Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)

AI Project I Report

Instructions on how to run the program:

To run our program, navigate to the working directory and run “python test.py” on the command line. You’ll be asked to provide the file paths of the input and output file (you want to save to) and the value of k (penalty) for the step cost function. To visualize the solution path, remove the first four lines of text from your output file and run “python vis.py [name of output file]” on the command line to see an illustration of the path.

Test.py source code:

```
import heapq

import math

import sys


# List of all possible directions the robot could move in the grid

directions = [(0, 1), (1, 1), (1, 0), (1, -1), (0, -1), (-1, -1), (-1, 0), (-1, 1)]


# Used to make the origin as the top-left corner initially to make it easier for us to work on the grid

def flipGrid(grid):

    return grid[::-1]


# Check if input grid is valid as per the instructions of input format

def checkInputGrid(start, goal, grid):

    # Number of rows = 30

    # Number of cols = 50

    # Start position depicted by '2' in grid

    # End position depicted by '5' in grid

    if len(grid) == 30 and len(grid[0]) == 50 and grid[goal[1]][goal[0]] == 5 and grid[start[1]][start[0]] == 2:

        return True
```

```
    return False

# Read input file returns start, goal, and grid
def read_input(file_path):
    with open(file_path, 'r') as file:
        # Read start and goal positions
        start_goal_line = file.readline().strip()
        start_i, start_j, goal_i, goal_j = map(int, start_goal_line.split())
        start = (start_i, start_j)
        goal = (goal_i, goal_j)
        # Read the workspace grid
        grid = []
        for _ in range(30):  # 30 rows as specified
            row = list(map(int, file.readline().strip().split()))
            grid.append(row)
    grid = flipGrid(grid)
    res = checkInputGrid(start, goal, grid)
    if not res:
        print('Inavlid input file. Please check specifications.')
        sys.exit(0)
    return start, goal, grid, res

def heuristicFunction(currPos, goalPos):
    # Euclidean distance as a heuristic, ensuring non-negative values
    return math.sqrt((goalPos[0] - currPos[0]) ** 2 + (goalPos[1] - currPos[1]) ** 2)

# Create a list of all valid neighbours
def get_neighbors(position, grid):
    neighbors = []
```

```
    # Use directions list to compute all possible neighbour indices in grid
    for direction in directions:
        new_i = position[0] + direction[0]
        new_j = position[1] + direction[1]
        # Do not include neighbours if out of bounds or black cells
        if 0 <= new_i < len(grid[0]) and 0 <= new_j < len(grid) and grid[new_j][new_i] != 1:
            neighbors.append((new_i, new_j))
    return neighbors


# Calculate stepcost = angular + distance cost
def stepCost(k, start, currPos, nextPos):
    direction = (nextPos[0] - currPos[0], nextPos[1] - currPos[1])
    # Ensure distCost calculation only involves real numbers
    distCost = math.sqrt(direction[0] ** 2 + direction[1] ** 2)
    if distCost == 1.0 or distCost == math.sqrt(2):
        # Handle angleCost calculation
        if currPos == start:
            angleCost = 0 # Angle cost is 0 for start as mentioned in question
        else:
            # Calculate difftheta
            diffTheta = abs(math.atan2(direction[1], direction[0]) * 180 / math.pi)
            # Adjust difftheta if more than 180
            if diffTheta > 180:
                diffTheta = 360 - diffTheta
            angleCost = k * (diffTheta / 180)
        return distCost + angleCost
    else:
        print(direction)
        print(distCost)
```

```
        print('Invalid distance cost while calculating step cost for neighbour.')
        sys.exit(0)

# Run the A* search algorithm
def a_star_search(start, goal, grid, k):
    # Open list is the Frontier (Sorted based on f(n) values of nodes)
    open_list = []
    heapq.heappush(open_list, (heuristicFunction(start, goal), start))
    # Came from keeps track of the parent node
    came_from = {start: None}
    # g_score / f_score dictionaries keep track of the scores
    g_score = {start: 0}
    f_score = {start: heuristicFunction(start, goal)}

    # While frontier not empty
    while open_list:
        f_score_curr, current = heapq.heappop(open_list)
        # If goal found in frontier return solution
        if current == goal:
            path = []
            while current:
                path.append(current)
                current = came_from[current]
            # Reverse path (Start goes to begining and Goal to end)
            path.reverse()
            return path, f_score, len(came_from)

        # If goal not found as current node explore neighbours to add to tree
        for neighbor in get_neighbors(current, grid):
```

```
            step_cost = stepCost(k, start, current, neighbor)
            # Update g_score of neighbours
            tentative_g_score = g_score[current] + step_cost
            tentative_f_score = tentative_g_score + heuristicFunction(neighbor, goal)
            # If lower f_score found for neighbor update dictioaries
            if neighbor not in g_score or tentative_f_score < f_score[neighbor]:
                came_from[neighbor] = current
                g_score[neighbor] = tentative_g_score
                f_score[neighbor] = tentative_f_score
                # Push new values to heap for resorting for next iteration
                if isinstance(f_score[neighbor], float) and not isinstance(f_score[neighbor], complex):
                    heapq.heappush(open_list, (f_score[neighbor], neighbor))
    # If no solution found
    return None, float('inf'), len(came_from)

def write_output(file_path, path, f_score, total_nodes, grid):
    with open(file_path, 'w') as file:
        # Depth of goal node = len(path) [LINE 1]
        file.write(f"{len(path)}\n")
        # len(came_from) = total_nodes [LINE 2]
        file.write(f"{total_nodes}\n")

        if path:
            moves = []
            f_score_print_list = [f_score[path[0]]]
            for i in range(1, len(path)):
                # Print index of appropriate direction
                di = path[i][1] - path[i - 1][1]
                dj = path[i][0] - path[i - 1][0]
```

```
            moves.append(directions.index((di, dj)))
            # Print f_score of each node in solution path
            f_score_print_list.append(f_score[path[i]])
            # Number of f_scores should be one more than number of directions
            if len(f_score_print_list) != (len(moves) + 1):
                print('Error in output format creation.')
                sys.exit(0)
            # Replace path grid indices with '4' instead of '0'
            if i < len(path) - 1:
                grid[path[i][1]][path[i][0]] = 4
        file.write(" ".join(map(str, moves)) + "\n") # [LINE 3]
        file.write(" ".join(map(str, f_score_print_list)) + "\n") # [LINE 4]

    # Updated grid
    grid = flipGrid(grid)
    for i in range(len(grid)):
        line = " ".join(map(str, grid[i]))
        file.write(line + "\n") # [LINE 5-34]

# MAIN
file_path = input('Enter filepath / filename: ')
start, goal, grid, res = read_input(file_path)
k = int(input('Enter value for k: '))
path, f_score, total_nodes = a_star_search(start, goal, grid, k)
write_output('Output1.txt', path, f_score, total_nodes, grid)
```

Output of Input1.txt [k = 0]:

32

194

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)

