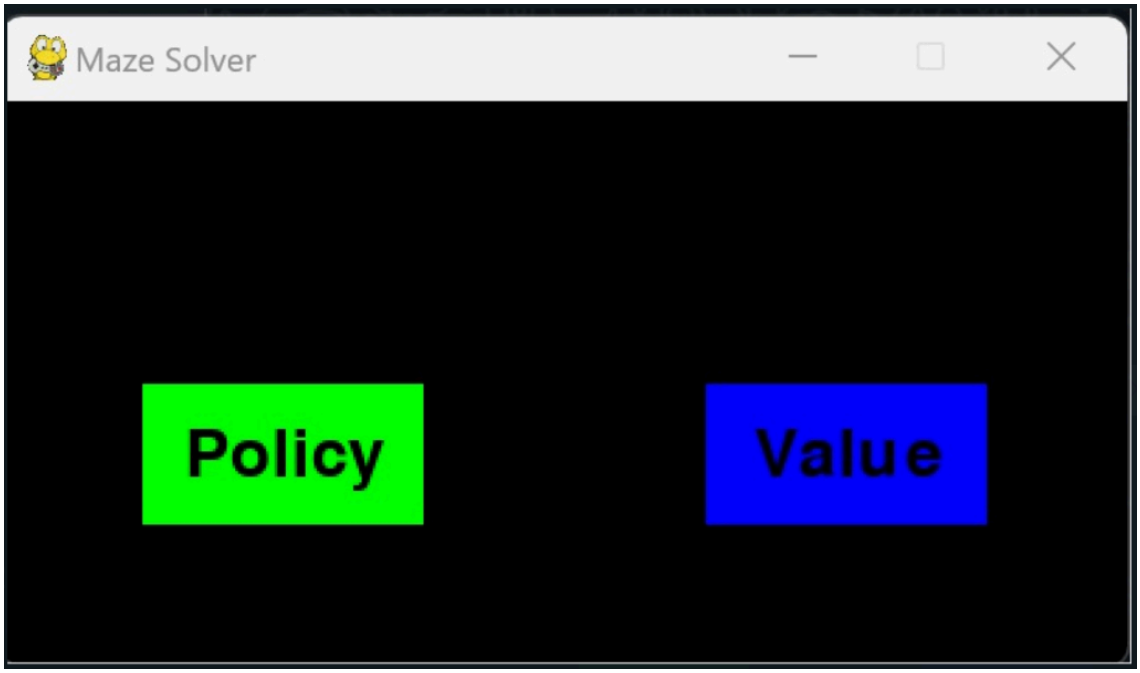
MDP Maze

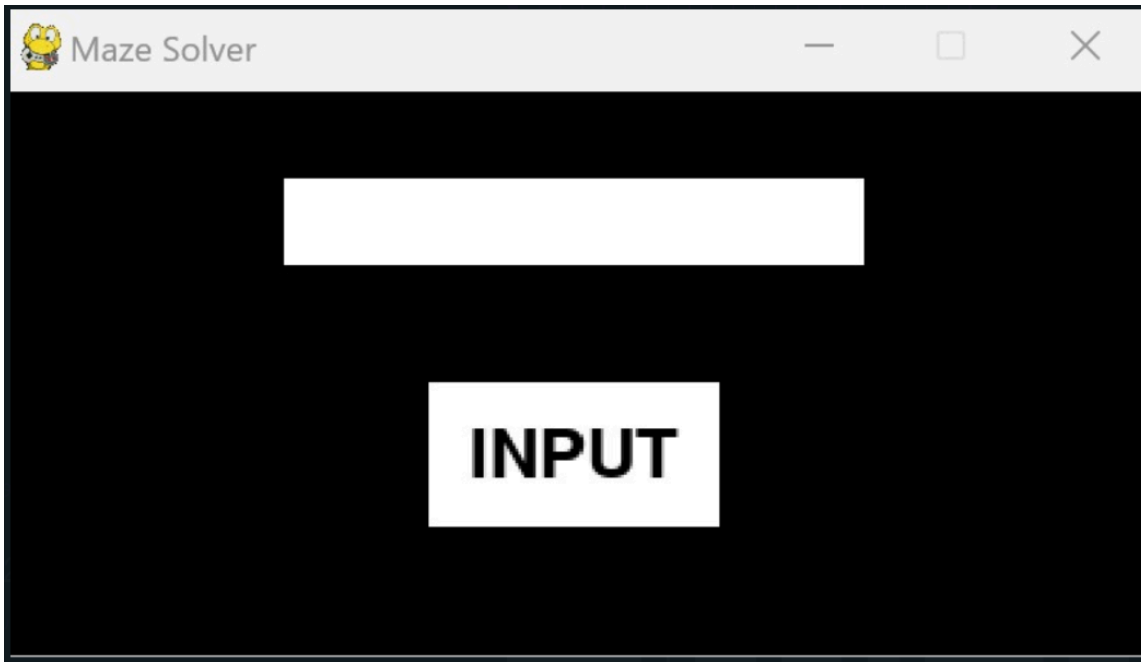
Salma ahmed sherif 7707

Mervat Tamer 7779

Menatallah Majdi 7754

This project utilises concepts learned in class (Value and Policy Iterations) to solve a Maze MDP. A maze is generated using Prim's algorithm, converted to Mdp. Then solved by value and policy Iterations.





We provide a readme for how to run the code as well as sample runs with everything required

