# Assignment 1

Jeffin Biju (EE19B085) and Rajdeep Paul (EE19B109)

In [ ]:

```
# Run this only if you are using Google Colab
from google.colab import drive
import os

drive.mount('/content/drive', force_remount=True)

# change path here as per your directory structure
os.chdir('drive/My Drive/CS6700/assignment_1')
```

```
Mounted at /content/drive
```

In [ ]:

```
from google.colab import drive
drive.mount('/content/drive')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remo
unt, call drive.mount("/content/drive", force_remount=True).
```

In [ ]:

```
# Install relevant libraries
!pip install numpy matplotlib tqdm scipy
```

```
Requirement already satisfied: numpy in /usr/local/lib/python3.7/dis
t-packages (1.21.5)
Requirement already satisfied: matplotlib in /usr/local/lib/python3.
7/dist-packages (3.2.2)
Requirement already satisfied: tqdm in /usr/local/lib/python3.7/dist
-packages (4.63.0)
Requirement already satisfied: scipy in /usr/local/lib/python3.7/dis
t-packages (1.4.1)
Requirement already satisfied: python-dateutil>=2.1 in /usr/local/li
b/python3.7/dist-packages (from matplotlib) (2.8.2)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/p
ython3.7/dist-packages (from matplotlib) (1.3.2)
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python
3.7/dist-packages (from matplotlib) (0.11.0)
Requirement already satisfied: pyparsing!=2.0.4,!=2.1.2,!=2.1.6,>=2.
0.1 in /usr/local/lib/python3.7/dist-packages (from matplotlib) (3.
0.7)
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.7/
dist-packages (from python-dateutil>=2.1->matplotlib) (1.15.0)
```

## Importing the environment

In [ ]:

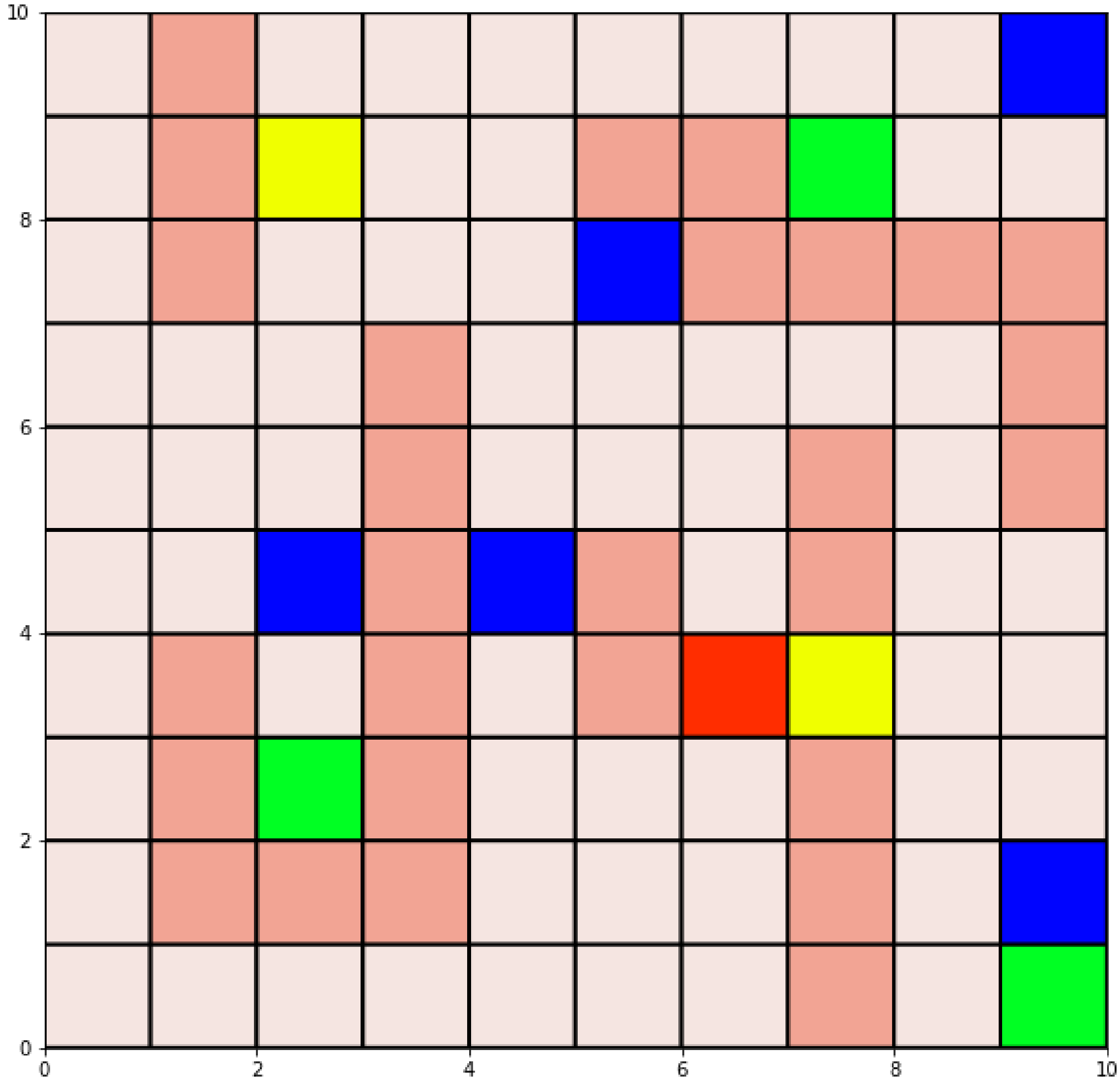
```
import numpy as np
import matplotlib.pyplot as plt
from tqdm import tqdm
from IPython.display import clear_output
from PA1 import GridWorld, seq_to_col_row
%matplotlib inline
```

In [ ]:

```
DOWN = 0
UP = 1
LEFT = 2
RIGHT = 3
actions = [DOWN, UP, LEFT, RIGHT]
```

In [ ]:

```
num_cols = 10
num_rows = 10
obstructions = np.array([[0,7],[1,1],[1,2],[1,3],[1,7],[2,1],[2,3],
                         [2,7],[3,1],[3,3],[3,5],[4,3],[4,5],[4,7],
                         [5,3],[5,7],[5,9],[6,3],[6,9],[7,1],[7,6],
                         [7,7],[7,8],[7,9],[8,1],[8,5],[8,6],[9,1]])
bad_states = np.array([[1,9],[4,2],[4,4],[7,5],[9,9]])
restart_states = np.array([[3,7],[8,2]])
start_state = np.array([[3,6]])
goal_states = np.array([[0,9],[2,2],[8,7]])

# create model
gw = GridWorld(num_rows=num_rows,
               num_cols=num_cols,
               start_state=start_state,
               goal_states=goal_states, wind = False)
gw.add_obstructions(obstructed_states=obstructions,
                    bad_states=bad_states,
                    restart_states=restart_states)
gw.add_rewards(step_reward=-1,
               goal_reward=10,
               bad_state_reward=-6,
               restart_state_reward=-10)
gw.add_transition_probability(p_good_transition=0.7,
                              bias=0.5)
env = gw.create_gridworld()
plt.figure(figsize=(10, 10))
env.render(ax=plt, render_agent=False)
```




## Legend

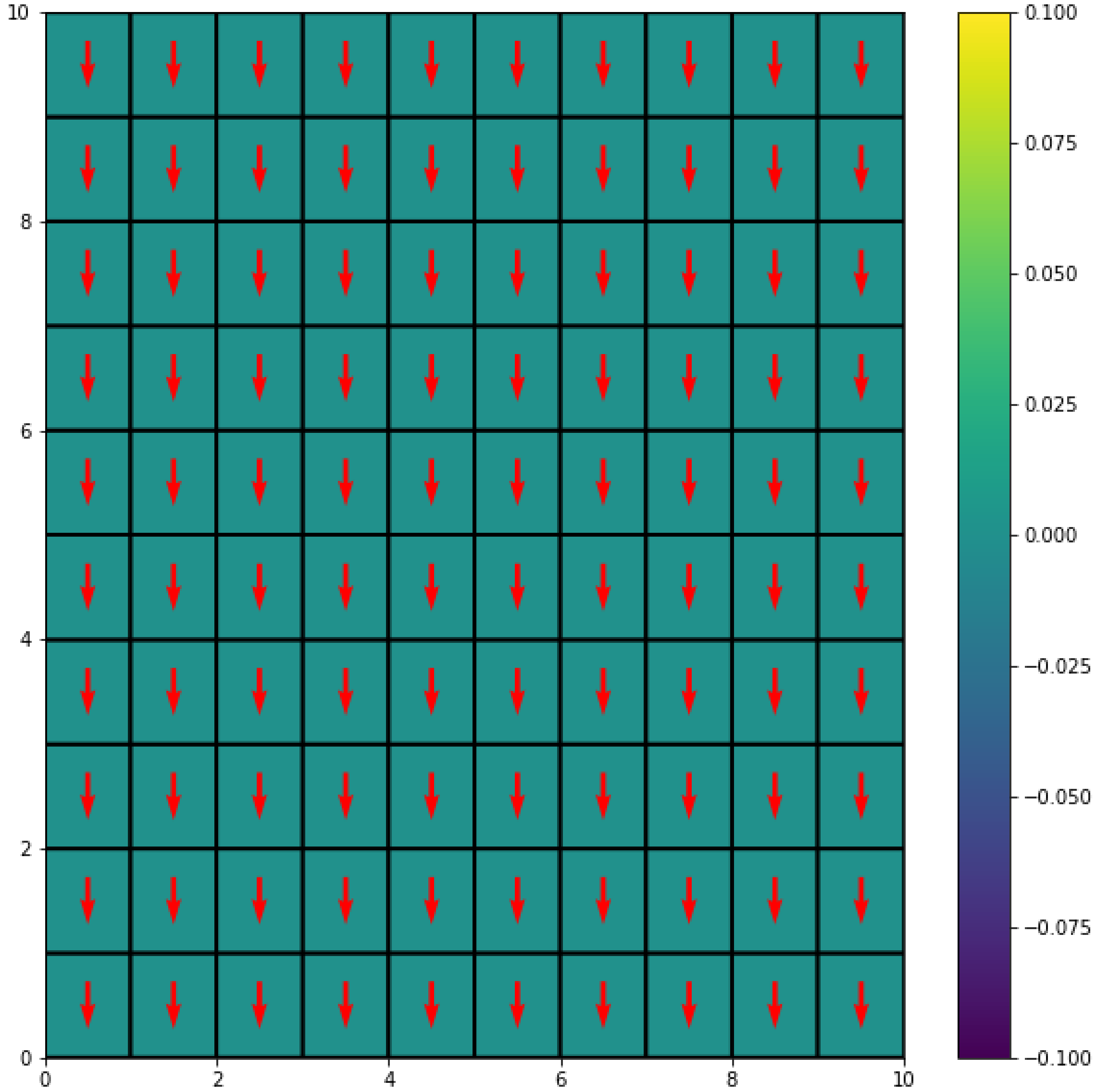
- *Light brown* is **normal states of the agent.**
- *Red* is the **start state.**
- *Green* is the **goal state.**
- *Dark brown* is **obstructed states of the agent.**
- *Blue* is **bad states of the agent.**
- *Yellow* is **restart states of the agent.**

