Intro to AI 16:520 Assignment 1: Mazerunner

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Git Repository: https://github.com/jyqchou/AI-Mazerunner

PART 1

1) For each of the implemented algorithms, how large the maps can be (in terms of dim) for the algorithm to return an answer in a reasonable amount of time (less than a minute) for a range of possible p values? Select a size so that running the algorithms multiple times will not be a huge time commitment, but that the maps are large enough to be interesting.

Before we discuss the performance of each Search Algorithm, we look at the nature of the maze itself; specifically, how likely a randomly generated maze will be solvable, for some probability *p* of a cell being occupied.

Using Dim = 3000 and testing 10,000 trials, we recorded the following number of mazes with solutions:
P = 0.3 : 5076/10,000
P = 0.35 : 2491/10,000
P = 0.4 : 180/10,000
P = 0.45 : 0/10,0000

Thus, we will select a range of *p* between (0, 0.4).

DFS

heap frequently runs out of memory when dim exceeds 10000 and p > 0.3

p = 0.1

Dim = 5000
Number of moves searched: 13269
DFS Search Took 146 ms

Dim = 10000
Number of moves searched: 24904
DFS Search Took 502 ms

Dim = 20000
Number of moves searched: 55183
DFS Search Took 1678 ms

For DFS p=0.1, any dim>20000 will frequently cause the heap to run out of memory

***p* = 0.2**

Dim = 10000
Number of moves searched: 5605884
DFS Search Took 10647 ms

Dim = 12000
Number of moves searched: 9649695
DFS Search Took 19760 ms

Dim = 13000
Number of moves searched: 57248
DFS Search Took 775 ms

Dim = 15000
Number of moves searched: 59545
Total # of Solutions found: 1
DFS Search Took 1012 ms

For DFS p=0.2, any dim>15000 fails to reliably be solved

***p* = 0.3**
Dim = 11000
Number of moves searched: 85978
DFS Search Took 734 ms

Dim = 11250
Number of moves searched: 11648108
DFS Search Took 53886 ms

For DFS p=0.3, any dim >11500 fails to be solved reliably

***p* = 0.35**

Dim = 10000
Number of moves searched: 7477502
DFS Search Took 17472 ms

Dim = 11000
Number of moves searched: 209052
DFS Search Took 1447 ms

For DFS p=0.35, any dim>11000 fails to be solved reliably

***p* =0.4**
Dim = 5000
Number of moves searched: 526022
DFS Search Took 984 ms

For p=0.4, rarely any mazes were even solvable to begin with. For large mazes in particular, an exorbitant amount of time was spent creating each maze, only for a majority of them to be unsolvable, run out of memory, or exceed 1 minute in search. After hundreds of trials, no data was collected for Dim > 5000

BFS
p = 0.1

Dim = 1000
Number of moves searched: 909072
BFS Search Took 705.514227 ms

Dim = 2000
Number of moves searched: 3600226
BFS Search Took 4218.759158 ms

Dim = 4000
Number of moves searched: 14396761
BFS Search Took 48399.768035 ms

For BFS p=0.1, no solution not reliably found for Dim>4000

p = 0.2

Dim = 2000
Number of moves searched: 3192939
BFS Search Took 5810.196849 ms

Dim = 3000
Number of moves searched: 7185877
BFS Search Took 17711.58402 ms

Dim = 4000
Number of moves searched: 12773778
BFS Search Took 40305.136637999996 ms

For BFS p=0.2, no solution not reliably found for Dim>4000

p = 0.3

Dim = 2000
Number of moves searched: 2751433
BFS Search Took 3419.818386 ms

Dim = 3000
Number of moves searched: 6194136
BFS Search Took 11967.485804 ms

Dim = 4000
Number of moves searched: 11009011

BFS Search Took 30746.163193999997 ms

For BFS p=0.3, no solutions not reliably found for Dim>4000

p = 0.35

Dim = 2000
Number of moves searched: 2470583
BFS Search Took 2130.0452889999997 ms

Dim = 3000
Number of moves searched: 5555785
BFS Search Took 5452.245898 ms

Dim = 4000
Number of moves searched: 9882169
BFS Search Took 24745.153311 ms

For BFS p=0.35, no solutions not reliably found for Dim>4000

p = 0.4
Dim = 2000
Number of moves searched: 1785790
BFS Search Took 1049.418795 ms

Dim = 3000
Number of moves searched: 3997615
BFS Search Took 3075.138909 ms

Dim = 4000 (solution was found after 229 attempts)
Number of moves searched: 7102096
BFS Search Took 5847.374229999999 ms

For BFS p=0.4, no solutions not reliably found for Dim>4000

Manhattan A*
p = 0.1
Dim = 2000
Number of moves searched: 1355399
Manhattan A* Search Took 2407.4644089999997 ms

Dim = 5000
Number of moves searched: 5374413
Manhattan A* Search Took 10583.997035999999 ms

Dim = 7000
Number of moves searched: 5332112

Manhattan A* Search Took 19337.357139 ms

Dim = 8000
Number of moves searched: 8824968
Manhattan A* Search Took 33531.864683 ms

For Manhattan A* p=0.1, no solutions not reliably found for Dim>8000

p = 0.2
Dim = 4000
Number of moves searched: 1228194
Manhattan A* Search Took 1945.093874 ms

Dim = 6000
Number of moves searched: 3644888
Manhattan A* Search Took 6901.99133 ms

Dim = 8000
Number of moves searched: 6630295
Manhattan A* Search Took 18344.551089 ms

For Manhattan A* p=0.2, no solutions reliably found for Dim>8000

p = 0.3
Dim = 4000
Number of moves searched: 1698868
Manhattan A* Search Took 2147.4280719999997 ms

Dim = 6000
Number of moves searched: 3454091
Manhattan A* Search Took 5393.575296999999 ms

Dim = 8000
Number of moves searched: 9274678
Manhattan A* Search Took 20442.530654 ms

For Manhattan A* p=0.3, no so solutions reliably found for Dim>3000

p = 0.35
Dim = 4000
Number of moves searched: 5142479
Manhattan A* Search Took 10405.187876 ms

Dim = 6000
Number of moves searched: 9545849
Manhattan A* Search Took 26859.131148 ms

For Manhattan A* p=0.35, no so solutions reliably found for Dim>6000

p = 0.4
Dim = 2000
Number of moves searched: 1228505
Manhattan A* Search Took 1526.0278739999999 ms

Dim = 3000
Number of moves searched: 2449366
Manhattan A* Search Took 2891.4114139999997 ms

Dim = 4000 (Solvable maze on the on 79th attempt)
Number of moves searched: 6614587
Manhattan A* Search Took 8982.760044999999 ms
For Manhattan A* p=0.4, no solutions reliably found for Dim>4000

Euclidian A*
p = 0.1
Dim = 2000
Number of moves searched: 3577859
Euclidean A* Search Took 7167.381286999999 ms

Dim = 3000
Number of moves searched: 8055884
Euclidean A* Search Took 18913.576305 ms

Dim = 4000
Number of moves searched: 14325650
Euclidean A* Search Took 40570.919795 ms

For Euclidean A* p=0.1, no solution reliably found for Dim>4000

p = 0.2
Dim = 2000
Number of moves searched: 3096814
Euclidean A* Search Took 6844.37116 ms

Dim = 3000
Number of moves searched: 6981892
Euclidean A* Search Took 18620.508004 ms

Dim = 4000
Number of moves searched: 12417992
Euclidean A* Search Took 42198.89535 ms

For Euclidean A* p=0.2, no solution reliably found for Dim>4000

p = 0.3
Dim = 2000
Number of moves searched: 2432992
Euclidean A* Search Took 4174.477165 ms

Dim = 3000
Number of moves searched: 5487366
Euclidean A* Search Took 11550.767533 ms

Dim = 4000
Number of moves searched: 9746834
Euclidean A* Search Took 20274.920278999998 ms

For Euclidean A* p=0.3, no solution reliably found for Dim >3000

p = 0.35
Dim = 2000
Number of moves searched: 2127282
Euclidean A* Search Took 3713.482173 ms

Dim = 3000
Number of moves searched: 4726011
Euclidean A* Search Took 6215.191067 ms

Dim = 4000
Number of moves searched: 8495276
Euclidean A* Search Took 16360.752396999998 ms

Dim = 5000
Number of moves searched: 13378471
Euclidean A* Search Took 27293.189845999997 ms

For Euclidean A* p=0.35, no solution reliably found for Dim>5000

p = 0.4
Dim = 2000
Number of moves searched: 1545920
Euclidean A* Search Took 1327.3756509999998 ms

Dim = 3000
Number of moves searched: 3912314
Euclidean A* Search Took 3980.8113839999996 ms

Dim = 4000
Number of moves searched: 6819173
Euclidean A* Search Took 9700.780448 ms

Dim = 5000
Number of moves searched: 10848513
Euclidean A* Search Took 25963.941349 ms

For Euclidean A* p=0.4, no solution reliably found for Dim>5000

2) Find a random map with p ≈ 0.2 that has a path from corner to corner. Show the paths returned for each algorithm. (Showing maps as ASCII printouts with paths indicated is sufficient; however 20 bonus points are available for coding good visualizations.)

Original Maze:

```
 0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0 -1  0  0  0 -1  0 -1  0 -1 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0
 0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0 -1  0  0  0 -1 -1 -1  0  0  0  0  0  0  0
 0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
-1  0  0  0 -1  0 -1  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1  0 -1  0  0  0 -1 -1  0 -1  0  0  0 -1  0 -1
-1  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1  0 -1  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1 -1 -1  0  0 -1  0
 0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1  0  0 -1  0  0  0  0 -1  0  0  0 -1 -1  0  0  0 -1 -1 -1 -1  0  0  0  0  0  0
 0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0 -1  0 -1 -1  0  0  0  0  0  0  0
 0  0  0 -1 -1  0 -1  0  0  0  0  0  0 -1  0 -1  0  0 -1  0  0  0  0  0 -1 -1 -1  0 -1 -1  0  0  0  0  0  0 -1 -1 -1  0  0  0  0  0 -1  0  0
 0 -1  0  0  0 -1  0  0 -1  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0  0 -1 -1 -1  0 -1  0  0 -1  0  0  0
 0 -1 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1 -1 -1  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0  0
 0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0 -1 -1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0
 0  0  0 -1  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0
 0  0  0 -1  0  0 -1  0  0  0  0  0  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0
 0  0  0  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0
 0  0  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1  0  0  0 -1 -1 -1  0 -1  0 -1 -1
 0  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0 -1 -1  0 -1 -1  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0  0  0  0
 0  0  0  0 -1  0 -1 -1  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0
 0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1  0  0 -1  0  0  0 -1  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0 -1  0
 0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0  0 -1  0  0  0
 0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0
 0  0  0 -1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
-1 -1  0  0  0  0  0  0 -1 -1  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0 -1 -1  0  0  0  0 -1  0  0  0  0  0  0  0
 0  0  0  0  0  0  0 -1  0  0 -1 -1  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0
 0  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0 -1  0 -1 -1  0  0 -1 -1  0  0  0  0 -1  0 -1  0 -1  0  0  0
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 0 -1  0  0  0  0  0 -1  0  0  0 -1  0  0 -1  0 -1  0  0 -1  0  0  0  0  0 -1  0  0  0  0 -1  0  0  0 -1  0  0 -1  0  0 -1  0  0  0 -1 -1  0  0  0
 0  0  0  0 -1 -1 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0
-1 -1  0 -1  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0 -1  0  0 -1  0  0 -1  0  0  0  0 -1  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0  0  0 -1  0
 0  0  0 -1 -1  0 -1  0  0 -1  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0
 0  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0 -1 -1  0 -1  0  0  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0  0  0 -1  0
 0  0  0 -1 -1  0 -1  0  0  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0
 0  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 0  0  0 -1 -1  0 -1  0  0  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0  0  0 -1  0
 0  0  0 -1 -1  0 -1  0  0  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0  0
 0  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
```

```
 0 -1  0  0  0  0  8  9 10 11 -1  0  0 -1  0  0 -1  0  0  0 -1  0 -1  0 -1 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0  0 -1 67 66 65
 1  2  3  4  5  6  7 -1 -1 12 13 14 15 16 17 18 19 20 -1  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0 -1  0  0  0 -1 -1 -1  0  0  0  0 62 63 64
 0  0  0  0  0  0  8 -1 -1  0  0  0  0  0  0  0  0 21 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0 56 57 58 59 60 61 62 63
-1  0  0  0 -1  0 -1  0  0 -1  0  0  0 -1  0  0  0 22 23 24 25 26 27 28 29 30 31 32 33 34 -1 38 39 40 -1  0 -1  0  0  0 -1 -1 55 -1  0  0 61 -1 63 -1
-1  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1  0 -1  0  0 -1  0  0  0  0 35 36 37 -1 41 42 -1  0  0  0 51 52 53 54 -1 -1 -1 62 63 -1  0
 0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1  0  0 -1  0  0  0  0 -1  0  0 43 -1 -1  0 49 50 -1 -1 -1 -1  0  0  0 64 65 66
 0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0 -1  0 44 45 46 47 48 -1  0 -1 -1  0  0  0  0  0  0 67
 0  0  0 -1 -1  0  0 -1  0  0  0  0  0 -1  0 -1  0  0 -1  0  0  0  0 -1 -1 -1  0 -1 -1  0  0  0  0  0  0 -1 -1 -1  0  0  0  0  0 -1  0 68
 0 -1  0  0  0 -1  0  0 -1  0  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1 -1 -1  0 -1  0  0 -1  0  0 69
 0 -1 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1  0  0  0  0 -1  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0 70
 0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0 -1 -1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0 71
 0  0  0 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 72
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 0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 78 -1 76
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 0  0  0  0 -1  0 -1  0  0  0  0  0  0 -1 -1 -1  0  0  0  0  0  0  0 -1  0  0  0 -1 -1  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0 81 82
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 0  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0 -1 -1  0 -1 -1  0  0 -1  0  0  0  0  0 -1  0  0  0 -1 -1  0  0 -1  0  0  0  0  0  0  0  0 88 89 90
 0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0  0 91
 0  0  0  0 -1  0 -1 -1  0 -1  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 92
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 0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1  0 -1  0  0  0  0 -1  0  0 94
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 0 -1  0  0  0  0  0 -1  0  0  0 -1  0  0 -1  0 -1  0  0 -1  0  0  0  0  0 -1  0  0  0 -1  0  0  0 -1  0  0 -1  0  0 -1  0  0  0 -1 -1  0  0  0 102
 0  0  0  0 -1 -1 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0 -1 -1  0  0  0 -1  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 103
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 0  0  0 -1 -1  0 -1  0  0  0  0  0  0 -1 -1  0  0  0 -1  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0 -1 -1  0 -1  0 -1  0 -1  0 106
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 0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1 -1 -1  0  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0 110111
 0  0  0  0  0 -1  0  0 -1  0  0  0 -1  0  0  0 -1  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1 111-1
 0  0 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0  0 112113
 0  0  0  0  0  0  0  0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0 -1  0 -1  0  0  0  0  0  0  0  0 114
 0 -1  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0 117116115
 0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1 -1  0 -1  0  0  0  0  0 -1 -1  0  0  0  0  0 -1  0 -1  0  0  0  0  0 -1  0  0 118-1 -1
 0 -1  0 -1  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1 119120121
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 0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0  0 -1  0 -1  0  0 -1 -1 123
 0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0 -1  0  0  0 -1 -1  0  0 -1  0  0  0  0  0 -1 -1  0  0 -1 -1  0  0  0  0  0 -1  0 -1  0 124
```

Number of moves searched: 140
DFS Search Took 17 ms
################################## DFS Search ##################################