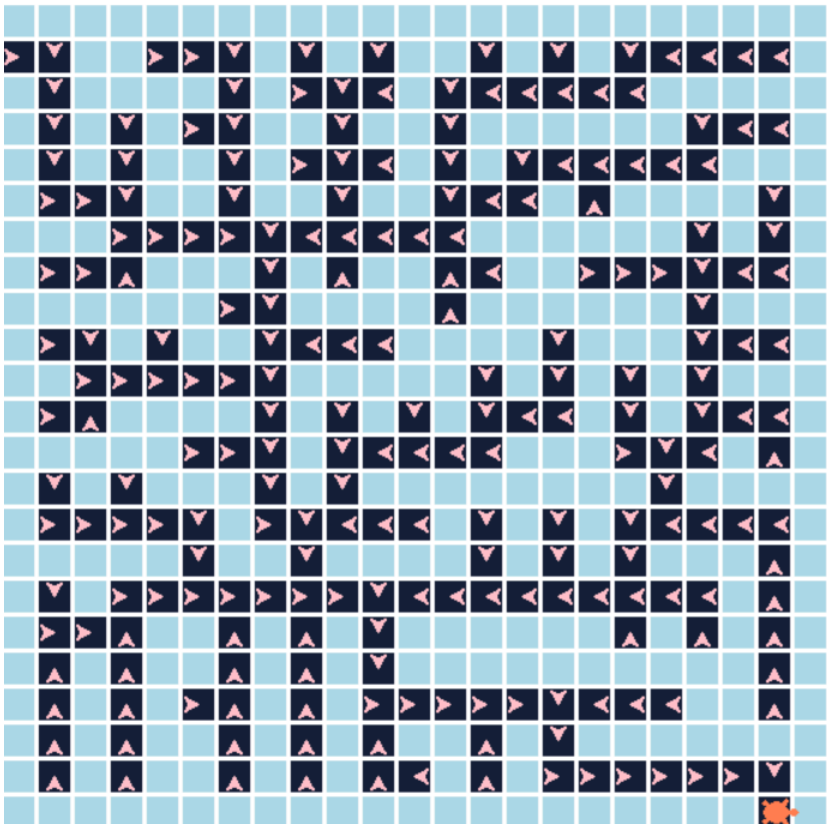
1. Assumptions

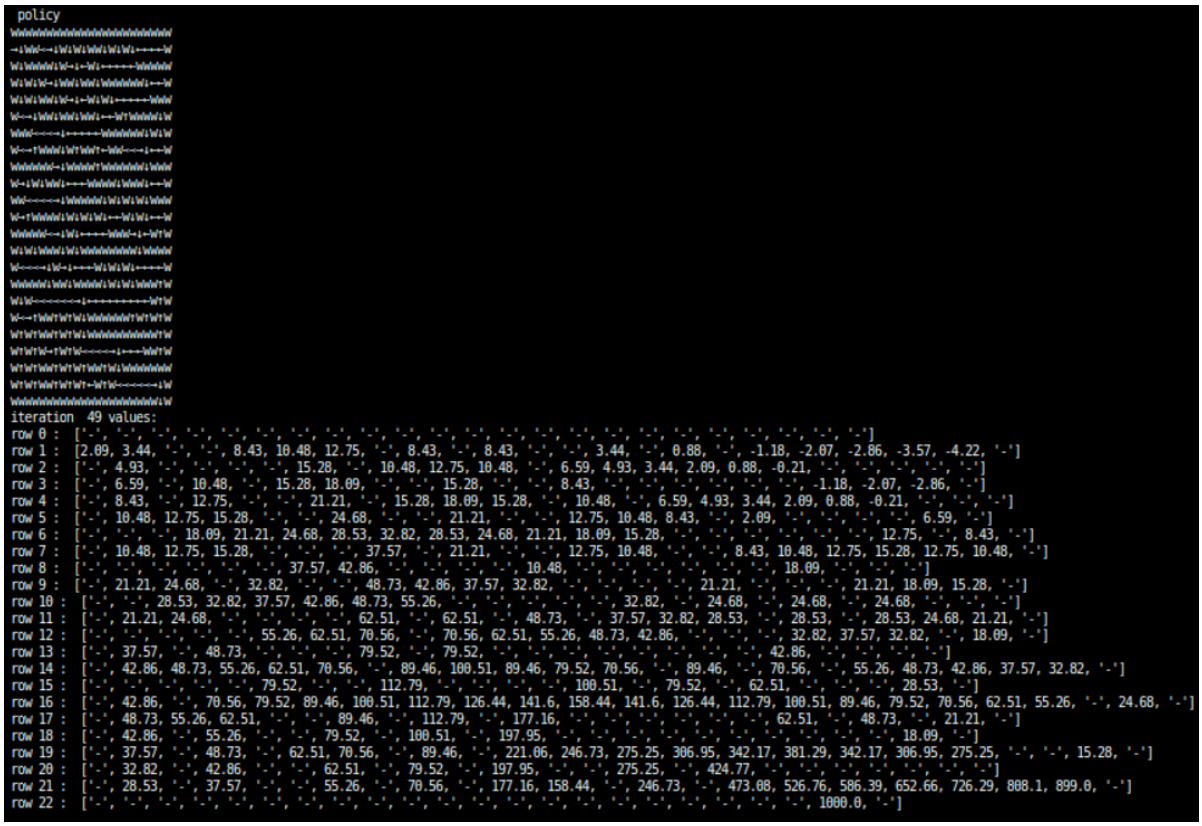
- 1 goal(the turtle)
- 1 maze entrance
- Cost and policy are calculated from any path in the maze
- Maze is generated using **Prim's** algorithms
- Entrance can be at the left/up 50%-50%
- Exit can be at the bottom/right 50%-50%
- Cost is calculated as the number of steps from any path to the goal unless it is a wall
- at first the policy is always up then as we perform the iterations it changes until coonvergence
- It is a square maze

2. Data structures

1. `test_maze` (2D list): This represents the maze, where each element in the list represents a cell in the maze. It contains information about the walls and paths.
2. `test_mdp` (2D list): This represents the Markov Decision Process (MDP) version of the maze. It is used for policy iteration and value iteration algorithms.
3. `policy` (2D list): This represents the policy for each state in the MDP. It stores the actions that should be taken at each state to maximize the expected return.
4. `actions` (list): This list contains the possible actions that can be taken in the maze, such as 'up', 'down', 'left', and 'right'.
5. `Pen` (turtle.Turtle): This class represents the pen object used for drawing the maze.
6. `gradient` (dictionary): This dictionary represents the gradient colors used for visualizing the values in the maze.
7. `gradient_dict` (dictionary): This dictionary maps values to colors based on the gradient. It is used for coloring the cells in the maze based on their values.

Sample (policy, n=22)




