Maze Search

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1. Setting up the Environment

To make our search methods more intuitive, we created Point and Maze objects for our search method to take in. A Maze is constructed by reading in a text file line by line, and reading each character in the line. Every time a character is read, a Point is created, and it is assigned a value depending on the character that is read. A “%” is a wall, a space is empty space, a “.” is a dot that is used either as the end Point or one of the Points that must be traverse depending on the search methods, and a “P” is the starting Point. We determine the number of columns in the Maze by counting the number of characters in the first line of the text file, and we determine the number of rows in the Maze by counting the number of lines in the text file. Each Point in a Maze is assigned to a certain spot in a two-dimensional array of Points based on its location in the text file.

A Maze also stores a reference to the start Point, the end Point (only used in 1.1 and 1.2) and an ArrayList of references to each dot (only used in 1.3).

In addition to storing its value, a Point object also stores its location with two integers, one that corresponds to its x coordinate, and another corresponds to its y coordinate. A Point also has a method called “*getAdjacentPoints*” that returns a Vector of the Points that are next to the Point that calls the method. *getAdjacentPoints* checks to see if the elements next to the Point that called the method in the array are valid Points that are in valid positions (not out of bounds) and adds them to the Vector that it returns. It first checks the Point that should be to the right of it, then the left of it, then the Point below it, and then above of it.

The Point and Maze classes both have a *toString()* method, which is what we use to print the solution. Point’s *toString* simply returns its corresponding character value in the form of a String, and Maze’s *toString* returns a String comprised of all of the *toString*s of the Points in the array of Points, with a new line after each row.

1.1 Basic Pathfinding

## Depth First Search

Our depth first search uses two methods: “*findSolution*” and “*getSolution*.”

*findSolution* operates by taking in a Maze object and pushing the starting Point to a Stack and adding it to a Vector called “visited,” which keeps track of the Points that have already been traversed.

*findSolution* then calls a while loop, which performs the actual searching algorithm. The loop lasts until the Stack is empty. A variable “currentPoint” of type Point is created that keeps track of the Point that is currently being inspected by being assigned to the Point that is popped off of the Stack. (currentPoint is initially the starting Point since the starting Point was the only Point on the Stack before the while loop started). Every time a Point is popped off of the Stack, an integer that keeps track of the number of Points that have been traversed is incremented. A nested for loop that goes through the current Point’s adjacent Points is then called. If the Point that the loop is going through is empty (not a wall or a dot) or is a dot, and if the Point has not previously been visited, the following things will happen:

* The Point will be pushed to the Stack
* The Point will be added to the Vector of visited Points
* The Point is added to a HashMap called “predecessor” which takes the Point that the for loop was going through as the value as the key, and currentPoint (the Point whose *getAdjacentPoints* was called).
  + The reasoning behind this is that *predecessor(*Point*)* will return the Point that was visited before the currently visited Point.
  + predecessor is used again in *getSolution*
* If the Point is the end Point, the Point will be returned.

The “last in, first out” nature of Stacks means that the last adjacent Point added to the Stack will be the next Point acted on by the loop, making this perfect for depth first search. By the end of *findSolution*, the end will have been found (and will be what currentPoint is currently pointing to), and the path from the start to the end will be stored in predecessor.

*getSolution* is then called. *getSolution* starts a while loop that goes through predecessor starting from the end Point, and sets everything on the path to a dot. The loop ends on the starting Point, as there is no predecessor to the starting Point.

The result of Depth First Search on the three provided Mazes is:

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Nodes Expanded = 53

Path Cost = 29

Medium Maze

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Nodes Expanded = 254

Path Cost = 162

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Nodes Expanded = 469

Path Cost = 210

## Breadth First Search

Our breadth first search is very similar to our depth first search with one main difference – it uses a Queue instead of a Stack. The reasoning behind this is that because the Point returned from removing it from a Queue will be the next Point that was added to the Queue after the previous Point that was acted on, making it more suitable for Breadth First Search. Despite this, it still uses the two methods: “*findSolution*” and “*getSolution*.” The latter is exactly the same as *getSolution* used in Depth First Search, while the former slightly differs.

*findSolution* operates by taking in a Maze object and adding the starting Point to a Queue and adding it to a Vector called “visited,” which keeps track of the Points that have already been traversed.

*findSolution* then calls a while loop, which performs the actual searching algorithm. The loop lasts until the Queue is empty. A variable “currentPoint” of type Point is created that keeps track of the Point that is currently being inspected by being assigned to the Point that is removed from the Queue. (currentPoint is initially the starting Point since the starting Point was the only Point on the Queue before the while loop started). Every time a Point is removed from the Queue, an integer that keeps track of the number of Points that have been traversed is incremented. A nested for loop that goes through the current Point’s adjacent Points is then called. If the Point that the loop is going through is empty (not a wall or a dot) or is a dot, and if the Point has not previously been visited, the following things will happen:

* The Point will be added to the Queue
* The Point will be added to the Vector of visited Points
* The Point is added to a HashMap called “predecessor” which takes the Point that the for loop was going through as the value as the key, and currentPoint (the Point whose *getAdjacentPoints* was called).
  + The reasoning behind this is that *predecessor(*Point*)* will return the Point that was visited before the currently visited Point.
  + predecessor is used again in *getSolution*
* If the Point is the end Point, the Point will be returned.