In [ ]:

```
def plot_Q(Q, message=None, save=False):

    plt.figure(figsize=(10,10))
    plt.title(message)
    plt.pcolor(Q.max(-1), edgecolors='k', linewidths=2)
    plt.colorbar()
    def x_direct(a):
        if a in [UP, DOWN]:
            return 0
        return 1 if a == RIGHT else -1
    def y_direct(a):
        if a in [RIGHT, LEFT]:
            return 0
        return 1 if a == UP else -1
    policy = Q.argmax(-1)
    policyx = np.vectorize(x_direct)(policy)
    policyy = np.vectorize(y_direct)(policy)
    idx = np.indices(policy.shape)
    plt.quiver(idx[1].ravel()+0.5, idx[0].ravel()+0.5, policyx.ravel(), policyy.
ravel(), pivot="middle", color='red')
    print(save)
    if save:
        plt.savefig(fname = message, format = 'pdf')
    plt.show()

def plot_T(T, message=None, save=False):
    plt.figure(figsize=(10,10))
    plt.title(message)
    plt.pcolor(T, edgecolors='k', linewidths=2)
    plt.colorbar()
    if save:
        plt.savefig(fname = message, format = 'pdf')
    plt.show()
```

In [ ]:

```
Q = np.zeros((env.num_rows, env.num_cols, env.num_actions))


plot_Q(Q, save=False)

Q.shape
```

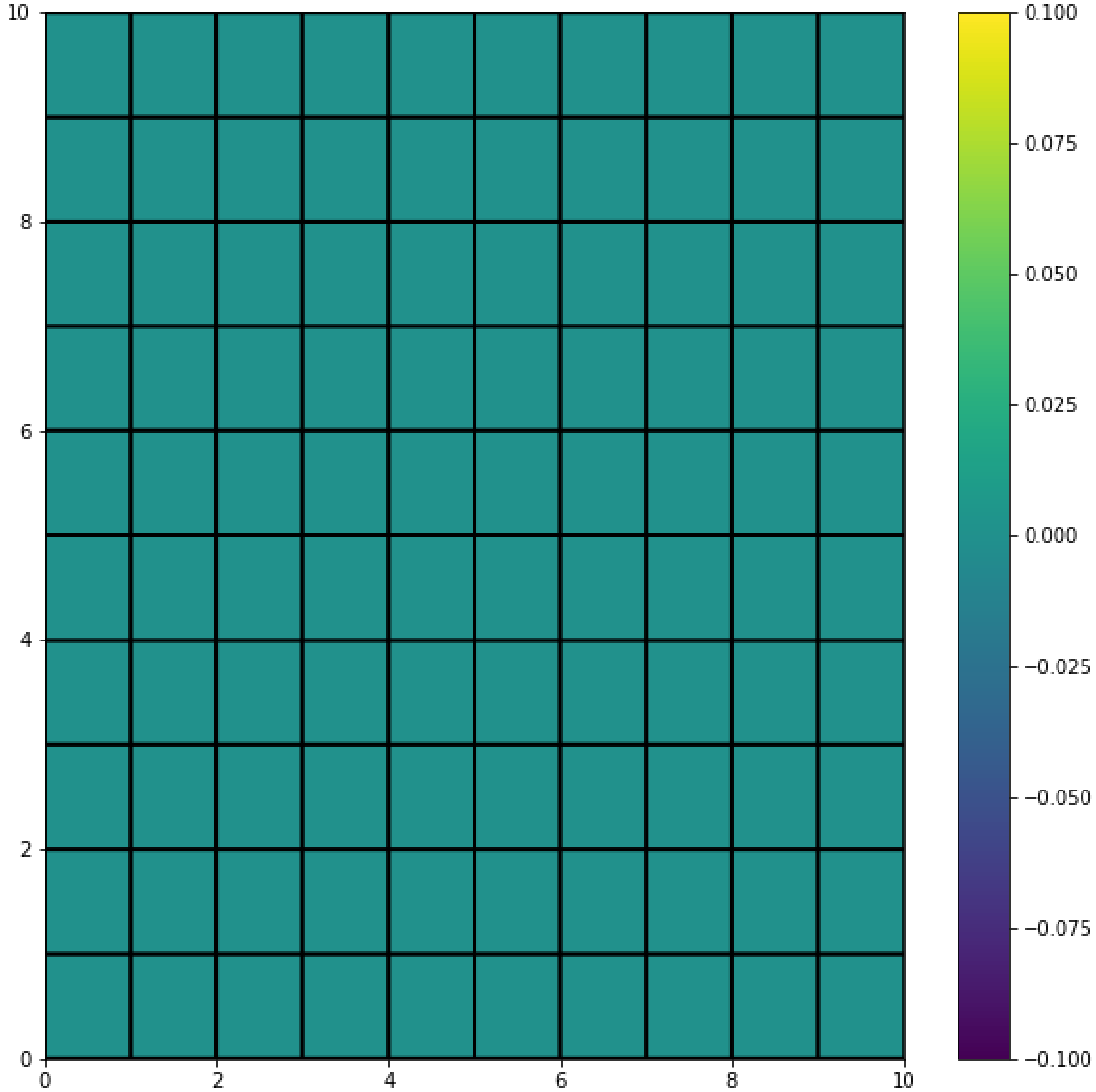

10
8
6
4
2
0
0
2
4
6
8
10
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100

Out[ ]:

```
(10, 10, 4)
```

In [ ]:

```
T = np.zeros((env.num_rows, env.num_cols))
plot_T(T, save=False)
```




## Exploration strategies

1. Epsilon-greedy
2. Softmax

In [ ]:

```
from scipy.special import softmax

seed = 42
rg = np.random.RandomState(seed)

# Epsilon greedy
def choose_action_epsilon(Q, state, rg=rg, epsilon = 0.1, temperature = 1):
    if not Q[state[0], state[1]].any() or rg.rand() < epsilon:
        return rg.choice(Q.shape[-1])
    else:
        return np.argmax(Q[state[0], state[1]])

# Softmax
def choose_action_softmax(Q, state, rg=rg, epsilon = 0.1 , temperature = 1):
    return rg.choice(Q.shape[-1], p = softmax(Q[state[0], state[1]]/temperature
))
```

## SARSA

Now we implement the SARSA algorithm.