0 0 7 7 7 7 7 7 7 7 0 0 0 0 1 0 0 0 0 0 0 0 7 7 0 0 0 0 0 7 0

32.57299494980466 32.622776601683796 32.67572330035593 32.82509590207858 32.988682805403634 33.1684647227918 33.366774513857266 33.586369156128 33.830516434096076 34.103098247786185 34.40873160871375 34.413459741226546 34.41868167352756 34.4244787752596 34.43095126760845 35.006742657457565 35.02498060213621 35.045743124634214 35.06958612548419 35.097238938210836 35.12967631234924 35.16822857026841 35.214755041863 35.388346874966274 35.627416997969526 35.63911171640227 35.65536869969684 35.67945481172171 35.71862684627243 35.792417163603844 35.97056274847714 35.97056274847714

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 0 0 0 0 0 0 0 0

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0 0 0 1 1 1 1 1 1 1 0 4 0 0 1 1 0 0 1 1 0 1 1 1 1 1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 1 0 0 0 0 4 0 1 1 1 0 1 0 0 1 1 1 1 1 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 0 0 0 0 0 4 0 1 1 0 0 0 0 0 0 1 1 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 1 0 0 0 0 0 4 1 1 1 0 0 1 1 0 0 1 1 0 0 1 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 0 1 1 1 0 1 1 0 0 0 4 1 1 0 0 0 4 4 4 4 4 4 4 4 1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 1 1 0 0 0 0 4 4 4 4 4 1 0 0 0 0 0 0 0 4 1 1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0

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0 0 0 1 1 0 1 1 1 0 1 1 0 0 0 1 1 0 0 0 0 1 1 1 0 0 1 1 0 0 4 4 4 4 4 4 1 0 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1 1 4 5 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 0 0 0 0 1 1 0 0 1 1 0 1 1 1 1 0 0 1 1 1 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 1 1 1 0 0 0 0 0 0 1 1 0 0 1 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

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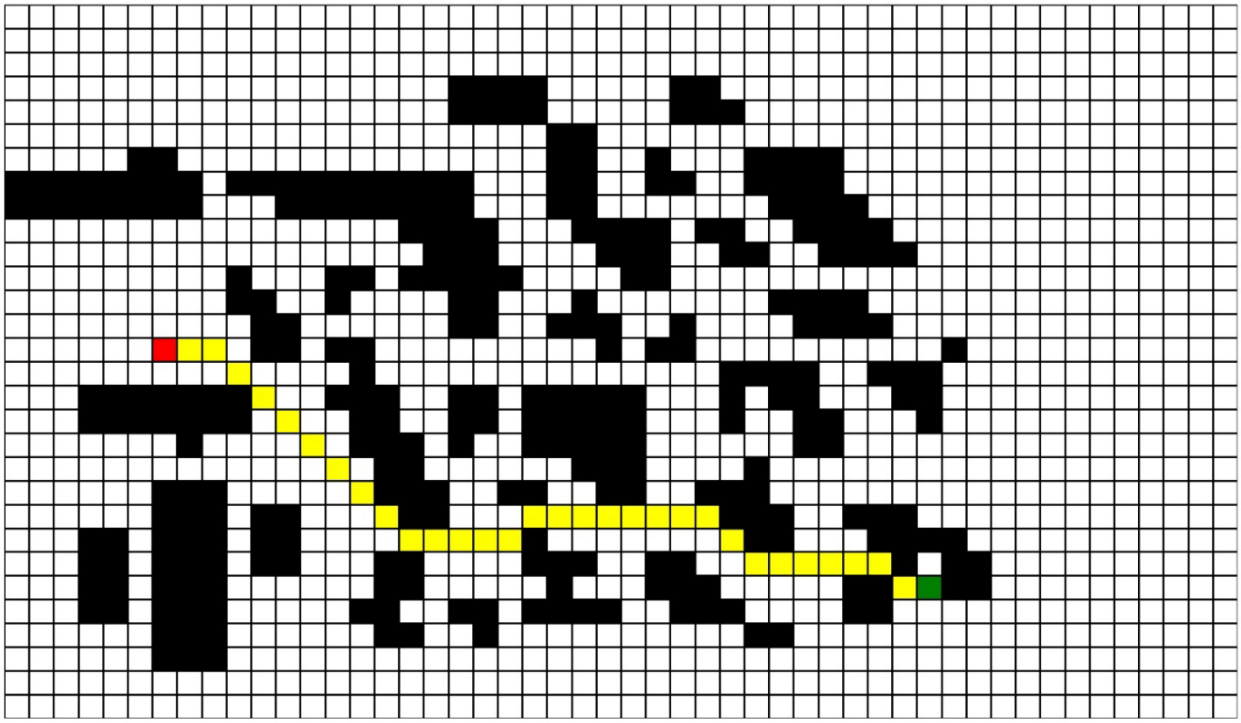
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0



Output of Input1.txt [k = 2]:

32

282

7 0 0 7 7 7 7 7 7 0 0 0 0 1 0 0 0 0 0 0 0 7 7 0 0 0 0 0 7 0

32.57299494980466 32.73513308910474 32.778666463751044 32.82509590207858
33.488682805403634 34.1684647227918 34.866774513857266 35.586369156128
36.330516434096076 37.103098247786185 37.90873160871375 37.913459741226546
37.91868167352756 37.9244787752596 37.93095126760845 39.006742657457565
39.02498060213621 39.045743124634214 39.06958612548419 39.097238938210836
39.12967631234924 39.16822857026841 39.214755041863 39.888346874966274

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Rohaan Advani (rna3535)

40.627416997969526 40.63911171640227 40.65536869969684 40.67945481172171
40.71862684627243 40.792417163603844 41.47056274847714 41.47056274847714