The “first in, first out” nature of Queues means that the first adjacent Point added to the Queue will be the next Point acted on by the loop followed by the next adjacent Point, making this perfect for breadth first search. By the end of *findSolution*, the end will have been found (and will be what currentPoint is currently pointing to), and the path from the start to the end will be stored in predecessor.

*getSolution* is then called, and the Maze solution is ready to be printed.

The result of Breadth First Search on the three provided Mazes is:

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Nodes Expanded = 90

Path Cost = 19

Medium Maze

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Nodes Expanded = 266

Path Cost = 68

Big Maze

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Nodes Expanded = 618

Path Cost = 210

## Greedy Best-First Search

Our Greedy Best-First Search is very similar to our Breadth First Search, with one exception – instead of a Queue, our Greedy Best-First used a PriorityQueue. Unlike a Queue, it uses a Comparator to determine which element is returned when remove() is called. In this case, our comparator is based on Manhattan Distance from the Point to the end Point. Therefore, the Point from the PriorityQueue that is removed and acted on in the loop will always be the Point closest to the end Point. Despite the differences, it still uses two similar methods: “*findSolution*” and “*getSolution*.” The latter is exactly the same as *getSolution* used in Depth First Search, while the former slightly differs.

*findSolution* operates by taking in a Maze object and adding the starting Point to a PriorityQueue and adding it to a Vector called “visited,” which keeps track of the Points that have already been traversed.

*findSolution* then calls a while loop, which performs the actual searching algorithm. The loop lasts until the PriorityQueue is empty. A variable “currentPoint” of type Point is created that keeps track of the Point that is currently being inspected by being assigned to the Point that is removed from the PriorityQueue. (currentPoint is initially the starting Point since the starting Point was the only Point on the Queue before the while loop started). Every time a Point is removed from the PriorityQueue, an integer that keeps track of the number of Points that have been traversed is incremented. A nested for loop that goes through the current Point’s adjacent Points is then called. If the Point that the loop is going through is empty (not a wall or a dot) or is a dot, and if the Point has not previously been visited, the following things will happen:

* The Point will be added to the PriorityQueue
* The Point will be added to the Vector of visited Points
* The Point is added to a HashMap called “predecessor” which takes the Point that the for loop was going through as the value as the key, and currentPoint (the Point whose *getAdjacentPoints* was called).
  + The reasoning behind this is that *predecessor(*Point*)* will return the Point that was visited before the currently visited Point.
  + predecessor is used again in *getSolution*
* If the Point is the end Point, the Point will be returned.

The nature of the PriorityQueue means that the Point closest to the end Point that hasn’t been acted on yet will be the next Point acted on by the loop followed by the next adjacent Point, making this perfect for Greedy Best-First search. By the end of *findSolution*, the end will have been found (and will be what currentPoint is currently pointing to), and the path from the start to the end will be stored in predecessor.

*getSolution* is then called, and the Maze solution is ready to be printed.

The result of Greedy Best-First Search on the three provided Mazes is:

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Nodes Expanded = 39

Path Cost = 29

Medium Maze

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Nodes Expanded = 156

Path Cost = 152

Big Maze

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Nodes Expanded = 452

Path Cost = 210

## A\* Search

Our A\* Search is very similar to our Greedy Best-First Search, with one exception – while the comparator still takes into account Manhattan distance to the end Point, it also takes into account distance already traveled to get to the Point in the PriorityQueue. It adds the two values, and that value is what is used to choose which Point in the Queue is removed next. Despite the differences, it still uses two similar methods: “*findSolution*” and “*getSolution*.” The latter is exactly the same as *getSolution* used in Depth First Search, while the former slightly differs.

*findSolution* operates by taking in a Maze object and adding the starting Point to a PriorityQueue and adding it to a Vector called “visited,” which keeps track of the Points that have already been traversed.

*findSolution* then calls a while loop, which performs the actual searching algorithm. The loop lasts until the PriorityQueue is empty. A variable “currentPoint” of type Point is created that keeps track of the Point that is currently being inspected by being assigned to the Point that is removed from the PriorityQueue. (currentPoint is initially the starting Point since the starting Point was the only Point on the Queue before the while loop started). Every time a Point is removed from the PriorityQueue, an integer that keeps track of the number of Points that have been traversed is incremented. A nested for loop that goes through the current Point’s adjacent Points is then called. If the Point that the loop is going through is empty (not a wall or a dot) or is a dot, and if the Point has not previously been visited, the following things will happen:

* The Point will be added to the PriorityQueue
* The Point will be added to the Vector of visited Points
* The Point is added to a HashMap called “predecessor” which takes the Point that the for loop was going through as the value as the key, and currentPoint (the Point whose *getAdjacentPoints* was called).
  + The reasoning behind this is that *predecessor(*Point*)* will return the Point that was visited before the currently visited Point.
  + predecessor is used again in *getSolution*
* If the Point is the end Point, the Point will be returned.