policy
iteration 49 values:
row 0 : ['-', '-']
row 1 : [2.09, 3.44, '-', '-', 8.43, 10.48, 12.75, '-', 8.43, '-', 8.43, '-', '-', 3.44, '-', 0.88, '-', -1.18, -2.07, -2.86, -3.57, -4.22, '-']
row 2 : ['-', 4.93, '-', '-', '-', '-', 15.28, '-', 10.48, 12.75, 10.48, '-', 6.59, 4.93, 3.44, 2.09, 0.88, -0.21, '-', '-', '-', '-', '-']
row 3 : ['-', 6.59, '-', 10.48, '-', 15.28, 18.09, '-', '-', 15.28, '-', '-', 8.43, '-', '-', '-', '-', '-', '-', -1.18, -2.07, -2.86, '-']
row 4 : ['-', 8.43, '-', 12.75, '-', '-', 21.21, '-', 15.28, 18.09, 15.28, '-', 10.48, '-', 6.59, 4.93, 3.44, 2.09, 0.88, -0.21, '-', '-', '-']
row 5 : ['-', 10.48, 12.75, 15.28, '-', '-', 24.68, '-', '-', 21.21, '-', '-', 12.75, 10.48, 8.43, '-', 2.09, '-', '-', '-', '-', 6.59, '-']
row 6 : ['-', '-', '-', 18.09, 21.21, 24.68, 28.53, 32.82, 28.53, 24.68, 21.21, 18.09, 15.28, '-', '-', '-', '-', '-', '-', 12.75, '-', 8.43, '-']
row 7 : ['-', 10.48, 12.75, 15.28, '-', '-', '-', 37.57, '-', 21.21, '-', '-', 12.75, 10.48, '-', '-', 8.43, 10.48, 12.75, 15.28, 12.75, 10.48, '-']
row 8 : ['-', '-', '-', '-', '-', '-', '-', 37.57, 42.86, '-', '-', '-', '-', 10.48, '-', '-', '-', '-', '-', '-', 18.09, '-', '-', '-']
row 9 : ['-', 21.21, 24.68, '-', 32.82, '-', '-', 48.73, 42.86, 37.57, 32.82, '-', '-', '-', '-', 21.21, '-', '-', '-', 21.21, 18.09, 15.28, '-']
row 10 : ['-', '-', 28.53, 32.82, 37.57, 42.86, 48.73, 55.26, '-', '-', '-', '-', '-', 32.82, '-', 24.68, '-', 24.68, '-', 24.68, '-', '-', '-']
row 11 : ['-', 21.21, 24.68, '-', '-', '-', '-', 62.51, '-', 62.51, '-', 48.73, '-', 37.57, 32.82, 28.53, '-', 28.53, '-', 28.53, 24.68, 21.21, '-']
row 12 : ['-', '-', '-', '-', '-', 55.26, 62.51, 70.56, '-', 70.56, 62.51, 55.26, 48.73, 42.86, '-', '-', '-', 32.82, 37.57, 32.82, '-', 18.09, '-']
row 13 : ['-', 37.57, '-', 48.73, '-', '-', '-', 79.52, '-', 79.52, '-', '-', '-', '-', '-', '-', '-', '-', 42.86, '-', '-', '-', '-', '-']
row 14 : ['-', 42.86, 48.73, 55.26, 62.51, 70.56, '-', 89.46, 100.51, 89.46, 79.52, 70.56, '-', 89.46, '-', 70.56, '-', 55.26, 48.73, 42.86, 37.57, 32.82, '-']
row 15 : ['-', '-', '-', '-', '-', '-', 79.52, '-', '-', 112.79, '-', '-', '-', '-', '-', 100.51, '-', 79.52, '-', 62.51, '-', '-', '-', 28.53, '-']
row 16 : ['-', 42.86, '-', 70.56, 79.52, 89.46, 100.51, 112.79, 126.44, 141.6, 158.44, 141.6, 126.44, 112.79, 100.51, 89.46, 79.52, 70.56, 62.51, 55.26, '-', 24.68, '-']
row 17 : ['-', 48.73, 55.26, 62.51, '-', '-', 89.46, '-', 112.79, '-', 177.16, '-', '-', '-', '-', '-', '-', '-', 62.51, '-', 48.73, '-', 21.21, '-']
row 18 : ['-', 42.86, '-', 55.26, '-', '-', 79.52, '-', 100.51, '-', 197.95, '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', 18.09, '-']
row 19 : ['-', 37.57, '-', 48.73, '-', 62.51, 70.56, '-', 89.46, '-', 221.06, 246.73, 275.25, 306.95, 342.17, 381.29, 342.17, 306.95, 275.25, '-', '-', 15.28, '-']
row 20 : ['-', 32.82, '-', 42.86, '-', '-', 62.51, '-', 79.52, '-', 197.95, '-', '-', 275.25, '-', 424.77, '-', '-', '-', '-', '-', '-', '-']
row 21 : ['-', 28.53, '-', 37.57, '-', '-', 55.26, '-', 70.56, '-', 177.16, 158.44, '-', 246.73, '-', 473.08, 526.76, 586.39, 652.66, 726.29, 808.1, 899.0, '-']
row 22 : ['-', 1000.0, '-']

```
 policy
WWWWWWWWWWWWWWWWWWWWWWW
→↓WW←→↓W↓W↓WW↓W↓W↓←←←←W
W↓WWWW↓W←↓←W↓←←←←←WWWWW
W↓W↓W←↓WW↓WW↓WWWWW↓←←W
W↓W↓WW↓W←↓←W↓W↓←←←←←WWW
W←→↓WW↓WW↓WW↓←→W↑WWWW↓W
WWW←←←←↓←←←←←WWWWWW↓W↓W
W←→↑WWW↓W↑WW↑←WW←←←↓←→W
WWWWWW←↓WWWW↑WWWWWW↓WWW
W←↓W↓WW↓←←←WWWW↓WWW↓←→W
WW←←←←←↓WWWWW↓W↓W↓W↓WWW
W←↑WWWW↓W↓W↓W↓←→W↓W↓←→W
WWWWW←→↓W↓←←←←WWW←↓←W↑W
W↓W↓WWW↓W↓WWWWWWW↓WWWW
W←←←←↓W←↓←←←W↓W↓W↓←←←←W
WWWWW↓WW↓WWWW↓W↓W↓WWW↑W
W↓W←←←←←←↓←←←←←←←W↑W
W←→↑WW↑W↑W↓WWWWW↑W↑W↑W
W↑W↑WW↑W↑W↓WWWWWWWW↑W
W↑W↑W←↑W↑W←←←←←↓←←←WW↑W
W↑W↑WW↑W↑W↑WW↑W↓WWWWWW
W↑W↑WW↑W↑W↑←W↑W←←←←←↓W
WWWWWWWWWWWWWWWWWW↓W
Policy iteration completed in 50 iterations.

 COST
[None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None]
[1, 5, None, None, 1, 2, 9, None, 2, None, 2, None, None, 6, None, 4, None, 2, 4, 3, 2, 1, None]
[None, 4, None, None, None, None, 8, None, 1, 8, 1, None, 5, 5, 4, 3, 2, 1, None, None, None, None, None]
[None, 3, None, 4, None, 1, 7, None, None, 7, None, None, 4, None, None, None, None, None, None, None, 2, 2, 1, None]
[None, 2, None, 3, None, None, 6, None, 1, 6, 1, None, 3, None, 2, 5, 4, 3, 2, 1, None, None, None]
[None, 1, 2, 2, None, None, 5, None, None, 5, None, None, 2, 2, 1, None, 5, None, None, None, None, 3, None]
[None, None, None, 1, 2, 3, 4, 9, 5, 4, 3, 2, 1, None, None, None, None, None, None, None, 7, None, 2, None]
[None, 1, 2, 2, None, None, None, 8, None, 5, None, None, 2, 1, None, None, 1, 2, 3, 6, 2, 1, None]
[None, None, None, None, None, None, 1, 7, None, None, None, None, 3, None, None, None, None, None, None, 5, None, None, None]
[None, 1, 2, None, 4, None, None, 6, 3, 2, 1, None, None, None, None, 3, None, None, None, 4, 2, 1, None]
[None, None, 1, 2, 3, 4, 5, 5, None, None, None, None, None, 3, None, 2, None, 3, None, 3, None, None, None]
[None, 1, 2, None, None, None, None, 4, None, 6, None, 4, None, 2, 2, 1, None, 2, None, 2, 2, 1, None]
[None, None, None, None, None, 1, 2, 3, None, 5, 4, 3, 2, 1, None, None, None, 1, 6, 1, None, 2, None]
[None, 2, None, 4, None, None, None, 2, None, 4, None, None, None, None, None, None, None, None, 5, None, None, None, None]
[None, 1, 2, 3, 4, 5, None, 1, 8, 3, 2, 1, None, 9, None, 7, None, 5, 4, 3, 2, 1, None]
[None, None, None, None, None, None, 4, None, None, 7, None, None, None, None, 8, None, 6, None, 4, None, None, None, 2, None]
[None, 2, None, 1, 2, 3, 4, 5, 6, 7, 4, 9, 8, 7, 6, 5, 4, 3, 2, 1, None, 3, None]
[None, 1, 2, 2, None, None, 5, None, 7, None, 3, None, None, None, None, None, None, None, 4, None, 2, None, 4, None]
[None, 2, None, 3, None, None, 6, None, 8, None, 2, None, None, None, None, None, None, None, None, None, None, None, 5, None]
[None, 3, None, 4, None, 1, 7, None, 9, None, 1, 2, 3, 4, 5, 3, 3, 2, 1, None, None, 6, None]
[None, 4, None, 5, None, None, 8, None, 10, None, 2, None, None, 5, None, 2, None, None, None, None, None, None, None]
[None, 5, None, 6, None, None, 9, None, 11, None, 3, 1, None, 6, None, 1, 2, 3, 4, 5, 6, 2, None]
[None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, 1, None]
```

```
Time taken: 9.20503830909729 seconds
```

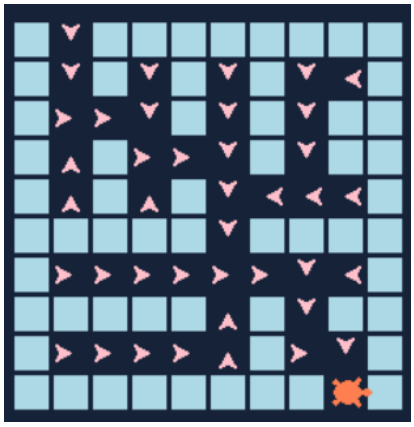
3.Sample 2-policy(n=5)

```
iteration  0 values:
row 0 :  ['-', -10.0, '-', '-', '-']
row 1 :  ['-', -10.0, -10.0, -10.0, '-']
row 2 :  ['-', -10.0, '-', '-', '-']
row 3 :  ['-', -10.0, -10.0, -10.0, 1000.0]
row 4 :  ['-', '-', '-', '-', '-']

 policy
wtwww
wtttw
wtwww
wtttt
wwwww
iteration  0 values:
row 0 :  ['-', -10.0, '-', '-', '-']
row 1 :  ['-', -10.0, -10.0, -10.0, '-']
row 2 :  ['-', -10.0, '-', '-', '-']
row 3 :  ['-', -10.0, -10.0, -10.0, 1000.0]
row 4 :  ['-', '-', '-', '-', '-']
```

```
 policy
W↓WWW
W↓←←W
W↓WWW
W→→→↑
WWWWW
iteration  7 values:
row 0 :  ['-', 526.76, '-', '-', '-']
row 1 :  ['-', 586.39, 526.76, 473.08, '-']
row 2 :  ['-', 652.66, '-', '-', '-']
row 3 :  ['-', 726.29, 808.1, 899.0, 1000.0]
row 4 :  ['-', '-', '-', '-', '-']

 policy
W↓WWW
W↓←←W
W↓WWW
W→→→↑
WWWWW
Policy iteration completed in 8 iterations.

 COST
[None, 4, None, None, None]
[None, 3, 2, 1, None]
[None, 2, None, None, None]
[None, 1, 2, 3, 1]
[None, None, None, None, None]
```

```
Time taken: 1.2741360664367676 seconds
```

