**. Once the virtual environment is created, activate it using the appropriate command based on your operating system. For Linux and Mac, use **‘source venv\_name/bin/activate’**; for Windows, use **‘venv\_name\Scripts\activate’**. After activating the virtual environment, install the required dependencies by running the command **‘pip install -r requirements.txt’**. This will ensure that all necessary libraries are installed and ready to use for executing the program.





5. **Execution:** To execute the program, ensure the virtual environment is activated as shown below and the required packages are installed from **‘requirements.txt’**.

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To run the program, use the command **‘python codes/algo\_test.py’** in your terminal.



Alternatively, you can open the Python file in your IDE and click the run button. This will start the execution of the program.

A screen shot of a computer

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6. **Using the program:**

Upon execution, the program will run the Breadth-First Search, A Star Search, and Uniform Cost Search algorithms to solve the Taxi-v3 environment. It will display the execution time, total steps, path taken, and reward for each algorithm.

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## **Source Program Listings**

The codes for this assignment can be found within the **“codes”** folder submitted along with this external documentation.

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