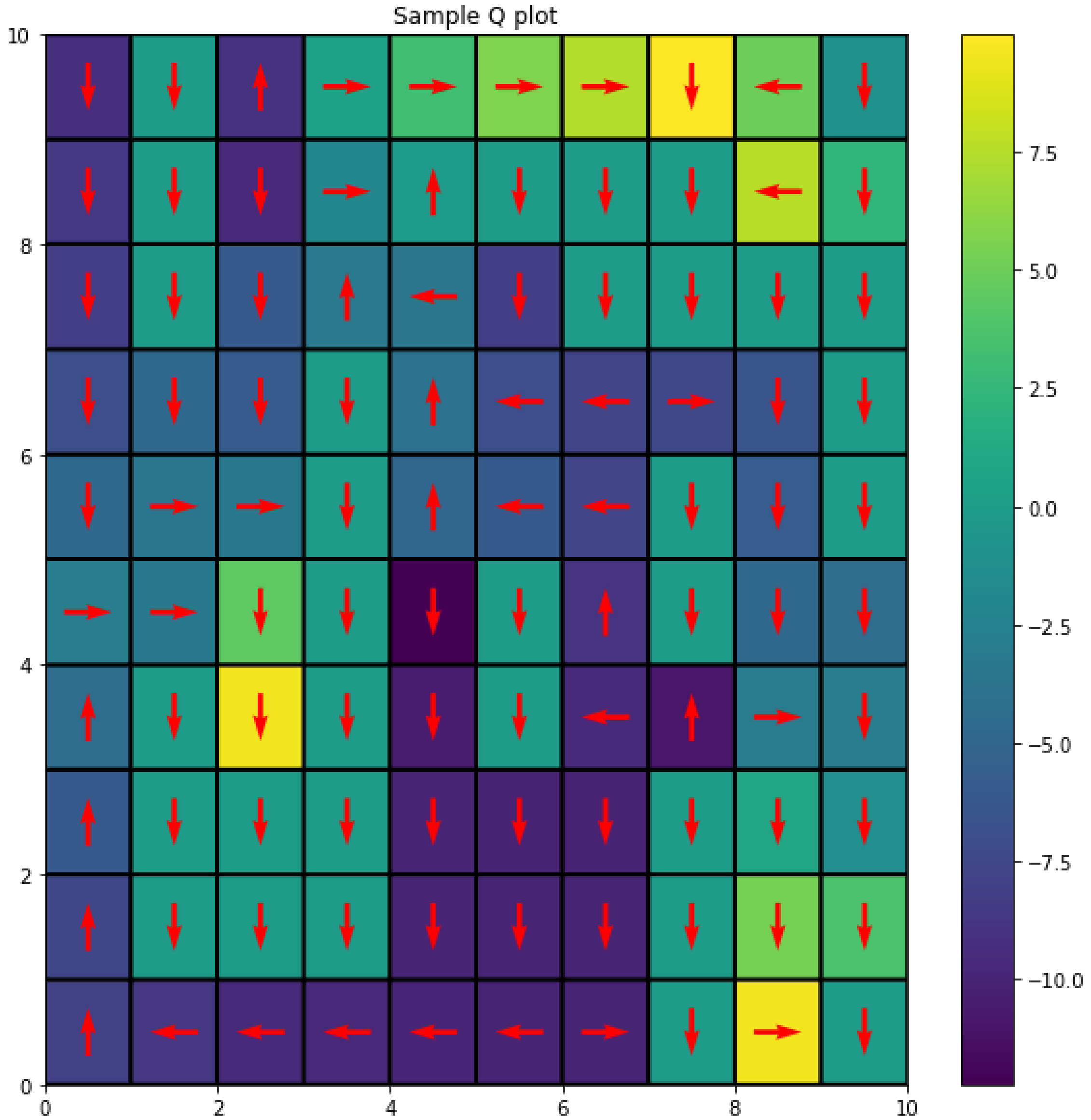
In [ ]:

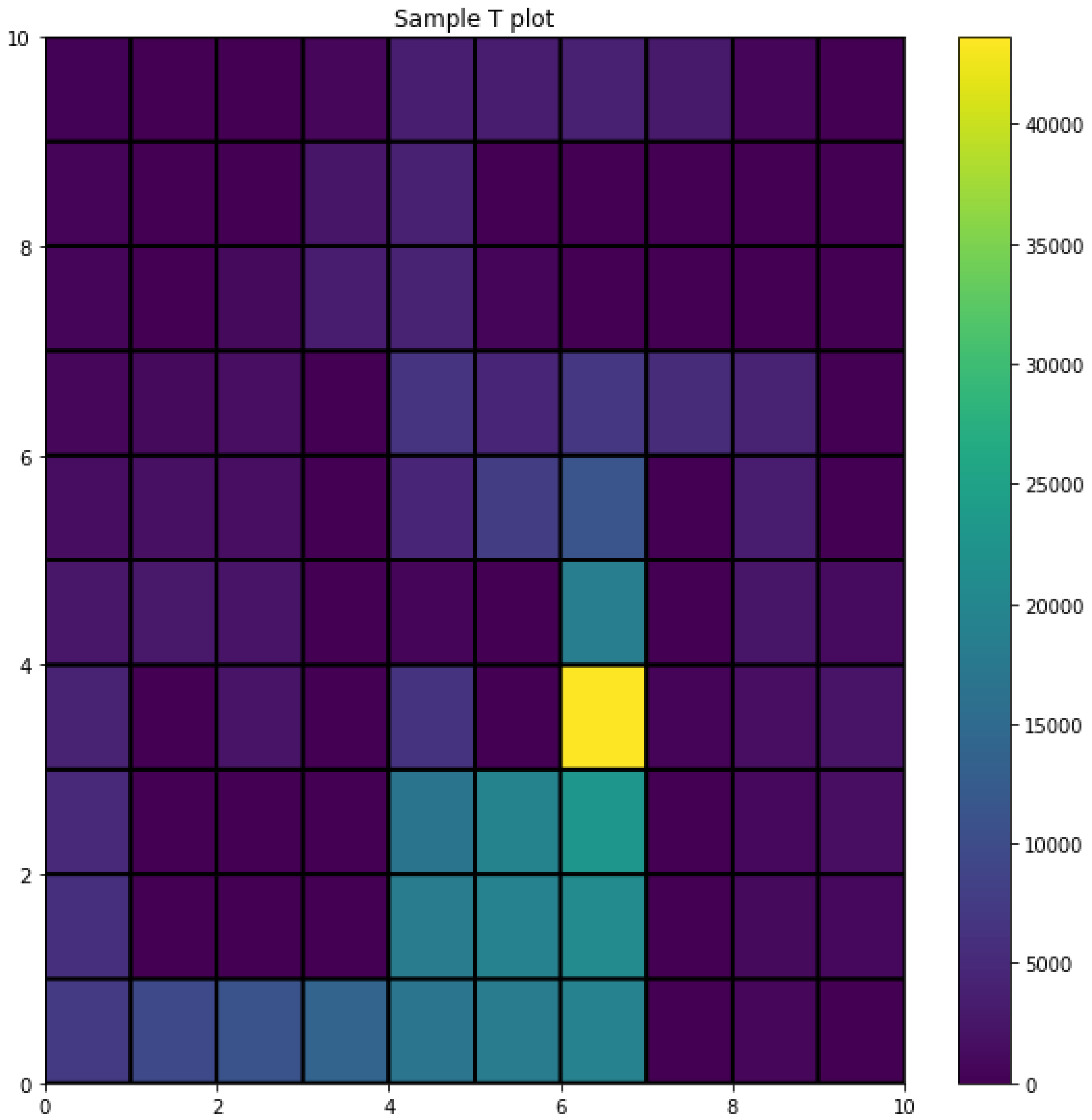
```
print_freq = 500
episodes = 5000

def sarsa(env, Q, T, epsilon=0.1, alpha=0.4, gamma=0.9, temperature = 1, plot_he
at = False, choose_action = choose_action_softmax, episodes = 5000):

    episode_rewards = np.zeros(episodes)
    steps_to_completion = np.zeros(episodes)
    if plot_heat:
        clear_output(wait=True)
        plot_Q(Q)
        plot_T(T)
    epsilon = epsilon
    for ep in tqdm(range(episodes)):
        tot_reward, steps = 0, 0

        # Reset environment
        state = env.reset()
        row_col_state = seq_to_col_row(state)[0]
        action = choose_action(Q, row_col_state)
        done = False
        while not done:

            state_next, reward, done = env.step(state, action)
            row_col_state_next = seq_to_col_row(state_next)[0]
            action_next = choose_action(Q, row_col_state_next, epsilon = epsilon
, temperature = temperature)

            # update equation
            Q[row_col_state[0], row_col_state[1], action] += alpha*(reward + gam
ma*Q[row_col_state_next[0], row_col_state_next[1], action_next] - Q[row_col_stat
e[0], row_col_state[1], action])
            T[row_col_state[0], row_col_state[1]] += 1
            tot_reward += reward
            steps += 1
            state, action = state_next, action_next
            row_col_state = seq_to_col_row(state)[0]
            if(steps > 10000):
                return Q, T, episode_rewards, steps_to_completion

        episode_rewards[ep] = tot_reward
        steps_to_completion[ep] = steps

        if (ep+1)%print_freq == 0 and plot_heat:
            clear_output(wait=True)
            plot_Q(Q = Q, message = "Sample Q plot", save = False)
            plot_T(T = T, message = "Sample T plot", save = False)

    return Q, T, episode_rewards, steps_to_completion
```

In [ ]:

```
Q = np.zeros((env.num_rows, env.num_cols, env.num_actions))
T = np.zeros((env.num_rows, env.num_cols))
#episodes = 10000
Q, T, rewards, steps = sarsa(env, Q, T, plot_heat=True, choose_action= choose_ac
tion_softmax)
```

```
False
```