################################## BFS Search ##################################

********** Path from Start to Goal **********
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********** Path from Start to Goal **********

```
 0 -1  4  5  6  7  8  9 10 11 -1 15 16 -1 18 19 -1 21 22 23 -1 27 -1 29 -1 -1 32 33 34 35 36 37 38 -1 56 55 54 53 54 -1 62 61 60 59 60 61 -1 63 64 65
 1  2  3  4  5  6  7 -1 -1 12 13 14 15 16 17 18 19 20 -1 24 25 26 27 28 29 30 31 32 33 -1 37 -1 39 40 -1 54 -1 52 53 54 -1 -1 -1 58 59 60 61 62 63 64
 2  3  4  5  6  7  8 -1 -1 13 14 15 16 17 18 19 20 21 -1 25 26 27 28 29 30 31 32 33 34 -1 38 39 40 -1 54 53 52 51 52 53 54 55 56 57 58 59 60 61 62 63
-1  4  5  6 -1  8 -1 16 15 -1 15 16 17 -1 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 -1 38 39 40 -1 54 -1 50 51 52 -1 -1 55 -1 59 60 61 -1 63 -1
-1  5  6  7  8  9 10 -1 14 15 16 17 18 -1 20 21 22 23 24 -1 26 -1 28 29 -1 31 32 33 34 35 36 37 -1 41 42 -1 50 49 50 51 52 53 54 -1 -1 -1 62 63 -1 67
 7  6  7 -1  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 -1 -1 -1 33 32 -1 34 35 36 37 -1 43 42 43 -1 -1 48 49 50 -1 -1 -1 -1 63 64 63 64 65 66
 8  7  8  9 10 -1 12 13 14 -1 16 17 18 19 20 21 22 23 24 25 26 27 -1 31 32 33 34 35 36 37 38 39 -1 43 44 45 46 47 48 -1  0 -1 -1 63 62 63 64 65 66 67
 9  8  9 -1 -1 14 13 -1 15 16 17 18 19 20 -1 22 -1 24 25 -1 27 28 29 30 31 -1 -1 -1 37 -1 -1 40 41 42 43 44 45 46 -1 -1 -1 64 63 62 61 62 63 -1 65 66
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12 13 14 13 14 -1 16 17 -1 19 20 21 22 23 24 25 -1 27 28 -1 30 31 -1 -1 34 35 36 37 -1 41 42 43 44 45 46 47 48 49 50 51 52 53 54 -1 58 -1 60 61 62 63
13 14 15 -1 15 16 17 18 -1 20 21 22 23 -1 25 26 27 28 29 30 -1 32 33 -1 35 36 37 38 39 40 41 42 -1 46 47 48 49 50 51 52 53 -1 55 56 57 58 59 60 61 62
14 15 16 -1 16 17 -1 19 20 21 22 23 24 -1 26 -1 28 29 30 31 32 33 -1 37 36 37 -1 39 40 -1 42 43 44 45 46 47 48 49 50 -1 54 55 56 57 58 59 -1 61 62 63
15 16 17 18 -1 18 19 20 21 22 23 24 25 -1 27 28 29 30 31 32 33 -1 37 38 -1 38 39 40 41 42 -1 44 45 46 47 48 49 50 51 52 53 54 55 -1 59 60 61 62 -1 64
16 17 18 -1 20 19 20 21 22 23 24 25 -1 29 28 29 30 31 32 33 34 35 36 -1 40 39 40 -1 42 43 44 -1 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 -1 65
17 18 19 -1 21 20 21 22 23 24 25 26 27 28 29 30 31 -1 33 34 35 -1 37 -1 41 40 41 42 -1 44 45 46 47 48 49 50 51 52 53 54 55 56 -1 58 59 60 61 62 -1 66
18 19 -1 23 22 -1 -1 23 24 25 -1 27 28 29 30 31 32 33 -1 35 36 37 -1 41 42 41 -1 43 44 -1 -1 47 48 49 50 51 52 53 -1 55 56 57 -1 59 60 -1 62 63 64 -1
19 20 21 22 -1 26 -1 24 25 26 27 28 29 30 -1 -1 -1 34 35 36 37 38 39 40 41 -1 45 44 45 -1 -1 48 49 50 51 52 -1 54 55 56 57 58 59 60 61 -1 63 64 65 66
20 21 22 23 24 25 26 25 26 27 28 29 30 -1 34 35 36 35 36 37 38 39 -1 41 -1 -1 46 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67
21 22 23 24 25 26 27 26 27 -1 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 -1 50 -1 52 -1 54 -1 56 57 -1 -1 60 -1 62 -1 64 65 66 67 68
22 23 24 -1 26 27 28 27 -1 31 30 31 32 33 34 -1 36 -1 38 39 40 41 42 -1 44 45 46 47 48 49 50 51 52 53 54 55 -1 -1 -1 63 62 61 -1 -1 -1 65 -1 67 -1 -1
23 24 25 26 -1 28 29 28 29 30 31 -1 33 34 35 -1 -1  0 -1 -1 41 42 -1 46 45 46 47 48 -1 50 51 52 53 -1 -1 56 57 -1 63 64 63 62 63 64 65 66 67 68 69 70
24 25 26 27 28 29 30 29 30 31 32 33 -1 35 36 37 38 -1 -1 43 42 43 44 45 46 47 48 49 50 51 52 -1 54 -1 58 57 -1 61 62 -1 64 63 64 65 66 67 68 69 70 71
25 26 27 28 -1 30 -1 -1 31 -1 33 34 -1 36 37 38 39 40 41 42 43 44 45 46 -1 48 49 50 51 52 53 54 55 -1 59 58 59 60 61 62 63 64 65 66 67 -1 69 70 71 72
26 -1 28 29 30 31 -1 -1 32 33 34 35 36 37 38 39 40 41 42 -1 -1 -1 -1 47 48 -1 50 51 52 -1 54 55 -1 59 60 59 60 61 62 63 -1 65 66 67 68 69 -1 71 -1 73
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29 30 31 -1 33 34 35 36 -1 -1 37 -1 39 40 41 42 43 -1 -1 46 47 48 49 50 51 52 -1 56 55 56 -1 58 59 -1 -1 -1 63 64 65 66 67 68 69 70 71 72 73 74 75 76
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-1 -1 33 34 35 36 37 38 39 -1 -1 40 -1 42 43 44 45 46 47 48 49 50 -1 52 53 54 55 56 57 58 59 60 61 -1 67 66 -1 -1 67 68 69 70 -1 72 73 74 75 76 77 78
36 35 34 35 36 37 38 39 -1 43 44 -1 -1 43 44 45 46 -1 48 49 50 -1 54 53 54 55 56 57 -1 59 60 61 -1 -1 68 67 68 69 68 69 -1 71 72 73 74 75 76 77 78 79
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41 -1 37 38 39 40 41 -1 43 44 45 -1 47 46 -1 48 -1 50 51 -1 53 54 55 56 57 -1 61 60 61 62 -1 70 69 70 -1 72 73 -1 71 72 -1 76 77 76 -1 -1 79 80 81 82
40 39 38 39 -1 -1 -1 45 44 45 46 -1 48 47 48 49 -1 51 52 53 54 -1 -1 57 58 59 60 -1 62 -1 66 -1 68 69 70 71 72 73 72 73 74 75 76 77 78 79 80 81 -1 83
-1 -1 39 -1 43 44 45 46 -1 46 47 48 -1 48 49 50 51 52 53 54 55 56 57 58 -1 60 61 62 63 64 65 66 67 68 -1 72 73 -1 73 74 -1 76 77 -1 79 80 81 82 -1 84
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44 43 42 43 44 -1  0 -1 48 49 50 51 52 53 54 53 54 55 56 57 58 59 60 61 -1 -1 64 65 66 67 -1 69 -1 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87
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49 48 49 48 49 50 51 52 53 -1 55 56 57 58 59 -1 -1 60 61 62 63 64 65 -1 69 70 69 70 71 72 73 74 75 76 77 -1 79 80 -1 82 -1 84 85 86 87 88 89 90 91 92
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51 52 51 -1 51 52 53 54 55 56 57 58 59 60 61 62 -1 64 63 64 -1 -1 67 -1 69 70 71 72 73 -1 -1 78 77 78 79 80 -1 82 -1 88 87 86 87 88 -1 90 91 92 -1 -1
52 -1 52 -1 52 53 54 55 -1 57 -1 59 60 61 62 63 64 65 64 65 -1  0 -1 71 70 71 72 73 74 75 76 -1 -1 79 80 -1 84 83 -1 87 88 87 88 89 90 91 -1 93 94 95
-1 54 53 54 53 54 55 56 57 58 59 60 -1 62 -1 -1 -1 66 65 66 67 -1 73 72 -1 72 73 -1 75 76 77 78 79 80 81 82 -1 84 85 86 -1 -1 89 90 91 -1 95 94 95 96
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```

Number of moves searched: 2008
BFS Search Took 14.179665 ms
################################ BFS Search ################################

############################## Manhattan A* Search ##############################

********** Path from Start to Goal **********
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********** Path from Start to Goal **********

```
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 1  2  3  4  5  0  0 -1 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0 -1  0  0  0 -1 -1 -1  0  0  0  0  0  0  0
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 0  0  8  9 10 -1  0 13 14 -1 16 17 18 19 20 21 22 23 24 25 26 27 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0 -1 -1  0  0  0  0  0  0  0
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 0  0  0  0  0 -1  0  0 -1 19 20  0  0 23 24 25 -1  0  0 -1 30 31 -1 -1 34 35 36 37 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0  0
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 0  0  0  0  0  0 -1  0  0  0  0  0  0 -1  0  0 -1  0  0 -1  0  0  0 -1 -1  0  0 -1  0  0  0  0  0 -1 -1  0 86 -1 -1  0 90 91 92 93 -1  0 -1  0 98
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Number of moves searched: 493
Manhattan A* Search Took 13.998826 ms
################################ Manhattan A* Search ################################

################################ Euclidean A* Search ################################

********** Path from Start to Goal **********
0-0 , 1-0 , 1-1 , 1-2 , 2-2 , 2-3 , 3-3 , 4-3 , 4-4 , 5-4 , 5-5 , 5-6 , 6-6 , 7-6 , 8-6 , 8-7 , 9-7 , 9-8 , 9-9 , 10-9 , 10-10 , 10-11 , 10-12 , 10-13 , 10-14 , 11-14 , 12-14 , 13-14 , 14-14 , 14-15 , 15-15 , 15-16 , 16-16 , 16-17 , 17-17 , 18-17 , 18-18 , 18-19 , 19-19 , 19-20 , 20-20 , 20-21 , 21-21 , 22-21 , 22-22 , 23-22 , 23-23 , 24-23 , 24-24 , 25-24 , 25-25 , 26-25 , 27-25 , 28-25 , 28-26 , 28-27 , 29-27 , 30-27 , 31-27 , 31-28 , 32-28 , 33-28 , 34-28 , 35-28 , 35-29 , 35-30 , 35-31 , 35-32 , 35-33 , 36-33 , 36-34 , 36-35 , 37-35 , 37-36 , 38-36 , 38-37 , 38-38 , 39-38 , 39-39 , 40-39 , 40-40 , 40-41 , 41-41 , 41-42 , 42-42 , 43-42 , 43-43 , 43-44 , 44-44 , 44-45 , 45-45 , 45-46 , 45-47 , 46-47 , 47-47 , 47-48 , 47-49 , 48-49 , 49-49
********** Path from Start to Goal **********

```
 0 -1  4  5  6  7  8  9 10 11 -1 15 16 -1 18 19 -1 21 22 23 -1 27 -1 29 -1 -1 32 33 34 35 36 37 38 -1  0  0  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0
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 8  7  8  9 10 -1 12 13 14 -1 16 17 18 19 20 21 22 23 24 25 26 27 -1 31 32 33 34 35 36 37 38 39 -1 43 44 45 46 47 48 -1  0 -1 -1  0  0  0  0  0  0  0
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16 17 18 -1 20 19 20 21 22 23 24 25 -1 29 28 29 30 31 32 33 34 35 36 -1 40 39 40 -1 42 43 44 -1 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 -1  0
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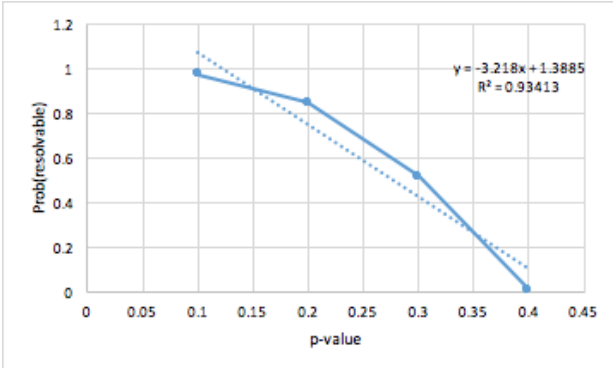
-1  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1 -1 -1  0 65 66 67 -1  0  0 -1 72 73 -1 75 76 77 78 79 80 81 82 -1 84 85 86 -1 -1 89 90 91 -1  0 94 95 96
 0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0 66 67 68 -1  0  0 -1 73 74 75 76 77 78 79 80 81 -1 83 -1 85 86 87 88 89 -1 91 -1  0  0 -1 -1 97
 0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1 67 68 -1  0  0  0 -1 -1 75  0 -1  0 79 80  0 82 -1 -1  0 86 -1 -1 89 90  0 92 93 -1  0 -1  0 98
```

Number of moves searched: 1828
Euclidean A* Search Took 12.022115 ms
################################ Euclidean A* Search ################################

3) For a fixed value of dim as determined in Question (1), for each p = 0.1, 0.2, 0.3, . . . , 0.9, generate a number of maps and try to find a path from start to goal - estimate the probability that a random map has a complete path from start to goal, for each value of p. Plot your data. Note that for p close to 0, the map is nearly empty and the path is clear; for p close to 1, the map is mostly filled and there is no clear path. There is some threshold value p0 so that for p < p0, there is usually a clear path, and p > p0 there is no path. Estimate p0. Which path finding algorithm is most useful here, and why?

Out of 1000 trials with Dim = 3000, we recorded the the numbers of mazes with solutions to get the resolvable probability. The Probability - p-value plots can visualize results:

p-value	0.1	0.2	0.3	0.4	0.5
Prob(resolvable)	0.97	0.844	0.515	0.007	0



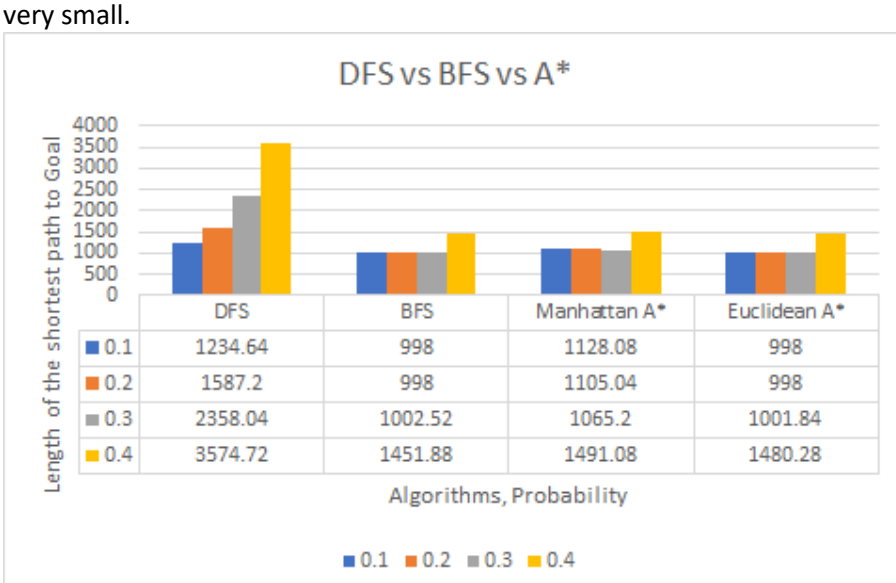
We can get clear path at 0.4 as the value of p, but no path at 0.5. According to the plot, we estimate the threshold value p0 by the trendline is 0.4315.

We used DFS here because we are not interested in the finding the shortest path, but rather we wish to find any solution in the shortest amount of time. When a maze is solvable, it is likely there are multiple solutions to the maze, and on average DFS allows us to find a path with the fewest number of nodes searched. We do not care how long this path is, as we only want to know if the maze is solvable.

4) For a range of p values (up to p0), generate a number of maps and estimate the average or expected length of the shortest path from start to goal. You may discard all maps where no path exists. Plot your data. What path finding algorithm is most useful here?

For this problem, data are collected with dimensions for the maze as 500.

