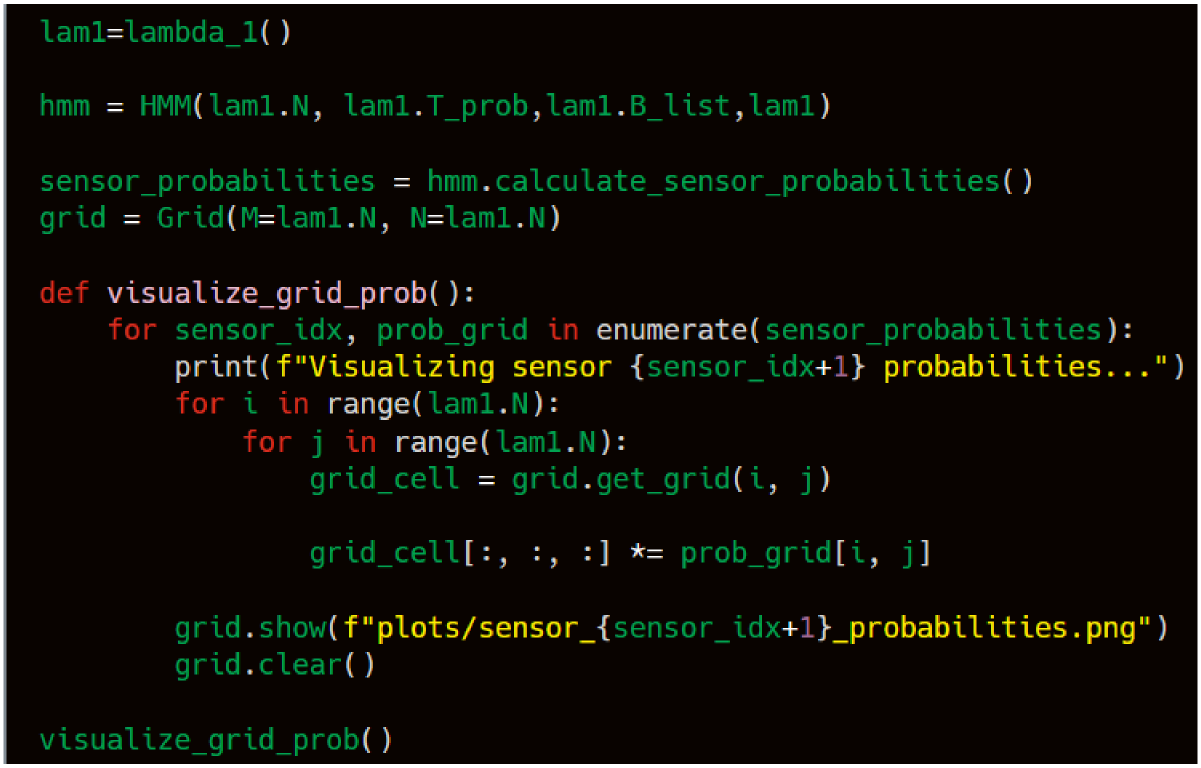
Assignment1

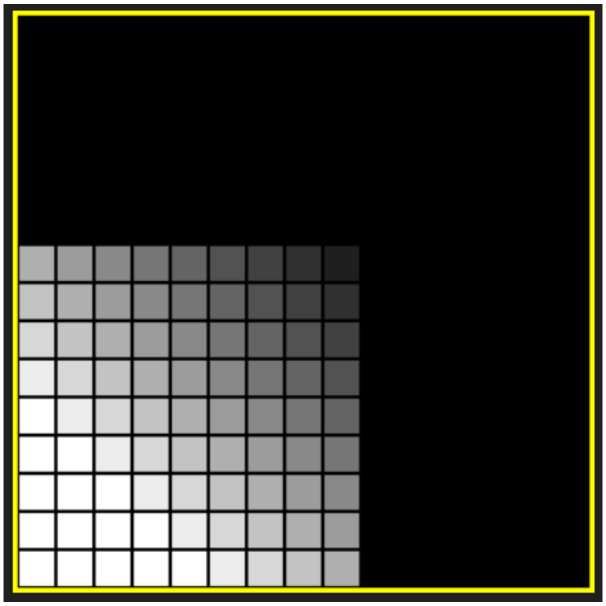
Part 1

A) Visualizing the sensor probabilities (Implemented in visualize.py)

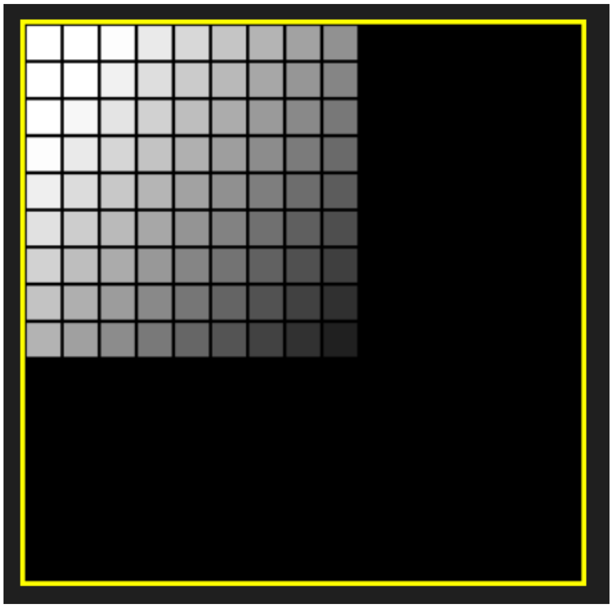


```
lam1=lambda_1()

hmm = HMM(lam1.N, lam1.T_prob,lam1.B_list,lam1)

sensor_probabilities = hmm.calculate_sensor_probabilities()
grid = Grid(M=lam1.N, N=lam1.N)

def visualize_grid_prob():
    for sensor_idx, prob_grid in enumerate(sensor_probabilities):
        print(f"Visualizing sensor {sensor_idx+1} probabilities...")
        for i in range(lam1.N):
            for j in range(lam1.N):
                grid_cell = grid.get_grid(i, j)

                grid_cell[:, :, :] *= prob_grid[i, j]

        grid.show(f"plots/sensor_{sensor_idx+1}_probabilities.png")
        grid.clear()

visualize_grid_prob()
```

