Cost-Based Grid Pathfinding

Project Report

1. Introduction and Motivation

In many intelligent systems, an autonomous agent is required to navigate an environment efficiently while operating under various constraints. Unlike simplified navigation problems in which all movements incur equal cost, real-world environments often involve heterogeneous conditions such as uneven terrain, obstacles, and variable energy consumption. Consequently, optimal navigation must account not only for reachability but also for the cost associated with each possible action.

This project investigates the **Cost-Based Grid Pathfinding problem**, in which an intelligent agent must determine the least costly path from a starting position to a designated goal within a structured environment. The problem is examined from an Artificial Intelligence perspective, with particular emphasis on formal problem representation, state-space modeling, and the comparative application of classical search algorithms.

2. Problem Definition

The problem addressed in this project is a **Cost-Based Grid Pathfinding Problem**, formally defined as follows:

An agent operates within a two-dimensional grid environment composed of traversable cells, impassable obstacles, and cells associated with varying traversal costs. The agent's objective is to move from a predefined initial position to a specified goal position while minimizing the **total accumulated movement cost**, rather than merely minimizing the number of steps taken.

This formulation extends standard grid navigation problems by incorporating non-uniform costs, thereby making the problem more representative of real-world navigation scenarios.

3. Environment Modeling

The environment is discretized into a two-dimensional grid with the following characteristics:

- Each **cell** corresponds to a possible agent location.

- Certain cells are **blocked** and represent obstacles that cannot be traversed.
- Traversable cells may have **different movement costs**, reflecting variations in terrain difficulty or resource consumption.

This grid-based abstraction enables the environment to be modeled as a state space, which is suitable for the application of classical Artificial Intelligence search techniques.

4. AI Problem Formulation

The problem is formulated using the standard **Problem-Solving Agent** framework:

Agent

The agent represents an autonomous decision-making entity tasked with navigating the grid environment to reach the goal state.

State Representation

A state is defined by the agent's current position within the grid:

State = (row, column)

Initial State

The initial state corresponds to the agent's starting location in the grid.

Goal State

The goal state represents the target cell that the agent aims to reach.

Actions

From any given state, the agent may execute one of the following movement actions:

- Move Up
- Move Down
- Move Left
- Move Right

Actions are valid only if the resulting cell lies within the grid boundaries and is not an obstacle.

Successor Function

The successor function generates all valid neighboring states reachable from the current state and associates each successor with the cost of entering the corresponding cell.

Path Cost Function

The cost of a solution path is computed as the cumulative sum of the traversal costs of all cells visited along the path.

5. Search Algorithms Applied

To solve the problem, several search algorithms studied in the course were implemented and analyzed.

Uninformed Search Algorithms

1. **Breadth-First Search (BFS)**
   Expands nodes in order of increasing depth and guarantees completeness, but does not account for varying movement costs.
2. **Depth-First Search (DFS)**
   Explores paths to maximum depth before backtracking, offering low memory usage but no guarantee of optimality.
3. **Iterative Deepening Search (IDS)**
   Combines the space efficiency of DFS with the completeness of BFS by gradually increasing the depth limit.
4. **Uniform-Cost Search (UCS)**
   Expands the node with the lowest cumulative path cost and guarantees optimality when all costs are non-negative.

These algorithms illustrate the limitations of uninformed search methods when applied to environments with non-uniform traversal costs.

Informed Search Algorithms

1. **A* Search**
   Utilizes an admissible heuristic (Manhattan distance) to guide the search toward the goal efficiently. A* is both complete and optimal when the heuristic is admissible.
2. **Hill Climbing**
   A local search strategy that selects the neighboring state with the best heuristic

value. This algorithm is included to demonstrate common limitations of local search methods, such as susceptibility to local maxima and plateaus.

6. Evaluation Methodology

All algorithms were evaluated using identical grid configurations to ensure fair comparison. The evaluation criteria included:

- **Completeness**: Whether the algorithm successfully found a solution.
- **Optimality**: Whether the resulting path had the minimum possible cost.
- **Total Path Cost**: The cumulative cost of the selected path.
- **Path Length**: The number of steps required to reach the goal.

The results highlight the superior efficiency and reliability of informed search algorithms, particularly A*, in solving cost-sensitive navigation problems.

7. Significance and Applications

Although the problem is implemented using a grid-based representation, it models a general navigation task applicable to a wide range of real-world domains, including:

- **Robotic motion planning**, such as autonomous exploration in unknown terrain.
- **Autonomous vehicles**, where route selection must balance distance, safety, and energy consumption.
- **Game AI**, particularly for non-player character (NPC) movement.
- **Intelligent agents** operating in structured or semi-structured environments.

This demonstrates the broad applicability and practical relevance of cost-based pathfinding in Artificial Intelligence.

8. Expected Outcomes

Through the completion of this project, the following learning outcomes were achieved:

- A clearer understanding of formal AI problem formulation.

- Practical insight into the strengths and weaknesses of uninformed versus informed search strategies.
- Demonstrated the necessity of cost-aware algorithms such as **Uniform-Cost Search** and **A*** for realistic navigation problems involving heterogeneous movement costs.