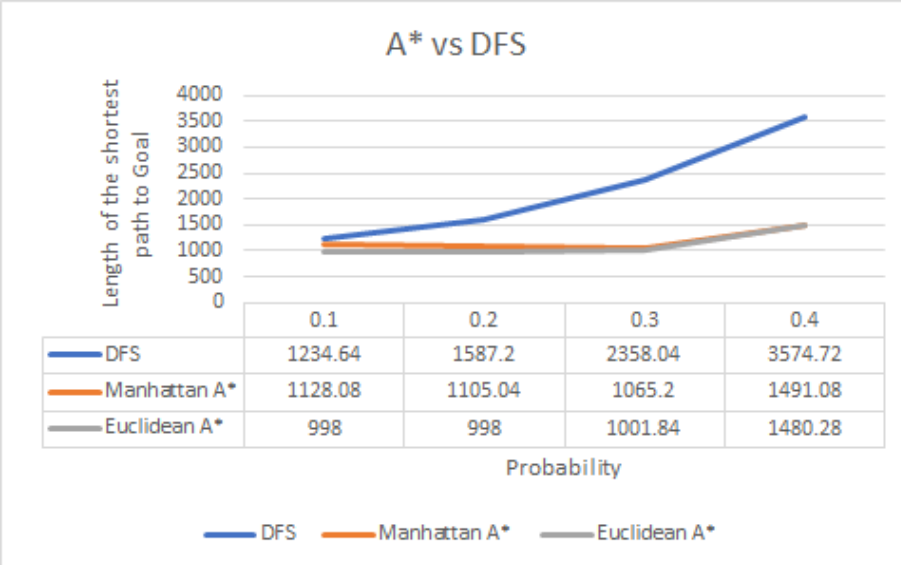
BFS and A* star algorithms perform fairly similar to one another for p values upto 0.4. DFS expands more number of nodes compared to these 3 algorithms. Comparing these 3 algorithms, BFS fairs slightly better than A* algorithms. For p values beyond 0.4, the probability of generating a maze with solvable path is very small.



	DFS	BFS	Manhattan A*	Euclidean A*
0.1	1234.64	998	1128.08	998
0.2	1587.2	998	1105.04	998
0.3	2358.04	1002.52	1065.2	1001.84
0.4	3574.72	1451.88	1491.08	1480.28

5) For a range of p values (up to p0), estimate the average length of the path generated by A∗ from start to goal (for either heuristic). Similarly, for the same p values, estimate the average length of the path generated by DFS from start to goal. How do they compare? Plot your data.

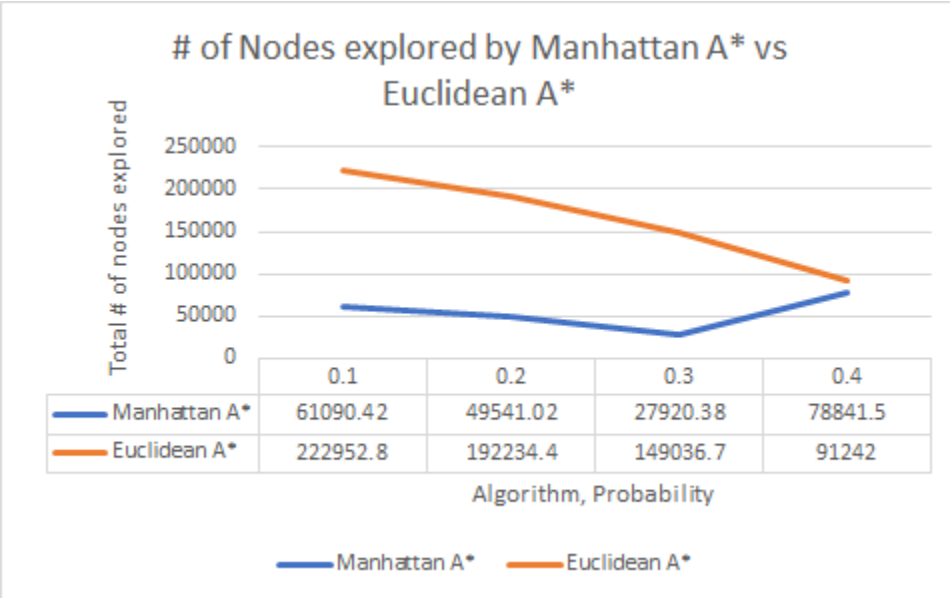
For this problem, data are collected with dimensions for the maze as 500.
The number of nodes searched by A* is significantly lower than that of DFS. DFS seems to search more and more nodes as p increases, as solutions to the maze become more and more twisted. A* solutions search relatively the same amount of nodes.



	0.1	0.2	0.3	0.4
DFS	1234.64	1587.2	2358.04	3574.72
Manhattan A*	1128.08	1105.04	1065.2	1491.08
Euclidean A*	998	998	1001.84	1480.28

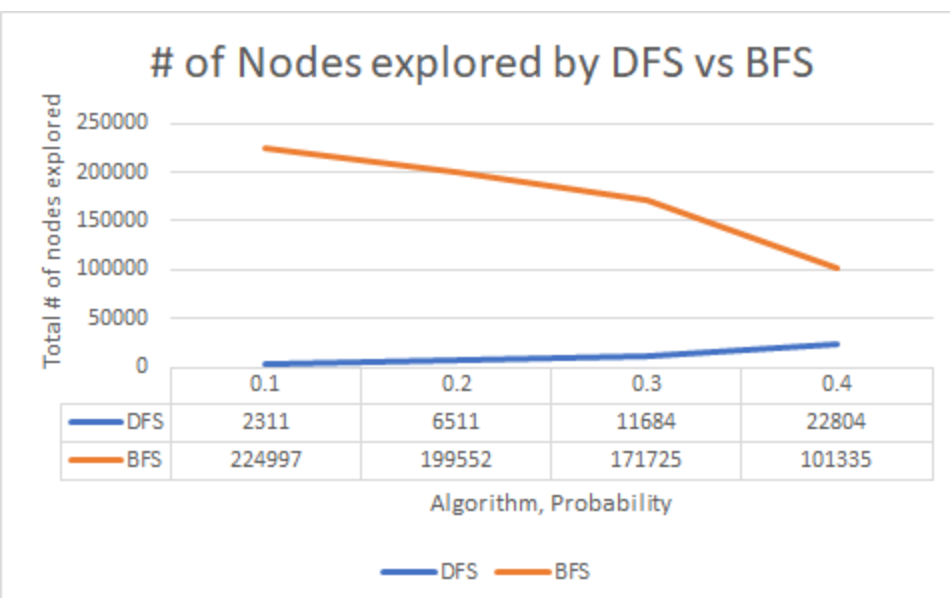
6) For a range of p values (up to p0), estimate the average number of nodes expanded in total for a random map, for A∗ using the Euclidean Distance as the heuristic, and using the Manhattan Distance as the heuristic. Plot your data. Which heuristic typically expands fewer nodes? Why? What about for p values above p0?

For this problem, data are collected with dimensions for the maze as 500.
For initial probability of 0.1, the Manhattan heuristic explores much lesser # of nodes compared to the Euclidean. As the value of p increases, the # of nodes explored by both converges towards each other. At the probability 0f 0.4, nodes explored by both the heuristics are almost same.
Euclidean prioritize the path based on the heuristic around the middle diagonal line. Most of the nearby nodes on top and bottom of the diagonal are explored which leads to the extra # of nodes when compared to Manhattan. Whereas, manhattan explores only along the diagonal path and thus resulting in fewer nodes.
For values of p0 beyond 0.4, the # of nodes explored are almost same.



7) For a range of p values (up to p0), estimate the average number of nodes expanded in total for a random map by DFS and by BFS. Plot your data. Which algorithm typically expands fewer nodes? Why? How does either algorithm compare with A∗ in Question (6)?

For this problem, data are collected with dimensions for the maze as 500.
BFS searched significantly more nodes than DFS. This can be due to the fact that as DFS expands nodes, the algorithm will explore moves that theoretically are closer to the destination, whereas BFS will search the nodes closest to the origin first. DFS searches fewer nodes than A* in Question 6, and BFS searches more nodes than A*.



Bonus 1) Why were you not asked to implement UFCS?

Uniform Cost Search prioritizes searching paths that have the least cost. In the current example with mazes, each new potential move adds the same cost of +1 to the distance travelled. Thus, UFCS, in this situation where all moves cost the same, is exactly the same as BFS.

Announcements to address:

For part one of the project, you are asked to implement DFS and compare its performance to A*. A* is optimal (under what conditions?), so will always return the shortest possible path. DFS does not have this guarantee, however, only that it will return /a/ path - the first one it finds. So the question is, on average what is 'lost' by using DFS instead of A*? How much savings could A* provide you in terms of length?

A* is optimal under the condition that the heuristic is admissible, meaning the calculated h(n) is less than or equal to the true cost of reaching the destination. In the case of the maze, the Manhattan distance is the greatest lower bound for the maximum cost to the destination (meaning the true cost is at best equal to the Manhattan Distance), and the Euclidean distance is less than the trust cost for the best solution. In the context of mazes, DFS and A* can return the same solution (if there is ONLY one path from origin to destination without any offtrailling moves), or A* can return the optimal path that is right down the diagonal, being n+n = 2n moves. In the worst case, DFS would then search every cell in the right diagonal of the maze before finding the path that A* found, which would be (n*n)/2 moves. In the best case, A* will allow us to find an optimal solution in linear time, whereas DFS would take quadratic time.

PART 2

8) What local search algorithm did you pick, and why? How are you representing the maze/environment, to be able to utilize your chosen search algorithm? What design choices did you have to make to apply this search algorithm to this problem?

We decided to design the hard maze using genetic algorithm:

Fitness - measure of longest path, most nodes explored, or largest fringe
Crossover - for two solutions, cross the solutions (join halves) to create a new solution — run search algorithm again on new maze & calculate fitness measures. Accept only if heuristics are larger.
Mutation - flipping random parts of the solution to blocked cells
SELECTION AFTER GENERATING NEW SOLUTION and mutating- longest path, nodes explored, or largest fringe

We designed our crossover to cross mazes across the bottom left to top right diagonal. This way, a maze's beginning and end would not be drastically changed. Crossing the other diagonal would simply mean a maze would have one maze's path downwards and one maze's path rightwards from the origin, and that intuitively seemed to make a path easier.
Originally, we thought of using a heuristic that has a weighted average between the fitness measures: 0.25*longestPath + 0.25*nodesExplored + 0.5*largestFringe, our rational being we would place half weight on time complexity and the other half on space complexity. It was difficult to support our rational with reasoning so we left the heuristic to only compare longest path, number of nodes, or size of fringe.

9) Unlike the problem of solving a maze, for which the 'goal' is well-defined, it is difficult to know when we have constructed the 'hardest' maze. That being so, what kind of termination conditions can you apply to your search algorithm to generate 'hard' if not the 'hardest' mazes?

The 'hardest' maze would have a particular search algorithm search every possible cell before finding the destination. In other words, the destination would be the last move searched. This means, for any given maze of size N and B number of blocked cells, the search algorithm should search close to N-B number of moves before finding a solution. Thus, we can set a lower bound on how many moves must be searched in order for the solution to be categorized as "hard", something that is less than but close to the value N-B. If an algorithm finds solution to a maze where the number of paths is less than our lowerbound, we can discard the solution as too easy. Additionally, we can apply our Genetic Algorithm a set number of times; we coded for 50. After each iteration, if a solvable maze is generated, the maze with the worse indicated property was selected for. That way, our maze would either stay the same or get worse after each application of our algorithm.

10) For each of the following algorithms, do the following: Using your local search algorithm, for each of the following properties indicated, generate and present three mazes that attempt to maximize the indicated property. Do you see any patterns or trends? How can you account for them? What can you hypothesize about the 'hardest' maze, and how close do you think you got to it?

DFS: There are a lot of twists and turns in the hard solutions. This occurs when DFS must "backtrack" after searching in a direction by running into a serious of blocks and being forced to search closer towards the origin. In this context, adjacent moves were added in the order of: right, bottom, left, top. So, moves to the right were popped off the stack first. Our DFS solutions would be long and intricate if there were a lot of blocked cells to the bottom of our path, thus forcing our algorithm to search to the left. The "hardest" maze would be one in which the path is straight across to the right of the i row, down 2, straight across to the left of the i row, etc. Many of our DFS paths displayed this back and forth pattern.

BFS: The bad BFS graphs are the ones in which the entirety of the maze is searched, and not many cells are blocked. In a completely empty maze, where are cells are unblocked, BFS would perform the worst and search all moves before reaching the destination. In the case where there are many blocked cells near the origin, many moves are ignored, actually improving the solution. Some of our hard solutions seemed to have very few blocked cells as desired.

Euclidean A*: All of our bad Euclidean graphs seem to have blocked cells along the diagonal that runs from the origin to the destination of the maze. This makes sense, as the Euclidean Heuristic prioritizes searching moves along the diagonal, and placing blocks in these positions forces the algorithm to search moves with higher heuristic costs. The hardest maze would block the middle portion entirely, and some of our graphs do have entirely blocked diagonals (at least for some parts of the graph).

Manhattan A*: Similar to Euclidean, hard Manhattan mazes have blocked cells near the center of the maze. In Euclidean Mazes, the position of the blocked cells is correlated to their absolute positions in on the graph, as that is where calculated Euclidean distances are minimized. For Manhattan Mazes, blocked cells that require the search algorithm to go up or left, regardless of where they are, make the maze difficult. Some of our graphs show a lot of branching, which means that blocked cells to the right and bottom of our path were selected for in our algorithm, as desired.