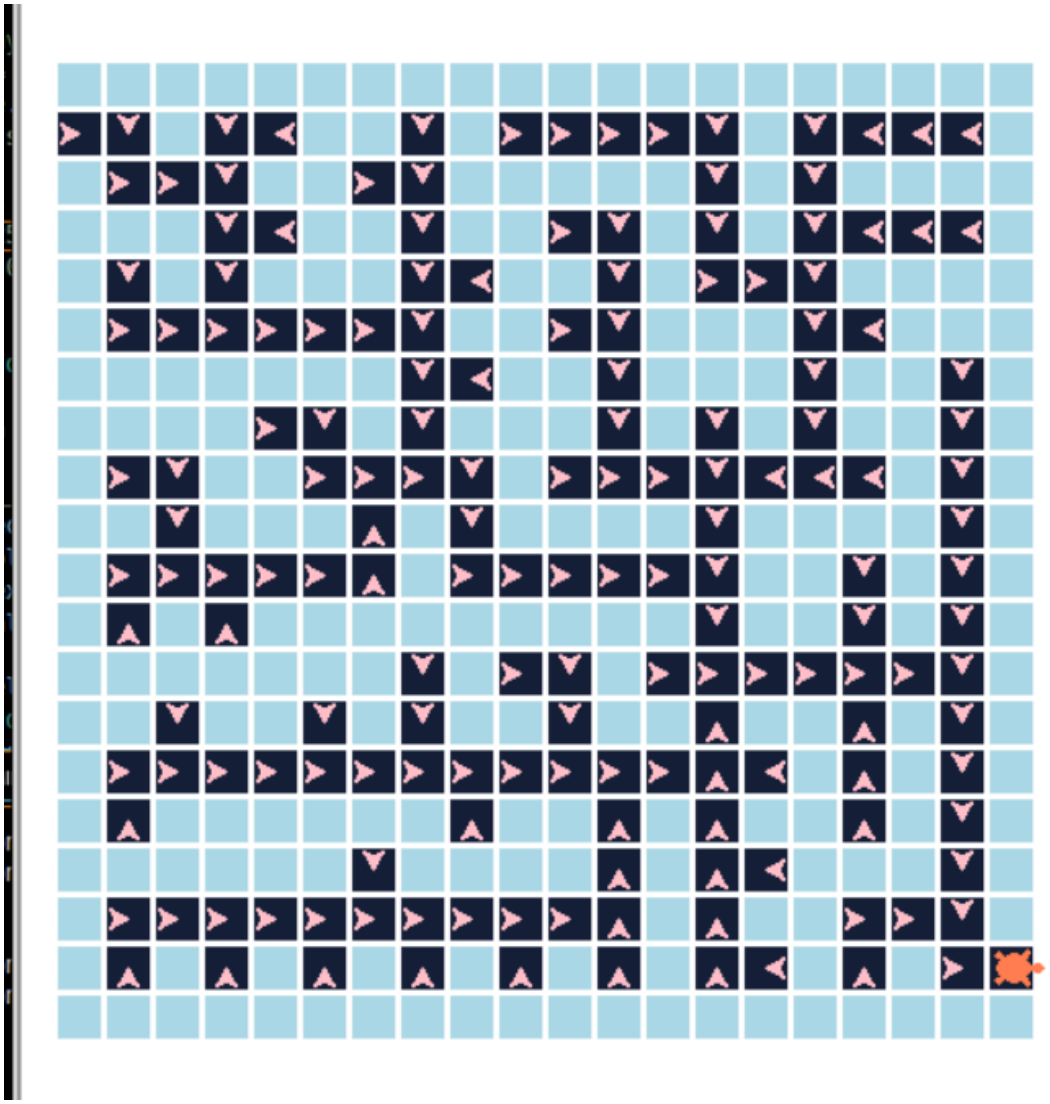
4. Sample 3 policy (n=10)



```
WtttWtWtWW
WtWtttWtWW
WtWtWttttW
WWWWWtWWWW
Wttttttt W
WWWWWtWtWW
WttttWt↓W
WWWWWWWW↓W
iteration  1 values:
row 0 :  ['-', -10.0, '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  ['-', -10.0, '-', -10.0, '-', -10.0, '-', -10.0, -10.0, '-']
row 2 :  ['-', -10.0, -10.0, -10.0, '-', -10.0, '-', -10.0, '-', '-']
row 3 :  ['-', -10.0, '-', -10.0, -10.0, -10.0, '-', -10.0, '-', '-']
row 4 :  ['-', -10.0, '-', -10.0, '-', -10.0, -10.0, -10.0, -10.0, '-']
row 5 :  ['-', '-', '-', '-', '-', -10.0, '-', '-', '-', '-']
row 6 :  ['-', -10.0, -10.0, -10.0, -10.0, -10.0, -10.0, -10.0, -10.0, '-']
row 7 :  ['-', '-', '-', '-', '-', -10.0, '-', -10.0, '-', '-']
row 8 :  ['-', -10.0, -10.0, -10.0, -10.0, -10.0, '-', -10.0, 899.0, '-']
row 9 :  ['-', '-', '-', '-', '-', '-', '-', '-', 1000.0, '-']

 policy
WtWWWWWWWW
WtWtWtWttW
WtttWtWtWW
WtWtttWtWW
WtWtWttttW
WWWWWtWWWW
Wttttttt W
WWWWWtWtWW
WttttWt↓W
WWWWWWWW↓W
iteration  1 values:
row 0 :  ['-', -10.0, '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  ['-', -10.0, '-', -10.0, '-', -10.0, '-', -10.0, -10.0, '-']
row 2 :  ['-', -10.0, -10.0, -10.0, '-', -10.0, '-', -10.0, '-', '-']
row 3 :  ['-', -10.0, '-', -10.0, -10.0, -10.0, '-', -10.0, '-', '-']
row 4 :  ['-', -10.0, '-', -10.0, '-', -10.0, -10.0, -10.0, -10.0, '-']
row 5 :  ['-', '-', '-', '-', '-', -10.0, '-', '-', '-', '-']
row 6 :  ['-', -10.0, -10.0, -10.0, -10.0, -10.0, -10.0, -10.0, -10.0, '-']
row 7 :  ['-', '-', '-', '-', '-', -10.0, '-', -10.0, '-', '-']
row 8 :  ['-', -10.0, -10.0, -10.0, -10.0, -10.0, '-', -10.0, 899.0, '-']
row 9 :  ['-', '-', '-', '-', '-', '-', '-', '-', 1000.0, '-']
```

```
wwwww↓wwww
w→→→→→→↓←w
wwwww↑w↓ww
w→→→→↑w→↓w
wwwwwwww↓w
iteration  16 values:
row 0 :  ['-', 177.16, '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  ['-', 197.95, '-', 246.73, '-', 306.95, '-', 246.73, 221.06, '-']
row 2 :  ['-', 221.06, 246.73, 275.25, '-', 342.17, '-', 275.25, '-', '-']
row 3 :  ['-', 197.95, '-', 306.95, 342.17, 381.29, '-', 306.95, '-', '-']
row 4 :  ['-', 177.16, '-', 275.25, '-', 424.77, 381.29, 342.17, 306.95, '-']
row 5 :  ['-', '-', '-', '-', '-', 473.08, '-', '-', '-', '-']
row 6 :  ['-', 342.17, 381.29, 424.77, 473.08, 526.76, 586.39, 652.66, 586.39, '-']
row 7 :  ['-', '-', '-', '-', '-', 473.08, '-', 726.29, '-', '-']
row 8 :  ['-', 275.25, 306.95, 342.17, 381.29, 424.77, '-', 808.1, 899.0, '-']
row 9 :  ['-', '-', '-', '-', '-', '-', '-', '-', 1000.0, '-']

 policy
w↓wwwwwwwww
w↓w↓w↓w↓←w
w→→↓w↓w↓ww
w↑w→→↓w↓ww
w↑w↑w↓←←←w
wwwww↓wwww
w→→→→→→↓←w
wwwww↑w↓ww
w→→→→↑w→↓w
wwwwwwwww↓w
Time taken: 3.6566779613494873 seconds
Policy iteration completed in 17 iterations.

 COST
[None, 3, None, None, None, None, None, None, None, None]
[None, 2, None, 3, None, 10, None, 5, 1, None]
[None, 1, 2, 2, None, 9, None, 4, None, None]
[None, 2, None, 1, 2, 8, None, 3, None, None]
[None, 3, None, 2, None, 7, 3, 2, 1, None]
[None, None, None, None, None, 6, None, None, None, None]
[None, 1, 2, 3, 4, 5, 6, 3, 1, None]
[None, None, None, None, None, 6, None, 2, None, None]
[None, 1, 2, 3, 4, 7, None, 1, 2, None]
[None, None, None, None, None, None, None, None, 1, None]
```