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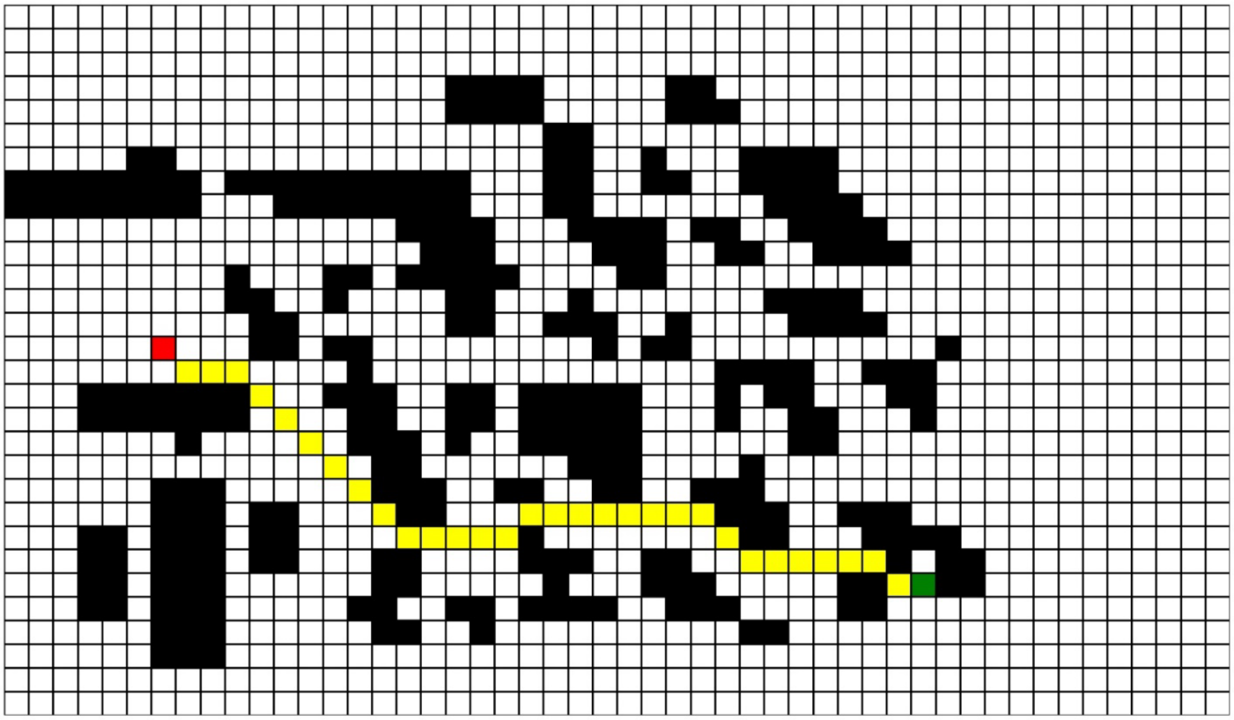
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0



Output for Input1.txt [k = 4]:

32

326

7 0 0 7 7 7 7 7 7 7 0 0 0 0 1 0 0 0 0 0 0 0 7 7 0 0 0 0 0 7 0

32.57299494980466 32.73513308910474 32.778666463751044 32.82509590207858
33.988682805403634 35.1684647227918 36.366774513857266 37.586369156128
38.830516434096076 40.103098247786185 41.40873160871375 41.413459741226546
41.41868167352756 41.4244787752596 41.43095126760845 43.006742657457565
43.02498060213621 43.045743124634214 43.06958612548419 43.097238938210836
43.12967631234924 43.16822857026841 43.214755041863 44.388346874966274
45.62741699796952 45.63911171640226 45.65536869969683 45.679454811721705
45.71862684627242 45.79241716360383 46.970562748477136 46.970562748477136

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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 0 0 0 0 0 0 0 0 0 0 0 0 0 0

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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 0 0 0 0 0 0 0 0

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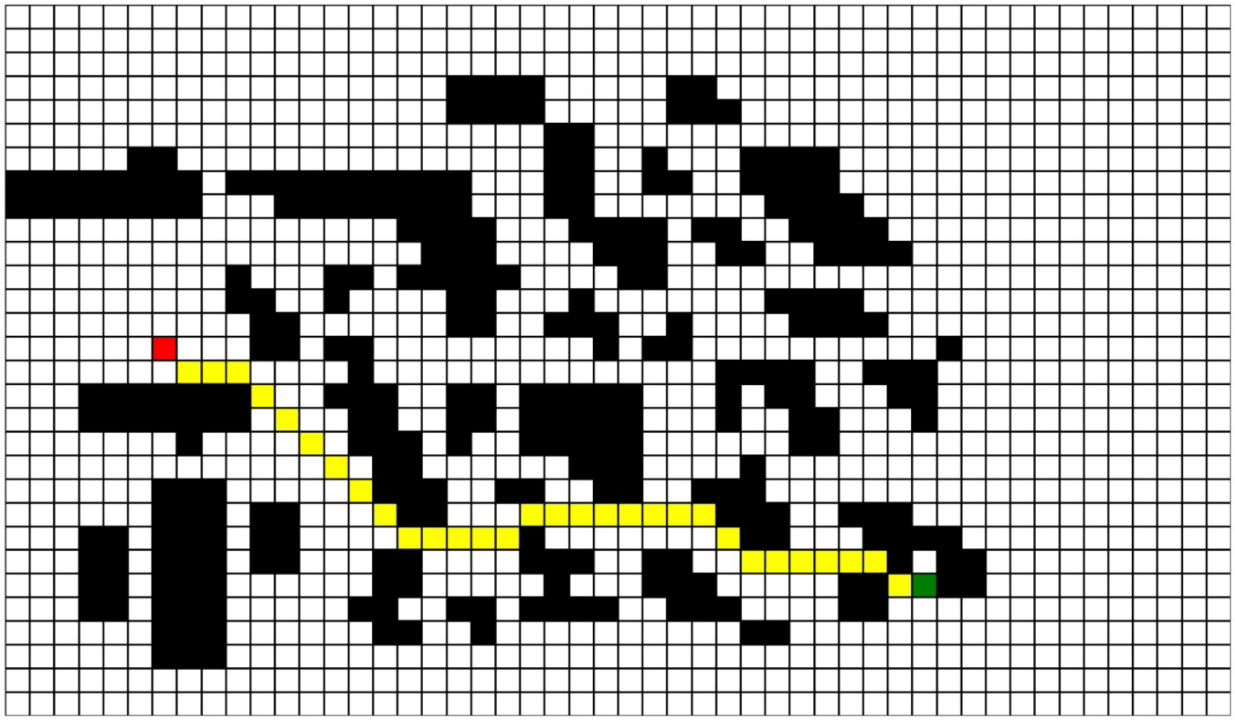

Output of Input2.txt [k = 0]:

38

380

0 0 7 0 0 1 1 1 1 1 1 0 0 0 1 1 1 2 2 2 1 0 0 0 1 1 1 2 2 2 1 1 2 1 0 0 1

37.8021163428716 38.013511046643494 38.235341863986875 39.538997298749976 39.797825588281356 40.06966046470001 40.069967401935514 40.07030161279838 40.07066690098348 40.071067811865476 40.071509822506016 40.07199959321647 40.35533905932738 40.65833174289156 40.98268409419626 40.98527659649403 40.98821368682716 40.991568865010166 41.24710879827376 41.52691193458119 41.83394163668508 41.83516978220376 42.112698372208094 42.42241793342256 42.76901958965595 42.77681122334285 42.78653056184162 42.798989873223334 43.01853433051622 43.2842712474619 43.60923954912999 43.616327673029275 43.62741699796952 44.0995529529691 44.20390822051099 44.2776985378424 44.4558441227157 44.4558441227157