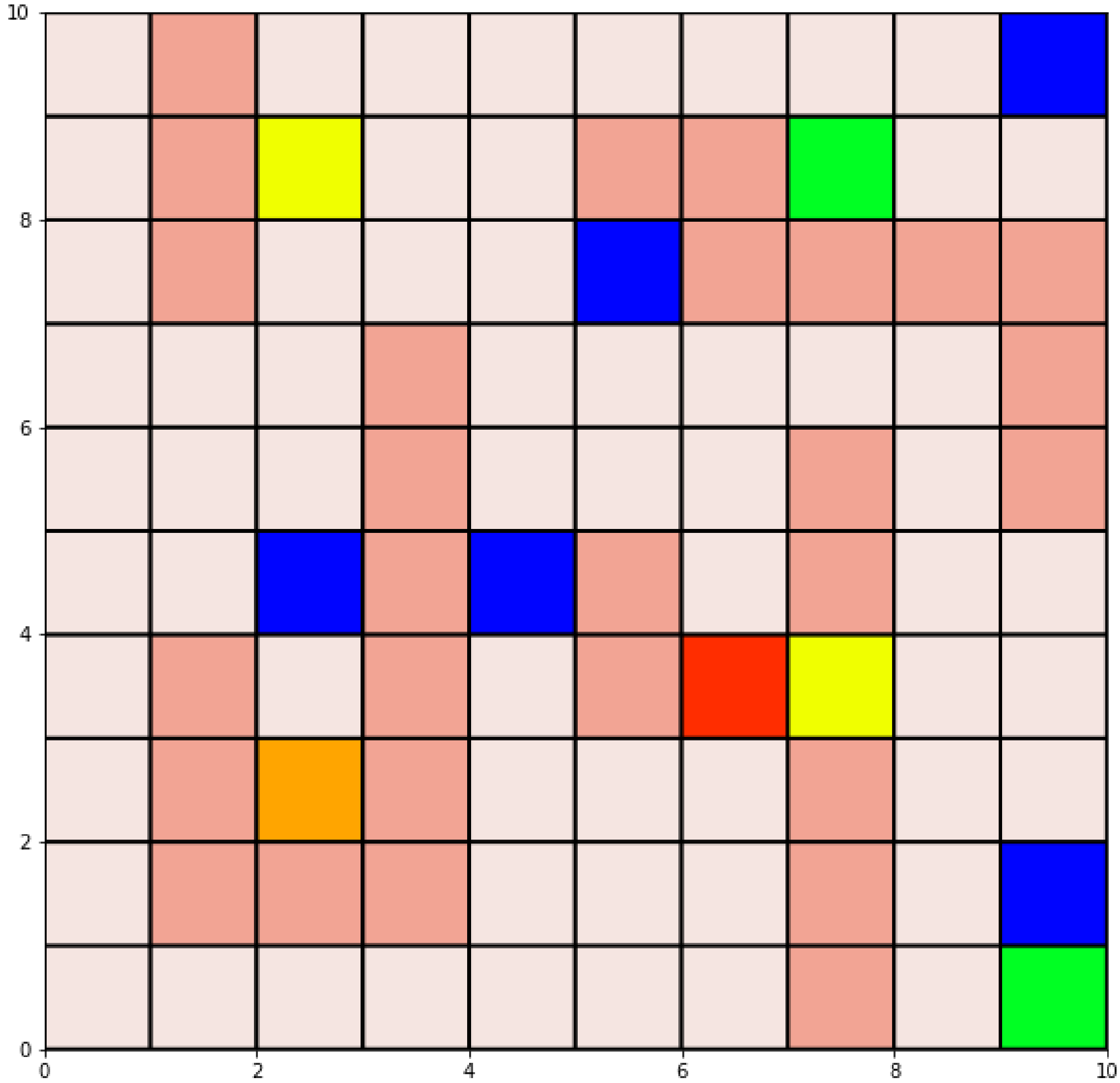

```
100%|██████████| 5000/5000 [02:12<00:00, 37.63it/s]
```

## Visualizing the policy

Now let's see the agent in action. Run the below cell (as many times) to render the policy;

In [ ]:

```
from time import sleep

state = env.reset()
done = False
steps = 0
tot_reward = 0
while not done:
    clear_output(wait=True)
    row_col_state = seq_to_col_row(state)[0]
    state, reward, done = env.step(state, Q[row_col_state[0], row_col_state[1]].
argmax())
    plt.figure(figsize=(10, 10))
    env.render(ax=plt, agent_state=state, render_agent=True)
    plt.show()
    steps += 1
    tot_reward += reward
    sleep(0.2)
print("Steps: %d, Total Reward: %d"%(steps, tot_reward))
```




```
Steps: 25, Total Reward: -19
```

## Analyzing performance of the policy

We use two metrics to analyze the:

1. Average steps to reach the goal
2. Total rewards from the episode

To ensure, we account for randomness in environment and algorithm (say when using epsilon-greedy exploration), we run the algorithm for multiple times and use the average of values over all runs.

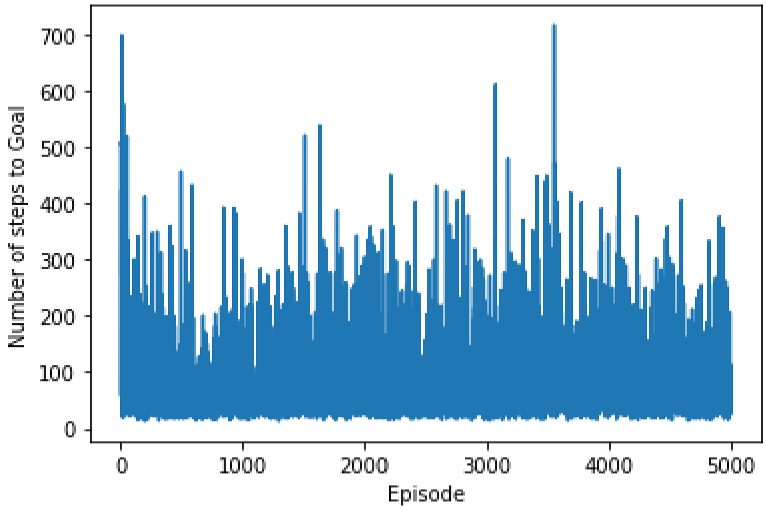
In [ ]:

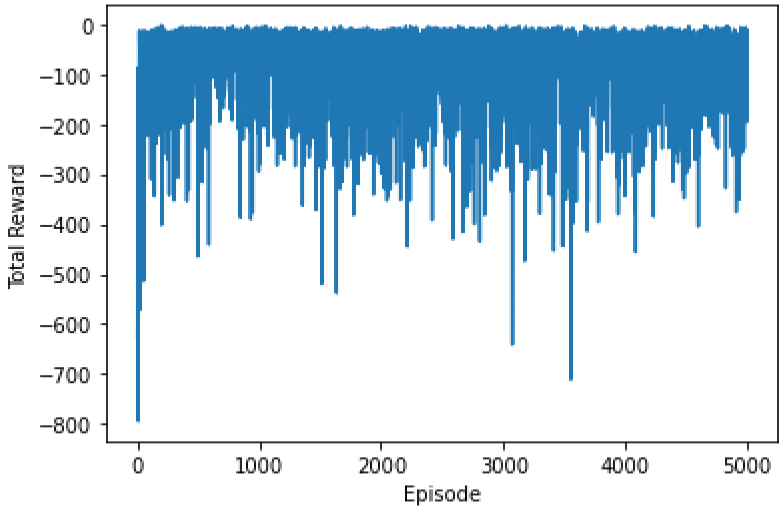
```
Q_avgs, reward_avgs, steps_avgs = [], [], []
num_expts = 1


for i in range(num_expts):
    print("Experiment: %d"%(i+1))
    Q = np.zeros((env.num_rows, env.num_cols, env.num_actions))
    T = np.zeros((env.num_rows, env.num_cols))
    rg = np.random.RandomState(i)
    Q, T, rewards, steps = sarsa(env, Q, T)
    Q_avgs.append(Q.copy())
    reward_avgs.append(rewards)
    steps_avgs.append(steps)
```

```
Experiment: 1

100%|██████████| 5000/5000 [02:00<00:00, 41.38it/s]
```

In [ ]:

```
plt.xlabel('Episode')
plt.ylabel('Number of steps to Goal')
plt.plot(np.arange(episodes),np.average(steps_avgs, 0))
plt.show()
plt.xlabel('Episode')
plt.ylabel('Total Reward')
plt.plot(np.arange(episodes),np.average(reward_avgs, 0))
plt.show()
```




## Q-Learning

Now lets implement the Q-Learning algorithm

In [ ]:

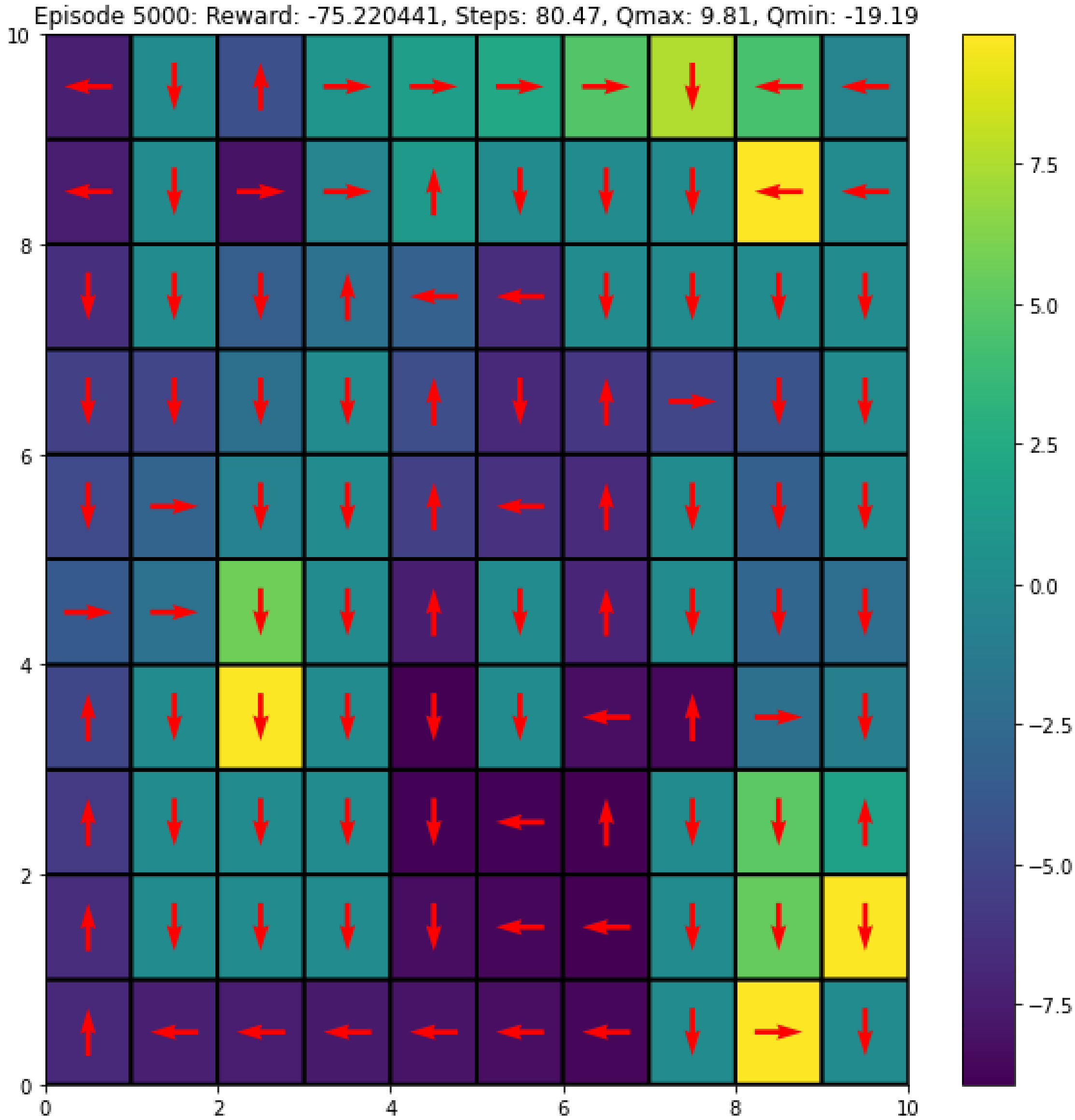
```
print_freq = 500
episodes = 5000
step_cnt = 0
def Q_Learning(env, Q, T, epsilon = 0.1, alpha = 0.4, gamma = 0.9, temperature = 
1, plot_heat = False, choose_action = choose_action_softmax, episodes = 5000):
  episode_rewards = np.zeros(episodes)
  steps_to_completion = np.zeros(episodes)
  if plot_heat:
    clear_output(wait = True)
    plot_Q(Q)
    plot_T(T)
  #epsilon = epsilon0
  #alpha = alpha0

  for ep in tqdm(range(episodes)):
    tot_reward = 0
    steps = 0
    done = False

    state = env.reset()
    steps_cnt = 0
    while not done:
      steps_cnt = steps_cnt + 1
      state_row_col = seq_to_col_row(state)[0]
      action = choose_action(Q,state_row_col, epsilon = epsilon , temperature = 
temperature)
      state_next,reward,done = env.step(state, action)
      state_next_row_col = seq_to_col_row(state_next)[0]
      steps_cnt = steps_cnt + 1


      #update equation
      v_pi_s = -np.inf
      for i in range(4):
        v_pi_s = max(v_pi_s,reward + gamma*(Q[state_next_row_col[0],state_next_r
ow_col[1],i]))

      Q[state_row_col[0],state_row_col[1],action] += alpha*(v_pi_s - Q[state_row
_col[0], state_row_col[1], action])
      T[state_row_col[0], state_row_col[1]] += 1

      tot_reward += reward
      steps += 1

      state = state_next
      if(steps_cnt > 10004):
        return Q, T, episode_rewards, steps_to_completion
    episode_rewards[ep] = tot_reward
    steps_to_completion[ep] = steps

    if (ep+1)%print_freq == 0 and plot_heat:
      clear_output(wait=True)
      plot_Q(Q, message = "Episode %d: Reward: %f, Steps: %.2f, Qmax: %.2f, Qmi
n: %.2f"%(ep+1, np.mean(episode_rewards[ep-print_freq+1:ep]),
                                                                           np.me
an(steps_to_completion[ep-print_freq+1:ep]),
                                                                           Q.max
(), Q.min()))
      plot_T(T, message = "Episode %d: Reward: %f, Steps: %.2f, Tmax: %.2f, Tmi
```

```
n: %.2f"%(ep+1, np.mean(episode_rewards[ep-print_freq+1:ep]),
                                                                    np.me
an(steps_to_completion[ep-print_freq+1:ep]),
                                                                    T.max
(), T.min()))

  return Q, T, episode_rewards, steps_to_completion
```

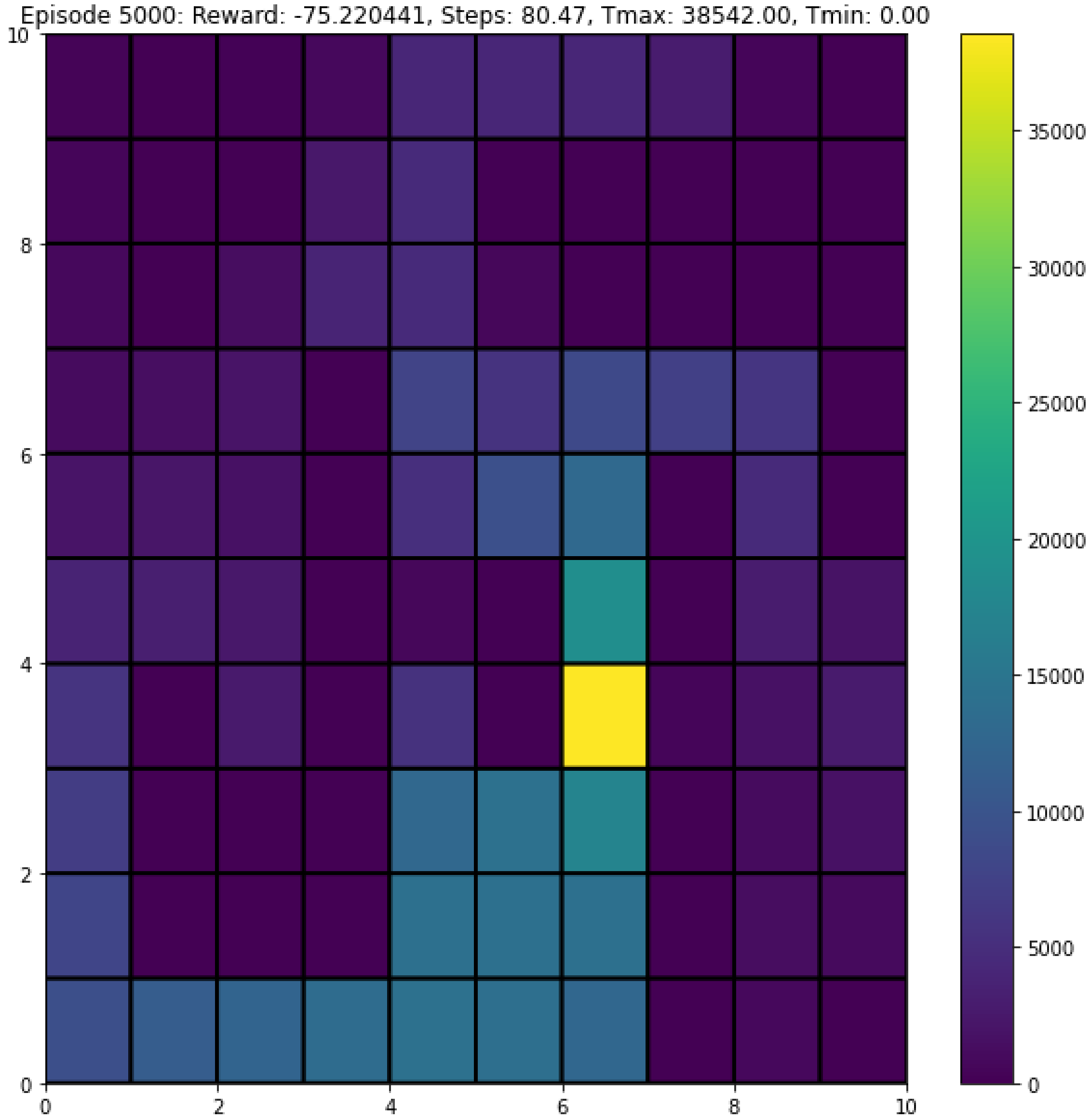
In [ ]:

```
Q = np.zeros((env.num_rows, env.num_cols, env.num_actions))
T = np.zeros((env.num_rows, env.num_cols))
episodes = 5000
Q, T, rewards, steps = Q_Learning(env, Q, T, plot_heat=True, choose_action= choo
se_action_softmax)
```

```
False
```