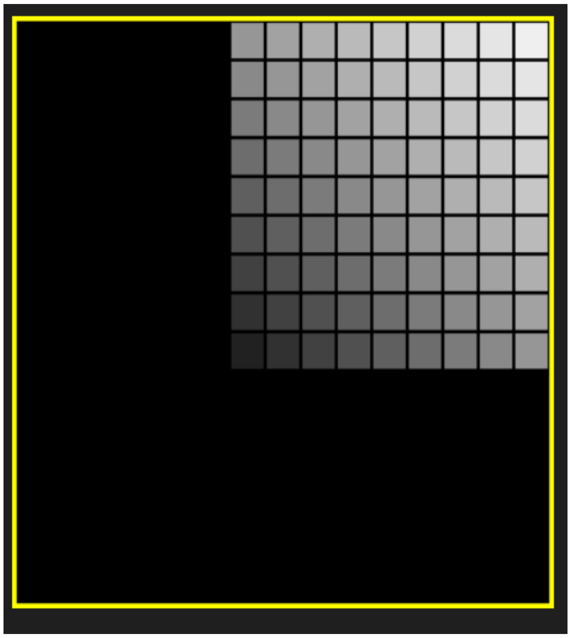
Sensor 1



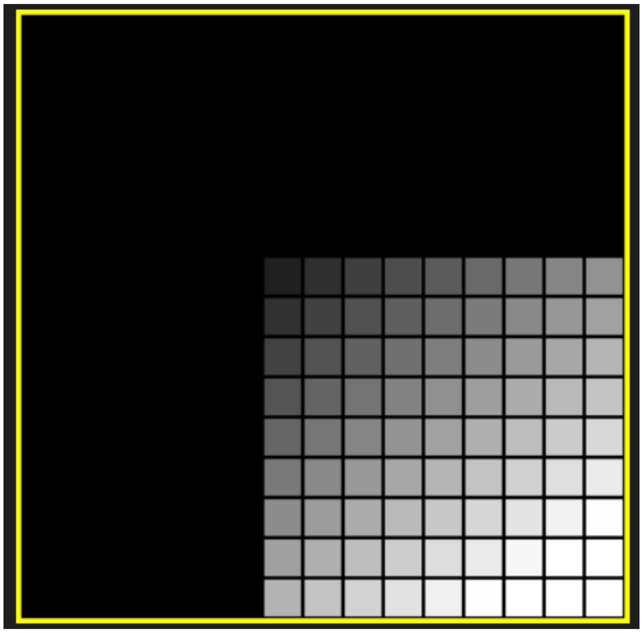
Sensor 2



Sensor 3

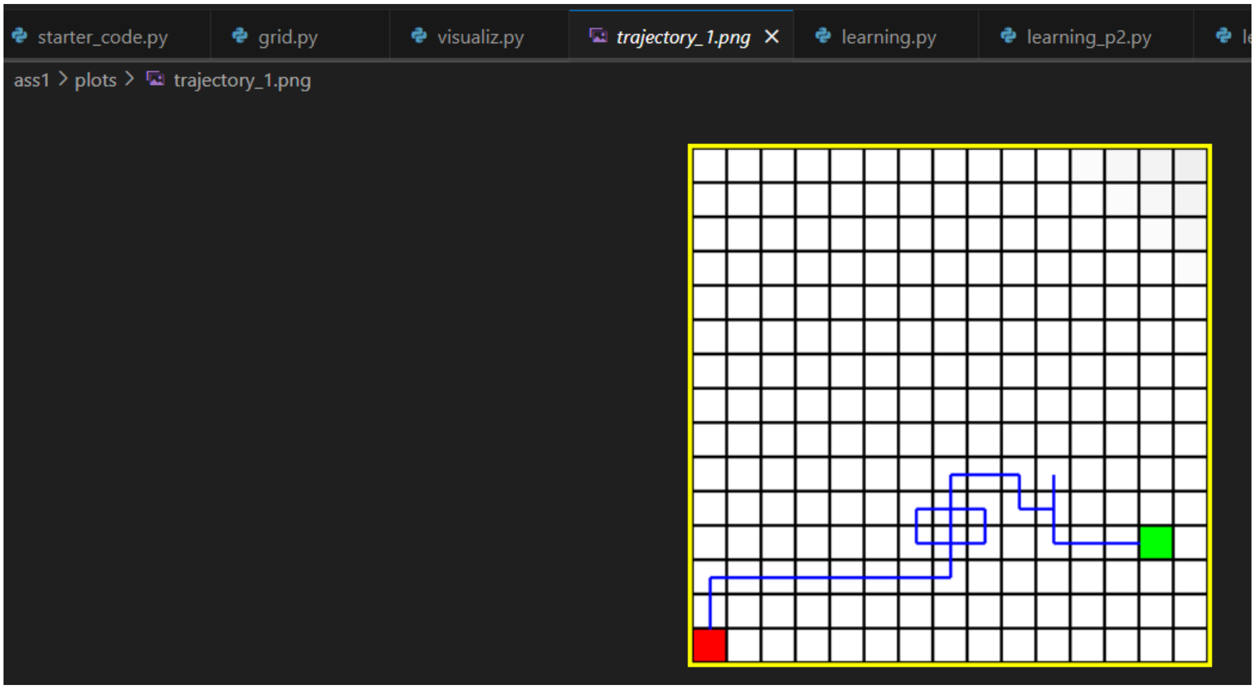


Sensor 4



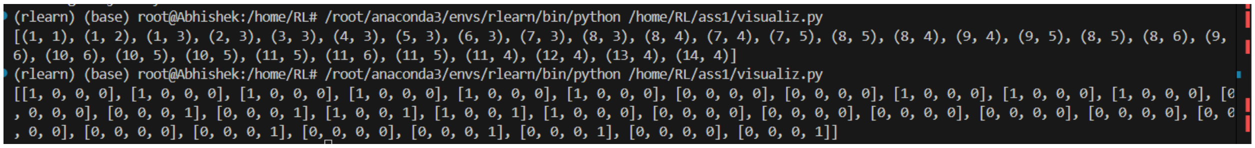
B, C) Sampling & Plotting trajectories (Implemented in visualize.py)

[(1, 1), (1, 2), (1, 3), (2, 3), (3, 3), (4, 3), (6, 3), (7, 3), (8, 3), (8, 4), (7, 4), (7, 5), (8, 5), (8, 4), (9, 4), (9, 5), (8, 5), (8, 6), (9, 6), (10, 6), (10, 5), (10, 5), (11, 5), (11, 6), (11, 5), (11, 4), (12, 4), (13, 4), (14, 4)]



Sensor observations for above trajectory

[[1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [0, 0, 0, 0], [0, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [0, 0, 0, 0], [0, 0, 0, 1], [0, 0, 0, 1], [1, 0, 0, 1], [1, 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, 1], [0, 0, 0, 0], [0, 0, 0, 1], [0, 0, 0, 1], [0, 0, 0, 0], [0, 0, 0, 1]]

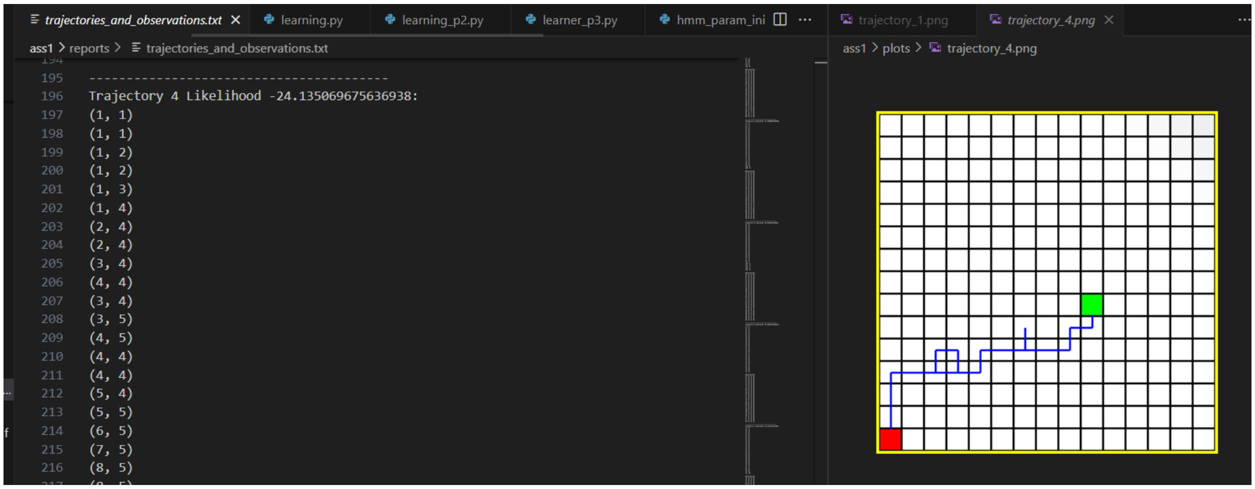


```