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 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 1 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Kirthan Reddy (kr3026)
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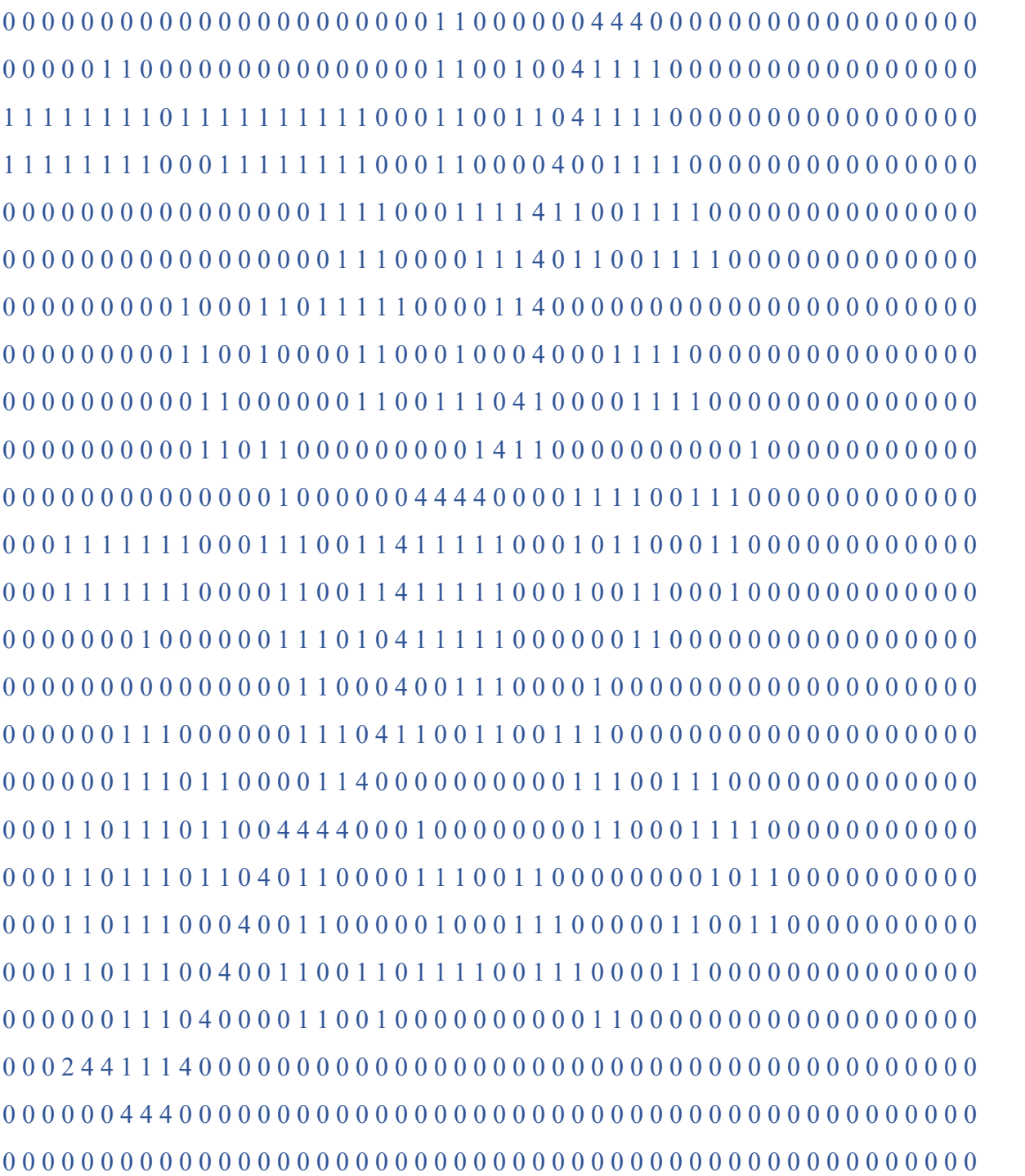

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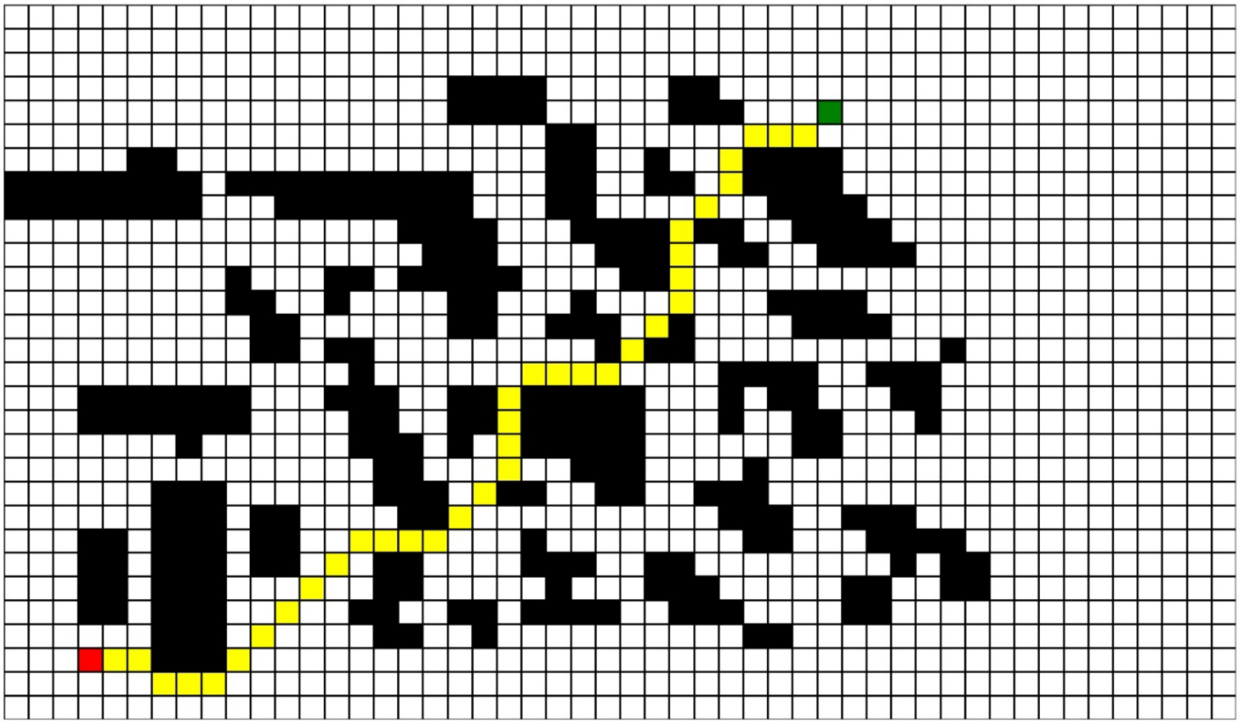


Output of Input2.txt [k = 2]:

38

599

7 0 0 0 0 0 1 1 1 1 1 1 0 0 1 1 1 2 2 2 1 0 0 0 1 1 1 2 2 2 1 1 2 1 0 0 1

37.8021163428716 39.05727401181051 39.29239139154464 39.538997298749976 39.797825588281356 40.06966046470001 40.35533905932737 40.85533905932738 41.35533905932738 41.85533905932738 42.35533905932738 42.85533905932738 43.35533905932738 43.65833174289156 43.98268409419626 44.48527659649403 44.98821368682716 45.491568865010166 46.74710879827376 48.02691193458119 49.33394163668508 49.83516978220376 50.112698372208094 50.42241793342256 50.76901958965595 51.27681122334284 51.786530561841616 52.29898987322333 53.51853433051622 54.784271247461895 56.10923954912998 56.61632767302927 57.12741699796951 58.59955295296909 59.20390822051098 59.2776985378424 59.455844122715696 59.955844122715696