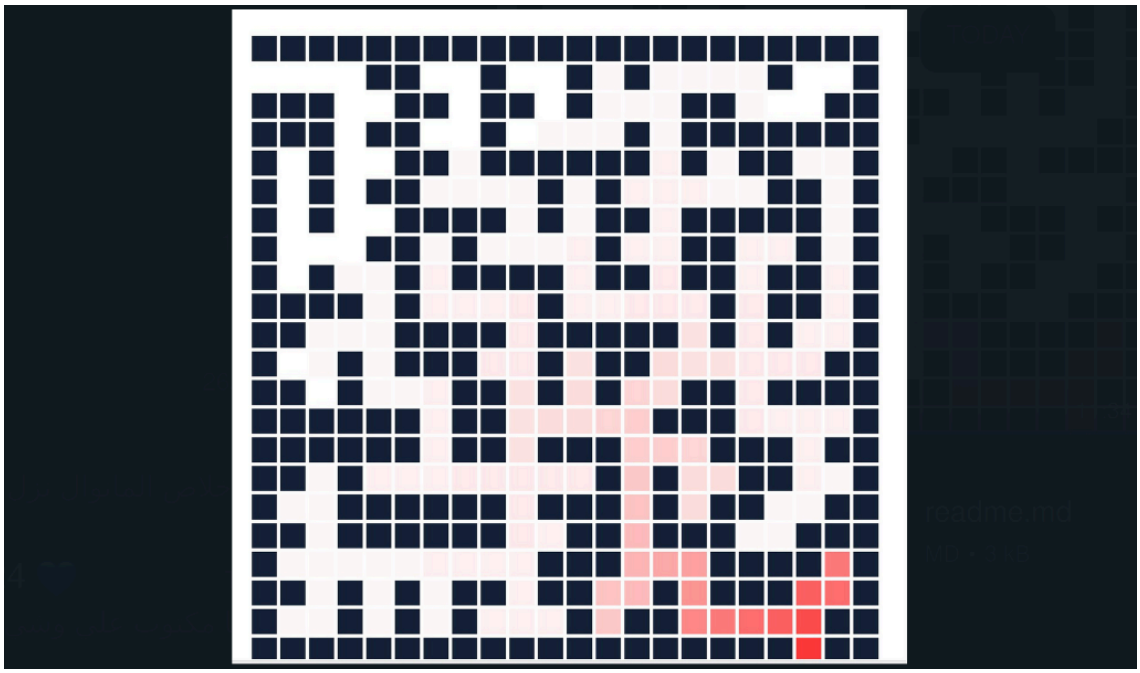
5. Sample 4 (n=20)



