Multi Agent Path Planning

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Problem:

[Multi Agent Path Finding] Consider a warehouse and a set of robots which pick up items from designated places, deliver those in desired locations, and finally the robots go to the end location. Assume that the warehouse is represented as a 2-D grid of size n × m. Each location (Li) on the warehouse floor can be denoted by a pair of integers Li = (xi, yi). Each cell on the grid can be categorized in one of the following ways (see diagram below) - source location (P1-P3), destination location (D1-D3), temporary storage location (TS1-TS4), obstacle (black square), normal (rest of the cells). Source & destination denote pick-up and drop locations respectively. Temporary storage location denotes the place where robots can keep some items. Obstacle presents a location where no robot can move. Rest of the cells are considered as normal cells.

Initial thought process:

Initial inference from the problem statement was that it is similar in nature to the single agent path finding problem that we had discussed earlier in class. This problem, however, is greatly higher in difficulty as multiple agents need to function, being aware of the position of the other agents functioning concurrently. The search space is exponentially larger as every branch can expand due to a move by any robot agent.

Due to the large search space, it is important to implement an algorithm that is sufficiently fast to solve these problems. Such algorithms are often needed in facilities like amazon, where such bots run to deliver objects to their specific aisles so it is important that they perform well in real time.

Setup and Project Description:

Language of choice: Python 3.8

Algorithms used:

- Space-Time A* Algorithm
- Prioritized Planning
- Conflict Based Search

Project Files:

- indepedendant.py: includes code to find independent paths of each robot, acting as if paths of other robots do not conflict.
- prioritized.py: includes code to solution using prioritized planning; which is incomplete and suboptimal
- runexpiremts.py: includes code to generate results and to run experiments on the code files
- cbs.py: includes code to solution using conflict based search which is complete and finds the optimal solution.
- visualise.py: includes code to visualise the findings in terms of a short animation
- single_agent_planner.py: includes code to plan the path of a single agent using space time a star algorithm.

Constraints:

There are some key differences in this problem from the traditional problem of single agent path finding. The main difference being some constraints in the motion of a particular bot introduced due to the motion of all other bots over the given terrain. These constraints are explained below:

1.) Vertex Constraints:

A bot cannot occupy a cell which is already occupied by another bot moving in the plane.

2.) Edge Constraints:

Two bots in consecutive gridpoints cannot simply switch places in the next time step.

Space Time A* Algorithm:

Conventional A* algorithm searches over the distance considerations only but in this problem it is crucial the algorithm is aware of the time considerations as well.

There are going to be constraints which are dependent on the timestep of the situation, hence the time variable needs to be taken into account.

Each node in the map which is visited by the robot needs to have a temporal variable associated with it.

As we search over the space, we can see if the robot is allowed to be in a cell at a given moment in time. If it is not permissible for the robot to be in some position. That branch in the search space can be pruned.

Hence this modified A* algorithm searches over the search space keeping in mind constraints.

Independent Planning:

While implementing independent planning. The constraints introduced due to multiple robots on the motion of each robot are ignored. The path of every robot is planned as if other bots do not exist. This algorithm returns a state space in which all the robots have a path to their goal which might intersect at a given time. The problem after this implementation is to resolve this configuration such that no paths collide.

Prioritized Planning:

Every robot has a goal destination. In prioritized planning the paths of robots are prioritized in order. The path of the robot having the highest priority is planned independently from others. When planning the path of the robots which follow; the first robot is treated as a dynamic obstacle. What this means is that the plane already has static obstacles, but the first moving robot can be treated as an obstacle whose position changes with every time step. As the priority list of robots are explored, the number of such dynamic obstacles increases. Prioritized planning is suboptimal and incomplete. It is incomplete because it starts with a priority order of bot planning, which almost always results in a suboptimal solution to the problem. What is worse is that it is possible that the algorithm never returns a solution as the initial priority order can be so that the planning of bots further down the line becomes impossible.

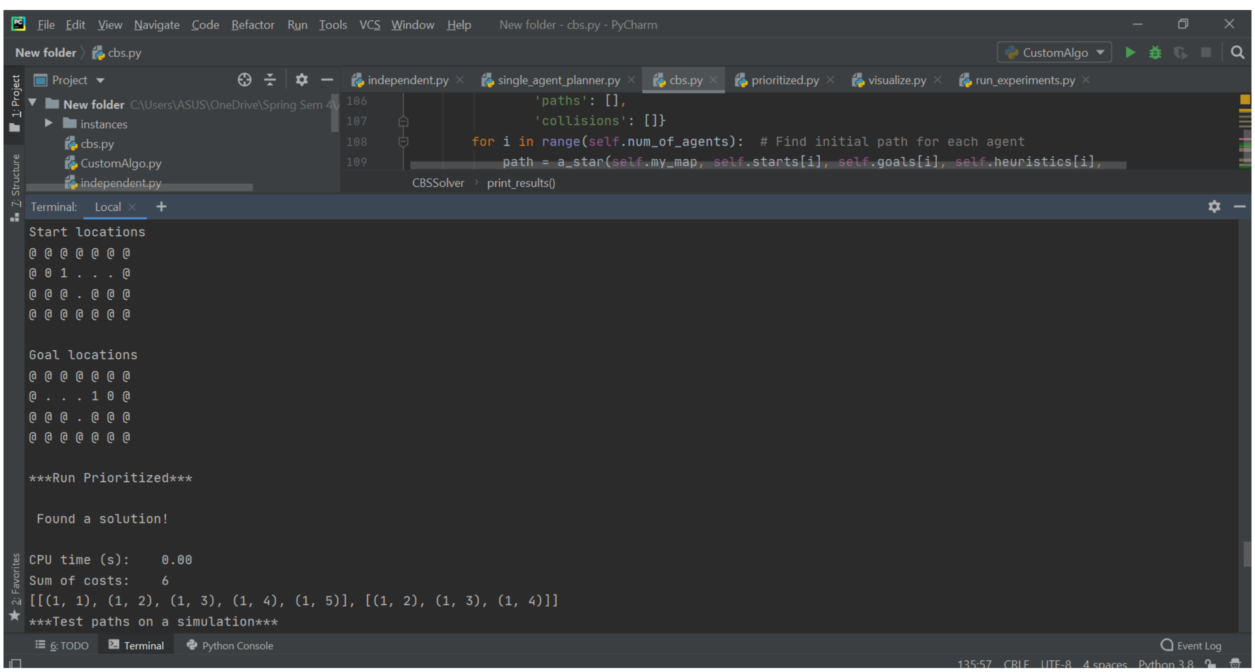
Conflict Based Search:

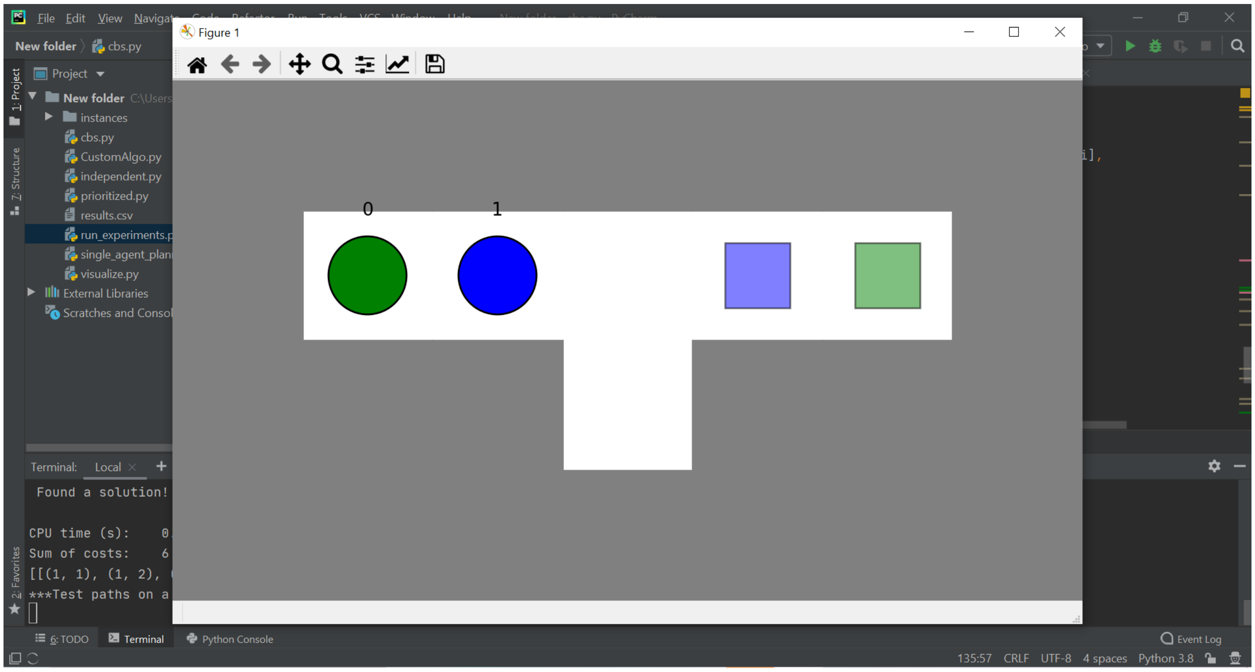
Conflict based is the most important algorithm for this solution. This is a complete and optimal solution as it can efficiently search over the entire search space.

It starts with an initial search space in which the paths of the robots are planned independently from each other. Each branch from this initial space is a resolution to a collision of the bots in the parent space. The algorithm expands first along the branch which results in the resolution of the most number of collisions and satisfying most number of constraints. This occurs iteratively and we finally arrive at a configuration that plans the path of the robots in a collision free manner.

Results:

Here are some screenshots of results after conducting some simple experiments on our code





Applications:

Multi agent path finding algorithms can be used in various different domains.

Amazon Fulfillment Centres: Such pickup and delivery robots are already put in use in amazon facility centres. Multiple robots arrange packages according to their labels. These robots have to work together in real time and any sort of collision or misplanning would result in loss of a lot of money to amazon.

Airports: Currently airplanes are carried by trucks driven by humans, which carry them to their required terminal. There are some discussions on automating this process. If automated, this MAPF Algorithm would come in very handy. These trucks can be automated and this process can be made a lot faster and safer. Airports can then have multiple such trucks running concurrently and the clearance value that is assigned to these planes could be reduced a lot. This clearance is high to accommodate human error. When the clearance value goes down; many more airplanes can be moved around the same time, this would drastically improve the efficiency of airplane management and boost profits.

Discussion:

- This was an interesting problem statement to work on. This provided a lot of insight into the work that goes into coming up with artificial intelligence algorithms and their structure.
- It made us appreciate their applications even more and changed our perception about such models.
- Researching this topic was fun and enlightening. Before we decided on working on this particular problem among the 3 problems provided to us, we also explored the other ones and it was wonderful understanding the vast scope of heuristic algorithms
- Some difficulties we faced were actually writing the code and implementing it. It was an extremely difficult problem to us as neither of us had any prior experience in developing such programs.

Sources:

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