a) DFS
a.i) Length of solution path returned

```
 0  1 -1  0  0 -1 12 13 14 15 -1  0 -1 21 22 23 24 25 -1 -1  0  0  0  0 -1 -1  0  0 -1  0 -1 -1  0  0  0  0  0 -1 -1 -1  0 -1 -1  0  0 -1  0 -1  0  0
-1  2 -1 -1 -1 -1 11 -1  0 16 17 18 19 20 -1  0 25 26 -1 -1 -1  0  0  0  0  0 -1  0  0 -1 -1  0  0 -1  0  0 -1 -1 -1 -1 -1 -1 -1  0 -1  0 -1  0 -1  0
-1  3  4  5 -1 -1 10 11 -1 -1  0 -1 -1 21 -1  0 26 -1 -1 -1 -1  0  0 -1  0  0 -1 -1 -1 -1  0 -1 -1 -1 -1  0 -1 -1  0  0 -1 -1 -1 -1  0 -1  0 -1 -1
 0  0 -1  6  7  8  9 10 11 -1 -1 -1 -1 -1  0 -1 27 28 29 -1  0  0  0  0 -1  0  0  0 -1 -1 -1  0 -1 -1  0 -1  0  0 -1 -1 -1  0  0 -1  0 -1 -1 -1  0 -1
-1  0  0 -1 -1  0 10 11 12 13 -1 -1  0 -1 -1 -1 -1 -1 30 -1 34 35 36 37 -1 -1 -1 -1  0  0 -1 -1 54 -1 -1  0 -1 -1 -1 -1  0  0  0 -1 -1 -1  0  0 -1 -1
 0  0  0  0  0  0 -1 -1 -1 -1  0 -1  0 -1  0 -1  0  0 31 32 33 -1 -1 38 39 -1 -1  0 -1 -1 49 -1 53 -1  0  0  0 -1  0  0 -1 -1 -1  0 -1  0  0  0  0  0
-1 -1  0  0  0 -1  0  0  0 -1 -1  0 -1  0  0  0 -1  0 -1 -1 34 -1 -1 -1 40 -1 -1 45 46 47 48 -1 52 53 -1 -1  0 -1 -1 -1 -1 -1 -1 -1  0  0 -1  0 -1 -1
 0  0  0  0  0 -1 -1 -1 -1  0 -1 -1 -1  0  0 -1 -1 -1 -1 -1 35 -1 39 -1 41 42 43 44 -1 48 49 50 51 -1 -1  0  0  0 -1  0  0 -1  0 -1  0  0  0  0  0  0
-1 -1  0 -1 -1 -1  0  0  0  0  0  0  0  0  0 -1  0 -1 -1 -1 -1 36 37 38 -1  0 -1 -1 -1 -1 49 -1 -1 -1 -1 -1 -1 -1  0 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1  0
-1  0 -1  0  0  0 -1  0 -1 -1  0  0 -1 -1  0 -1  0  0 -1  0 -1 38 -1 -1 -1 -1  0  0  0 50 -1  0 -1  0  0 -1  0  0  0  0  0 -1 -1  0 -1  0 -1  0  0
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-1 -1  0  0  0 -1  0 -1 -1  0 -1  0  0 -1 -1  0 -1 -1  0  0  0  0 -1 -1  0  0 -1 -1 -1 -1 53 -1  0  0 -1 -1 -1 -1  0 -1 -1  0  0  0  0 -1 -1 -1  0 -1
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-1 -1 -1 -1 -1  0  0 -1 -1 -1  0 -1 -1 -1  0 -1  0 -1 -1  0 -1 -1 -1  0  0  0 -1 -1 57 -1 55 -1  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0
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-1 -1  0  0  0  0 -1 -1 -1  0  0  0  0 -1  0  0 -1  0  0  0  0 -1 -1  0  0  0 -1 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1 -1  0 107108109-1
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 0 -1 -1  0 -1 -1  0  0 -1 -1  0  0  0 -1  0  0  0 -1  0  0  0 -1  0  0  0  0 -1  0 -1 -1  0  0 -1  0  0 -1  0  0 -1  0  0  0 -1  0  0 120119118-1 114113112111112
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 0  0  0 -1 -1  0  0 -1  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0 -1  0  0 -1  0 -1  0 -1  0  0 -1  0 187-1 149-1 145 0 137136137 0 99 100-1 102101102
 0  0  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0 -1  0 -1 -1  0  0  0 -1  0 -1  0  0  0  0 190189188 0 148147146147 0 135-1 135 0 101-1 -1 102103
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 0  0  0  0  0  0  0  0 -1 -1 -1  0  0  0 -1 -1  0  0  0 -1 -1  0 -1 -1  0  0 -1  0 194193-1 -1 190-1 -1 -1 148-1 212-1 132133 0 103-1 107108-1
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 0  0  0  0 -1  0  0 -1  0  0 -1  0  0  0  0 -1  0 -1  0  0 -1 -1  0  0 -1  0  0  0  0  0 200201-1 -1 206207208209-1 129 0 107108109-1 -1 -1
-1  0 -1  0 -1  0  0  0  0  0  0 -1  0  0 -1 -1  0  0 -1  0  0 -1 -1  0  0  0 -1  0  0  0  0  0 202203204205-1 209 0 127128129-1 -1 110111-1 -1
 0 -1  0  0 -1  0  0 -1  0 -1 -1 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0 203-1 -1 -1  0 -1 -1 126-1 -1 -1  0 111112-1 -1
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 0  0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0 -1  0 -1  0 -1 -1  0 -1  0  0 -1  0 -1  0  0  0 207206205206-1 218-1  0  0 -1 123124125 0 113114-1 -1
 0  0  0  0 -1 -1  0  0  0 -1 -1  0  0  0  0  0  0 -1  0  0  0  0 -1  0  0 -1 -1 -1  0 -1  0 -1 208-1 206-1 218217-1 -1  0  0 122-1  0 115114-1 -1 -1
 0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1 -1  0  0 -1  0  0  0  0 -1  0  0  0  0 209-1 -1  0 215216-1  0  0  0 121 0 117116-1 -1  0 -1
 0  0  0  0  0  0  0  0  0 -1 -1  0  0 -1 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0 210211212213214215-1 -1  0  0 120119118-1  0 -1  0  0
 0 -1  0  0  0  0  0  0 -1  0 -1  0 -1 -1  0 -1 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0 214215216-1  0  0  0 -1 -1 -1 -1  0  0  0
-1 -1  0 -1 -1 -1  0  0  0 -1  0 -1 -1  0 -1  0  0  0  0  0  0  0  0  0 -1  0 -1  0 -1  0  0 -1 -1 215-1 -1 220221222223224225-1 -1  0 -1  0  0
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 0  0  0  0  0  0 -1 -1 -1  0  0 -1 -1 -1  0  0 -1  0  0 -1  0  0 -1  0 -1  0 -1  0 -1 -1 -1 -1  0 -1  0  0  0 -1 -1 -1  0  0 226227228-1  0  0  0  0
 0  0 -1  0  0  0  0  0 -1  0  0 -1  0  0 -1 -1  0  0 -1 -1  0  0 -1  0  0  0  0 -1  0 -1  0  0 -1  0  0  0  0 -1 -1  0  0 -1  0 229230231232-1  0
 0 -1  0  0 -1  0  0 -1  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1 -1  0  0  0 -1 -1 -1  0  0  0  0 -1 -1 -1 -1 -1 -1 -1  0 -1 233234-1
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 0  1  2  3  4  5  6 -1 -1  0 -1 -1 -1 -1 -1 -1  0 -1  0  0  0 -1 -1 -1  0  0  0  0 -1  0  0  0 -1  0 -1  0 -1  0  0  0 -1  0 -1  0 -1 -1  0  0
 0  0  0  0  0  0  7  8  9 10 11 -1 -1  0  0  0  0  0  0  0  0 -1 -1  0  0  0 -1  0 -1  0  0 -1  0 -1  0 -1 -1  0  0  0  0  0  0 -1  0 -1  0 -1
 0 -1  0 -1 -1  0  0  0  0 11 -1  0  0  0 -1  0  0 -1  0  0  0 -1  0  0  0 -1  0 -1  0  0  0  0  0 -1  0  0 -1 -1  0  0  0  0  0 -1  0 -1  0  0
 0 -1  0  0  0 -1  0 -1  0 12 -1 -1 -1  0  0 -1 -1 -1  0  0  0 -1  0 -1  0  0 -1  0 -1  0  0  0  0  0  0 -1 -1 -1 -1  0 -1 -1  0 -1 -1 -1 -1
-1 -1 -1 -1  0  0  0  0  0 13 -1  0 -1  0  0  0 -1  0  0  0  0  0 -1 -1 -1  0  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0 -1  0 -1  0  0  0  0  0
-1 -1  0  0 -1 -1 -1  0 -1 14 15 16 -1  0  0  0  0  0 -1 -1 -1  0 -1  0 -1 -1 -1 -1 -1  0 -1  0 -1 -1  0 -1 -1  0  0 -1  0 -1  0 -1 -1  0 -1 -1
-1  0  0 -1  0 -1  0  0  0 -1 -1 17 -1  0  0  0 -1  0  0  0 -1 -1  0  0 -1 -1  0 -1  0 -1  0  0  0 -1  0  0  0  0 -1  0  0 -1  0  0 -1  0  0 -1  0  0
 0 -1  0  0  0  0 -1  0  0 -1  0 18 -1  0  0  0 -1  0  0 -1 -1  0 -1 -1  0 -1 -1  0 -1 43 44 45 46 47 -1  0  0 -1 -1  0 -1 -1  0  0  0  0  0  0  0
-1  0  0  0  0  0  0 -1  0  0 -1 19 20 21 -1  0 -1 -1  0  0 -1  0 -1  0 -1 -1  0  0 42 -1 -1  0 48 49 50 -1 -1  0  0  0 -1 -1  0  0 -1  0  0  0  0  0
-1  0  0 -1  0 -1  0  0 -1  0  0  0 -1 22 23 24 25 26 27 28 29 30 31 32 33 -1  0  0 41 42 43 -1 -1  0 51 -1  0  0  0 -1  0 -1  0 -1  0  0  0  0  0 -1
 0 -1 -1 -1 -1 -1 -1  0  0  0 -1  0  0  0 -1  0 -1 -1  0 -1 -1  0 33 -1 -1 -1 39 40 41 -1 -1 -1 -1 52 53 54 55 56 57 58 59 60 -1  0 -1  0  0 -1 -1
-1 -1 -1 -1  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0 -1  0  0 -1 34 35 36 37 38 -1 -1 -1 -1  0 -1  0 -1  0 -1 -1 -1 -1  0 61 62 63 64 65 66 67 68
 0 -1  0 -1 -1  0  0  0 -1 -1  0  0  0  0 -1  0  0  0  0 -1 -1 -1  0  0  0 -1 39 40 41 42 -1 -1 -1 -1 -1 -1 154153152151-1  0  0 -1  0  0 -1 67 68 69
 0  0  0  0  0 -1  0  0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0 -1  0 -1 -1 -1 -1 40 -1 42 43 44 45 46 -1 -1 155154-1 150-1  0 -1 150149-1 69 68 -1 70
-1 -1 -1  0 -1 -1  0  0  0 -1  0 -1  0  0  0 -1 -1  0 -1  0 -1 -1  0 -1  0 -1 46 45 44 45 -1 -1 -1 -1 156155150149148-1 148147148-1 70 -1  0 -1
 0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1  0 -1 -1 -1  0 -1  0 -1 46 -1 -1 159-1 -1  0 -1 -1 151-1 147146-1 146147-1 71 72 -1 -1
 0  0  0 -1  0 -1  0 -1  0 -1  0 -1 -1  0  0 -1  0  0 -1 -1  0  0 -1  0  0  0  0 -1  0 159158157 0 151150149-1 147146145144145-1 -1 72 -1 80 79
-1  0  0  0  0  0  0 -1 -1  0 -1  0 -1  0  0  0  0 -1  0  0  0 -1  0 -1 -1 -1  0 -1 -1 -1 160 0 156 0 152 0 148-1 -1 147142143144-1  0 73 74 -1 78
 0  0  0  0 -1  0 -1 -1  0  0  0 -1 -1  0 -1 -1  0 -1 -1 -1  0 -1  0  0 -1  0  0  0  0  0  0 161 0 155154153-1 147 0 143142141142-1 134133 0 75 76 77
-1  0  0 -1 -1  0  0  0  0  0  0  0 -1 -1  0 -1 -1  0 -1 -1  0 -1 -1  0  0  0  0  0  0  0 162-1 156-1 154-1 146145144-1 140 0 134133132 0 76 -1 -1
-1  0 -1 -1 -1 -1  0  0 -1  0 -1 -1 -1  0  0  0  0  0  0  0 -1  0 -1  0 -1  0 -1  0 164163164-1 -1 -1  0 -1 -1 -1  0 139 0 135-1 131 0 77 -1 -1
 0  0 -1 -1  0  0  0 -1 -1  0  0 -1 -1 -1 -1  0 -1  0 -1 -1  0 -1  0 -1 -1  0  0  0  0 165-1 -1  0  0 -1 -1 -1  0  0 -1 138137136-1 130 0 78 79 -1
-1 -1 -1 -1  0 -1  0  0 -1  0  0 -1  0 -1 -1 -1  0  0  0  0 -1 -1 -1 -1  0  0  0  0 166167-1 -1  0  0  0  0  0  0  0  0 -1  0 128129-1 79 80 -1
-1  0 -1  0  0 -1  0 -1  0 -1 -1  0  0 -1  0 -1 -1  0  0 -1  0 -1 -1  0 -1 -1  0 -1 -1  0 167-1  0  0  0 -1  0  0  0  0  0 124125126127-1  0 80 -1 -1
 0 -1 -1  0  0  0 -1 -1 -1  0 -1 -1  0  0 -1  0  0 -1  0 -1 -1  0 -1  0 -1 -1  0 -1 170169168-1  0 -1 -1  0  0  0 -1  0  0 123-1  0 128129-1 81 -1  0
 0 -1  0  0  0 -1 -1  0  0 -1  0  0  0 -1  0 -1 -1 -1  0 -1  0 -1  0 -1  0 171-1 -1  0  0  0  0  0  0  0  0 -1 122-1 -1 -1 -1  0 82 83 -1
 0  0 -1  0 -1 -1  0  0  0  0  0 -1  0  0 -1 -1 -1  0  0  0  0  0 -1 -1 -1 -1  0 172173-1  0  0 -1  0  0  0 -1 -1  0 120121122-1 126125124 0 84 85
-1 -1 -1  0 -1  0 -1 -1  0 -1 -1  0 -1 -1  0 -1  0  0 -1  0  0  0  0  0  0 -1  0  0 173-1 -1  0  0  0 -1  0 -1  0  0 119-1 -1 120121-1 123124 0 86
-1 -1 -1 -1  0 -1  0  0  0  0 -1 -1  0  0  0 -1 -1 -1 -1 -1 -1  0 -1  0 -1  0 174175176-1  0 -1  0  0  0  0  0  0 118117118119120121122 0 88 87
 0  0 -1 -1  0  0  0 -1  0 -1  0 -1  0 -1  0  0  0  0  0  0 -1  0  0 -1  0 175176-1 -1 -1  0  0  0  0  0  0 -1  0 116-1 -1 121122123 0 89 -1
 0  0  0 -1  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0 -1 -1  0  0  0 -1  0 176-1 -1  0  0  0  0  0  0 -1  0 -1 114115-1 123122-1 -1 -1 90 91
-1 -1 -1  0  0  0  0 -1  0  0 -1 -1  0  0 -1  0 -1  0 -1  0  0 -1  0  0 -1 -1 0 177178179180181182183184185-1  0  0 113-1  0 -1  0 -1 -1  0 -1 92
 0  0  0  0  0  0 -1  0  0  0  0 -1  0 -1 -1 -1 -1 -1 -1  0  0  0  0  0 -1  0 -1 -1 -1  0 -1  0 -1  0  0 -1 186187-1 -1 112111-1 -1 106105104-1 -1 93
 0 -1  0 -1  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0 -1  0 -1 -1  0  0  0  0  0  0  0 -1 -1  0 188189190-1 110109108107 0 103-1  0 94
 0  0  0  0  0  0 -1 -1 -1  0 -1  0  0  0  0  0 -1  0 -1 -1  0 -1  0  0 -1  0  0 -1 -1  0  0 -1  0  0 -1 -1  0 191192-1 110-1 -1  0 102-1  0 95
 0  0 -1  0  0  0 -1  0 -1  0 -1 -1  0 -1 -1  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0 -1  0  0 193194-1  0  0  0 101100 0 96
-1  0  0 -1  0 -1  0  0 -1 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0 -1  0 -1  0  0  0  0 -1 195196197-1 -1  0 99 98 97
-1 -1  0  0 -1  0  0 -1  0  0  0 -1 -1 -1 -1  0  0 -1  0  0 -1 -1 -1 -1  0  0  0  0  0  0  0 -1  0  0 -1 -1 -1 -1 -1  0  0  0 198199200-1 100-1 98
-1  0  0 -1  0 -1  0 -1  0 -1 -1  0  0  0  0  0  0 -1 -1  0 -1  0 -1  0  0  0 -1  0  0 -1 -1  0  0 -1  0 -1  0  0 -1  0  0 200-1  0 -1 210-1
 0 -1  0  0  0  0 -1  0  0 -1  0 -1  0  0  0  0  0 -1 -1  0 -1  0  0  0  0  0  0 -1  0  0 -1  0 -1 -1  0 -1  0  0  0  0  0 201202-1 -1 209210
 0  0  0 -1 -1 -1  0 -1  0  0  0  0  0 -1  0 -1 -1  0  0  0 -1 -1  0  0  0 -1  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1 203-1 207208209
-1  0 -1  0  0  0 -1  0  0 -1  0  0  0 -1  0  0 -1 -1  0  0  0 -1 -1  0  0  0 -1  0  0  0 -1  0  0  0 -1 -1  0  0 -1  0 -1 -1  0 204205206-1 210
 0  0  0 -1 -1  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0 -1  0 206-1  0 -1
 0 -1 -1  0  0 -1 -1  0 -1 -1 -1  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0 -1  0 -1  0  0  0 -1  0 -1  0  0 207-1  0  0
-1  0 -1  0  0 -1 -1  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0 -1 -1  0  0  0 -1 -1  0  0  0  0  0  0 -1 -1  0  0  0 -1  0  0 -1 -1  0 208209210-1
-1  0  0  0  0 -1  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0 -1  0  0  0  0 -1 -1  0  0  0 -1  0  0  0 -1 -1  0  0 -1  0 -1 -1  0  0 -1  0 211-1
 0 -1  0 -1 -1  0  0 -1 -1  0 -1  0  0  0 -1 -1  0  0  0  0 -1  0  0 -1 -1  0  0 -1 -1  0  0 -1  0 -1 -1  0 -1  0  0 -1  0  0  0  0  0  0 213212213
 0  0 -1  0  0 -1 -1  0  0  0  0  0  0  0  0 -1  0  0 -1  0 -1 -1  0 -1 -1  0  0  0 -1  0  0  0  0  0 -1  0 -1 -1  0 -1 -1  0  0  0  0 214-1 -1
-1 -1 -1  0  0 -1  0  0  0 -1  0  0 -1 -1  0  0  0  0  0  0 -1  0 -1 -1  0 -1  0  0  0 -1  0  0  0 -1  0  0  0  0 -1  0  0  0 -1  0  0 -1  0 215216217
 0  0 -1  0  0 -1  0  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0 -1  0 -1  0 -1 -1  0  0 -1  0 -1  0  0  0  0 -1  0  0  0  0  0 218
```