(rlearn) (base) root@Abhishek:/home/RL# /root/anaconda3/envs/rlearn/bin/python /home/RL/ass1/visualiz.py
[(1, 1), (1, 2), (1, 3), (2, 3), (3, 3), (4, 3), (5, 3), (6, 3), (7, 3), (8, 3), (8, 4), (7, 4), (7, 5), (8, 5), (8, 4), (9, 4), (9, 5), (8, 5), (8, 6), (9,
6), (10, 6), (10, 5), (10, 5), (11, 5), (11, 6), (11, 5), (11, 4), (12, 4), (13, 4), (14, 4)]
(rlearn) (base) root@Abhishek:/home/RL# /root/anaconda3/envs/rlearn/bin/python /home/RL/ass1/visualiz.py
[[1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [0, 0, 0, 0], [0, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [1, 0, 0, 0], [0
, 0, 0, 0], [0, 0, 0, 1], [0, 0, 0, 1], [1, 0, 0, 1], [1, 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, 1], [0, 0, 0, 0], [0, 0, 0, 1], [0, 0, 0, 1], [0, 0, 0, 0], [0, 0, 0, 1]]
```

Part 2

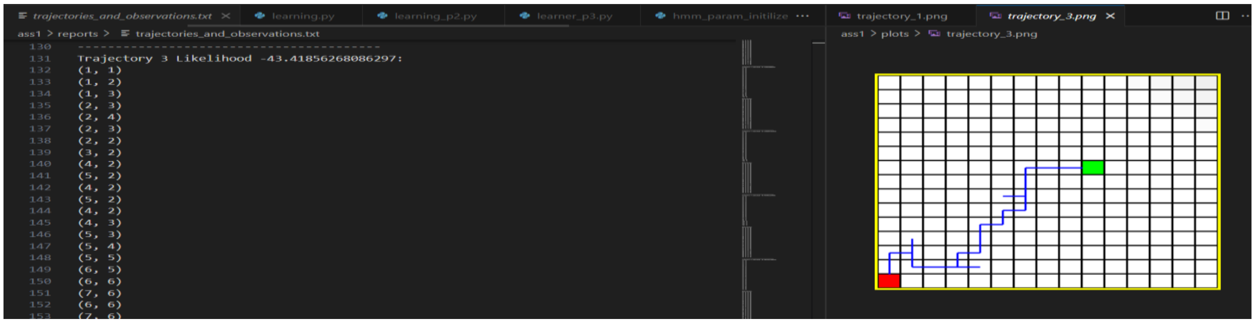
A) Log Likelihood are given in the file trajectories_and_observations.txt (Implemented in visualize.py)

