Airplanes Group 2 Report

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2   Initial Insights and Observations

When we first started working on this project, our initial intuition was to solve the problem at a single-agent level without doing any sort of pre-calculation or simulation; one would simply need to develop some simple rules for directing the airplanes toward their goal while avoiding other airplanes, and the rest should fall into place. Our initial implementation, to this end, was a simple agent wherein each plane would be influenced by a "force vector" at each timestep, similar to a "boid" simulation seen in computer graphics. The basis for this force vector would be a vector pointing from the plane's current location to its destination. At every time step, one would modify this vector by adding a "repulsive" vector pointed away from any nearby planes or walls. Once the final vector was calculated, the plane would manuever toward this vector unwaveringly.

Upon testing our player, it became apparent that our initial approach was insufficient for this problem. While scenarios with very few planes were solved easily, the scaling of the problem to maps with tens of airplanes would result in frequent collisions as planes attempts to avoid one another would inevitably result in collisions with other planes within the simulation. This limitation primarily arose from the fact that each agent only considered the immediate state of the board at each timestep, disregarding both the implications of its potential move and the potential actions of all other planes in the simulation; by disregarding such information, it was easy to fall into cases where the "optimal" actions taken by any two individual planes in the simulation would lead them to a course which was uncorrectable, and thus would result in a collision. From this, we realized that a more unified, intelligent strategy was necessary to succeed.

3   Strategies & Concepts

3.1   Launch-Time Simulation

3.2   Fire-and-Forget Flight Paths

3.3   A* Pathfinding

3.4   Minimum Theoretical Runtime

4   Implementation

5   Results

6   Contributions

7   Future Directions & Limitations

7.1   Flow Optimization

One minor shortcoming of our solution as presented was its performance on so-called "flow" boards, characterized by large numbers of planes that shared their source, destination, and departure times and so-named from the serialized flow of planes that would form between the source and destination. While we were able to improve our performance on these boards by adding flow detection to the pre-simulation training in the code (implemented by detecting the presence of five or more planes sharing a source an destination), our solution was limited by the fact that only one flow of planes was allow between any source-destination pair. On boards such as `DiagonalFlows` with large amounts of free airspace, Group 5's player was able to detect the possibility of multiple flows between the source and destination and subsequently schedule planes to proceed to the destination in two slightly-staggered flows. While the staggering (necessary for any particular plane to avoid collision with a plane in another flow immediately at takeoff, before that other plane had cleared the airspace) severely reduced the runtime improvements of this strategy, it was nonetheless better than a one-flow solution; Group 5's player demonstrated a runtime of 666 steps on `DiagonalFlows` , while our player demonstrated a runtime of 711 steps.

One could improve on this limitation by adding detection for multiple flow paths between a source-destination pair during the training phase of our player. Our current implementation of flow-detection works by finding a shortest path between the source-destination pair, treating other flows as obstacles obstructing this path. One possibility would be to generate some number of paths between the source-destination pair, determine which paths are close enough to the optimal path as to not increase the overall runtime of the simulation after necessary staggering was taken into account, and dispatch planes to each of these flows in turn. Potential implementation difficulties would be being able to determine prior to simulation that such a splitting would not simply increase the runtime of the entire simulation.

7.2   Pathfinding Prioritization / Sorting

Another problem with our solution was the possibility of giving planes whose paths were determined last in the sequence of planes overly long paths. As outlined above, our method of determining paths was greedy in that we would determine the path for any particular plane P_i by simply simulating the shortest A* path between the source and destination of P_i in an environment with planes $P_0...P_{i-1}$, resetting the simulation and trying again with a obstacle placed at the collision point in the event of a collision. This methodology resulted in a greater number of collisions for the last planes to have their path decided, which would lead them to be given longer paths to avoid collisions. Problems arose in that the ordering for resolving plane paths was more-or-less arbitrary; it was very possible that a plane with a short path in an optimal solution would be given a longer path, potentially to the detriment of simulation runtime, due to the fact that it had to consider more obstacles than other planes in determining its final path.

We attempted to address this problem by prioritizing the order with which planes' paths were determined in our pre-flight simulations. Methods tried include...

- `Shortest Path First:`   Order the planes in ascending order by path length, and resolve flight paths in that order. The intuition behind this was that shorter paths would have fewer intersections with other paths, and thus their resolution would generate fewer obstacles for later-resolved flights.

- `Longest Path First:`   Order the planes in descending order by path length, and resolve flight paths in that order. The intuition behind this was that longer flights are more likely to be the limiting factor in the overall runtime of the simulation, so resolving them first would ensure their runtime would not be increased by collisions with shorter flights.

- `Least Intersections First:`   Determine the straight line paths between all source-destination pairs in the simulation. Order the planes in descending order by number of intersections with other straight line paths,

and resolve flight paths in that order. This method attempted to resolve flights that would be interfered with by many other flights first, thus prevent their runtimes from skyrocketing.

In experiments, we found that each of the above methods yielded superior results in different simulations, with no clear trend of certain strategies working better on certain maps. Due to the fact that our implementation of sorting was incompatible with our flow detection, our final solution ultimately scrapped prioritization of plane flights. One issue that would have to be solved if this were implemented in the future would be gathering useful information for prioritizing flights from the information that is available at the beginning of the simulation. One only knows when the simulation starts what the source, destination, and departure time of each plane is. As of time of writing, we were unable to find any way of extrapolating from this data a prioritization that would reliably yield better results on most boards.

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9   Conclusion