The nature of the PriorityQueue means that the next Point removed from the Queue will be the Point that has the smallest sum of Manhattan distance to the end Point and the number of steps already taken to get to that Point, making it perfect for A\* search. By the end of *findSolution*, the end will have been found (and will be what currentPoint is currently pointing to), and the path from the start to the end will be stored in predecessor.

*getSolution* is then called, and the Maze solution is ready to be printed.

The result of A\* Search on the three provided Mazes is:

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Nodes Expanded = 52

Path Cost = 19

Medium Maze

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Nodes Expanded = 221

Path Cost = 68

Big Maze

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Nodes Expanded = 549

Path Cost = 210

1.2 Designing "Difficult" Inputs for Different Search Algorithms

Our Maze that A\* Search runs through well but Greedy Best-First Search has some difficulty with is

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Nodes Expanded = 112

Solution Cost = 33

A\* Search

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Nodes Expanded = 60

Solution Cost = 33

The reasoning that Greedy Best-First Search struggles with this Maze is that it first goes right and then goes through all of the empty space in the middle, since those Points are closer to the end Point than the Points that are on the right path. A\* search does the same thing at first, but then the sum of the distance from the active Point to the end Point and the number of steps already taken to get to the Point ends up exceeding that of the Point above the starting Point, so it proceeds to continue on that path and get to the end Point while expanding less nodes than Greedy Best-First Search. Greedy Best-First search expanded almost twice as many nodes.

Our Maze that Greedy Best-First Search runs through well but A\* Search has some difficulty with is

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Nodes Expanded = 34

Path Cost = 33

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Nodes Expanded = 142

Path Cost = 33

The reasoning that Greedy Best-First Search does better with this Maze is that it first goes right and then continues up to each free Point closest to the end Point, which in this case is the best solution. A\* search does the same thing at first, but then the sum of the distance from the active Point to the end Point and the number of steps already taken to get to the Point ends up exceeding that of other Points, so it proceeds to traverse those instead of continuing on the right path for some time. A\* search had to expand four times as many nodes.

1.3 Search With Multiple Dots

For our complete traversal to collect all our dots, we used an A\* approach along with modified heuristics from our single target search. The heuristics we used were benchmarking the number of dots left with the closest dot by Manhattan distance. An important part of this task was that we had to make sure our heuristics were admissible. The number of dots left is an admissible heuristic because it takes at least that many steps if not more to collect all those dots, and the closest dot by Manhattan distance is correct because it takes at least the Manhattan distance to traverse to that dot.

We represented the search with a State rather than a Point. A State object contained the current Point we are on in the maze, a list of the remaining dots in the maze, the path cost so far to reach that point, and the heuristic to compare. Instead of having a visited list like we did in our single target A\* search, we compared each new state with our previous states, not allowing any duplicates. The main advantage to this is that while we can be at the same point in the maze, the states might be different because there would be less dots left and a higher path cost. This allows us to backtrack, a crucial part of a complete traversal, but not be stuck in an infinite loop.

Our algorithm for searching is very similar to the single target search:

* Add the state to the PriorityQueue
* Remove the first element in the PriorityQueue
* Expand the node and inspect all adjacent States
* If there are no more dots in the maze, terminate
* If the frontier doesn’t contain the adjacent state, add it to the PQ

The nature of our algorithm as well as the results show us that our solution was optimal. Our heuristic takes into account both the current path we travelled, and the distance to the nearest node. It is admissible on both counts and optimal in that it finds a good path to take. We combined the two heuristics and subtracted one, the movement that we traverse in that one step. The sum is still admissible.

The result of A\* complete traversal on the two provided Mazes is:

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Tests for Section 1.3

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Nodes Expanded = 34896

Solution Distance = 34

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Nodes Expanded = 126156

Solution Distance = 60

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Nodes Expanded = 614404

Solution Distance = 294

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Nodes Expanded = 399677

Solution Distance = 448

For the larger mazes, an optimal solution can be found faster with a weighted A\* search, which would heavily reduce the nodes expanded and run much quicker. However, our optimal solution can work on all sized mazes with a significant amount of time.

Individual Contribution:

Krish Masand:

Created the maze environment, including scanning text files and constructing maze objects, creating the Point object, the main class, the Direction enumerated type. He also created the majority of the report.

Aravind Sundaresan:

Implemented 3 of the 4 search functions: BFS, Greedy Best-First, and A\* Search for single target goals. He also did the Part 2 bonus, the 8-puzzle solver. He and Rodney worked together to develop an algorithm for part 1.3

Rodney Shaghoulian:

Implemented the DFS search algorithm, prototyped and created mazes for 1.2, and helped develop the algorithm and heuristics for 1.3. He also wrote the algorithm and the heuristic comparators for 1.3.