B) Below is route 4 and its Log Likelihood is –24.


trajectories_and_observations.txt
learning.py
learning_p2.py
learner_p3.py
hmm_param_ini
trajectory_1.png
trajectory_4.png
ass1 > reports > trajectories_and_observations.txt
ass1 > plots > trajectory_4.png

```
---------------------------------------
Trajectory 4 Likelihood -24.135069675636938:
(1, 1)
(1, 1)
(1, 2)
(1, 2)
(1, 3)
(1, 4)
(2, 4)
(2, 4)
(3, 4)
(4, 4)
(3, 4)
(3, 5)
(4, 5)
(4, 4)
(4, 4)
(5, 4)
(5, 5)
(6, 5)
(7, 5)
(8, 5)
```

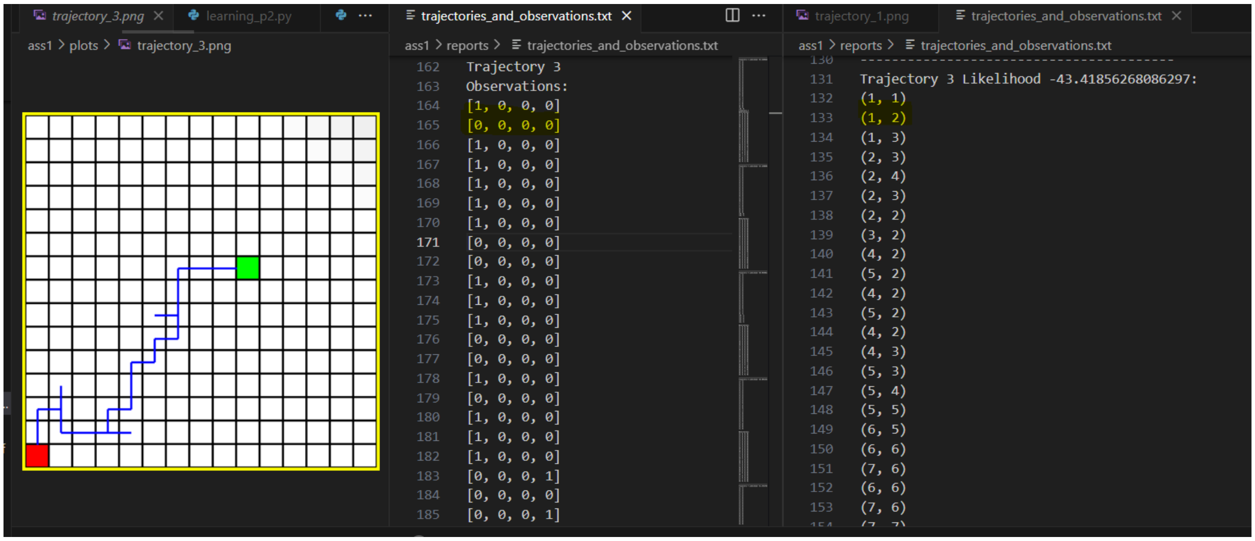
And this is route 3. It’s loglikelihood is –43


trajectories_and_observations.txt
learning.py
learning_p2.py
learner_p3.py
hmm_param_initilize
trajectory_1.png
trajectory_3.png
ass1 > reports > trajectories_and_observations.txt
ass1 > plots > trajectory_3.png

```
---------------------------------------
Trajectory 3 Likelihood -43.41856268086297:
(1, 1)
(1, 2)
(1, 3)
(2, 3)
(2, 4)
(2, 3)
(2, 2)
(3, 2)
(4, 2)
(5, 2)
(4, 2)
(5, 2)
(4, 2)
(4, 3)
(5, 3)
(5, 4)
(5, 5)
(6, 5)
(6, 6)
(7, 6)
(6, 6)
(7, 6)
```

Comments

1. Through trajectory it appears that trajectories that have more UP, RIGHT directions have a higher likelihood than those having unexpected turns. Trajectory 4 has a high likelihood but trajectory 3 has low likelihood because of this reason.
2. Also, likelihood decreases with unlikely observation from observation sampling. For trajectory 3, observation at (1,2) is [0,0,0,0] which is unlikely as point is quite close to sensor 1.


trajectory_3.png
learning_p2.py
ass1 > plots > trajectory_3.png
trajectories_and_observations.txt
ass1 > reports > trajectories_and_observations.txt
trajectory_1.png
trajectories_and_observations.txt
ass1 > reports > trajectories_and_observations.txt

