Report First Project IAJ

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1 Introduction

The goal of this project was to create different levels of path finding algorithms, and compare their performance.
We compared 4 differente algorithms: Basic A* (unordered list for open set, unordered list for closed set), Basic A* but using tiebreaking (unordered list for open set, unordered list for closed set), NodeArray A* (NodeArray for open and closed set) and NodeArray A* with Goal Bounding.

2 Basic A*

2.1 Algorithm

The A* is a search algorithm that uses a heuristic to find the best path between 2 nodes. Even though it's a basic algorithm, it shows relatively good performance when compared to other algorithms like djikstra. It's also a very modular algorithm, meaning, it's performance can be improved by using better data structures, or using other optimizations like we're going to show in the next sections.

2.2 Data

Table 1: Basic A* performance (Path 1)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	10181.85
GetBestAndRemove	1904	44.09
AddToOpen	1954	1.82
SearchInOpen	18564	269.64
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	1904	1.45
SearchInClosed	18460	9710.25
RemoveFromClosed	0	0

Table 2: Basic A* performance (Path 2)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	21432.88
GetBestAndRemove	2890	114.64
AddToOpen	3021	2.54
SearchInOpen	28291	759.53
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	2890	1.76
SearchInClosed	27990	20319.63
RemoveFromClosed	0	0

Table 3: Basic A* grid information (Path 1)

TotalPNodes	MaxOpenNodes	Fill
1904	77	Very Large

Table 4: Basic A* grid information (Path 2)

TotalPNodes	MaxOpenNodes	Fill
2889	133	Very Large

2.3 Initial Analysis

The algorithm performs quite well, even in it's most basic form. It spends most time searching in the closed set, because in the neighbour processing we start by searching if it's in it. Searching in the open list is the second most time consuming operation. The algorithm also has a big fill, which accentuates the cost of the previously mentioned operations.

3 Basic A* with tiebreaking

3.1 Algorithm

This algorithm is the same as the previous one, but we use tiebreaking between nodes with the same f value. We choose to prefer nodes with lower h cost, so that we pick the node that is closer to the goal. This way, we can reduce the number of explored nodes, by still choosing a node over the other, instead of randomly exploring one of them.

3.2 Data

Table 5: Basic A* with tiebreaking performance (Path 1)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	10029.02
GetBestAndRemove	1904	112.83
AddToOpen	1954	1.56
SearchInOpen	18564	260.07
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	1904	1.27
SearchInClosed	18460	9524.91
RemoveFromClosed	0	0

Table 6: Basic A* with tiebreaking performance (Path 2)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	21970.11
GetBestAndRemove	2890	282.13
AddToOpen	3021	1.94
SearchInOpen	28291	768.2
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	2890	1.61
SearchInClosed	27990	20761.34
RemoveFromClosed	0	0

Table 7: Basic A* with tiebreaking grid information (Path 1)

TotalPNodes	MaxOpenNodes	Fill
1904	77	Very Large

Table 8: Basic A* with tiebreaking* grid information (Path 2)

TotalPNodes	MaxOpenNodes	Fill
2889	133	Very Large

3.3 Comparison

In the chosen paths we saw no gains by adding tiebreaking, this may be because there are no ties in these paths. Also, there's more time spent getting the best node from the open set, due to more comparisons.

4 NodeArray A*

4.1 Algorithm

NodeArray A* is an A* implementation that uses a NodeArray to store all the nodes. We use this array to keep track of what nodes are in our open and closed set, and we change the status property of the nodes when we add them to the open or closed set. This way, we can search if nodes are in the open and closed sets in constant time.

4.2 Data (Next Page)

4.3 Comparison

NodeArray A* is faster than the previous algorithms, due to the fact that we can search for nodes in the open and closed set in constant time, as we can see by the reduction of the SearchInOpen and SearchInClosed time, which were the 2 most time consuming operations in the previous versions. On the other hand, we see an increase in the time spent on the AddToOpen due to the use of a PriotrityHeap, which has higher insertion time, but the reduction in search times heavily outweights this increase.