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 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 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 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 1 1 1 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 1 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)

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 4 4 4 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 0 0 0 0 0 1 1 0 0 1 0 0 4 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1 1 0 4 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 0 0 4 0 0 1 1 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 0 0 0 0 0 0 0 1 1 1 1 0 0 0 1 1 1 1 4 1 1 0 0 1 1 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 0 0 0 0 0 0 1 1 1 0 0 0 0 1 1 1 4 0 1 1 0 0 1 1 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 1 1 0 1 1 1 1 1 0 0 0 0 1 1 4 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 1 0 0 1 0 0 0 0 1 1 0 0 0 1 0 0 0 4 0 0 0 1 1 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 0 0 0 0 0 1 1 0 0 1 1 1 0 4 1 0 0 0 0 1 1 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 1 1 0 1 1 0 0 0 0 0 0 0 0 0 1 4 1 1 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 1 0 0 0 0 0 0 0 4 4 4 4 0 0 0 0 1 1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 1 1 1 1 1 0 0 0 1 1 1 0 0 1 1 4 1 1 1 1 1 0 0 0 1 0 1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 1 1 1 1 1 0 0 0 0 1 1 0 0 1 1 4 1 1 1 1 1 0 0 0 1 0 0 1 1 0 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 0 0 0 1 1 1 0 1 0 4 1 1 1 1 1 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 0 0 0 0 0 0 1 1 0 0 0 4 0 0 1 1 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 1 1 1 0 0 0 0 0 0 0 1 1 1 0 4 1 1 0 0 1 1 0 0 1 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 1 1 1 0 1 1 0 0 0 0 1 1 4 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 1 1 0 0 0 4 4 4 0 0 0 1 0 0 0 0 0 0 0 0 1 1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 1 1 0 0 4 1 1 0 0 0 0 1 1 1 0 0 1 1 0 0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 0 0 4 0 1 1 0 0 0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 0 0 4 0 1 1 0 0 1 1 0 1 1 1 1 0 0 1 1 1 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0

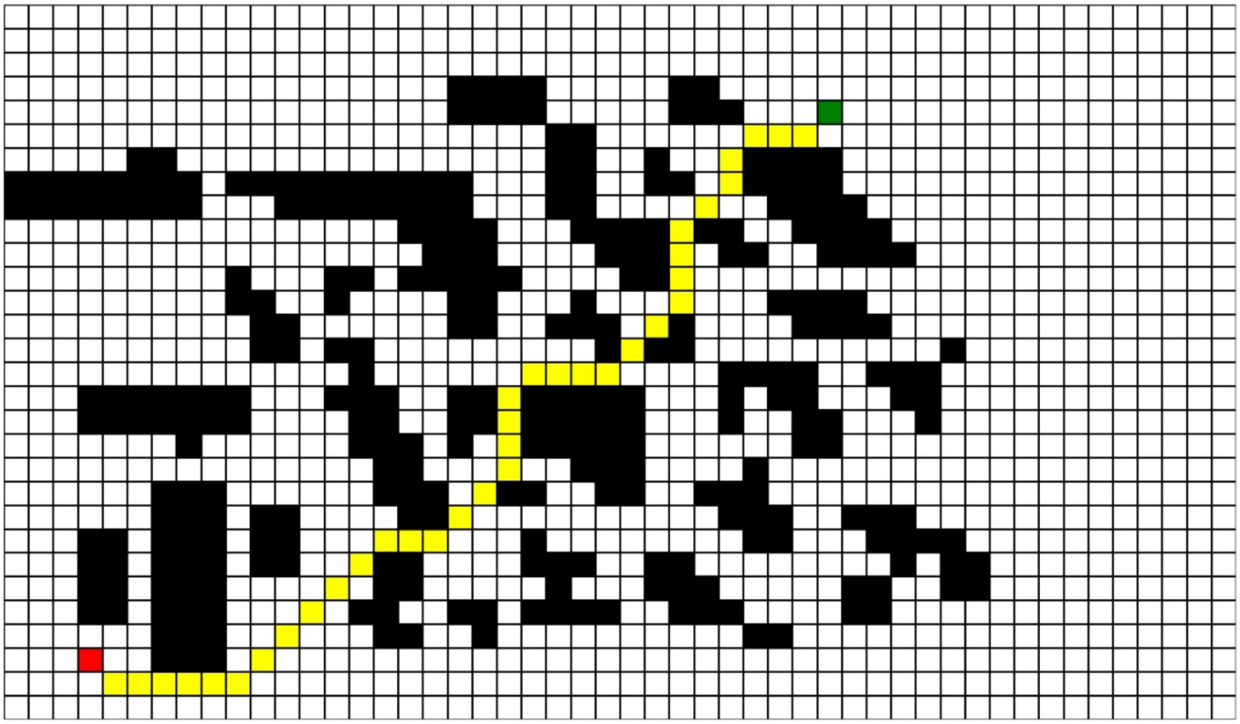
0 0 0 0 0 0 1 1 1 0 0 4 0 0 0 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 2 0 0 1 1 1 0 4 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 4 4 4 4 4 4 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 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 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)



Output for Input2.txt [k = 4]:

38

780

7 0 0 0 0 0 1 1 1 1 1 1 0 0 1 1 1 2 2 2 1 0 0 0 1 1 1 2 2 2 1 1 2 1 0 0 1

37.8021163428716 39.05727401181051 39.29239139154464 39.538997298749976 39.797825588281356 40.06966046470001 40.35533905932737 41.35533905932738 42.35533905932738 43.35533905932738 44.35533905932738 45.35533905932738 46.35533905932738 46.65833174289156 46.98268409419626 47.98527659649403 48.98821368682716 49.991568865010166 52.24710879827375 54.526911934581186 56.83394163668508 57.83516978220375 58.11269837220809 58.42241793342255 58.76901958965594 59.77681122334283 60.78653056184161 61.79898987322332 64.0185343305162 66.28427124746189 68.60923954912997 69.61632767302926 70.6274169979695 73.09955295296908 74.20390822051098 74.27769853784238 74.45584412271569 75.45584412271569

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 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 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 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 1 1 1 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 1 0 0 0 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)