a.iii) Maximum size of fringe during runtime

```
 0  1 -1 -1  0  0  0 -1 -1  0 -1 -1  0 -1 -1 -1 -1 -1 -1  0  0 -1  0  0  0  0 -1  0  0 -1 -1 -1 -1 -1  0 -1 -1  0 -1 -1  0  0  0  0 -1  0  0  0  0  0
 0  2  3 -1  0  0  0  0 11 -1 -1 -1  0  0 -1  0  0  0  0  0  0 -1 -1 -1  0  0  0  0  0 -1  0 -1 -1  0  0 -1  0  0  0  0 -1 -1 -1  0  0  0 -1 -1 -1  0
 0 -1  4  5  6  7  8  9 10 -1 -1 -1 -1  0  0 -1  0  0 -1  0 -1  0  0 -1 -1  0 -1  0 -1  0 -1  0 -1  0  0  0  0  0 -1  0 -1  0  0  0 -1  0 -1  0  0 -1
-1  0  0  0  0  0 -1 10 -1 -1  0  0 -1 20 21 22 23 24 25 -1 -1 -1 -1  0 -1  0  0 -1 -1  0 -1  0  0  0  0  0  0  0 -1 -1 -1 -1  0 -1  0  0 -1  0  0  0
 0 -1  0 -1  0  0 -1 11 12 13 14 -1  0 19 -1 -1  0  0 26 27 28 29 30 31 -1  0  0  0 -1 -1  0  0  0  0 -1  0  0  0 -1  0  0  0 -1  0  0 -1  0  0  0
 0  0 -1  0  0 -1  0  0 -1  0 15 16 17 18 19 -1 -1 -1  0  0  0 -1  0 32 -1  0 -1 -1  0 -1 -1  0  0  0 -1  0  0 -1  0 -1  0 -1  0  0 -1  0  0  0 -1  0  0
 0 -1 -1 -1  0  0  0 -1  0  0 -1 -1  0 -1 -1  0 -1  0  0 -1 -1  0  0 33 -1  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1 -1 -1  0  0 -1 -1 -1  0  0  0
 0 -1  0 -1  0  0 -1 -1 -1  0 -1  0 -1 -1  0  0  0  0 -1 -1  0 -1  0 34 -1  0  0 -1  0 -1  0 -1  0  0  0  0  0  0  0 -1 -1  0  0  0 -1 -1  0  0 -1  0
 0  0 -1  0 -1 -1  0  0  0 -1  0  0 -1 -1  0  0  0  0  0  0 -1  0  0 35 36 -1  0 -1 -1 -1  0  0  0 -1  0  0 -1 -1 -1  0  0 -1 -1 -1  0  0  0  0  0
 0  0  0  0 -1  0 -1 -1  0  0  0 -1 -1  0  0 -1 -1  0 -1  0 -1  0 -1  0 37 36 -1 -1  0 -1 -1  0  0 -1  0  0  0 -1 -1  0  0 -1 -1 -1  0  0  0  0  0  0
-1 -1  0  0  0 -1  0  0 -1 -1 -1  0  0  0  0  0  0  0  0  0  0 39 38 -1 -1 -1 -1 -1  0  0  0  0 -1  0 -1  0  0 -1 -1 -1  0  0 -1  0 -1  0  0  0  0
 0  0  0 -1 -1  0 -1  0 -1  0 -1  0  0  0  0 -1  0  0  0  0 41 40 -1  0  0 -1  0 -1 -1  0  0  0 -1 -1 -1 -1  0  0 -1  0  0  0  0 -1  0 -1  0  0 -1  0
-1 -1  0 -1  0 -1  0 -1 -1 -1 -1  0  0  0  0  0  0  0  0 42 -1  0 -1 -1 -1 -1 -1  0 -1 -1 -1 -1  0 -1 -1  0 -1  0  0  0  0 -1 -1 -1  0 -1  0 -1
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 0  0  0  0  0  0  0  0 -1 -1  0 -1  0 -1 -1  0  0 -1 -1 44 45 46 47 -1  0  0 -1 66 67 -1 -1  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0
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-1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0 -1 -1  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0  0 125126
```

```
 0  1  2  3 -1  0  0 -1 -1  0 -1  0  0 -1 -1  0  0 -1  0  0  0 -1  0  0 -1  0 -1 -1 -1 -1 -1  0 -1  0  0  0 -1 -1 -1  0 -1 -1 -1  0  0 -1  0  0  0 -1
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-1  0  0 -1  7  8  9 -1 -1 14 -1 -1 -1  0  0 -1 -1 -1 -1  0 -1 -1  0  0  0 -1 -1  0  0 -1  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0 -1  0  0 -1
 0 -1 -1  0  0  0 10 11 12 13 -1 -1 -1  0  0 -1  0  0  0 -1  0  0 -1 -1  0  0 -1 -1 -1  0  0  0  0  0  0  0  0 -1 84 85 86 87 -1  0 -1  0  0  0  0
 0  0  0  0  0  0 -1 12 -1 14 -1  0 -1  0  0 -1  0 -1 -1  0 -1 -1  0 -1  0 -1 -1  0 -1 -1  0  0 -1 -1 -1  0  0 83 -1  0 88 89 90 91 92 -1  0 -1  0
-1 -1 -1  0 -1  0 -1 13 14 -1  0 -1 -1 -1  0 -1  0  0 -1  0  0 -1  0  0  0 67 68 69 70 -1  0  0  0  0 80 81 82 -1  0  0 -1 -1  0 93 94 95 96 -1
 0 -1  0  0 -1 -1  0 -1 15 16 -1  0  0 -1  0 -1 -1 -1  0  0  0  0  0 -1  0 64 65 66 -1  0 71 72 -1  0 -1  0 79 -1 -1  0  0  0  0 -1 -1  0  0  0 97 98
 0  0 -1 -1  0  0  0 17 16 -1  0  0  0  0 -1  0 -1  0  0 -1  0 -1 -1  0  0 63 -1 67 -1 -1 -1 73 74 75 76 77 78 79 -1 -1 -1  0  0 -1  0  0  0  0  0 99
 0  0  0 -1  0  0 -1 18 -1  0  0 -1  0 -1  0  0  0 -1  0  0 -1 -1  0 -1  0 62 -1 -1 59 58 -1 -1  0 -1  0  0 79 -1 -1  0  0  0 -1 -1 -1  0 -1  0  0 100
 0  0  0 -1  0  0 -1 19 20 21 22 23 -1  0 -1  0  0 -1 -1 -1  0  0  0  0  0 61 60 59 -1 57 58 59 -1 -1 82 81 80 81 82 -1  0 -1  0 -1  0  0  0  0 102101
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 0  0  0 -1  0  0  0 -1  0  0 -1 26 27 28 29 -1 -1  0 -1  0  0 -1  0 -1  0 -1 -1 -1 55 -1 -1  0 -1 -1 -1 84 83 -1  0 -1  0 -1  0  0  0  0  0 104105
 0  0 -1  0 -1  0  0  0 -1  0  0 -1 -1 30 31 32 33 34 35 -1 -1 40 41 42 43 44 -1 54 53 52 -1  0  0 -1 -1 -1  0  0 -1  0  0 -1 -1 -1 -1 105-1
 0  0  0 -1 -1 -1 -1  0  0 -1  0 -1  0  0 -1 -1  0  0  0 36 37 38 39 -1  0 44 -1  0  0  0 51 52 -1  0  0 -1 -1  0  0 -1  0  0 -1  0 -1  0 106107
-1  0  0  0 -1  0 -1 -1  0 -1 -1  0 -1  0 -1  0  0  0  0  0  0 -1  0 40 -1  0 45 46 47 48 49 50 -1 -1  0 -1  0 -1 -1 -1 -1  0  0 -1 -1  0  0  0 108
-1  0 -1  0  0 -1  0 -1 -1  0  0 -1  0  0 -1  0  0 -1 -1  0 -1 -1 -1 -1 -1  0 -1  0  0 -1 -1 -1  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0 109
-1  0 -1  0  0  0  0 -1  0 -1  0  0 -1  0 -1  0 -1  0  0 -1  0 -1 -1  0 -1  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0 -1  0 110
 0  0 -1  0 -1 -1 -1  0  0  0 -1  0  0  0  0 -1 -1  0 -1  0 -1  0 -1  0  0 -1  0  0 -1  0  0 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0  0 -1  0  0 111
-1  0  0 -1  0  0  0 -1  0  0  0 -1  0 -1  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0 -1  0  0  0 -1  0  0 -1  0  0  0 -1  0  0  0 -1 -1  0  0  0 113112
 0  0  0  0  0 -1 -1  0  0  0  0 -1  0 -1 -1  0  0  0  0  0 -1  0  0 -1 -1  0  0 -1  0  0  0  0  0  0  0  0 -1  0  0  0  0  0  0  0 -1  0  0  0 114-1
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 0  0  0  0 -1  0 -1  0 -1  0  0 -1 -1 -1  0  0 -1  0  0  0 -1  0  0  0 -1  0  0  0 -1  0  0  0 -1 -1 -1  0 -1 -1  0  0  0 -1 -1  0 -1  0  0  0  0 117
 0 -1  0 -1  0  0  0 -1 -1  0  0  0  0  0 -1 -1  0  0  0  0 -1  0  0  0  0 -1 -1  0  0  0 -1 -1  0  0  0 -1  0  0  0  0 -1  0  0  0  0  0  0  0 118
 0  0  0 -1 -1  0 -1  0  0  0 -1 -1  0  0  0  0  0  0 -1 -1  0  0  0  0  0 -1 -1  0 -1  0 -1 -1  0  0  0  0 -1 -1 -1  0 -1  0  0  0  0  0  0 119
 0  0  0  0 -1  0  0 -1  0  0 -1 -1 -1 -1  0  0 -1  0  0  0 -1  0  0  0  0  0 -1  0  0 -1  0 -1  0 -1  0  0  0  0  0  0  0 -1  0 -1  0  0 120
 0 -1 -1 -1  0  0  0  0 -1  0 -1 -1 -1  0  0  0 -1 -1 -1  0  0  0  0  0  0 -1 -1  0  0 -1  0 -1  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0 121
 0 -1 -1  0  0  0 -1  0  0 -1  0 -1  0  0  0 -1 -1 -1 -1  0 -1  0  0  0 -1  0  0  0  0  0  0 -1  0 -1 -1 -1  0  0  0  0  0  0  0 -1 123122
-1 -1  0  0  0 -1 -1  0  0 -1  0 -1  0 -1  0 -1 -1  0  0  0  0  0 -1  0  0 -1  0 -1  0  0  0 -1  0  0 -1 -1 -1  0  0  0  0  0  0  0 124-1
 0 -1 -1  0  0  0 -1  0 -1  0 -1 -1 -1  0  0  0  0 -1 -1  0 -1  0 -1  0  0 -1 -1  0  0 -1  0  0  0 -1 -1  0 -1  0  0 -1  0 -1  0  0 -1  0 -1 125-1
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-1  0 -1  0  0  0  0 -1  0  0  0  0  0 -1  0  0 -1 -1 -1 -1  0  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0 -1  0 -1  0  0  0 -1 -1 -1 -1 130-1 128129
 0  0  0 -1 -1 -1  0  0 -1  0  0  0 -1 -1  0  0 -1  0  0 -1  0 -1  0 -1  0  0  0  0 -1  0  0  0  0  0  0 -1  0 -1  0  0  0  0 -1  0 -1  0 -1 131-1 -1 -1
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 0  0  0  0  0  0 -1 -1  0 -1 -1 -1  0 -1  0  0 -1  0  0  0  0  0  0  0  0  0  0  0  0  0 -1  0  0  0 -1  0 -1  0  0  0  0 -1  0  0 133134135-1
 0 -1 -1 -1 -1  0 -1  0  0  0 -1  0 -1  0  0 -1  0  0  0  0  0 -1  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0  0  0  0 -1  0  0 -1 -1  0 -1 136-1
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 0  0 -1  0  0 -1  0 -1 -1  0 -1 -1  0  0  0  0 -1 -1 -1 -1  0  0  0  0  0 -1  0  0  0 -1 -1  0  0 -1  0  0  0 -1  0  0 -1 -1  0  0 -1  0  0  0  0 139
-1  0  0  0 -1  0 -1 -1 -1  0  0  0 -1  0 -1  0 -1  0 -1  0  0  0  0  0  0  0  0  0 -1 -1 -1  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0 142141140
 0 -1  0 -1  0 -1  0  0 -1  0 -1  0  0  0  0 -1 -1  0  0  0  0  0 -1  0 -1 -1 -1 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1 -1 144143-1 -1
 0  0  0 -1 -1 -1  0  0 -1  0  0  0  0  0 -1  0  0  0  0 -1  0  0  0 -1 -1  0  0  0  0 -1  0 -1 -1  0 -1  0 -1  0  0  0  0  0  0  0  0 146145-1  0  0
 0  0 -1  0 -1  0  0 -1  0 -1  0 -1  0  0  0  0 -1  0 -1  0 -1  0  0  0  0 -1  0  0  0  0  0  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1 147-1  0 -1 -1
 0  0  0  0  0  0 -1  0 -1  0  0  0  0  0  0  0  0 -1  0 -1  0 -1 -1  0 -1 -1  0 -1  0  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0  0 -1  0  0 148149150151152
-1  0 -1  0  0 -1 -1  0  0 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0 -1 -1  0  0 -1  0  0 -1  0 -1  0  0  0 -1 -1  0  0  0  0  0  0  0  0 -1 151-1 153
 0 -1  0 -1 -1 -1  0  0  0  0 -1 -1  0  0  0  0 -1  0  0 -1  0 -1  0  0 -1 -1 -1  0  0  0  0  0  0  0  0  0 -1 -1  0 -1  0  0  0  0 -1 -1 -1  0 152153-1
 0 -1 -1 -1  0  0  0 -1  0 -1  0 -1  0  0 -1  0 -1  0  0 -1 -1 -1 -1  0 -1  0  0  0  0 -1  0  0 -1 -1 -1  0  0 -1  0  0  0  0  0  0  0 -1 154155
 0 -1 -1  0 -1  0 -1 -1  0  0 -1 -1  0  0  0  0  0  0  0 -1 -1 -1  0 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0 -1  0  0  0  0  0 156
 0  0  0  0  0  0  0  0  0  0  0 -1 -1  0 -1  0 -1 -1 -1  0  0 -1  0  0 -1 -1  0 -1  0  0  0  0  0  0  0  0  0  0  0 -1 -1  0  0  0  0  0 -1 157
-1 -1  0  0  0 -1 -1  0  0  0 -1  0  0 -1  0 -1 -1  0  0  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0 -1 -1  0 -1  0  0  0 -1 -1  0  0  0  0  0 158
```