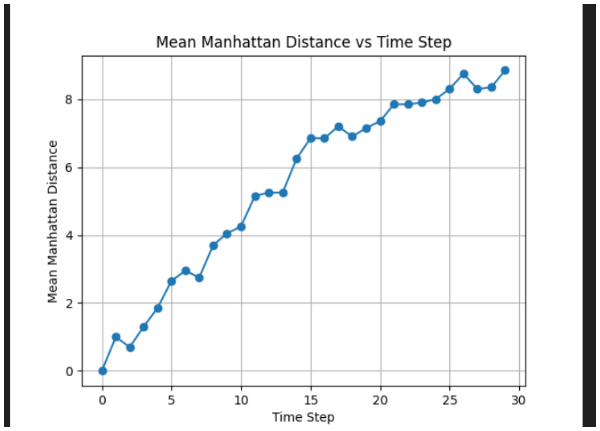
```
Trajectory 3
Observations:
[1, 0, 0, 0]
[0, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[0, 0, 0, 0]
[0, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[0, 0, 0, 0]
[0, 0, 0, 0]
[1, 0, 0, 0]
[0, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 0, 0, 0]
[0, 0, 0, 1]
```

```
----------------------------------------
Trajectory 3 Likelihood -43.41856268086297:
(1, 1)
(1, 2)
(1, 3)
(2, 3)
(2, 4)
(2, 3)
(2, 2)
(3, 2)
(4, 2)
(5, 2)
(4, 2)
(5, 2)
(4, 2)
(4, 3)
(5, 3)
(5, 4)
(5, 5)
(6, 5)
(6, 6)
(7, 6)
(6, 6)
(7, 6)
```

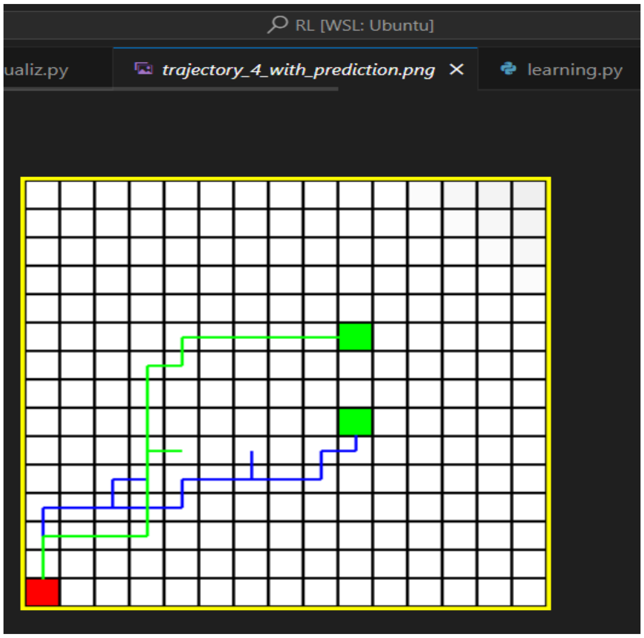
Part 3

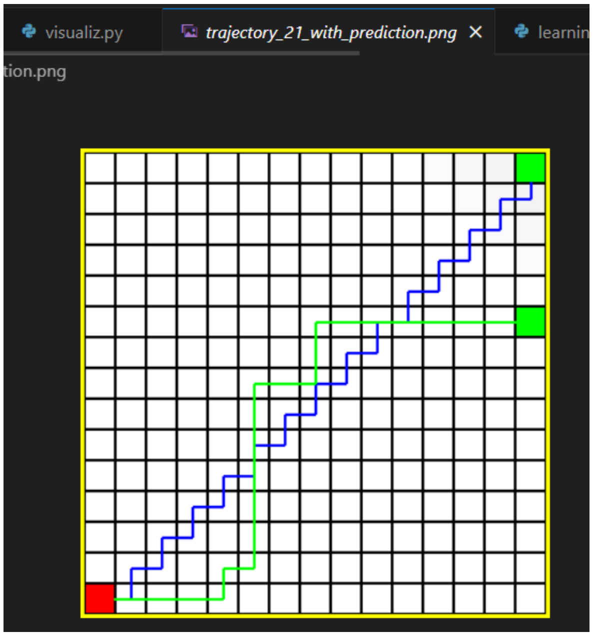
A) Code in viterbi.py file and plotted in visualize.py

B) Plots are inside the plot folder. Mean Manhattan distance (20 Trajectories) vs Time.



C) Predicted using Viterbi (Green), Actual (Blue)