Episode 5000: Reward: -75.220441, Steps: 80.47, Qmax: 9.81, Qmin: -19.19
0
2
4
6
8
10
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5

Episode 5000: Reward: -75.220441, Steps: 80.47, Tmax: 38542.00, Tmin: 0.00



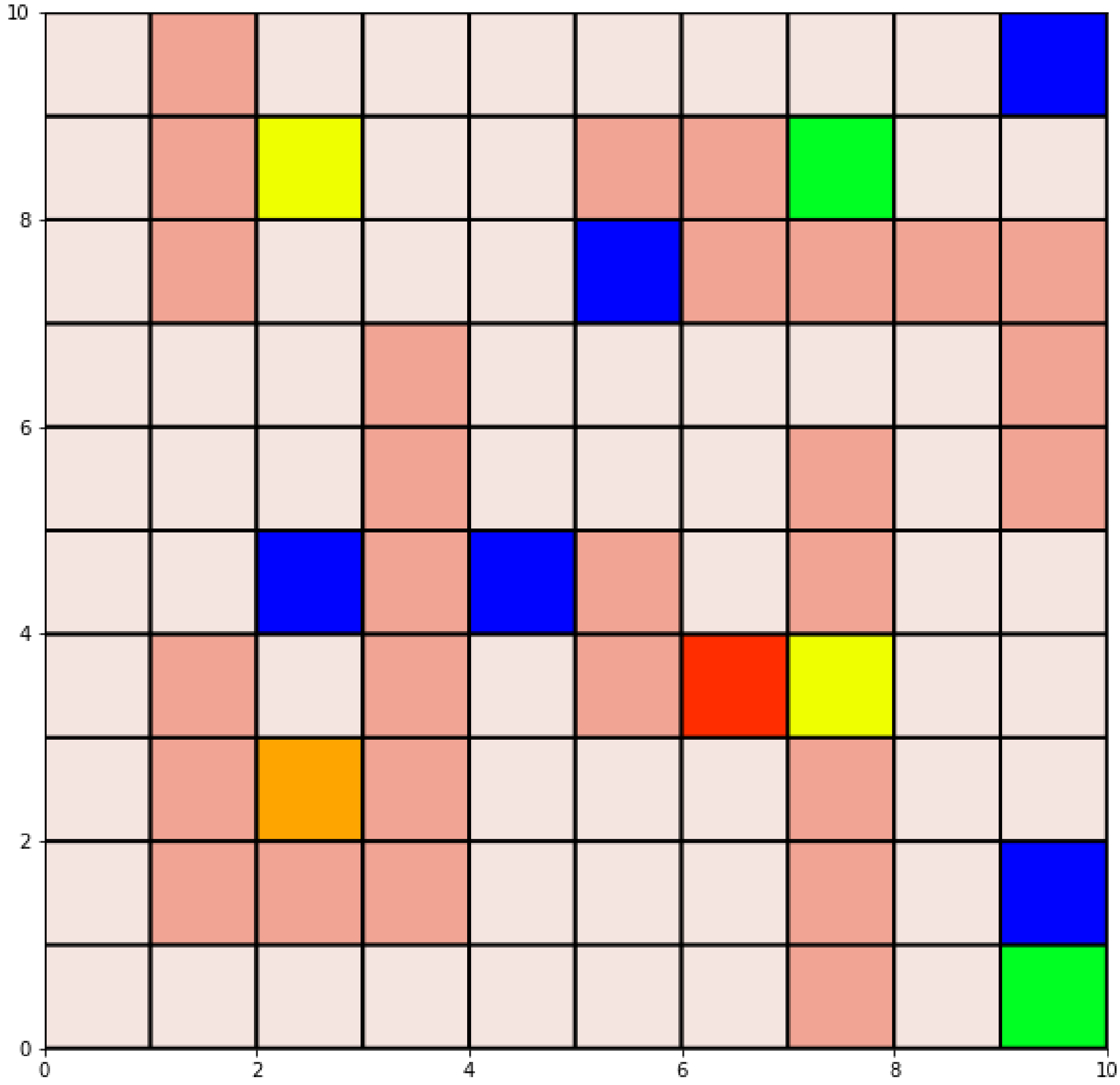

```
100%|██████████| 5000/5000 [02:13<00:00, 37.36it/s]
```

## Visualizing the policy

Now let's see the agent in action. Run the below cell (as many times) to render the policy;

In [ ]:

```
from time import sleep

state = env.reset()
done = False
steps = 0
tot_reward = 0
while not done:
    clear_output(wait=True)
    row_col_state = seq_to_col_row(state)[0]
    state, reward, done = env.step(state, Q[row_col_state[0], row_col_state[1]].
argmax())
    plt.figure(figsize=(10, 10))
    env.render(ax=plt, agent_state=state, render_agent=True)
    plt.show()
    steps += 1
    tot_reward += reward
    sleep(0.2)
print("Steps: %d, Total Reward: %d"%(steps, tot_reward))
```




```
Steps: 28, Total Reward: -27
```

## Analyzing performance of the policy

We use two metrics to analyze:

1. Average steps to reach the goal
2. Total rewards from the episode

To ensure, we account for randomness in environment and algorithm (say when using epsilon-greedy exploration), we run the algorithm for multiple times and use the average of values over all runs.

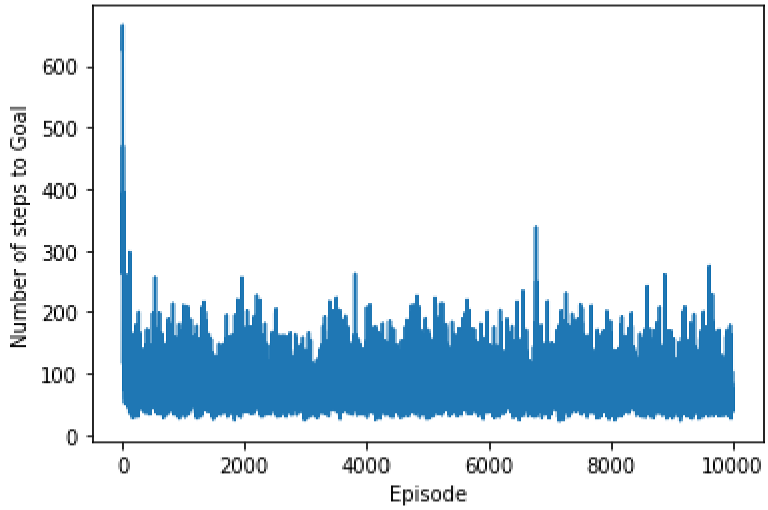
In [ ]:

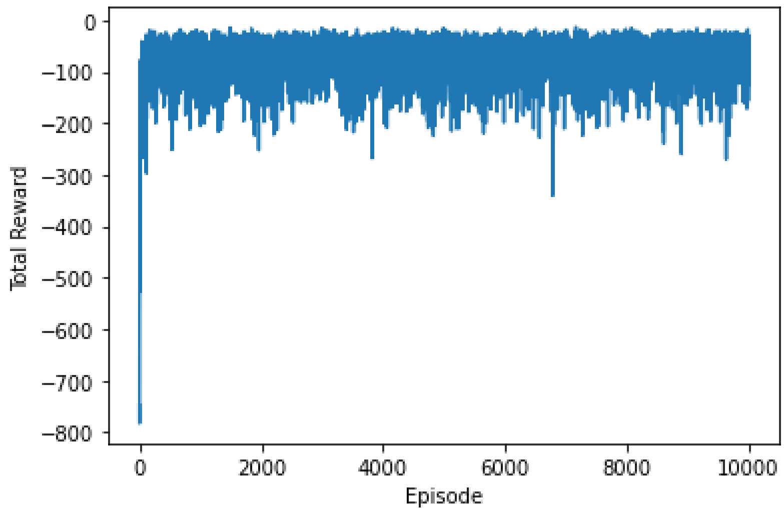
```
Q_avgs, reward_avgs, steps_avgs = [], [], []
num_expts = 5

for i in range(num_expts):
    print("Experiment: %d"%(i+1))
    Q = np.zeros((env.num_rows, env.num_cols, env.num_actions))
    rg = np.random.RandomState(i)
    Q, rewards, steps = sarsa(env, Q)
    Q_avgs.append(Q.copy())
    reward_avgs.append(rewards)
    steps_avgs.append(steps)
```

```
Experiment: 1

100%|██████████| 10000/10000 [02:38<00:00, 62.92it/s]

Experiment: 2

100%|██████████| 10000/10000 [02:41<00:00, 61.98it/s]

Experiment: 3

100%|██████████| 10000/10000 [02:55<00:00, 56.94it/s]

Experiment: 4

100%|██████████| 10000/10000 [02:52<00:00, 57.89it/s]

Experiment: 5

100%|██████████| 10000/10000 [02:40<00:00, 62.15it/s]
```

In [ ]:

```
plt.xlabel('Episode')
plt.ylabel('Number of steps to Goal')
plt.plot(np.arange(episodes),np.average(steps_avgs, 0))
plt.show()
plt.xlabel('Episode')
plt.ylabel('Total Reward')
plt.plot(np.arange(episodes),np.average(reward_avgs, 0))
plt.show()
```