b) BFS

b.i) Length of solution path returned

```
 0  1 -1 -1 -1  0  0  0 -1  0 -1 -1  0  0 -1 -1  0  0 -1  0  0  0 -1  0 -1 -1 -1  0 -1  0 -1  0  0 -1  0  0 -1  0 -1  0 -1  0 -1  0 -1  0  0  0
 1 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1  0 -1  0 -1  0 -1  0 -1 -1  0 -1 -1 -1 -1  0 -1 -1 -1 -1 -1 -1 -1  0  0 -1  0 -1  0 -1  0 -1 -1 -1 -1  0 -1  0 -1
 2  3 -1  0 -1 -1 -1 -1 16 17 -1 -1  0 -1  0  0 -1  0  0  0  0  0 -1  0  0 -1 -1  0  0  0  0  0  0 -1  0 -1 -1  0  0  0  0 -1  0 -1 -1  0  0 -1  0 -1
-1  4 -1 -1 -1  0 -1 16 15 -1 -1 -1 -1  0 -1  0  0  0 -1 -1  0  0 -1 -1  0 -1 -1  0 -1  0  0  0  0  0  0  0 -1  0  0  0 -1 -1 -1 -1 -1  0 -1  0  0
 6  5  6  7  8 -1 -1 -1 14 15 16 -1 -1 -1  0  0 -1 -1  0  0 -1 -1  0 -1 -1  0  0  0  0  0 -1  0 -1 -1  0  0  0  0  0 -1  0 -1  0 -1 -1  0 -1  0
 7  6 -1  8  9 10 11 12 13 -1 -1  0  0  0 -1 -1  0 -1 -1 -1 -1  0  0 -1 -1  0  0  0  0 -1 -1 -1  0  0  0 -1 -1 -1  0  0  0  0 -1  0  0  0
 8 -1 -1 -1 10 -1 12 -1 -1  0 -1 -1 -1  0  0 -1 -1  0 -1 -1  0 -1  0 -1  0 -1 -1 -1 -1  0  0  0 -1  0 -1  0  0  0  0 -1  0  0 -1 -1  0  0  0  0
 9 10 11 -1 -1 14 13 -1  0  0 -1 -1  0 -1  0 -1  0 -1  0  0  0  0 -1  0  0 -1  0 -1  0 -1 -1 -1  0  0  0 -1 -1  0 -1  0  0  0  0  0  0  0  0
-1 -1 12 13 14 -1 14 15 -1 -1  0 -1  0 -1  0 -1 -1  0 -1 -1  0 -1  0 -1 -1 -1 -1  0 -1 -1 -1  0  0 -1  0  0  0  0 -1  0  0 -1  0  0  0  0 -1  0
-1 -1 -1 -1 -1 16 15 -1 -1 -1 -1 -1  0 -1 -1  0 -1 -1  0 -1 -1  0 -1  0  0  0  0 -1 -1 -1 -1  0  0 -1  0  0  0  0  0  0  0 -1  0  0 -1 -1 -1  0
 0  0 -1  0 -1 17 16 -1  0 -1  0  0 -1  0 -1  0  0  0  0 -1 122-1 -1  0 -1 -1 -1 -1  0 -1 -1  0 -1  0 -1 -1  0  0  0  0 -1  0  0 -1 -1 -1  0  0
-1 -1 23 -1 19 18 -1 -1 -1  0 -1 -1 -1 -1  0  0  0 -1 23122121122123-1  0 -1  0 -1 -1 -1 -1  0  0  0  0  0  0 -1 -1  0 -1 -1 123 0  0 -1  0  0  0  0
30 -1 22 21 20 19 20 21 22 -1  0 -1  0  0  0  0  0 -1 -1 121120-1 -1  0 -1 -1 -1  0 -1  0 -1  0 -1 -1  0 -1 -1  0 -1  0 123122123 0 -1  0  0 -1  0
29 28 -1 22 21 20 21 -1 -1  0  0  0 -1  0  0 -1 -1  0 -1 120119118-1 -1  0 -1 -1  0 -1 -1  0 -1 -1 -1  0 -1 -1 121120-1 122121122-1  0  0  0  0 -1
-1 27 -1 23 -1 -1 -1 -1 -1 -1  0 -1  0  0 -1 -1  0  0 -1 -1 118117-1  0  0  0 -1 -1 -1 -1 -1 -1 -1  0 -1  0  0 -1 -1 119120121120-1 -1 123 0  0  0 -1
-1 26 25 24 25 -1 -1 -1 35 -1 -1  0 -1 -1 49 -1 -1  0  0 -1 117116115-1 -1 -1 -1 -1 -1 -1  0 -1 -1  0 -1  0 -1 118117118119-1 119-1 -1 122123 0  0  0
-1 -1 -1 25 26 -1 -1 33 34 35 36 -1 46 47 48 -1 -1  0 -1 -1 -1 115114113112113-1 -1 -1 -1 -1  0 -1 -1 -1 118117116-1 -1 119118119120121122-1  0  0
-1  0  0 -1 27 28 -1 32 -1 36 37 -1 45 46 -1 48 -1  0  0  0 -1 114-1 112111-1 -1 -1 -1  0 -1 -1 121-1 119118117116115114-1 -1 117118119-1 121122123 0
-1 -1 -1 -1 -1 29 30 31 -1 37 -1 43 44 45 -1 47 -1  0  0 -1 114113112111110109108107-1 -1 -1 12112011911811 7-1 115114113114115116117118119120121122123
-1  0 -1 -1 -1 -1 -1 39 38 -1 42 43 44 46 -1 -1 -1 116115-1 -1 -1 -1 108-1 106-1 -1  0 -1 -1 -1 -1 116-1 -1 113112-1 -1 115116-1 120121-1 123 0
-1  0 -1 -1  0 -1 -1 41 40 39 40 41 -1 45 46 -1 -1 -1  0 -1 -1 -1 -1  0 -1 107106105-1 -1 -1 -1 118117116115114113112111112113114115-1 119-1 121122123
 0  0  0 -1  0  0 -1 -1 41 40 41 -1 -1 -1 47 48 49 50 -1 54 -1 -1 -1 -1 -1 108-1 104103-1 119-1 117116115114115-1 111110-1 114115116117118119120121122
-1 -1 -1  0  0 -1  0 -1 42 -1 -1  0 -1  0 -1 -1 50 51 52 53 -1 -1 -1  0 -1 -1 -1 103102-1 118117116115114113-1 -1 110109-1 115-1 -1 118119120121122123
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-1  0  0 -1 -1 -1 -1 45 44 45 46 47 -1 -1 54 53 52 53 54 -1 -1 57 -1 67 66 65 66 -1 100-1 98 -1 116115114113-1 109-1 107-1 109110-1 120-1 -1 123 0  0
-1  0  0  0 -1 50 -1 46 45 46 -1 48 49 -1 -1 54 -1 -1 55 -1 -1 58 59 -1 -1 64 -1 -1 99 98 97 98 -1 116-1 -1 -1 108107106107108-1 -1 121122123 0  0  0
 0  0  0 -1 50 49 48 47 46 47 48 -1 -1  0 -1 -1  0  0 -1 61 60 59 60 61 62 63 -1  0 -1 -1 96 97 -1 -1 -1  0 -1 109-1 105-1 -1 108109-1 -1 -1 -1  0 -1
 0  0 -1 -1 -1 50 -1 48 -1 48 49 50 51 -1  0 -1  0 -1 -1 62 61 60 -1 62 63 -1  0 -1 93 94 95 96 97 98 99 -1 101-1 105104-1 -1 107108-1 110111112-1 116
 0  0  0  0 -1 -1 -1 49 -1 -1 50 -1 -1 -1  0 -1 -1 67 -1 63 -1 61 62 -1 64 65 -1 93 92 -1 96 97 96 -1 10099 100101-1 103-1 105106107108109-1 113114115
 0 -1  0  0 -1  0 -1 -1  0  0 -1 -1  0 -1 -1 67 66 65 64 65 -1 63 -1 65 -1 -1 -1 91 92 -1 -1 95 96 -1 98 99 100101102103104105-1 109110111-1 -1 -1
 0 -1  0 -1 -1  0 -1  0  0 -1  0 -1 -1  0 -1  0 -1 67 -1 -1 66 -1 64 65 66 67 -1 89 90 91 -1 -1 94 95 96 97 98 99 100-1 104-1 -1 111110111112-1 -1 117
 0  0  0  0  0  0  0 -1  0  0  0 -1  0  0 -1  0 -1 71 70 -1 -1 65 -1 67 -1 -1 88 89 90 -1 -1 93 94 -1 -1 97 -1 -1  0 -1 -1 111110111112113114115116
 0  0  0 -1  0 -1 -1 -1  0  0  0  0  0 -1 -1  0 -1 70 69 68 67 66 67 -1 87 86 87 88 89 90 91 92 93 94 95 96 -1  0  0 -1  0 -1 109110-1 114115-1 117
 0  0 -1 -1  0  0 -1  0  0  0  0 -1  0 -1  0 -1 -1 72 71 -1 -1 68 -1 -1  0 -1 85 -1 89 90 -1 92 93 94 -1 96 97 98 -1 -1 -1 -1 107108-1 116115116-1 118
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 0  0 -1 -1  0  0 -1  0  0 -1 -1 -1 86 -1 -1 -1 -1 73 74 -1  0  0 -1  0  0 -1 -1 77 -1 79 -1 81 -1 85 86 87 86 87 88 89 90 91 92 93 94 -1  0  0  0
 0  0 -1 -1  0  0  0 -1 -1 -1 87 86 85 -1 -1 -1 75 74 -1  0 -1  0  0 -1  0 -1 -1 81 80 -1 82 83 84 85 86 87 88 89 90 -1 92 93 94 95 96 -1  0 -1
 0 -1  0  0  0 -1  0 -1 -1 92 -1 88 -1 84 83 82 -1 76 75 76 -1  0  0 -1 -1 -1 87 86 -1 -1 81 82 -1 84 85 86 87 88 -1 90 91 92 93 94 95 -1 97 98 -1 102
-1 -1 -1  0 -1 -1  0 -1 92 91 90 89 -1 83 82 81 -1 77 76 77 -1 -1  0 -1 -1 -1 86 85 84 83 82 83 84 85 86 -1 -1 89 90 91 -1 -1 -1 95 96 97 98 99 100101
-1 -1  0 -1 -1 -1 -1 94 93 -1 -1 -1 83 82 81 80 79 78 77 78 -1 82 -1  0 -1 88 87 86 -1 -1 -1 84 85 86 87 -1 95 -1 91 92 93 -1 97 96 97 -1 99 100101102
-1  0  0  0  0  0  0 -1 -1 -1 86 85 84 -1 82 81 80 -1 78 79 80 81 -1 -1 -1 -1 -1 87 -1 97 -1 85 86 87 -1 -1 94 93 92 -1 94 95 96 -1 -1 101100-1 -1 -1
-1 -1  0  0 -1 -1 -1 -1 91 -1 87 86 -1 -1 83 82 81 -1 79 80 81 82 83 -1 93 92 -1 -1 -1 96 -1 86 87 88 -1 -1 93 94 93 -1 95 96 97 -1 -1 102101-1  0  0
 0  0 -1 -1  0 -1 92 91 90 89 88 87 -1 -1 84 -1 82 -1 -1 -1 82 83 84 85 -1 91 -1 93 94 95 94 -1 -1 89 90 91 92 93 94 95 96 97 98 -1 -1 103-1 -1  0 111
-1 -1  0  0 -1 98 -1 -1 91 90 -1 88 87 86 85 -1 83 84 85 -1 83 84 85 86 -1 90 91 92 93 94 93 92 91 90 91 92 -1 94 -1 96 97 98 99 -1 105104-1 108-1 110
 0 -1 -1  0 -1 97 -1 93 92 91 -1 89 -1 87 86 87 -1 85 86 87 -1 85 86 87 88 89 90 91 92 93 94 -1 92 91 92 93 94 95 -1 -1 98 -1 -1 107106105106107108109
 0 -1  0 -1 -1 96 95 94 -1 92 -1 90 91 -1 -1 88 87 86 87 -1 87 86 -1 -1 89 -1 91 92 -1 94 -1 -1 -1 -1 -1 94 95 -1 -1  0 -1  0 -1 108107-1 107108109-1
-1  0  0  0 -1 -1 -1 -1 94 93 92 91 92 -1  0 -1 88 87 88 -1 88 87 -1 -1 90 91 92 93 94 -1  0 -1 -1 -1 96 95 96 -1 -1  0  0  0 -1 109-1 109108-1 110111
-1  0  0 -1 -1 -1 97 96 95 94 -1 92 93 94 -1 90 89 -1 89 -1 89 88 89 90 91 -1 -1 -1 95 96 -1 -1 99 98 97 96 97 -1  0  0 -1 112111110111110109110111112
```