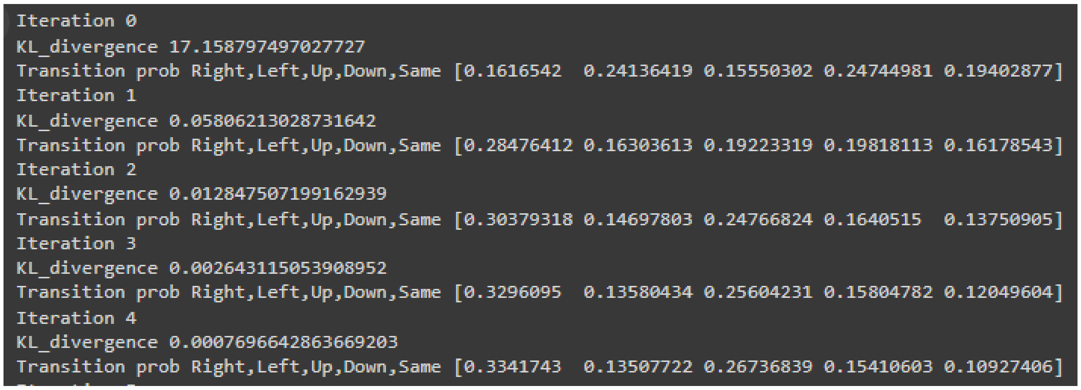




Part 4

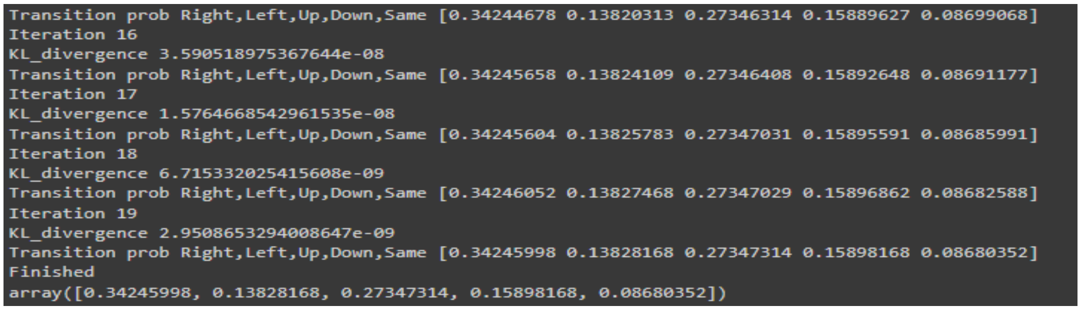
A) Code in learning.py

Fist few iterations



```
Iteration 0
KL_divergence 17.158797497027727
Transition prob Right,Left,Up,Down,Same [0.1616542  0.24136419 0.15550302 0.24744981 0.19402877]
Iteration 1
KL_divergence 0.05806213028731642
Transition prob Right,Left,Up,Down,Same [0.28476412 0.16303613 0.19223319 0.19818113 0.16178543]
Iteration 2
KL_divergence 0.012847507199162939
Transition prob Right,Left,Up,Down,Same [0.30379318 0.14697803 0.24766824 0.1640515  0.13750905]
Iteration 3
KL_divergence 0.002643115053908952
Transition prob Right,Left,Up,Down,Same [0.3296095  0.13580434 0.25604231 0.15804782 0.12049604]
Iteration 4
KL_divergence 0.0007696642863669203
Transition prob Right,Left,Up,Down,Same [0.3341743  0.13507722 0.26736839 0.15410603 0.10927406]
```

Last few iterations



```
Transition prob Right,Left,Up,Down,Same [0.34244678 0.13820313 0.27346314 0.15889627 0.08699068]
Iteration 16
KL_divergence 3.590518975367644e-08
Transition prob Right,Left,Up,Down,Same [0.34245658 0.13824109 0.27346408 0.15892648 0.08691177]
Iteration 17
KL_divergence 1.5764668542961535e-08
Transition prob Right,Left,Up,Down,Same [0.34245604 0.13825783 0.27347031 0.15895591 0.08685991]
Iteration 18
KL_divergence 6.715332025415608e-09
Transition prob Right,Left,Up,Down,Same [0.34246052 0.13827468 0.27347029 0.15896862 0.08682588]
Iteration 19
KL_divergence 2.9508653294008647e-09
Transition prob Right,Left,Up,Down,Same [0.34245998 0.13828168 0.27347314 0.15898168 0.08680352]
Finished
array([0.34245998, 0.13828168, 0.27347314, 0.15898168, 0.08680352])
```

Final KL divergence was 2.9508653294008647e-09

Final T is
Right,Left,Up,Down,Same [0.34245998 0.13828168 0.27347314 0.15898168 0.08680352]
Collab link
https://colab.research.google.com/drive/1MDoU3XOyILIUHcaVsjw4HQ9bRXte8Xfb?usp=sharing
Logs are present in logs folder

B) Learning both T & B (file name -leaner_p2.py)

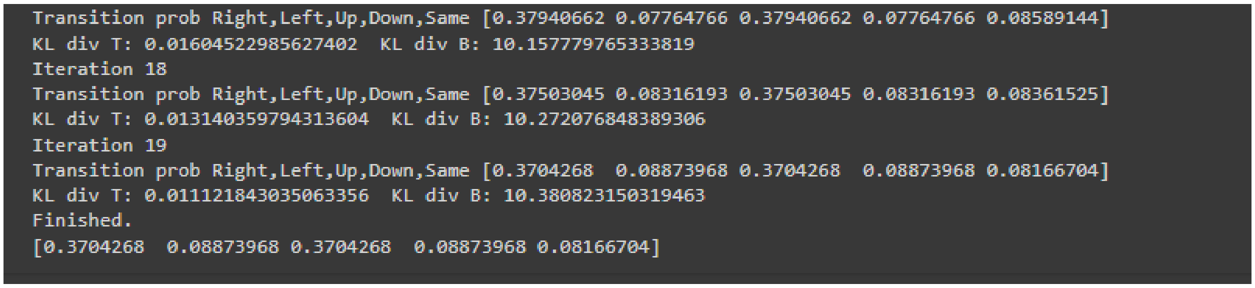
KL divergence for T = 0.011

KL divergence for B = 10 after 20 iterations

Predicted T is quite near the original one.

I converged for T and diverged for B. I tried many kinds of normalization & smoothing ways to make it converge. Logs are present in log folder.

https://colab.research.google.com/drive/1-AjqOqIG--a0WbkIcMDUuEmkfB3GHmw9?usp=sharing