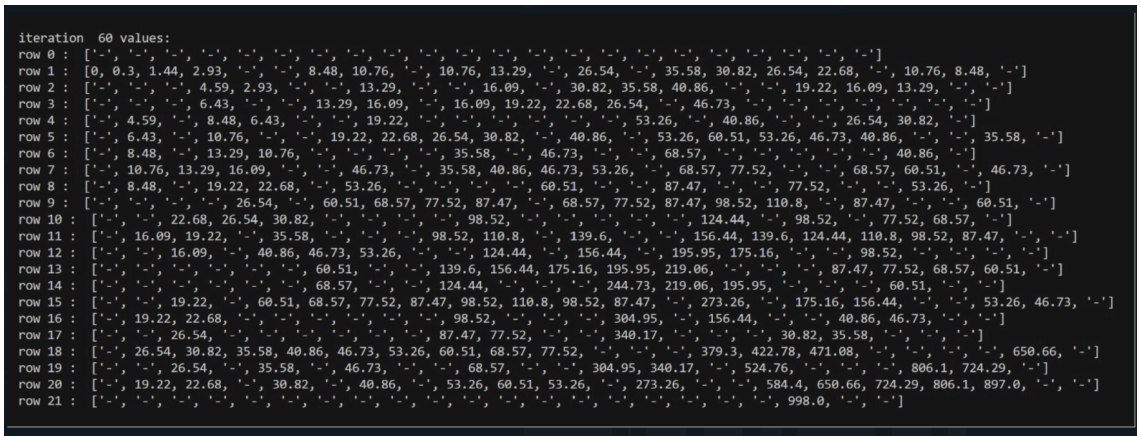
```
row 18 :  ['-', 32.82, '-', 42.86, '-', 55.26, '-', 70.56, '-', 89.46, '-', 112.79, '-', 141.6, 126.44, '-', 586.39, '-', 899.0, 1000.0]
row 19 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-']

 policy
wwwwwwwwwwwwwwwwwwww
→↓W↓←WW↓W→→→↓W↓←→→W
W→→↓WW→↓WWWWW↓W↓WWWW
WWW↓←WW↓WW→↓W↓W↓←→→W
W↓W↓WWW↓←WW↓W→→↓WWWW
W→→→→→→↓WW→↓WWW↓←WWW
WWWWWWW↓←WW↓WWW↓WW↓W
WWWW→↓W↓WWW↓W↓W↓WW↓W
W→↓WW→→→↓W→→→↓←→→W↓W
WW↓WWW↑W↓WWWW↓WWWW↓W
W→→→→↑W→→→→→↓WW↓W↓W
W↑W↑WWWWWWWWW↓WW↓W↓W
WWWWWWW↓W→↓W→→→→→↓W
WW↓WW↓W↓WW↓WW↑WW↑W↓W
W→→→→→→→→→→↑←W↑W↓W
W↑WWWWWW↑WW↑W↑WW↑W↓W
WWWWWW↓WWWW↑W↑←WWW↓W
W→→→→→→→→→↑W↑WW→→↓W
W↑W↑W↑W↑W↑W↑W↑←W↑W→↑
WWWWWWWWWWWWWWWWWWWW
iteration  36 values:
row 0 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  [12.75, 15.28, '-', 21.21, 18.09, '-', '-', 37.57, '-', 28.53, 32.82, 37.57, 42.86, 48.73, '-', 62.51, 55.26, 48.73, 42.86, '-']
row 2 :  ['-', 18.09, 21.21, 24.68, '-', '-', 37.57, 42.86, '-', '-', '-', '-', '-', 55.26, '-', 70.56, '-', '-', '-', '-']
row 3 :  ['-', '-', '-', 28.53, 24.68, '-', '-', 48.73, '-', '-', 70.56, 79.52, '-', 62.51, '-', 79.52, 70.56, 62.51, 55.26, '-']
row 4 :  ['-', 24.68, '-', 32.82, '-', '-', '-', 55.26, 48.73, '-', '-', 89.46, '-', 70.56, 79.52, 89.46, '-', '-', '-', '-']
row 5 :  ['-', 28.53, 32.82, 37.57, 42.86, 48.73, 55.26, 62.51, '-', '-', 89.46, 100.51, '-', '-', '-', 100.51, 89.46, '-', '-', '-']
row 6 :  ['-', '-', '-', '-', '-', '-', '-', 70.56, 62.51, '-', '-', 112.79, '-', '-', '-', 112.79, '-', '-', 246.73, '-']
row 7 :  ['-', '-', '-', '-', 55.26, 62.51, '-', 79.52, '-', '-', '-', 126.44, '-', 158.44, '-', 126.44, '-', '-', 275.25, '-']
row 8 :  ['-', 24.68, 28.53, '-', '-', 70.56, 79.52, 89.46, 100.51, '-', 126.44, 141.6, 158.44, 177.16, 158.44, 141.6, 126.44, '-', 306.95, '-']
row 9 :  ['-', '-', 32.82, '-', '-', '-', 70.56, '-', 112.79, '-', '-', '-', '-', 197.95, '-', '-', '-', '-', 342.17, '-']
row 10 :  ['-', 32.82, 37.57, 42.86, 48.73, 55.26, 62.51, '-', 126.44, 141.6, 158.44, 177.16, 197.95, 221.06, '-', '-', 306.95, '-', 381.29, '-']
row 11 :  ['-', 28.53, '-', 37.57, '-', '-', '-', '-', '-', '-', '-', '-', '-', 246.73, '-', '-', 342.17, '-', 424.77, '-']
row 12 :  ['-', '-', '-', '-', '-', '-', '-', '-', 89.46, '-', 112.79, 126.44, '-', 246.73, 275.25, 306.95, 342.17, 381.29, 424.77, 473.08, '-']
row 13 :  ['-', '-', 55.26, '-', '-', 79.52, '-', 100.51, '-', '-', 141.6, '-', '-', 246.73, '-', '-', 342.17, '-', 526.76, '-']
row 14 :  ['-', 55.26, 62.51, 70.56, 79.52, 89.46, 100.51, 112.79, 126.44, 141.6, 158.44, 177.16, 197.95, 221.06, 197.95, '-', 306.95, '-', 586.39, '-']
row 15 :  ['-', 48.73, '-', '-', '-', '-', '-', '-', 112.79, '-', '-', 158.44, '-', 197.95, '-', '-', 275.25, '-', 652.66, '-']
row 16 :  ['-', '-', '-', '-', '-', '-', 62.51, '-', '-', '-', '-', 141.6, '-', 177.16, 158.44, '-', '-', '-', 726.29, '-']
row 17 :  ['-', 37.57, 42.86, 48.73, 55.26, 62.51, 70.56, 79.52, 89.46, 100.51, 112.79, 126.44, '-', 158.44, '-', '-', 652.66, 726.29, 808.1, '-']
row 18 :  ['-', 32.82, '-', 42.86, '-', 55.26, '-', 70.56, '-', 89.46, '-', 112.79, '-', 141.6, 126.44, '-', 586.39, '-', 899.0, 1000.0]
row 19 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-']
```

```
 policy
WWWWWWWWWWWWWWWWWWWW
→↓W↓←WW↓W→→→↓W↓←→→W
W→→↓WW→↓WWWWW↓W↓WWWW
WWW↓←WW↓WW→↓W↓W↓←→→W
W↓W↓WWW↓←WW↓W→→↓WWWW
W→→→→→→↓WW→↓WWW↓←WWW
WWWWWWW↓←WW↓WWW↓WW↓W
WWWW→↓W↓WWW↓W↓W↓WW↓W
W→↓WW→→→↓W→→→↓←→→W↓W
WW↓WWW↑W↓WWWW↓WWWW↓W
W→→→→↑W→→→→→↓WW↓W↓W
W↑W↑WWWWWWWWW↓WW↓W↓W
WWWWWWW↓W→↓W→→→→→↓W
WW↓WW↓W↓WW↓WW↑WW↑W↓W
W→→→→→→→→→→↑←W↑W↓W
W↑WWWWWW↑WW↑W↑WW↑W↓W
WWWWWW↓WWWW↑W↑←WWW↓W
W→→→→→→→→→↑W↑WW→→↓W
W↑W↑W↑W↑W↑W↑W↑←W↑W→↑
WWWWWWWWWWWWWWWWWWWW
Time taken: 9.20503830909729 seconds
Policy iteration completed in 37 iterations.

 COST
[None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None]
[1, 2, None, 7, 1, None, None, 10, None, 1, 2, 3, 4, 4, None, 9, 3, 2, 1, None]
[None, 1, 2, 6, None, None, 1, 9, None, None, None, None, None, 3, None, 8, None, None, None, None]
[None, None, None, 5, 1, None, None, 8, None, None, 1, 7, None, 2, None, 7, 3, 2, 1, None]
[None, 2, None, 4, None, None, None, 7, 1, None, None, 6, None, 1, 2, 6, None, None, None, None]
[None, 1, 2, 3, 4, 5, 6, 6, None, None, 1, 5, None, None, None, 5, 1, None, None, None]
[None, None, None, None, None, None, None, 5, 1, None, None, 4, None, None, None, 4, None, None, 13, None]
[None, None, None, None, 1, 2, None, 4, None, None, None, 3, None, 7, None, 3, None, None, 12, None]
[None, 1, 4, None, None, 1, 2, 3, 3, None, 1, 2, 3, 6, 3, 2, 1, None, 11, None]
[None, None, 3, None, None, None, 3, None, 2, None, None, None, None, 5, None, None, None, None, 10, None]
[None, 1, 2, 3, 4, 5, 4, None, 1, 2, 3, 4, 5, 4, None, None, 7, None, 9, None]
[None, 2, None, 4, None, None, None, None, None, None, None, None, None, None, 3, None, None, 6, None, 8, None]
[None, None, None, None, None, None, None, None, 9, None, 1, 12, None, 1, 2, 3, 4, 5, 6, 7, None]
[None, None, 3, None, None, 6, None, 8, None, None, 11, None, None, 3, None, None, 6, None, 6, None]
[None, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 4, 1, None, 7, None, 5, None]
[None, 2, None, None, None, None, None, None, 9, None, None, 12, None, 5, None, None, 8, None, 4, None]
[None, None, None, None, None, None, None, 7, None, None, None, None, 13, None, 6, 1, None, None, None, 3, None]
[None, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 14, None, 7, None, None, 1, 2, 2, None]
[None, 2, None, 4, None, 6, None, 8, None, 10, None, 15, None, 8, 1, None, 2, None, 1, 1]
[None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None, None]
```