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 4 4 4 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 0 0 0 0 0 1 1 0 0 1 0 0 4 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1 1 0 4 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 0 0 4 0 0 1 1 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 0 0 0 0 0 0 0 1 1 1 1 0 0 0 1 1 1 1 4 1 1 0 0 1 1 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 0 0 0 0 0 0 1 1 1 0 0 0 0 1 1 1 4 0 1 1 0 0 1 1 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 1 1 0 1 1 1 1 1 0 0 0 0 1 1 4 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 1 0 0 1 0 0 0 0 1 1 0 0 0 1 0 0 0 4 0 0 0 1 1 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 0 0 0 0 0 1 1 0 0 1 1 1 0 4 1 0 0 0 0 1 1 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 1 1 0 1 1 0 0 0 0 0 0 0 0 0 1 4 1 1 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 1 0 0 0 0 0 0 0 4 4 4 4 0 0 0 0 1 1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 1 1 1 1 1 0 0 0 1 1 1 0 0 1 1 4 1 1 1 1 1 0 0 0 1 0 1 1 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 1 1 1 1 1 0 0 0 0 1 1 0 0 1 1 4 1 1 1 1 1 0 0 0 1 0 0 1 1 0 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 0 0 0 1 1 1 0 1 0 4 1 1 1 1 1 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 0 0 0 0 0 0 1 1 0 0 0 4 0 0 1 1 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 1 1 1 0 0 0 0 0 0 0 1 1 1 0 4 1 1 0 0 1 1 0 0 1 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 1 1 1 0 1 1 0 0 0 0 1 1 4 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 1 1 0 0 0 4 4 4 0 0 0 1 0 0 0 0 0 0 0 0 1 1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 1 1 0 0 4 1 1 0 0 0 0 1 1 1 0 0 1 1 0 0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 0 0 4 0 1 1 0 0 0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 0 1 1 1 0 0 0 4 0 1 1 0 0 1 1 0 1 1 1 1 0 0 1 1 1 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0

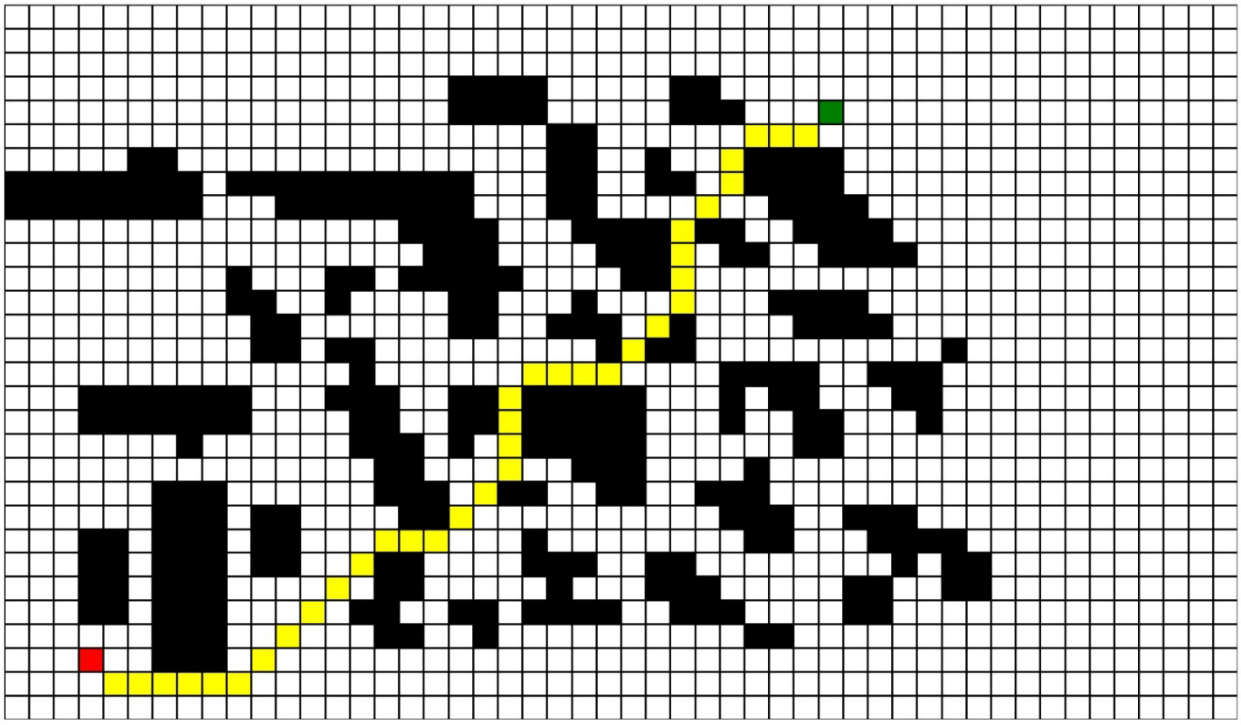
0 0 0 0 0 0 1 1 1 0 0 4 0 0 0 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 2 0 0 1 1 1 0 4 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 4 4 4 4 4 4 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 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 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)



Output of Input3.txt [k=0]:

49

395

1 1 2 2 2 2 2 1 0 0 1 1 1 1 2 1 0 0 0 0 7 0 0 0 0 0 7 0 0 0 1 1 1 1 0 0 0 0 0 0 1 0 1 0 1 0 0 1