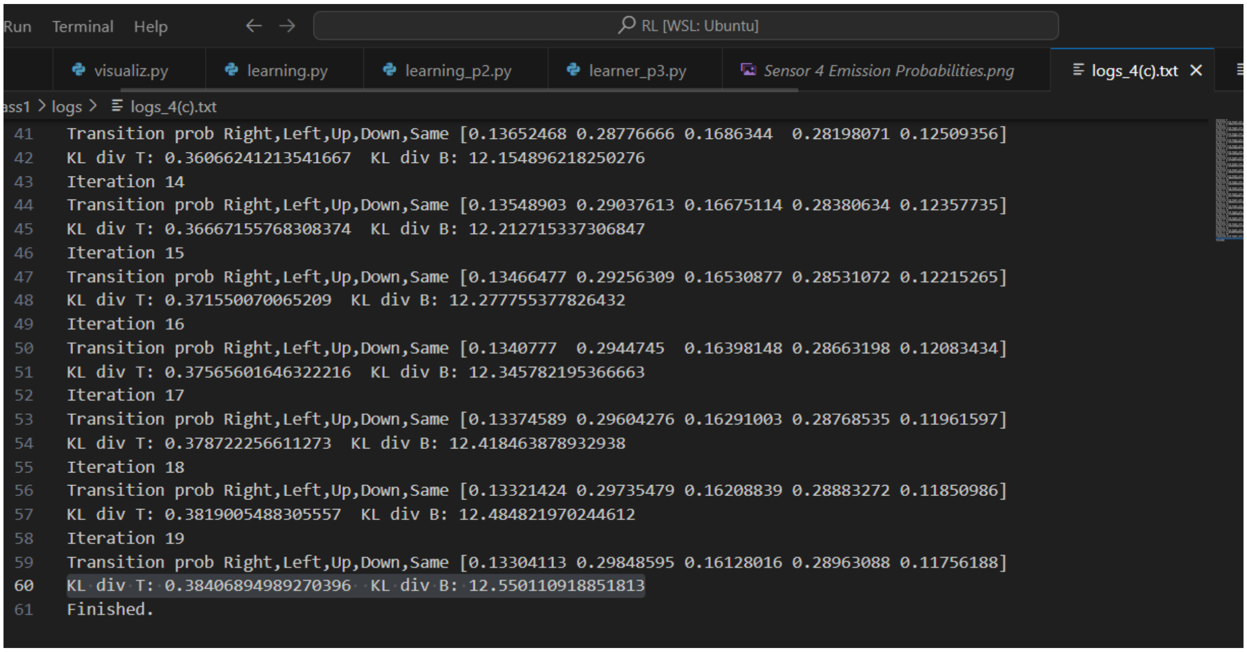


```
Transition prob Right,Left,Up,Down,Same [0.37940662 0.07764766 0.37940662 0.07764766 0.08589144]
KL div T: 0.01604522985627402  KL div B: 10.157779765333819
Iteration 18
Transition prob Right,Left,Up,Down,Same [0.37503045 0.08316193 0.37503045 0.08316193 0.08361525]
KL div T: 0.013140359794313604  KL div B: 10.272076848389306
Iteration 19
Transition prob Right,Left,Up,Down,Same [0.3704268  0.08873968 0.3704268  0.08873968 0.08166704]
KL div T: 0.011121843035063356  KL div B: 10.380823150319463
Finished.
[0.3704268  0.08873968 0.3704268  0.08873968 0.08166704]
```

C) Learning B and T using sensor independence

KL div T: 0.38 KL div B: 12.55

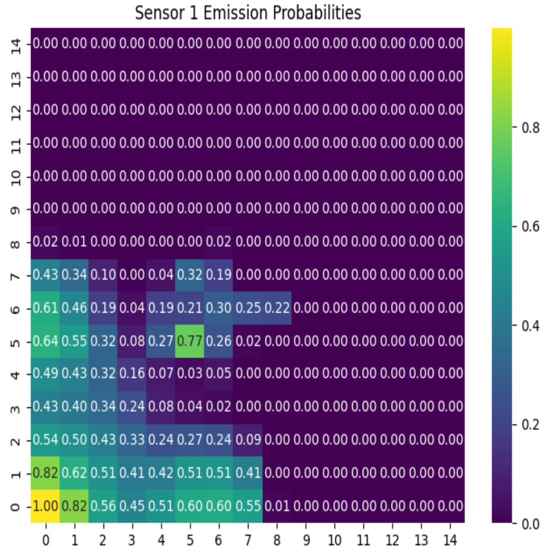
Code is in leaner_p3.py file.



```
Transition prob Right,Left,Up,Down,Same [0.13652468 0.28776666 0.1686344  0.28198071 0.12509356]
KL div T: 0.36066241213541667  KL div B: 12.154896218250276
Iteration 14
Transition prob Right,Left,Up,Down,Same [0.13548903 0.29037613 0.16675114 0.28380634 0.12357735]
KL div T: 0.36667155768308374  KL div B: 12.212715337306847
Iteration 15
Transition prob Right,Left,Up,Down,Same [0.13466477 0.29256309 0.16530877 0.28531072 0.12215265]
KL div T: 0.371550070065209  KL div B: 12.277755377826432
Iteration 16
Transition prob Right,Left,Up,Down,Same [0.1340777  0.2944745  0.16398148 0.28663198 0.12083434]
KL div T: 0.37565601646322216  KL div B: 12.345782195366663
Iteration 17
Transition prob Right,Left,Up,Down,Same [0.13374589 0.29604276 0.16291003 0.28768535 0.11961597]
KL div T: 0.378722256611273  KL div B: 12.418463878932938
Iteration 18
Transition prob Right,Left,Up,Down,Same [0.13321424 0.29735479 0.16208839 0.28883272 0.11850986]
KL div T: 0.3819005488305557  KL div B: 12.484821970244612
Iteration 19
Transition prob Right,Left,Up,Down,Same [0.13304113 0.29848595 0.16128016 0.28963088 0.11756188]
KL div T: 0.38406894989270396  KL div B: 12.550110918851813
Finished.
```