Table 9: NodeArray A* performance (Path 1)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	5.48
GetBestAndRemove	200	1.96
AddToOpen	232	1.13
SearchInOpen	1044	0.04
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	100	0.01
SearchInClosed	1009	0.04
RemoveFromClosed	0	0

Table 10: NodeArray A* performance (Path 2)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	159.11
GetBestAndRemove	2890	38.36
AddToOpen	3019	9.31
SearchInOpen	28247	1.84
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	2885	0.58
SearchInClosed	27932	1.73
RemoveFromClosed	0	0

Table 11: NodeArray A* grid information (Path 1)

TotalPNodes	MaxOpenNodes	Fill
1904	77	Very Large

Table 12: NodeArray A* grid information (Path 2)

TotalPNodes	MaxOpenNodes	Fill
2884	135	Very Large

5 NodeArray A* with Goal Bounding

5.1 Algorithm

By using precomputation of the grid, we can make bounding boxes for each node and improve the NodeArray A* algorithm. We do this by using djikstra to calculate fastest path from each node to all other nodes. This way, we know which direction we should choose when trying to go to a specific node. This optimization causes an increase on the starting time, due to the precomputation, but it can significantly improve the runtime performance of the algorithm.

5.2 Data

Table 13: NodeArray A* with Goal Bounding performance (Path 1)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	10.62
GetBestAndRemove	200	0.43
AddToOpen	216	0.34
SearchInOpen	235	0
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	100	0.01
SearchInClosed	126	0
RemoveFromClosed	0	0

Table 14: NodeArray A* with Goal Bounding performance (Path 2)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	17.12
GetBestAndRemove	158	0.40
AddToOpen	165	0.35
SearchInOpen	388	0.01
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	158	0.03
SearchInClosed	282	0.01
RemoveFromClosed	0	0

Table 15: NodeArray A* with Goal Bounding grid information (Path 1)

TotalPNodes	MaxOpenNodes	Fill
228	9	Very Small

Table 16: NodeArray A* with Goal Bounding grid information (Path 2)

TotalPNodes	MaxOpenNodes	Fill
157	8	Very Small

5.3 Comparison

Comparing this data with the previous ones, we can see that this is by far the best optimization in terms of runtime. This is due to the use of bounding boxes, that shorten the amounts of nodes we process, and thus the amount of calls to add, remove and search in the open and closed set.

6 Bonus Level - Dead-End Heuristic

6.1 Algorithm

For the Bonus Level, we implemented the A* algorithm with the Dead-End heuristic. This heuristic is calculated by using a precomputation of the grid, where we create clusters for each room. This clusters are created using a floodfill in the beginning of the precomputation. At runtime, we calculate the possible paths in the room graph and update the heurisitic. This algorithm is based on the A* version that uses PriorityHeap for open set and Dictionary for closed set.

6.2 Data

Table 17: A* with Dead-End performance (Path 2)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	356.91 ms
GetBestAndRemove	1760	22.70
AddToOpen	1868	5.56
SearchInOpen	17434	210.4
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	1760	4.41
SearchInClosed	17180	30.9
RemoveFromClosed	1	0.35

Table 18: A* with Dead-End performance (Path 3)

Method	Calls	Execution Time (ms)
A*Pathfinding.Search	1	196.75
GetBestAndRemove	1497	14.89
AddToOpen	1541	3.91
SearchInOpen	14788	2.21
RemoveFromOpen	0	0
Replace	0	0
AddToClosed	1497	3.17
SearchInClosed	14691	20.45
RemoveFromClosed	0	0

Table 19: A* with Dead-End grid information (Path 2)

TotalPNodes	MaxOpenNodes	Fill
1759	110	Large

Table 20: A* with Dead-End grid information (Path 3)

TotalPNodes	MaxOpenNodes	Fill
1496	78	Large

6.3 Comparison

We can see in the data that the Dead-End heuristic is a good heuristic, since it improves the time of Search function, which is the most time consuming function in the A* algorithm, even though it has a big initialization cost calculating the DFS in the room graph. But it's still not a big optimization, since it shows results worse than NodeArray A*.

7 Conclusions

Analysing all algorithms we can acess that A* by itself is already a good algorithm, but it's optimizations can make it much faster, without compromising finding the best path.

Implementing better data structures that significantly reduce time spend on commonly used operations, like in the case of the Array Node A*, gave good results, but we still explored many nodes which were not part of the best path.

Then, we saw that adding preprocessing to the algorithm can improve it's runtime performance a lot, although it can take some time to perform it, especially on bigger maps, with many nodes. This is the case with goal bouding and the calculation of the Dead-End heurisitic.

The combination of the search efficiency of the Array Node A* with bouding boxes, which significantly reduced the nodes explored in directions other than the desired one, resolved both main issues with the basic A* algorithm. Due to this, goal bouding proved to be the best algorithm.