b.ii) Total number of nodes expanded

| | | |

```
 0  1  2  3  4  5  6  7  8  9 10 -1 -1  0 -1  0 -1  0 -1  0  0 -1  0  0  0 -1 38 -1 40 41 42 43 -1 49 50 51 52 53 54 -1 -1  0  0  0  0  0 -1 81 80 79
 1 -1  3 -1 -1 -1  7  8  9 -1 11 12 -1 -1  0 -1 -1 -1  0  0  0 -1 -1  0 -1 -1 37 -1 39 40 -1 42 -1 48 49 50 -1 -1 55 56 57 -1  0 -1  0  0  0 -1 79 78
 2  3  4 -1 -1  9  8 -1 10 -1 12 13 14 -1  0 -1 24 25 -1  0 -1 33 32 -1 -1 35 36 37 38 39 40 41 -1 47 48 -1 60 -1 56 57 58 59 -1 63 -1  0 -1  0 -1 77
 3  4 -1 14 13 -1 -1 -1 11 12 -1 -1 15 -1 -1 22 23 24 -1 -1 29 -1 31 32 33 34 35 -1 39 -1 -1 42 -1 46 -1 -1 59 58 57 58 59 60 61 62 63 -1 73 -1 -1 76
 4  5 -1 13 12 -1 -1 13 12 -1 18 17 16 -1 20 21 22 -1 -1 27 28 29 30 -1 34 -1 36 -1 40 41 42 43 44 45 46 47 -1 59 -1 -1 -1 -1 62 63 -1 71 72 -1 -1 75
-1  6  7 -1 11 -1 -1 14 13 14 -1 18 17 18 19 -1 23 24 25 26 27 28 29 30 -1 38 37 38 -1 42 -1 44 -1 46 47 -1 61 60 61 -1 -1 68 -1 64 -1 70 -1 72 73 74
 8  7  8  9 10 -1 14 -1 14 15 16 -1 18 -1 -1 23 -1 -1 26 27 28 -1 30 -1 -1 -1 38 39 -1 43 44 45 46 -1 48 -1 62 61 62 -1 68 67 66 65 -1 69 70 71 -1 75
 9  8  9 -1 11 12 13 14 15 -1 17 -1 19 20 21 22 23 24 25 26 27 28 29 30 -1 40 39 40 -1 44 45 46 47 48 49 -1 63 62 63 64 -1 -1 -1 66 67 68 69 70 -1 76
10  9 10 11 12 13 -1 15 16 17 -1  0 -1 21 22 23 24 25 26 27 -1 29 30 31 -1 41 -1 41 42 -1 46 -1 48 -1 -1 -1 -1 63 -1 -1  0 -1 -1 67 68 69 70 -1 74 -1
-1 -1 -1 12 13 14 15 16 17 18 -1  0 -1 22 -1 24 -1 26 27 -1 -1 30 -1 -1 43 42 -1 42 43 44 -1 48 49 -1 -1  0  0 -1  0  0  0 -1 -1 68 69 70 71 72 73 74
18 -1 14 13 14 -1 -1 17 -1 19 20 -1 24 23 24 25 26 -1 28 29 30 -1 42 43 -1 43 44 43 -1 45 46 47 -1 -1 52 -1 -1 55 -1  0  0 -1 -1 69 68 69 70 71 72 73
17 16 15 14 15 16 17 18 -1 20 -1 24 25 24 25 -1 27 -1 29 30 31 -1 41 42 -1 44 45 44 45 46 47 48 49 50 51 52 53 54 55 -1  0  0  0 -1 67 -1 69 70 -1 74
18 -1 16 15 16 17 18 -1 22 21 22 23 24 25 26 27 -1 31 30 31 -1 -1 40 41 42 43 44 -1 46 -1 48 -1 50 51 52 53 54 -1 56 57 -1  0 -1 65 66 -1 68 69 -1 -1
19 20 -1 -1 -1 18 -1 24 23 22 23 24 25 -1 27 28 -1 32 31 32 -1 38 39 40 -1 44 45 46 47 48 49 50 -1 -1 53 54 55 -1 -1 58 59 -1 -1 64 65 66 67 -1 71 -1
20 21 -1 21 20 19 -1 -1 24 -1 -1 25 26 27 28 29 30 31 32 -1 36 37 38 39 -1 -1 -1 47 -1 -1 50 51 52 53 54 -1 56 57 58 59 60 61 62 63 64 -1 68 69 70 -1
-1 22 23 22 21 -1 25 26 25 -1 -1 -1 -1 28 -1 30 31 32 33 34 35 -1 39 40 41 42 -1 -1 53 54 -1 52 53 54 -1 58 57 58 59 60 61 62 -1 -1 65 66 67 68 -1 72
24 23 -1 23 22 23 24 25 -1 -1 30 -1 30 29 30 31 32 33 -1 35 36 37 38 39 40 -1 52 51 52 -1 54 53 -1 -1 -1 59 58 59 -1 -1 -1 63 64 65 66 67 -1 69 70 71
-1 24 25 24 23 -1 25 26 27 28 29 30 31 -1 31 32 -1 -1 37 36 -1 38 -1 40 -1 48 -1 50 -1 56 55 54 55 -1 63 -1 59 -1 63 64 65 64 65 66 67 -1 -1 70 -1 -1
26 25 -1 -1 24 25 26 27 28 29 30 -1 -1 -1 32 33 34 35 36 37 -1 39 40 41 -1 47 48 49 -1 -1 -1 55 -1 61 62 61 60 61 62 -1 66 65 66 67 68 69 70 71 -1 75
27 -1 27 26 25 26 27 -1 -1 30 -1 36 35 34 33 34 -1 36 -1 -1 -1 -1 41 42 -1 46 -1 50 51 -1 55 -1 59 60 61 62 -1 62 63 64 65 66 67 -1 69 70 71 72 73 74
-1 87 -1 27 26 27 28 29 30 31 -1 37 36 35 34 -1  0 -1 50 49 48 47 -1 43 44 45 -1 -1 52 53 54 -1 58 59 60 -1 64 63 64 65 -1 67 68 69 70 71 -1 73 -1 -1
85 86 -1 -1 -1 -1 29 -1 31 32 -1 -1 -1 36 35 36 -1 -1 51 50 -1 46 45 44 45 -1 -1 54 53 54 55 56 57 58 -1 -1 65 64 -1 66 67 68 69 70 71 72 73 74 75 -1
84 -1 -1 81 -1 79 -1 77 -1 -1 74 73 -1 37 -1 37 38 -1 -1 49 48 47 46 45 46 47 48 -1 -1 53 54 55 56 57 58 59 -1 65 66 67 -1 69 70 71 72 73 74 75 76 77
83 -1 -1 80 79 78 -1 76 75 74 -1 72 -1 -1 -1 38 -1 56 57 -1 49 48 47 46 -1 48 49 50 51 52 -1 56 57 58 59 60 -1 66 67 68 69 -1 71 -1 73 74 -1 -1 77 78
82 81 -1 -1 78 77 76 75 74 73 72 71 70 -1 72 -1 56 55 -1 -1 50 49 48 -1 -1 -1 50 51 52 53 54 -1 58 59 60 61 62 -1 66 67 68 -1 -1  0 -1 75 -1  0 -1 79
81 80 79 78 -1 -1 75 74 73 72 71 70 69 70 71 72 -1 54 53 52 51 50 49 50 51 52 51 52 -1 54 55 -1 59 60 61 62 63 64 65 -1 -1  0 -1  0 -1 -1 79 -1 81 80
80 79 78 77 76 -1 74 73 72 -1 70 -1 68 69 70 71 -1 55 54 -1 -1 51 50 -1 52 53 -1 53 -1 55 56 57 58 -1 -1 63 64 -1 66 67 -1 -1 -1 -1 76 77 78 79 80 81
81 80 79 -1 75 74 73 72 71 70 69 68 67 -1 -1 -1 -1 -1 55 -1 53 52 -1 54 53 54 55 54 55 56 57 58 59 -1 65 64 -1 -1 67 -1 71 72 -1 74 75 76 77 78 79 80
80 79 78 77 76 -1 74 73 72 -1 -1 67 66 65 -1 61 60 -1 56 55 54 53 -1 55 -1 -1 56 55 -1 57 -1 59 60 -1 66 -1 68 69 68 69 70 71 72 73 74 75 76 -1 -1 81
-1 80 -1 78 77 -1 75 -1 73 74 -1 -1 -1 64 63 -1 59 58 57 56 55 54 55 56 57 -1 -1 56 57 58 59 60 61 -1 65 66 67 -1 69 -1 -1 72 73 74 75 -1 -1 84 83 82
82 81 -1 -1 78 -1 76 77 -1 -1 66 65 64 63 62 61 60 59 58 57 56 55 56 57 58 -1 -1 -1 58 59 60 -1 62 63 64 -1 -1 71 70 71 72 73 -1 75 -1 81 -1 85 84 -1
83 82 -1 80 79 80 -1 78 -1 68 67 66 65 64 63 62 61 60 59 58 -1 -1 -1 -1 59 60 61 60 59 60 -1 64 63 64 -1 70 71 72 71 -1 73 74 75 76 -1 80 81 -1 85 86
-1 83 82 81 80 79 78 77 -1 -1 68 -1 66 65 64 -1 62 -1 -1 59 60 61 62 63 -1 61 62 61 -1 61 62 -1 64 -1 68 69 70 71 -1 75 74 75 76 77 78 79 80 -1 84 -1
83 82 81 82 -1 78 77 76 75 76 -1 -1 67 -1 65 66 -1 72 71 -1 61 62 63 -1 63 62 63 62 63 62 63 -1 65 66 67 68 69 70 71 -1 -1 76 77 -1 -1 80 81 82 83 84
82 81 80 -1 78 77 76 -1 74 -1 70 69 68 -1 66 -1 -1 71 70 71 -1 63 64 65 64 -1 64 63 64 63 64 65 66 67 -1 69 70 71 72 73 74 -1 -1 79 80 81 -1 83 84 85
81 80 79 78 77 76 75 74 73 72 71 -1 -1 68 67 68 69 70 69 -1 65 64 65 -1 65 66 -1 64 -1 64 -1 -1 67 68 69 -1 71 72 73 74 75 76 77 78 79 80 -1 84 -1 86
82 81 80 79 -1 77 -1 -1 74 -1 -1 89 88 -1 -1 -1 70 69 68 67 66 65 -1 67 66 67 66 65 -1 65 66 67 -1 69 70 71 72 73 74 75 76 77 -1 79 80 -1 86 85 86 -1
83 82 81 -1 -1 78 77 76 75 -1 -1 88 87 -1 75 -1 -1 70 -1 68 -1 66 -1 -1 -1 -1 66 -1 -1 -1 68 69 70 -1 72 -1 74 -1 -1 -1 78 -1 -1 81 82 -1 -1 87 -1
-1 83 -1 83 -1 79 78 77 -1 -1 86 -1 86 -1 74 73 72 71 70 69 -1 -1 84 83 -1 -1 -1 67 68 69 70 69 -1 -1 74 73 -1 75 76 -1 80 79 80 81 82 83 84 -1 88 89
85 84 83 82 81 80 -1 -1 -1 86 85 84 85 86 -1 74 73 72 71 -1 -1  0 -1 82 -1 84 85 -1 69 70 -1 70 71 -1 75 74 75 -1 77 78 79 80 -1 82 83 -1 85 86 87 -1
86 85 -1 83 82 81 82 -1 88 -1 84 83 84 85 -1 -1 74 73 72 73 74 -1 -1 81 82 83 84 85 -1 71 72 71 -1 77 76 -1 76 -1 78 79 80 81 82 83 84 85 86 87 88 89
-1 86 -1 84 83 -1 -1 -1 87 -1 83 82 -1 -1 -1 -1 75 74 73 74 75 -1 79 80 -1 -1 -1 86 87 -1 -1 72 -1 -1 77 78 -1 -1 79 80 81 82 83 84 -1 86 87 88 89 90
88 87 88 -1 -1 -1 88 87 86 -1 82 81 80 79 78 77 76 75 74 -1 76 77 78 -1 82 83 84 -1 88 89 90 -1 88 87 -1 -1 -1 81 80 81 -1 83 84 85 86 87 88 -1 90 91
89 88 89 90 -1 -1 -1 86 85 84 83 82 81 -1 79 -1 -1 -1 75 76 77 78 79 80 81 82 83 -1 87 88 -1 90 -1 86 85 84 83 82 81 -1 -1 -1 85 86 87 88 -1 -1 91 -1
90 -1 90 91 92 91 -1 87 -1 85 84 -1 82 83 -1 -1  0 -1 76 77 78 -1 -1 81 -1 83 84 85 86 87 88 89 88 87 86 85 84 83 82 -1 90 -1 86 -1 88 -1 94 93 92 93
91 92 91 92 -1 90 89 88 87 86 85 -1 -1 84 85 -1 -1 78 77 78 -1 82 83 -1 -1 84 85 86 87 88 -1 90 89 -1 87 -1 85 84 -1 88 89 -1 -1 -1 89 90 -1 94 93 94
92 93 92 -1 92 91 90 89 88 -1 -1 -1 86 85 86 87 -1 79 78 79 80 81 82 83 84 85 -1 87 88 89 90 -1 90 89 88 87 86 85 86 87 -1 91 92 93 -1 -1 -1 95 94 95
93 -1 93 94 -1 92 91 90 -1 98 -1 96 -1 -1 -1 88 -1 80 79 80 81 82 -1 84 85 86 87 -1 -1 -1 91 92 91 90 89 88 87 86 87 88 89 90 -1 -1  0 -1 -1 96 95 96
94 95 -1 95 94 93 -1 91 -1 97 96 95 -1 91 90 89 90 -1 -1 81 82 83 -1 85 -1 -1 88 -1 94 93 92 93 92 91 90 89 88 87 88 -1 90 91 92 93 -1  0 98 97 96 97
95 96 97 96 95 -1 93 92 93 -1 95 94 93 92 91 -1 -1  0 -1 82 -1 -1 87 86 -1 -1 89 -1 95 -1 93 -1 -1 92 -1 90 89 88 -1 92 91 92 -1 94 95 -1  0 98 97 98
```

b.iii) Maximum size of fringe during runtime

```
 0  1 -1  0 -1  0  0 -1 -1 -1 -1  0  0  0 -1 88 87 86 87 -1 -1  0 -1  0 -1 81 -1 87 86 87 88 89 90 -1 100-1 98 -1 -1 -1 -1 -1  0 -1  0 -1  0  0
 1  2 -1 -1  0  0  0 -1 -1 -1 -1 -1  0 -1 89 88 -1 -1 85 86 85 86 -1  0 -1 78 79 80 81 -1 85 86 87 -1 -1 10099 -1 97 96 -1 94 95 96 -1  0 -1 -1 -1 -1
 2 -1 -1 -1  0  0  0 -1  0 -1  0 -1 -1 -1 87 86 -1 84 -1 84 85 86 -1 78 77 78 -1 82 83 84 -1 -1 10110099 98 97 96 95 94 93 94 -1 -1 -1 96 -1 94 95
 3  4  5 -1 -1  0 -1 -1 -1 -1 96 95 94 95 -1 85 84 83 82 83 -1 -1 80 -1 76 -1 -1 83 -1 -1 104103102-1 100-1 98 97 -1 93 92 93 94 95 -1 95 94 93 94
-1  5  6  7  8 -1 16 15 -1 -1 -1 97 -1 93 -1 -1 86 -1 -1 81 -1 -1 78 79 -1 75 -1  0 -1  0 -1 105-1 -1  0 -1 -1 -1 98 -1 -1 91 92 93 94 -1 -1 -1 92 93
-1 -1 -1 -1  9 10 -1 14 -1 -1 -1 -1 -1 92 -1 88 87 -1 -1 80 79 78 77 -1 75 74 -1 -1  0  0  0  0  0  0  0  0  0  0 -1 -1 89 90 91 -1 95 -1 91 90 91 -1
 0  0 -1 -1 10 11 12 13 14 -1 -1 -1 -1 91 90 89 -1 -1 -1 81 -1 77 76 75 74 73 72 -1 -1  0  0  0  0  0  0  0  0  0  0 -1 88 -1 -1 87 -1 -1 -1 89 90 -1
-1 -1  0 -1 -1 -1 -1 14 -1 18 19 20 21 -1 -1 -1 -1 84 83 82 83 -1 75 -1 -1 -1 71 70 -1  0  0  0 -1  0  0 -1  0 -1  0 -1 86 87 88 87 86 85 -1 87 88 89 90
-1 -1  0 -1 -1  0 -1 15 16 17 -1 21 -1 -1 -1 27 28 -1 84 83 -1 75 74 73 -1 71 70 69 -1 -1  0  0 -1 -1  0  0  0 -1 86 85 -1 -1 -1 85 84 85 86 87 88 -1
-1 -1 -1  0 -1  0 -1 16 -1 18 19 -1 23 24 25 26 -1  0 -1 -1 -1 -1 72 71 70 69 68 67 -1  0 -1 -1  0  0 -1 -1 86 85 84 83 82 81 -1 83 -1 85 86 -1 -1
 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 20 21 22 23 24 25 -1 -1 -1 -1  0  0  0 -1 -1 -1 68 67 66 -1 -1 -1 -1 -1 -1 -1 87 86 -1 -1 -1 80 81 82 83 84 85 86 -1
 0 -1 -1  0  0 -1 -1  0  0 -1 -1 22 23 -1 -1 26 -1 -1  0  0  0  0  0 -1 68 67 66 65 -1 65 64 -1  0  0 -1 89 88 -1 78 77 78 79 80 -1 82 83 84 85 86
 0  0  0 -1 -1 -1  0  0 -1 -1 -1 24 25 26 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 68 -1 64 -1 64 63 64 -1  0 -1 -1 -1 74 -1 76 77 78 79 80 81 82 83 -1 87
 0 -1  0 -1  0  0  0  0  0 -1 -1 -1 -1 26 27 28 29 -1 -1 -1 41 42 43 -1 45 46 -1 -1 63 64 -1 62 -1 64 -1 -1 -1 -1 73 -1 75 -1 79 -1 -1 80 -1 82 -1 -1
-1 -1 -1 -1  0 -1 -1 -1 -1  0 -1 41 40 -1 28 -1 30 31 -1 41 40 -1 42 43 44 -1 64 63 62 -1 62 61 62 63 64 65 -1 73 72 73 74 75 -1 -1 78 79 80 81 82 83
 0  0  0 -1  0 -1 -1  0  0 -1 -1 40 39 -1 -1 36 -1 32 -1 -1 39 40 41 -1 45 -1 65 -1 61 60 -1 60 61 -1 -1 64 -1 -1 71 72 73 74 75 76 77 78 79 80 81 82
 0 -1  0 -1  0  0  0 -1 -1 -1  0 -1 38 37 36 35 34 33 34 -1 38 -1 42 43 -1 -1 -1  0 -1 59 -1 59 -1 61 62 63 -1 69 70 -1 72 73 74 75 -1 77 78 79 80 -1
 0  0  0 -1  0 -1 -1 -1 -1 -1  0 -1 39 38 37 -1 -1 -1 35 36 37 38 -1 44 45 -1 -1 -1 -1 58 57 58 59 60 -1 -1 -1 68 69 70 71 72 -1 74 -1 76 77 -1 -1  0
 0  0 -1 -1 -1  0 -1 -1  0  0 -1 40 39 38 39 -1 -1 36 -1 38 39 -1 -1 46 -1 50 -1  0 -1 56 57 58 59 60 61 -1 67 -1 -1 -1 71 72 73 74 75 76 -1 -1 -1
 0  0  0 -1  0 -1 -1 -1  0 -1 47 -1 -1 40 -1 -1  0 -1 37 38 -1 -1 -1 -1 47 48 49 50 -1 54 55 56 -1 60 -1 62 -1 66 -1 68 69 70 -1 74 75 76 77 78 79 -1
-1  0  0 -1  0 -1  0  0 -1 -1 46 -1 42 41 42 43 -1 -1 -1 -1 -1 -1 50 49 48 49 -1 51 52 53 -1 57 58 -1 62 63 64 65 66 67 -1 -1  0 -1 76 -1 -1 79 -1 85
-1  0 -1  0 -1  0  0  0 -1 45 44 43 42 -1 -1  0  0  0  0 -1 -1 50 -1 50 51 52 -1 -1 59 58 59 60 61 62 -1 66 67 -1 -1  0 -1 78 -1 80 -1 -1 83 84
-1  0 -1 -1  0 -1 -1 -1 -1  0 -1 -1 44 43 44 -1  0 -1  0  0  0  0 -1 51 -1 51 -1 53 54 -1 58 59 60 61 62 63 64 65 66 -1  0 -1 78 77 78 79 80 81 82 83
-1 -1  0  0  0 -1  0 -1  0  0 -1 46 45 44 45 -1 -1  0  0  0 -1 53 52 53 52 53 54 55 56 57 58 59 -1 63 -1 -1 -1 67 68 -1 74 -1 76 -1 80 -1 80 -1 82
 0  0 -1  0  0 -1  0 -1 -1  0 -1 47 46 -1 -1  0 -1 -1  0  0 -1 54 53 54 53 54 55 56 57 58 59 60 61 62 63 -1  0 -1 -1 74 73 74 75 -1 81 -1 79 80 81
 0  0 -1  0  0  0  0 -1  0  0 -1 47 -1 -1  0 -1  0 -1 -1  0 -1 55 54 55 54 55 -1 -1 58 -1 60 61 62 63 64 65 -1 69 70 -1 72 -1 74 -1 -1 77 78 79 80
 0 -1 -1 -1 -1 -1 -1  0 -1  0 -1 -1 -1 -1  0  0 -1 -1  0 -1 -1  0 -1 55 56 -1 56 57 58 59 60 -1 62 -1 -1 65 66 67 68 69 70 71 72 73 74 75 76 -1 80 81
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-1  0  0  0 -1  0 -1 -1 -1 88 87 86 85 86 -1 -1 -1  0  0 -1 65 -1 61 -1 59 60 -1 60 61 62 63 64 65 -1 69 70 71 72 73 72 73 74 -1 76 -1 78 -1 82 83 84
 0 -1 -1 -1  0  0 -1 89 88 -1 -1 -1 84 85 -1  0 -1 -1 -1 65 64 63 62 -1 -1 -1 62 61 62 63 64 65 66 67 68 69 70 -1 -1 -1 74 75 -1 -1 80 79 80 81 82 83
 0  0 -1  0 -1 -1 89 88 87 -1 -1 -1 83 -1 -1  0 -1 -1 67 66 65 64 63 64 -1 -1 63 62 -1 -1 65 66 67 -1 -1 70 -1 -1 75 76 75 -1 81 -1 81 80 -1 82 -1 84
-1  0  0 -1 -1 95 -1 -1 86 85 84 83 82 -1 -1 -1 -1 -1 68 67 66 65 64 65 -1 65 64 -1 -1 -1 66 -1 68 -1 -1 71 72 73 74 -1 76 -1 80 -1 82 81 -1 83 84 85
 0  0 -1 96 95 94 -1 92 -1 86 -1 -1 81 82 -1 72 71 70 69 -1 67 -1 65 66 67 66 -1 70 71 72 -1 70 69 -1 73 72 73 74 75 -1 77 78 79 -1 83 82 83 84 85 86
 0  0  0 -1 94 93 92 91 -1 87 -1 -1 80 -1 76 -1 72 71 70 -1 68 67 66 67 68 67 68 69 70 71 -1 71 -1 -1 -1 -1 74 75 -1 79 78 79 80 81 82 83 -1 85 86 87
-1  0 -1 96 95 -1 91 90 89 88 -1 80 79 -1 75 74 73 -1 -1 -1 69 68 67 68 69 -1 69 -1 71 72 73 72 73 74 75 76 -1 76 77 -1 79 80 -1 82 83 84 85 86 -1 -1
 0 -1  0 -1 -1  0 -1 91 -1 -1 80 79 78 77 76 -1 -1 75 -1 71 70 69 68 69 -1 -1 70 71 72 73 74 73 74 -1 -1 77 78 77 78 79 80 81 82 83 84 85 86 87 88 -1
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 0  0 -1 -1 -1  0  0 -1  0  0  0  0 -1 -1 79 80 -1  0 -1 -1 73 72 -1 70 71 72 73 -1 73 74 75 76 -1  0 -1 80 79 -1 79 80 -1 84 83 84 -1 86 87 -1 -1 90 91
 0 -1 -1 -1 -1  0  0 -1  0 -1 82 81 80 81 82 -1 76 75 74 73 72 71 72 73 74 -1 74 75 76 77 78 -1 82 81 80 81 80 81 82 83 84 85 -1 87 -1 105-1 -1 -1
-1  0 -1 105106 0  0  0 -1 -1 -1 -1 -1 81 -1 83 84 -1 76 75 74 -1 72 73 -1 75 76 75 -1 77 78 79 -1 83 82 81 -1 -1 -1 -1 84 85 -1 -1 -1 -1 104103104105
 0 -1 105104105106-1  0  0  0  0  0 -1 -1 83 82 -1 78 77 76 -1 74 73 74 75 76 -1 76 77 -1 -1 80 81 -1 83 -1 87 88 89 90 -1 -1 97 98 99 100-1 102103104
 0 -1 104103-1 -1 100-1 -1  0 -1  0 -1 83 82 81 80 79 -1 77 76 75 74 -1 76 -1  0 -1 78 -1 82 -1 -1 85 84 85 86 -1 -1 -1 94 95 96 97 -1 99 100101102103
 0 -1 -1 102-1 -1 99 -1 -1  0 -1 -1 85 84 83 82 81 80 79 78 77 -1 -1 -1 -1 -1 -1 -1 79 80 81 -1 85 86 -1 -1 87 88 -1 92 93 94 95 96 97 98 99 -1 -1 104
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 0 -1 -1 114113-1 113-1 -1 -1 -1 -1  0 -1  0  0  0 -1 109110111112113114115116 0 -1 101100101102103-1  0 -1 107108109110-1 112-1 -1 115-1 -1 116-1 116
```