In [ ]:

```
def get_avg(env, algorithm, alpha = 0.4 , epsilon = 0.1 , gamma = 0.9, choose_ac
tion = choose_action_softmax, temperature = 1, episodes=5000):
  Q_avgs, T_avgs, reward_avgs, steps_avgs = [], [], [], []
  num_expts = 1

  for i in range(num_expts):
    #print("Experiment: %d"%(i+1))
    Q = np.zeros((env.num_rows, env.num_cols, env.num_actions))
    T = np.zeros((env.num_rows, env.num_cols))
    rg = np.random.RandomState(i)
    Q, T, rewards, steps = algorithm(env, Q, T, epsilon = epsilon, alpha = alpha
, gamma = gamma, temperature = temperature, plot_heat = False, choose_action = c
hoose_action, episodes=episodes)
    Q_avgs.append(Q.copy())
    T_avgs.append(T.copy())
    reward_avgs.append(rewards)
    steps_avgs.append(steps)

  return Q_avgs, T_avgs, reward_avgs , steps_avgs
```

## Hyperparameter Tuning

Now we plot the reward curves and step curves while varying a single hyperparameter to get the best value. 3 plots (each having 4 possible values of a hyperparameter) are plotted for each of the 16 configurations under each algorihm (Q-learning / Sarsa)

Total number of plots = 3 x 16 x 2 x 2

These plots for Q-Learning are available here => https://drive.google.com/drive/folders/1OCsHMIBsTSMZhXsATauXm_YxdpgkdpMc?usp=sharing (https://drive.google.com/drive/folders/1OCsHMIBsTSMZhXsATauXm_YxdpgkdpMc?usp=sharing)

And those for Sarsa are available here => https://drive.google.com/drive/folders/1AKkHsuAaeMEuRrNOpUuAOAA36SKIj4tZ (https://drive.google.com/drive/folders/1AKkHsuAaeMEuRrNOpUuAOAA36SKIj4tZ)

In [ ]:

```
# run this cell to make all the plots with variations of hyperplots (3 plots sho
wing variation of 3 parameters (for 4 values each) for each configuration )
import string
num_cols = 10
num_rows = 10
epsiodes = 10000
obstructions = np.array([[0,7],[1,1],[1,2],[1,3],[1,7],[2,1],[2,3],
                        [2,7],[3,1],[3,3],[3,5],[4,3],[4,5],[4,7],
                        [5,3],[5,7],[5,9],[6,3],[6,9],[7,1],[7,6],
                        [7,7],[7,8],[7,9],[8,1],[8,5],[8,6],[9,1]])
bad_states = np.array([[1,9],[4,2],[4,4],[7,5],[9,9]])
restart_states = np.array([[3,7],[8,2]])
goal_states = np.array([[0,9],[2,2],[8,7]])
for wind in [True]:
    for start_state in [np.array([[3, 6]])]:
        for p in [1.0, 0.7]:
            gw = GridWorld(num_rows=num_rows,
                        num_cols=num_cols,
                        start_state=start_state,
                        goal_states=goal_states, wind = wind)
            gw.add_obstructions(obstructed_states=obstructions,
                              bad_states=bad_states,
                              restart_states=restart_states)
            gw.add_rewards(step_reward=-1,
                        goal_reward=10,
                        bad_state_reward=-6,
                        restart_state_reward=-100)
            gw.add_transition_probability(p_good_transition=p,
                                        bias=0.5)

            env = gw.create_gridworld()
            for algorithm in [Q_Learning]:
                for choose_action in [choose_action_softmax, choose_action_epsil
on]:
                    action_category = 'softmax'
                    if(choose_action == choose_action_epsilon):
                      action_category = 'epsilon-greedy'
                    algo = 'Sarsa'
                    if(algorithm == Q_Learning): algo = 'Q_Learning'

                    if(choose_action != choose_action_softmax):
                      epsilons = [0.01, 0.05, 0.1, 0.2]
                      #print('lala')


                      step_graph = []
                      plt.figure(figsize = (10,16))

                      fig,axs = plt.subplots(2,2)
                      cnt = 0
                      for epsilon in epsilons:

                        Q_avgs, T_avgs, reward_avgs, steps_avgs = get_avg(env, a
lgorithm, alpha = 0.2, epsilon = epsilon , gamma = 0.9, choose_action = choose_a
ction, temperature = 1)
                        step_graph.append(steps_avgs)
                        axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.averag
e(reward_avgs,0))
                        axs[(cnt//2),(cnt%2)].set_title('\u03B5 = {}'.format(eps
```

```
ilon))
                        cnt = cnt + 1
                      name1 = ('start_state = {}  Wind = {}  p = {}  algorithm =
{}  action = {}  \u03B3 = {}  \u03B1 = {}  \u03F4 = {}'.format(str(start_state),
str(wind), str(p) , algo , action_category,
                              str(0.9), str(0.4), str(1)))
                      fig.suptitle(name1)
                      for ax in axs.flat:
                        ax.set(xlabel = 'Episodes')
                        ax.set(ylabel = 'Total Reward')

                      for ax in axs.flat:
                        ax.label_outer()

                      #print(name1)
                      #print(type(name1))

                      plt.savefig(fname = name1,format = 'jpeg')
                      plt.show()

                      plt.figure(figsize = (10,16))
                      fig,axs = plt.subplots(2,2)
                      cnt = 0
                      for steps_avgs in step_graph:

                        axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.averag
e(steps_avgs,0))
                        axs[(cnt//2),(cnt%2)].set_title('\u03B5 = {}'.format(eps
ilons[cnt]))
                        cnt = cnt + 1
                      name1 = ('start_state = {}  Wind = {}  p = {}  algorithm =
{}  action = {}  \u03B3 = {}  \u03B1 = {}  \u03F4 = {}'.format(str(start_state),
str(wind), str(p) , algo , action_category,
                              str(0.9), str(0.4), str(1)))
                      fig.suptitle(name1)
                      for ax in axs.flat:
                        ax.set(xlabel = 'Episodes')
                        ax.set(ylabel = 'Number of Steps')
                      for ax in axs.flat:
                        ax.label_outer()


                      plt.savefig(fname = name1+"*",format = 'jpeg')
                      plt.show()



                    alphas = [0.01, 0.1 , 0.2, 0.5]
                    plt.figure(figsize = (10,16))
                    fig,axs = plt.subplots(2,2)
                    step_graph = []
                    cnt = 0
                    for alpha in alphas:
                      Q_avgs, T_avgs, reward_avgs, steps_avgs = get_avg(env, alg
orithm, alpha = alpha, epsilon = 0.1 , gamma = 0.9, choose_action = choose_actio
n, temperature = 1)
                      step_graph.append(steps_avgs)
                      axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.average
(reward_avgs,0))
                      axs[(cnt//2),(cnt%2)].set_title('\u03B1 = {}'.format(alph
a))
```

```
                    cnt = cnt + 1
                  name1 = ('start_state = {}  Wind = {}  p = {}  algorithm = 
{}  action = {}  epsilon = {}  \u03B3 = {}  \u03F4 = {}'.format(str(start_state
), str(wind), str(p) , algo , action_category,
                              str(0.1), str(0.9), str(1)))
                  fig.suptitle(name1)
                  for ax in axs.flat:
                    ax.set(xlabel = 'Episodes')
                    ax.set(ylabel = 'Total Reward')
                  for ax in axs.flat:
                    ax.label_outer()

                  plt.savefig(fname = name1,format = 'jpeg')
                  plt.show()



                  cnt = 0
                  plt.figure(figsize = (10,16))
                  fig,axs = plt.subplots(2,2)
                  for steps_avgs in step_graph:

                    axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.average
(steps_avgs,0))
                    axs[(cnt//2),(cnt%2)].set_title('\u03B1 = {}'.format(alpha
s[cnt]))
                    cnt = cnt + 1

                  for ax in axs.flat:
                    ax.set(xlabel = 'Episodes')
                    ax.set(ylabel = 'Number of Steps')
                  for ax in axs.flat:
                    ax.label_outer()
                  name1 = ('start_state = {}  Wind = {}  p = {}  algorithm = 
{}  action = {}  epsilon = {}  \u03B3 = {}  \u03F4 = {}'.format(str(start_state
), str(wind), str(p) , algo , action_category,
                              str(0.1), str(0.9), str(1)))
                  fig.suptitle(name1)

                  plt.savefig(fname = name1+"*",format = 'jpeg')
                  plt.show()


                  gammas = [0.1,0.5, 0.9, 0.99]


                  step_graph = []
                  cnt = 0
                  plt.figure(figsize = (10,16))
                  fig,axs = plt.subplots(2,2)
                  for gamma in gammas:
                    Q_avgs, T_avgs, reward_avgs, steps_avgs = get_avg(env, alg
orithm, alpha = 0.4, epsilon = 0.1 , gamma = gamma, choose_action = choose_actio
n, temperature = 1)
                    step_graph.append(steps_avgs)
                    axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.average
(reward_avgs,0))
                    axs[(cnt//2),(cnt%2)].set_title('\u03B3 = {}'.format(gamm
a))
                    cnt = cnt + 1
                  name1 = ('start_state = {}  Wind = {}  p = {}  algorithm = 
```

```
{}  action = {}  epsilon = {}  \u03B1 = {}  \u03F4 = {}'.format(str(start_state
), str(wind), str(p) , algo , action_category,
                              str(0.1), str(0.4), str(1)))
                    fig.suptitle(name1)
                    for ax in axs.flat:
                      ax.set(xlabel = 'Episodes')
                      ax.set(ylabel = 'Rewards')
                    for ax in axs.flat:
                      ax.label_outer()

                    plt.savefig(fname = name1,format = 'jpeg')
                    plt.show()


                    cnt = 0
                    plt.figure(figsize = (10,16))
                    fig,axs = plt.subplots(2,2)
                    for steps_avgs in step_graph:
                      axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.average
(steps_avgs,0))
                      axs[(cnt//2),(cnt%2)].set_title('\u03B3 = {}'.format(gamma
s[cnt]))
                      cnt = cnt + 1
                    name1 = ('start_state = {}  Wind = {}  p = {}  algorithm =
{}  action = {}  epsilon = {}  \u03B1 = {}  \u03F4 = {}'.format(str(start_state
), str(wind), str(p) , algo , action_category,
                              str(0.1), str(0.4), str(1)))
                    fig.suptitle(name1)
                    for ax in axs.flat:
                      ax.set(xlabel = 'Episodes')
                      ax.set(ylabel = 'Number of Steps')
                    for ax in axs.flat:
                      ax.label_outer()

                    plt.savefig(fname = name1+"*",format = 'pdf')
                    plt.show()


                    if(choose_action == choose_action_epsilon):
                      continue
                    temperatures = [0.5 ,1, 1.5,5]


                    cnt = 0
                    plt.figure(figsize = (10,16))
                    fig,axs = plt.subplots(2,2)
                    step_graph = []
                    for temperature in temperatures:
                      Q_avgs, T_avgs, reward_avgs, steps_avgs = get_avg(env, alg
orithm, alpha = 0.4, epsilon = 0.1 , choose_action = choose_action, temperature
= temperature)
                      step_graph.append(steps_avgs)
                      axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.average
(reward_avgs,0),)
                      axs[(cnt//2),(cnt%2)].set_title('\u03F4 = {}'.format(tempe
rature))
                      cnt = cnt + 1
                    name1 = ('start_state = {}  Wind = {}  p = {}  algorithm =
{}  action = {}  epsilon = {}  \u03B3 = {}  \u03B1 = {}'.format(str(start_state
), str(wind), str(p) , algo , action_category,
                              str(0.1), str(0.9), str(0.4)))
```

```
                    fig.suptitle(name1)
                    for ax in axs.flat:
                      ax.set(xlabel = 'Episodes')
                      ax.set(ylabel = 'Rewards')
                    for ax in axs.flat:
                      ax.label_outer()
                    plt.savefig(fname = name1,format = 'pdf')
                    plt.show()


                    cnt = 0
                    plt.figure(figsize = (10,16))
                    fig,axs = plt.subplots(2,2)
                    for steps_avgs in step_graph:
                      axs[(cnt//2),(cnt%2)].plot(np.arange(episodes),np.average
(steps_avgs,0))
                      axs[(cnt//2),(cnt%2)].set_title('\u03F4 = {}'.format(tempe
ratures[cnt]))
                      cnt = cnt + 1
                    name1 = ('start_state = {}  Wind = {}  p = {}  algorithm =
{}  action = {}  epsilon = {}  \u03B3 = {}  \u03B1 = {}'.format(str(start_state
), str(wind), str(p) , algo , action_category,
                              str(0.1), str(0.9), str(0.4)))
                    fig.suptitle(name1)
                    for ax in axs.flat:
                      ax.set(xlabel = 'Episodes')
                      ax.set(ylabel = 'Number of Steps')
                    for ax in axs.flat:
                      ax.label_outer()
                    plt.savefig(fname = name1+"*",format = 'pdf')
                    plt.show()
```