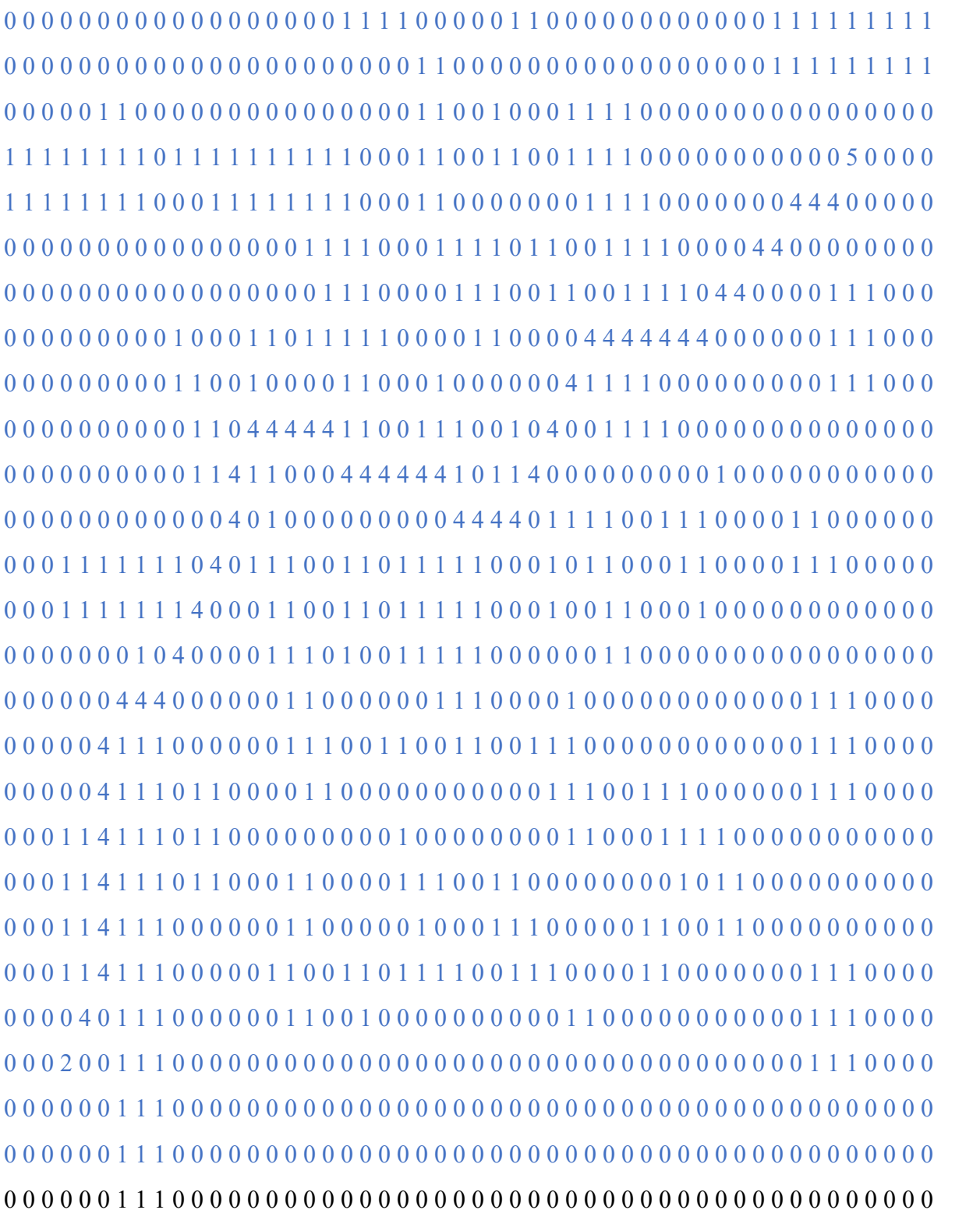
46.51881339845203 46.602707673153105 46.69185152366881 47.29105474894765
47.90974558182222 48.548445851333845 49.207667325580374 49.88790881437237
50.047052213325614 50.092358377461835 50.13994136467273 50.299914698929804
50.47161725826807 50.656292164376524 50.85534862931096 51.633750523477666
51.87134969118418 51.88901530667865 51.90782558054147 51.92789428890646
51.94935062553747 52.620573423320565 52.65374609703038 52.689432032852196
52.72792206135786 52.76955262170047 52.81471482258825 53.614340677975186
53.68279485226897 53.75766375181925 53.83985122732316 53.94112549695428
54.0585702391122 54.196164611692126 54.359209651784354 54.400460381958766
54.44810051389684 54.503689783942946 54.56931948749233 54.64784767501942
54.74326178322248 54.82897654146032 54.921407368095785 55.012581805104006
55.099552952969084 55.203908220510975 55.27769853784238 55.45584412271569
55.45584412271569

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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

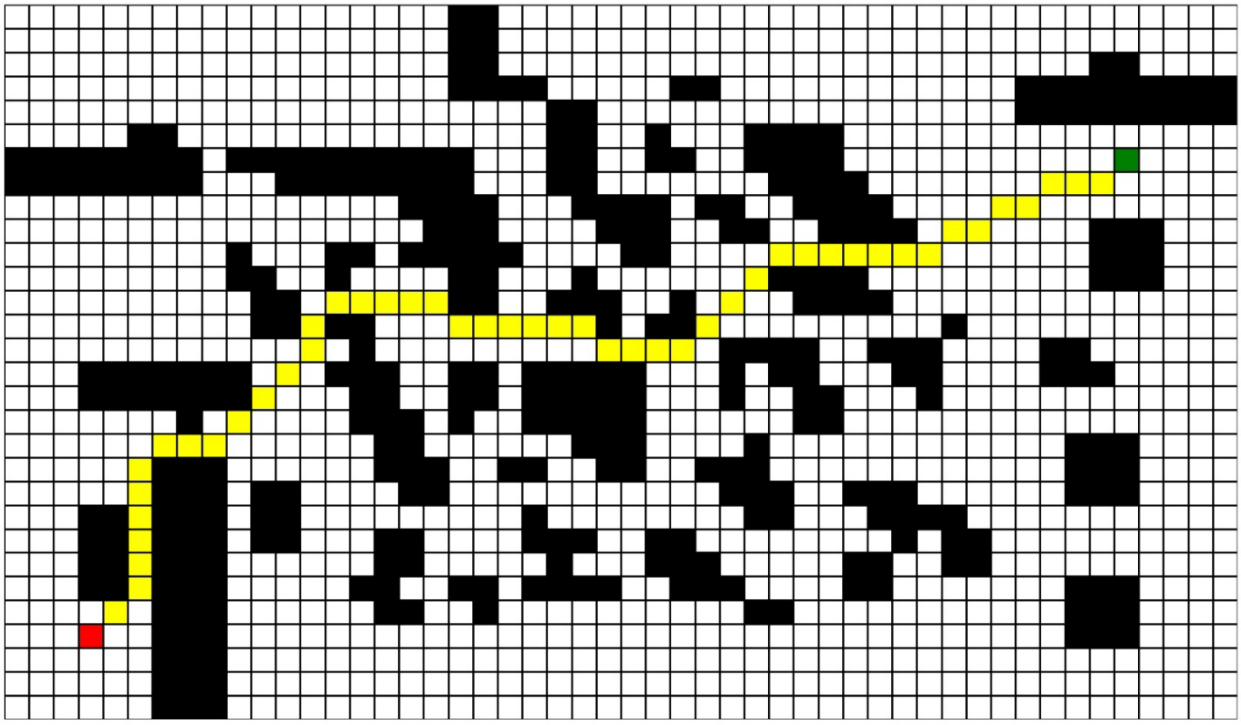
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 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 0 1 1 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)



Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)



Output for Input3.txt [k=2]:

49

571

1 1 2 2 2 2 2 1 0 0 1 1 1 1 2 1 0 0 0 0 7 0 0 0 0 0 7 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1 1

46.51881339845203 46.602707673153105 47.19185152366881 48.79105474894765
50.40974558182222 52.048445851333845 53.707667325580374 55.38790881437237
56.047052213325614 56.092358377461835 56.13994136467273 56.7999146989298
57.47161725826807 58.156292164376524 58.85534862931096 60.633750523477666
61.37134969118418 61.38901530667865 61.40782558054147 61.42789428890646
61.44935062553748 62.620573423320565 62.65374609703038 62.689432032852196
62.72792206135786 62.76955262170047 62.81471482258825 64.11434067797518
64.18279485226897 64.25766375181925 64.33985122732315 64.43042985178688
65.02059838267702 65.1092945433509 65.20882502860258 65.32117224633744
65.44879317555385 65.59475399650934 65.76290480183775 65.95810343709542
66.1864949988387 66.69010720577002 66.9558441227157 67.4558441227157
67.9558441227157 68.4558441227157 68.95584412271569 69.45584412271569
69.95584412271569

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 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 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 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 0 0 1 1 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1

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 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1

0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1 1 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 5 0 0 0 0