c) A∗ with Euclidean Distance Heuristic

c.i) Length of solution path returned

| | | |

| | | |

```
 0 -1  4  5 -1  0  0 -1  0  0 -1  0  0 -1 -1  0 -1 -1  0 -1  0  0  0  0 -1  0 -1  0 -1 -1  0  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1 -1  0 -1  0 -1
 1  2  3  4  5 -1 -1 -1  0 -1  0 -1 -1  0  0 -1  0  0 -1  0  0 -1 -1  0  0  0 -1  0  0 -1 -1  0 -1  0 -1  0  0  0  0 -1  0 -1  0  0 -1  0  0 -1  0  0
 2  3  4  5 -1 -1  0 -1 -1  0  0  0 -1  0  0  0 -1 -1 -1 -1  0 -1  0 -1  0  0  0  0 -1  0  0  0 -1  0  0  0  0 -1 -1  0 -1  0  0  0 -1  0  0 -1  0  0
-1  4  5  6  7 -1 -1  0  0  0 -1 -1  0  0 -1  0  0 -1  0 -1  0 -1  0 -1  0 -1  0  0  0  0  0  0 -1 -1 -1 -1  0  0  0  0 -1 -1 -1 -1  0  0 -1 -1 -1  0
 6  5  6 -1  8 -1 12 -1 -1  0 -1 -1  0  0 -1 -1  0  0  0 -1  0  0 -1  0  0  0 -1 -1 -1 -1  0  0  0  0 -1 -1  0  0  0  0 -1  0  0  0  0 -1  0  0  0 -1  0
-1 -1 -1 10  9 10 11 12 13 -1  0  0 -1  0 -1 -1  0 -1 -1 -1  0  0  0  0 -1  0 -1  0  0  0  0 -1  0 -1  0 -1  0  0  0  0  0  0  0 -1 -1  0 -1 -1 -1  0 -1
-1 -1 -1 11 -1 11 12 -1 -1  0  0  0  0 -1 -1  0 -1 -1 -1  0  0  0 -1  0 -1  0  0  0  0  0  0  0 -1 -1  0 -1  0  0  0  0 -1  0  0  0  0  0 -1 -1 -1
-1 14 13 12 13 12 -1 -1  0 -1  0  0  0  0  0  0  0 -1  0  0 -1  0  0 -1 -1 -1 -1  0  0  0 -1  0  0 -1  0  0  0  0 -1  0 -1 -1 -1  0  0  0 -1 -1  0
-1 15 14 -1 -1 -1  0  0  0 -1 -1 -1 -1  0  0 -1 -1  0 -1 -1  0  0 -1  0  0 -1 -1 -1  0  0  0 -1 -1  0  0 -1  0 -1 -1 -1  0  0 -1  0  0  0 -1  0  0 -1
-1 -1 15 16 17 -1  0 -1  0  0  0  0  0  0 -1 -1  0  0 -1 -1 -1  0  0  0 -1  0 -1 -1 -1  0  0  0 -1  0  0  0  0  0  0  0  0  0 -1  0  0  0  0 -1 -1  0
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-1 -1 18 -1 -1 -1 26 27 28 29 -1 -1 -1  0  0  0  0 -1  0  0 -1 -1  0  0  0 -1 -1 -1  0  0 -1  0  0 -1 -1  0 -1  0 -1 -1  0  0 -1  0 -1  0 -1 -1  0 -1
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-1 -1  0 -1 -1  0 -1 -1 -1  0  0 -1 61 60 61 62 61 62 63 64 65 -1 67 66 67 68 -1 72 -1 72 73 74 75 76 77 -1 81 -1 83 -1 -1 -1  0  0  0  0 -1  0 -1
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 0  0 -1 -1  0  0  0  0  0  0 -1 -1 -1  0  0 -1  0  0 70 71 72 73 72 73 74 75 76 77 78 79 80 -1 -1  0 -1 85 86 -1 88 89 90 91 92 -1 -1  0 -1  0 -1
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 1  2  3 -1 -1  6  7  8  9 10 -1 -1  0  0  0  0  0 -1  0  0  0 -1 -1 -1  0  0 -1  0  0  0 -1 -1  0  0 -1 -1  0  0 -1  0 -1 -1  0  0  0 -1  0 -1 -1  0
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-1 19 18 17 -1  9 10 11 12 -1 -1 -1 -1 55 54 -1 -1 55 -1 -1 -1 -1 -1  0  0  0 -1  0  0  0  0  0  0  0 -1 -1  0 -1  0 -1 -1  0 -1  0  0 -1  0 -1  0
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18 17 16 15 14 13 12 13 14 -1 -1 -1 56 -1 52 51 52 53 54 -1 -1 -1  0  0  0 -1  0 -1 -1  0  0  0 -1 -1  0  0  0  0 -1  0  0  0  0 -1 -1  0 -1  0
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58 57 56 -1 -1 -1 56 57 -1  0 -1 -1  0 -1  0  0 -1  0  0  0 -1 -1  0 -1 85 84 83 -1 81 -1 83 -1 85 86 -1 88 89 90 -1 94 93 94 -1  0  0 100 0  0 -1
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-1 61 60 61 62 -1 68 -1  0  0  0 -1  0  0 -1  0  0  0  0  0  0  0  0  0 -1  0 -1 -1 89 88 -1 -1 -1 -1 -1  0  0 -1 -1 10099 98 99 100101102103104-1
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c.iii) Maximum size of fringe during runtime

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-1  0  0 -1  0 -1  0 -1  0 -1 -1  0  0 69 70 -1 -1 -1  0 75 76 -1 78 79 80 81 -1  0  0 -1  0  0 88 87 -1 87 88 -1 92 -1 94 93 94 95 -1 97 -1 -1
 0 -1  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0  0 -1  0  0  0 -1 -1  0 -1 -1 -1  0  0 -1  0 -1  0 -1 89 90 91 -1 95 94 95 -1 99 98 99 100
-1 -1  0 -1  0  0 -1  0 -1  0  0  0  0  0  0  0 -1  0 -1  0  0 -1  0 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1  0 -1 -1 91 92 93 94 95 96 97 98 99 100101
-1 -1 -1 -1  0 -1 -1  0  0 -1  0  0 -1 -1  0  0 -1 -1  0  0  0  0  0  0  0  0  0 -1 -1 -1 -1  0  0  0  0  0  0 -1 93 94 95 96 97 98 99 -1 101102
-1  0  0 -1  0  0  0  0  0 -1  0  0  0  0  0 -1 -1  0  0  0 -1 -1  0  0 -1 -1  0  0 -1 -1  0  0  0  0 -1  0  0  0 -1 94 -1 96 97 -1 -1 100101102103
 0  0 -1 -1 -1  0  0 -1 -1 -1 -1  0  0 -1 -1  0  0  0  0 -1  0  0  0  0  0 -1 -1  0  0  0  0  0  0  0 -1  0  0  0  0 95 96 97 -1  0  0 -1 -1  0 104
```

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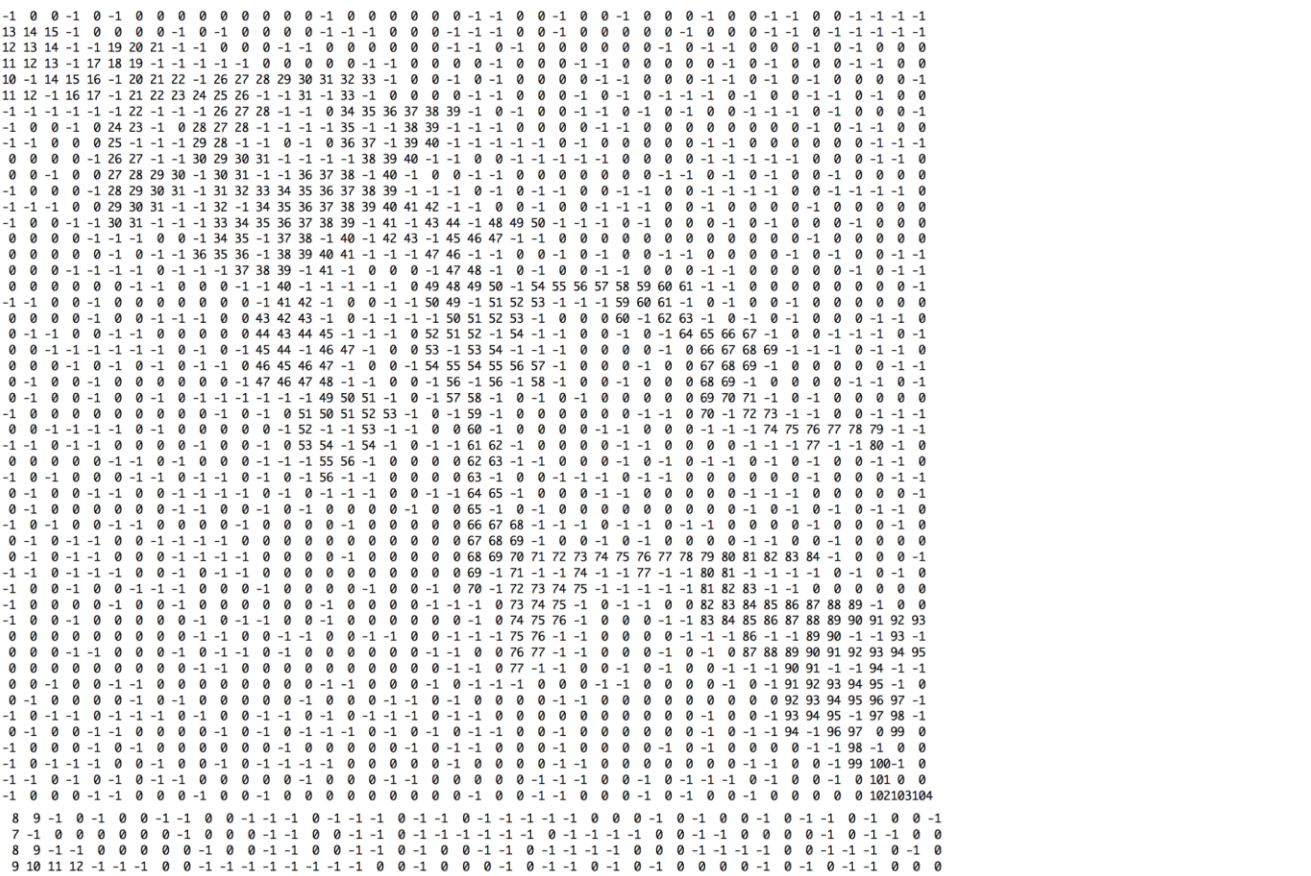

d.iii) Maximum size of fringe during runtime

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