Value Iteration(same sample1)- ass



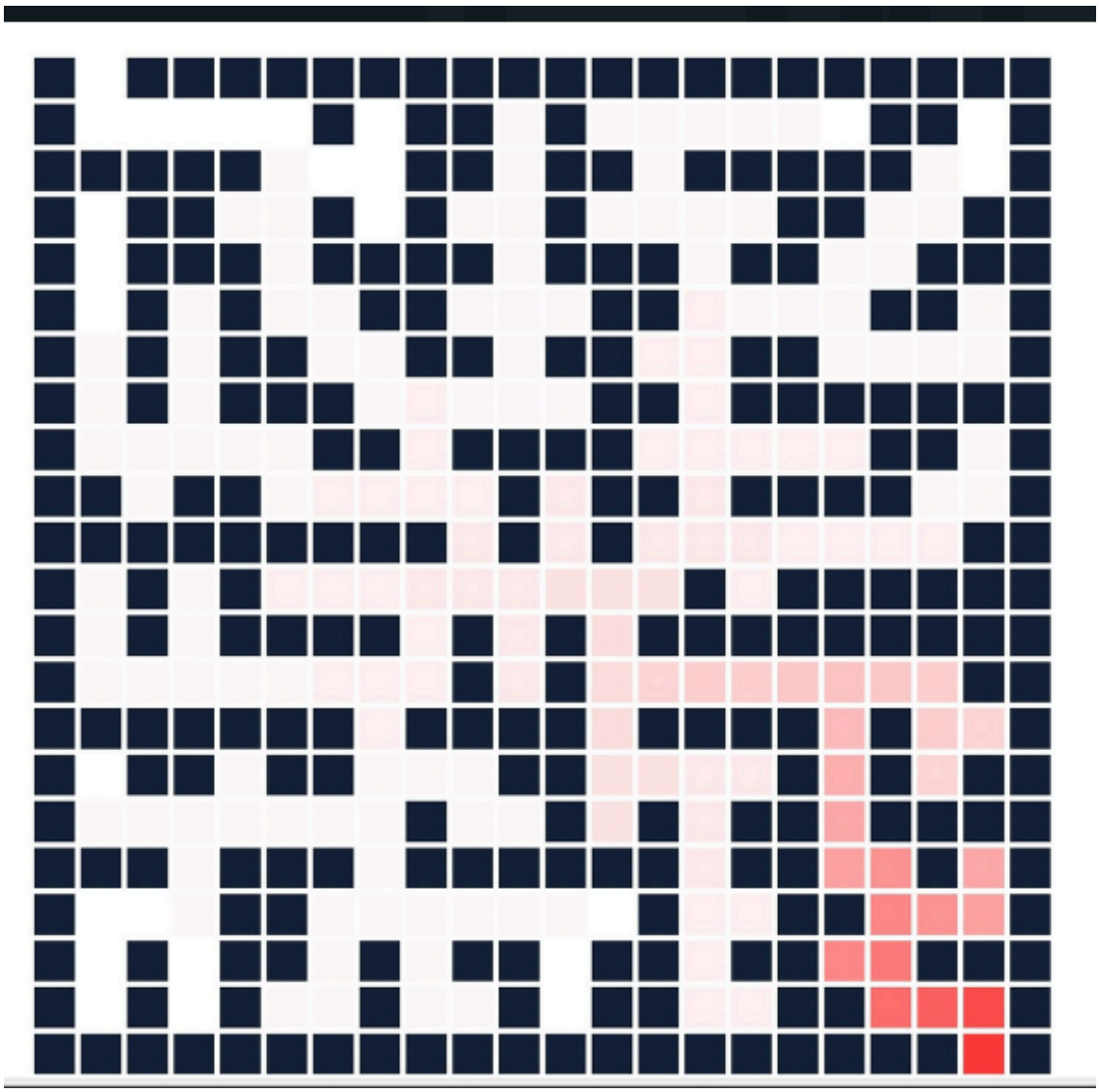
```
iteration  21 values:
row 0 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  [0, 0, 0, 0, '-', '-', 0, 0, '-', 0, 0, '-', 0, '-', 0, 0, 0, 0, '-', 0, 0, '-']
row 2 :  ['-', '-', '-', 0, 0, '-', '-', 0, '-', '-', 0, '-', 0, 0, 0, '-', '-', 0, 0, 0, '-', '-']
row 3 :  ['-', '-', '-', 0, '-', '-', 0, 0, '-', 0, 0, 0, 0, '-', 0, '-', '-', '-', '-', '-', '-', '-']
row 4 :  ['-', 0, '-', 0, 0, '-', '-', 0, '-', '-', '-', '-', '-', '-', 0, '-', 0, '-', '-', 0, 0, '-']
row 5 :  ['-', 0, '-', 0, '-', '-', 0, 0, 0, 0, '-', 0, '-', 0, 0, 0, 0, 0, 0, '-', '-', 0, '-']
row 6 :  ['-', 0, '-', 0, 0, '-', '-', '-', '-', 0, '-', 0, '-', '-', 0, '-', '-', '-', '-', '-', '-', 0, '-']
row 7 :  ['-', 0, 0, 0, '-', '-', 0, '-', 0, 0, 0, 0, 0, '-', 0, 0, '-', '-', 0, 0, '-', 0, '-']
row 8 :  ['-', 0, '-', 0, 0, 0, '-', 0, '-', '-', '-', '-', '-', 0, '-', '-', 0.83, '-', '-', 7.73, '-', '-', 2.92, '-']
row 9 :  ['-', '-', '-', '-', '-', 0, '-', 0, 0, 0, 0, '-', 0, 0, 0.83, 11.88, 24.16, '-', 17.67, '-', '-', 10.17, '-']
row 10 :  ['-', '-', 0, 0, 0, 0, '-', '-', '-', '-', 0, '-', '-', '-', '-', '-', '-', 37.81, '-', 28.72, '-', 21.37, 18.23, '-']
row 11 :  ['-', 0, 0, '-', 0, '-', '-', '-', '-', 0, 3.37, '-', 32.18, '-', '-', 59.96, 52.97, 46.67, 41.0, 35.9, 31.31, '-', '-']
row 12 :  ['-', '-', 0, '-', 0, 0, 0, '-', '-', 17.02, '-', 49.02, '-', 88.53, 78.68, '-', '-', 35.9, '-', '-', '-', '-', '-']
row 13 :  ['-', '-', '-', '-', '-', '-', '-', 0, '-', '-', 32.18, 49.02, 67.74, 88.53, 111.64, '-', '-', '-', 31.31, 27.18, 23.46, 20.12, '-']
row 14 :  ['-', '-', '-', '-', '-', '-', '-', 0, '-', '-', 27.96, '-', '-', '-', 137.31, 122.58, 109.32, '-', '-', '-', 20.12, '-', '-']
row 15 :  ['-', '-', 0, '-', 0, 0, 0, 0.83, 11.88, 24.16, 20.75, 17.67, '-', 165.83, '-', 97.39, 86.65, '-', '-', 17.1, 14.39, '-']
row 16 :  ['-', 0, 0, '-', '-', '-', '-', '-', '-', 20.75, '-', '-', '-', 197.53, '-', 86.65, '-', '-', 8.52, 14.39, '-', '-']
row 17 :  ['-', '-', 0, '-', '-', '-', '-', '-', '-', 17.67, 14.9, '-', '-', 232.75, '-', '-', '-', 1.91, 6.67, '-', '-', '-']
row 18 :  ['-', 0, 0, 0, 0, 0, 0, 0, 5.95, 14.9, '-', '-', '-', 271.88, 315.35, 363.66, '-', '-', '-', '-', 554.18, '-']
row 19 :  ['-', '-', 0, '-', 0, '-', 0, '-', 0, '-', 12.41, '-', '-', 208.47, 243.69, '-', 417.34, '-', '-', '-', 698.68, 627.81, '-']
row 20 :  ['-', 0, 0, '-', 0, '-', 0, '-', 2.92, 10.17, 8.16, '-', 186.62, '-', '-', 476.98, 543.24, 616.87, 698.68, 789.58, '-', '-']
row 21 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', 890.58, '-', '-']
```