1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 4 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 0 0 0 1 1 1 1 0 1 1 0 0 1 1 1 1 0 0 0 0 0 0 0 4 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 1 0 0 0 0 1 1 1 0 0 1 1 0 0 1 1 1 1 0 0 0 0 0 4 0 1 1 1 0 0 0

0 0 0 0 0 0 0 0 0 1 0 0 0 1 1 0 1 1 1 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 4 0 0 1 1 1 0 0 0

0 0 0 0 0 0 0 0 0 1 1 0 0 1 0 0 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 1 1 1 1 0 0 0 0 0 4 0 0 0 1 1 1 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 0 4 4 4 4 4 1 1 0 0 1 1 1 0 0 1 0 0 0 0 1 1 1 1 0 0 4 4 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 1 1 4 1 1 0 0 0 4 4 4 4 4 4 1 0 1 1 0 4 4 4 4 4 4 4 4 4 1 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0 0 0 0 4 0 1 0 0 0 0 0 0 0 0 0 4 4 4 4 4 1 1 1 1 0 0 1 1 1 0 0 0 0 1 1 0 0 0 0 0 0

0 0 0 1 1 1 1 1 1 1 0 4 0 1 1 1 0 0 1 1 0 1 1 1 1 1 0 0 0 1 0 1 1 0 0 0 1 1 0 0 0 0 1 1 1 0 0 0 0 0

0 0 0 1 1 1 1 1 1 1 4 0 0 0 1 1 0 0 1 1 0 1 1 1 1 1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 1 0 4 0 0 0 0 1 1 1 0 1 0 0 1 1 1 1 1 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 4 4 4 0 0 0 0 0 0 1 1 0 0 0 0 0 0 1 1 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0

0 0 0 0 0 4 1 1 1 0 0 0 0 0 0 1 1 1 0 0 1 1 0 0 1 1 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0

0 0 0 0 0 4 1 1 1 0 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 1 1 1 0 0 0 0 0 0 1 1 1 0 0 0 0

0 0 0 1 1 4 1 1 1 0 1 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 1 0 0 0 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 4 1 1 1 0 1 1 0 0 0 1 1 0 0 0 0 1 1 1 0 0 1 1 0 0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 4 1 1 1 0 0 0 0 0 0 1 1 0 0 0 0 0 1 0 0 0 1 1 1 0 0 0 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0 0 0 0

0 0 0 1 1 4 1 1 1 0 0 0 0 0 1 1 0 0 1 1 0 1 1 1 1 0 0 1 1 1 0 0 0 0 1 1 0 0 0 0 0 0 0 1 1 1 0 0 0 0

0 0 0 0 4 0 1 1 1 0 0 0 0 0 0 1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0

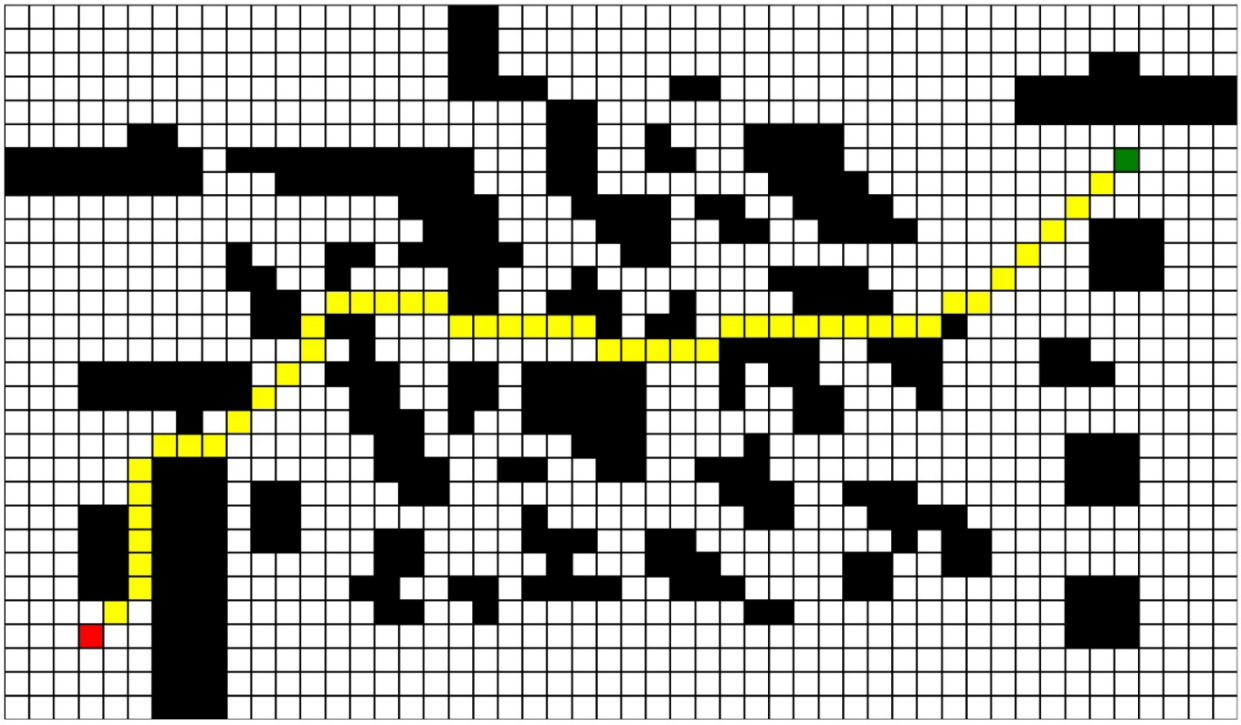
0 0 0 2 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 0 0 0 0

0 0 0 0 0 0 1 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 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 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 0 0 0 0 0 1 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)



Output for Input3.txt [k=4]:

49

678

1 1 2 2 2 2 2 1 0 0 1 1 1 1 2 1 0 0 0 0 7 0 0 0 0 0 7 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 1 1 1 1 1 1

46.51881339845203 46.602707673153105 47.69185152366881 50.29105474894765
52.90974558182222 55.548445851333845 58.207667325580374 60.88790881437237
62.047052213325614 62.092358377461835 62.13994136467274 63.299914698929804
64.47161725826807 65.65629216437652 66.85534862931095 69.63375052347766
70.87134969118418 70.88901530667864 70.90782558054147 70.92789428890646
70.94935062553746 72.62057342332056 72.65374609703036 72.6894320328522
72.72792206135784 72.76955262170047 72.81471482258824 74.61434067797518
74.68279485226896 74.75766375181925 74.83985122732315 74.93042985178688
76.02059838267701 76.10929454335088 76.20882502860256 76.32117224633744
76.44879317555385 76.59475399650934 76.76290480183773 76.9581034370954
77.18649499883868 78.19010720577 78.45584412271569 79.45584412271569
80.45584412271569 81.45584412271569 82.45584412271567 83.45584412271567
84.45584412271567

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 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 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 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 0 0 0 0 1 1 0 0 0 0

Kirthan Reddy (kr3026)
Rohaan Advani (rna3535)

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