Gradient plots are in plots folder

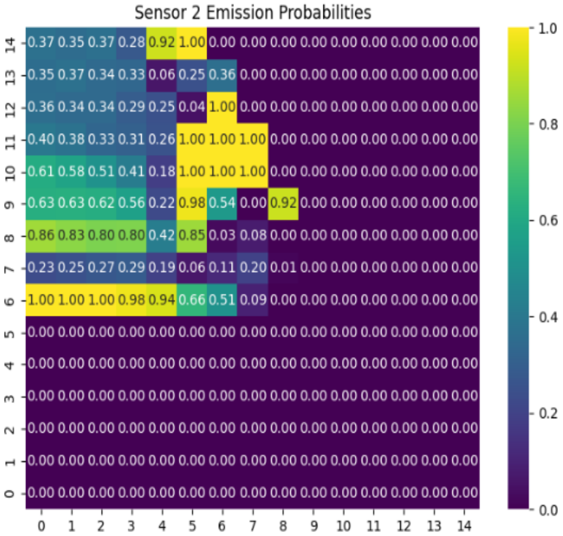
S1 sensor gradient



Sensor 1 Emission Probabilities

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.43	0.34	0.10	0.00	0.04	0.32	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.61	0.46	0.19	0.04	0.19	0.21	0.30	0.25	0.22	0.00	0.00	0.00	0.00	0.00	0.00
5	0.64	0.55	0.32	0.08	0.27	0.77	0.26	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.49	0.43	0.32	0.16	0.07	0.03	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.43	0.40	0.34	0.24	0.08	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.54	0.50	0.43	0.33	0.24	0.27	0.24	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.82	0.62	0.51	0.41	0.42	0.51	0.51	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	1.00	0.82	0.56	0.45	0.51	0.60	0.60	0.55	0.01	0.00	0.00	0.00	0.00	0.00	0.00

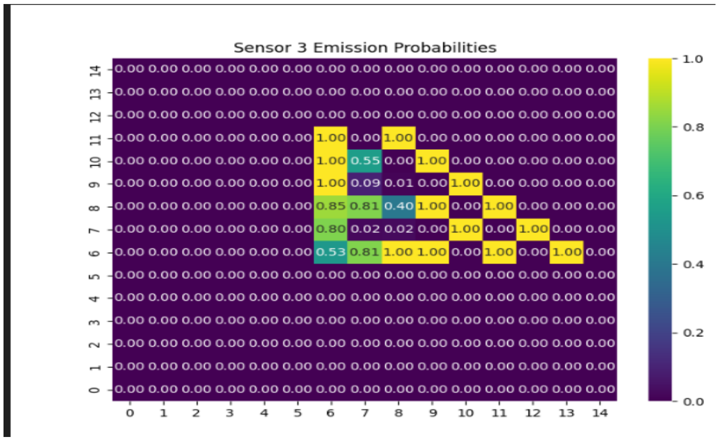
S2 sensor gradient



Sensor 2 Emission Probabilities

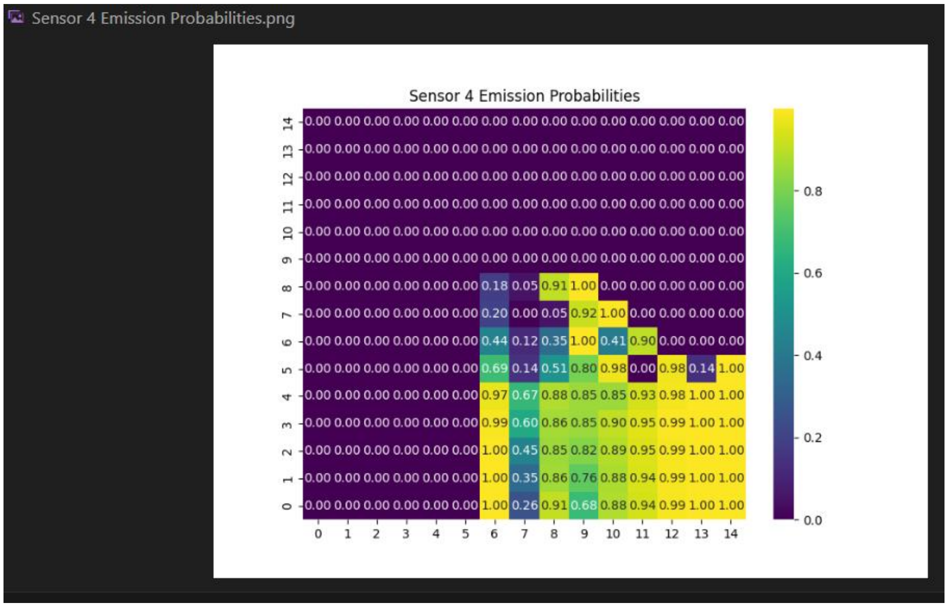
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
14	0.37	0.35	0.37	0.28	0.92	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.35	0.37	0.34	0.33	0.06	0.25	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.36	0.34	0.34	0.29	0.25	0.04	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.40	0.38	0.33	0.31	0.26	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.61	0.58	0.51	0.41	0.18	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.63	0.63	0.62	0.56	0.22	0.98	0.54	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00
8	0.86	0.83	0.80	0.80	0.42	0.85	0.03	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.23	0.25	0.27	0.29	0.19	0.06	0.11	0.20	0.01	0.00	0.00	0.00	0.00	0.00	0.00
6	1.00	1.00	1.00	0.98	0.94	0.66	0.51	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

S3 sensor gradient



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.55	0.00	1.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.09	0.01	0.00	1.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.85	0.81	0.40	1.00	0.00	1.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.02	0.02	0.00	1.00	0.00	1.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.81	1.00	1.00	0.00	1.00	0.00	1.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

S4 sensor gradient



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.05	0.91	1.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.05	0.92	1.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.12	0.35	1.00	0.41	0.90	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.69	0.14	0.51	0.80	0.98	0.00	0.98	0.14	1.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.67	0.88	0.85	0.85	0.93	0.98	1.00	1.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.60	0.86	0.85	0.90	0.95	0.99	1.00	1.00
2	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.45	0.85	0.82	0.89	0.95	0.99	1.00	1.00
1	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.35	0.86	0.76	0.88	0.94	0.99	1.00	1.00
0	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.26	0.91	0.68	0.88	0.94	0.99	1.00	1.00

Abhishek Goyal

2023AIB2073