iteration 60 values:
row 0 : ['-', '-']
row 1 : [0, 0.3, 1.44, 2.93, '-', '-', 8.48, 10.76, '-', 10.76, 13.29, '-', 26.54, '-', 35.58, 30.82, 26.54, 22.68, '-', 10.76, 8.48, '-']
row 2 : ['-', '-', '-', 4.59, 2.93, '-', '-', 13.29, '-', '-', 16.09, '-', 30.82, 35.58, 40.86, '-', '-', 19.22, 16.09, 13.29, '-', '-']
row 3 : ['-', '-', '-', 6.43, '-', '-', 13.29, 16.09, '-', 16.09, 19.22, 22.68, 26.54, '-', 46.73, '-', '-', '-', '-', '-', '-', '-', '-']
row 4 : ['-', 4.59, '-', 8.48, 6.43, '-', '-', 19.22, '-', '-', '-', '-', '-', '-', 53.26, '-', 40.86, '-', '-', 26.54, 30.82, '-']
row 5 : ['-', 6.43, '-', 10.76, '-', '-', 19.22, 22.68, 26.54, 30.82, '-', 40.86, '-', 53.26, 60.51, 53.26, 46.73, 40.86, '-', '-', 35.58, '-']
row 6 : ['-', 8.48, '-', 13.29, 10.76, '-', '-', '-', '-', 35.58, '-', 46.73, '-', '-', 68.57, '-', '-', '-', '-', '-', 40.86, '-']
row 7 : ['-', 10.76, 13.29, 16.09, '-', '-', 46.73, '-', 35.58, 40.86, 46.73, 53.26, '-', 68.57, 77.52, '-', '-', 68.57, 60.51, '-', 46.73, '-']
row 8 : ['-', 8.48, '-', 19.22, 22.68, '-', 53.26, '-', '-', '-', '-', 60.51, '-', '-', 87.47, '-', '-', 77.52, '-', '-', 53.26, '-']
row 9 : ['-', '-', '-', '-', '-', 26.54, '-', 60.51, 68.57, 77.52, 87.47, '-', 68.57, 77.52, 87.47, 98.52, 110.8, '-', 87.47, '-', '-', 60.51, '-']
row 10 : ['-', '-', 22.68, 26.54, 30.82, '-', '-', '-', '-', 98.52, '-', '-', '-', '-', '-', 124.44, '-', 98.52, '-', 77.52, 68.57, '-']
row 11 : ['-', 16.09, 19.22, '-', 35.58, '-', '-', '-', 98.52, 110.8, '-', 139.6, '-', '-', 156.44, 139.6, 124.44, 110.8, 98.52, 87.47, '-', '-']
row 12 : ['-', '-', 16.09, '-', 40.86, 46.73, 53.26, '-', '-', 124.44, '-', 156.44, '-', 195.95, 175.16, '-', '-', 98.52, '-', '-', '-', '-']
row 13 : ['-', '-', '-', '-', '-', '-', 60.51, '-', '-', 139.6, 156.44, 175.16, 195.95, 219.06, '-', '-', '-', 87.47, 77.52, 68.57, 60.51, '-']
row 14 : ['-', '-', '-', '-', '-', '-', 68.57, '-', '-', 124.44, '-', '-', '-', 244.73, 219.06, 195.95, '-', '-', '-', 60.51, '-', '-']
row 15 : ['-', '-', 19.22, '-', 60.51, 68.57, 77.52, 87.47, 98.52, 110.8, 98.52, 87.47, '-', 273.26, '-', 175.16, 156.44, '-', '-', 53.26, 46.73, '-']
row 16 : ['-', 19.22, 22.68, '-', '-', '-', '-', '-', '-', 98.52, '-', '-', '-', 304.95, '-', 156.44, '-', '-', 40.86, 46.73, '-', '-']
row 17 : ['-', '-', 26.54, '-', '-', '-', '-', '-', '-', 87.47, 77.52, '-', '-', 340.17, '-', '-', '-', 30.82, 35.58, '-', '-', '-']
row 18 : ['-', 26.54, 30.82, 35.58, 40.86, 46.73, 53.26, 60.51, 68.57, 77.52, '-', '-', '-', 379.3, 422.78, 471.08, '-', '-', '-', '-', 650.66, '-']
row 19 : ['-', '-', 26.54, '-', 35.58, '-', 46.73, '-', '-', 68.57, '-', '-', 304.95, 340.17, '-', 524.76, '-', '-', '-', 806.1, 724.29, '-']
row 20 : ['-', 19.22, 22.68, '-', 30.82, '-', 40.86, '-', 53.26, 60.51, 53.26, '-', 273.26, '-', '-', 584.4, 650.66, 724.29, 806.1, 897.0, '-', '-']
row 21 : ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', '-', 998.0, '-', '-']

time:10s

Sample 2

Using Value Iteration



Sample 3:

```
iteration  334 values:
row 0 :  ['-', 526.76, '-', '-', '-']
row 1 :  ['-', 586.39, '-', '-', '-']
row 2 :  ['-', 652.66, 726.29, '-', '-']
row 3 :  ['-', '-', 808.1, 899.0, '-']
row 4 :  ['-', '-', '-', 1000.0, '-']


iteration  335 values:
row 0 :  ['-', 526.76, '-', '-', '-']
row 1 :  ['-', 586.39, '-', '-', '-']
row 2 :  ['-', 652.66, 726.29, '-', '-']
row 3 :  ['-', '-', 808.1, 899.0, '-']
row 4 :  ['-', '-', '-', 1000.0, '-']


iteration  336 values:
row 0 :  ['-', 526.76, '-', '-', '-']
row 1 :  ['-', 586.39, '-', '-', '-']
row 2 :  ['-', 652.66, 726.29, '-', '-']
row 3 :  ['-', '-', 808.1, 899.0, '-']
row 4 :  ['-', '-', '-', 1000.0, '-']


iteration  337 values:
row 0 :  ['-', 526.76, '-', '-', '-']
row 1 :  ['-', 586.39, '-', '-', '-']
row 2 :  ['-', 652.66, 726.29, '-', '-']
row 3 :  ['-', '-', 808.1, 899.0, '-']
row 4 :  ['-', '-', '-', 1000.0, '-']


iteration  338 values:
row 0 :  ['-', 526.76, '-', '-', '-']
row 1 :  ['-', 586.39, '-', '-', '-']
row 2 :  ['-', 652.66, 726.29, '-', '-']
row 3 :  ['-', '-', 808.1, 899.0, '-']
row 4 :  ['-', '-', '-', 1000.0, '-']
```

```
Time taken: 0.16675448417663574 seconds
```

Value Iteration- sample 4

```
iteration  344 values:
row 0 :  ['-', 177.16, '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  ['-', 197.95, '-', 246.73, '-', 306.95, 275.25, '-', 342.17, '-']
row 2 :  ['-', 221.06, '-', 275.25, '-', 342.17, '-', '-', 381.29, '-']
row 3 :  ['-', 246.73, '-', 306.95, '-', 381.29, '-', '-', 424.77, '-']
row 4 :  ['-', 275.25, '-', 342.17, '-', 424.77, '-', 526.76, 473.08, '-']
row 5 :  ['-', 306.95, 342.17, 381.29, '-', 473.08, '-', 586.39, '-', '-']
row 6 :  ['-', '-', '-', 424.77, '-', 526.76, '-', 652.66, 586.39, '-']
row 7 :  ['-', 381.29, 424.77, 473.08, 526.76, 586.39, '-', 726.29, '-', '-']
row 8 :  ['-', 342.17, '-', 424.77, '-', 652.66, 726.29, 808.1, 899.0, 1000.0]
row 9 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-']


iteration  345 values:
row 0 :  ['-', 177.16, '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  ['-', 197.95, '-', 246.73, '-', 306.95, 275.25, '-', 342.17, '-']
row 2 :  ['-', 221.06, '-', 275.25, '-', 342.17, '-', '-', 381.29, '-']
row 3 :  ['-', 246.73, '-', 306.95, '-', 381.29, '-', '-', 424.77, '-']
row 4 :  ['-', 275.25, '-', 342.17, '-', 424.77, '-', 526.76, 473.08, '-']
row 5 :  ['-', 306.95, 342.17, 381.29, '-', 473.08, '-', 586.39, '-', '-']
row 6 :  ['-', '-', '-', 424.77, '-', 526.76, '-', 652.66, 586.39, '-']
row 7 :  ['-', 381.29, 424.77, 473.08, 526.76, 586.39, '-', 726.29, '-', '-']
row 8 :  ['-', 342.17, '-', 424.77, '-', 652.66, 726.29, 808.1, 899.0, 1000.0]
row 9 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-']


iteration  346 values:
row 0 :  ['-', 177.16, '-', '-', '-', '-', '-', '-', '-', '-']
row 1 :  ['-', 197.95, '-', 246.73, '-', 306.95, 275.25, '-', 342.17, '-']
row 2 :  ['-', 221.06, '-', 275.25, '-', 342.17, '-', '-', 381.29, '-']
row 3 :  ['-', 246.73, '-', 306.95, '-', 381.29, '-', '-', 424.77, '-']
row 4 :  ['-', 275.25, '-', 342.17, '-', 424.77, '-', 526.76, 473.08, '-']
row 5 :  ['-', 306.95, 342.17, 381.29, '-', 473.08, '-', 586.39, '-', '-']
row 6 :  ['-', '-', '-', 424.77, '-', 526.76, '-', 652.66, 586.39, '-']
row 7 :  ['-', 381.29, 424.77, 473.08, 526.76, 586.39, '-', 726.29, '-', '-']
row 8 :  ['-', 342.17, '-', 424.77, '-', 652.66, 726.29, 808.1, 899.0, 1000.0]
row 9 :  ['-', '-', '-', '-', '-', '-', '-', '-', '-', '-']


Time taken: 0.21153831481933594 seconds
```