## Best plots

In [ ]:

```
def plot_reward(reward_avgs, message):
  plt.title(message)
  plt.xlabel('Episode')
  plt.ylabel('Total Reward')
  plt.plot(np.arange(episodes),np.average(reward_avgs, 0))
  plt.savefig(fname = message, format = 'pdf')
  plt.show()

def plot_steps(steps_avgs,message):
  plt.title(message)
  plt.xlabel('Episode')
  plt.ylabel('Number of steps to Goal')
  plt.plot(np.arange(episodes),np.average(steps_avgs, 0))
  plt.savefig(fname = message, format = 'pdf')
  plt.show()
```

After analyzing the above rendered plots, we plot the best plots for each configuration with the best possible value of the hyperparameters

Number of plots = 4 (2 heat maps, reward, step curves) x 16 x 2 (Q-Learning /Sarsa)

In [ ]:

```
#Best plots:
#run this cell to generate best plots (4 plots(2 heatmaps, rewards curve and ste
p curve) X 16 configurations X 2 Algorithms (Q-Learning and Sarsa))


num_cols = 10
episodes = 5000
num_rows = 10
obstructions = np.array([[0,7],[1,1],[1,2],[1,3],[1,7],[2,1],[2,3],
                         [2,7],[3,1],[3,3],[3,5],[4,3],[4,5],[4,7],
                         [5,3],[5,7],[5,9],[6,3],[6,9],[7,1],[7,6],
                         [7,7],[7,8],[7,9],[8,1],[8,5],[8,6],[9,1]])
bad_states = np.array([[1,9],[4,2],[4,4],[7,5],[9,9]])
restart_states = np.array([[3,7],[8,2]])
goal_states = np.array([[0,9],[2,2],[8,7]])
config = 0
for wind in [False, True]:
    for start_state in [np.array([[0, 4]]), np.array([[3, 6]])]:
        for p in [1.0, 0.7]:
            gw = GridWorld(num_rows=num_rows,
                           num_cols=num_cols,
                           start_state=start_state,
                           goal_states=goal_states, wind = wind)
            gw.add_obstructions(obstructed_states=obstructions,
                                bad_states=bad_states,
                                restart_states=restart_states)
            gw.add_rewards(step_reward=-1,
                           goal_reward=10,
                           bad_state_reward=-6,
                           restart_state_reward=-100)
            gw.add_transition_probability(p_good_transition=p,
                                          bias=0.5)

            env = gw.create_gridworld()

            for choose_action in [choose_action_epsilon, choose_action_softmax]:

                for algorithm in [Q_Learning,sarsa]:


                    if config is 0:
                      if(algorithm == sarsa):
                        [epsilon, alpha, gamma, temp] = [0.2, 0.2, 0.9, 1]
                      else:
                        [epsilon, alpha, gamma, temp] = [0.2, 0.2, 0.99, 1]

                    elif config is 1:
                      if(algorithm == sarsa):
                        [epsilon, alpha, gamma, temp] = [1, 0.5, 0.99, 1]
                      else:
                        [epsilon, alpha, gamma, temp] = [0.1, 0.2, 0.99, 1.5]

                    elif config is 2:
                      if(algorithm == sarsa):
                        [epsilon, alpha, gamma, temp] = [0.01, 0.2, 0.99, 1]
                      else:
                        [epsilon, alpha, gamma, temp] = [0.1, 0.2, 0.9, 1]

                    elif config is 3:
```

```
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [1, 0.2, 0.9, 0.5]
      else:
        [epsilon, alpha, gamma, temp] = [1, 0.2, 0.99, 1.5]

    elif config is 4:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [0.2, 0.5, 0.9, 1]
      else:
        [epsilon, alpha, gamma, temp] = [0.1, 0.5, 0.99, 1]

    elif config is 5:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [1, 0.2, 0.9, 1.5]
      else:
        [epsilon, alpha, gamma, temp] = [1, 0.5, 0.99, 1.5]

    elif config is 6:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [0.05, 0.1, 0.99, 1]
      else:
        [epsilon, alpha, gamma, temp] = [0.1, 0.2, 0.9, 1]

    elif config is 7:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [1, 0.2, 0.9, 1]
      else:
        [epsilon, alpha, gamma, temp] = [1, 0.1, 0.99, 1]

    elif config is 8:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [0.2, 0.5, 0.9, 1]
      else:
        [epsilon, alpha, gamma, temp] = [0.05, 0.5, 0.99, 1]


    elif config is 9:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [1, 0.01, 0.99, 0.5]
      else:
        [epsilon, alpha, gamma, temp] = [1, 0.01, 0.99, 0.5]

    elif config is 10:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [0.1, 0.1, 0.99, 1]
      else:
        [epsilon, alpha, gamma, temp] = [0.05, 0.2, 0.9, 1]


    elif config is 11:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [1, 0.2, 0.99, 5]
      else:
        [epsilon, alpha, gamma, temp] = [1, 0.01, 0.99, 5]

    elif config is 12:
      if(algorithm == sarsa):
        [epsilon, alpha, gamma, temp] = [0.05, 0.5, 0.9, 1]
      else:
        [epsilon, alpha, gamma, temp] = [0.1, 0.2, 0.9, 1]
```

```
                    elif config is 13:
                      if(algorithm == sarsa):
                        [epsilon, alpha, gamma, temp] = [1, 0.01, 0.99, 0.5]
                      else:
                        [epsilon, alpha, gamma, temp] = [1, 0.5, 0.9, 0.5]


                    elif config is 14:
                      if(algorithm == sarsa):
                        [epsilon, alpha, gamma, temp] = [0.1, 0.2, 0.9, 1]
                      else:
                        [epsilon, alpha, gamma, temp] = [0.2, 0.2, 0.9, 1]


                    elif config is 15:
                      if(algorithm == sarsa):
                        [epsilon, alpha, gamma, temp] = [1, 0.01, 0.99, 5]
                      else:
                        [epsilon, alpha, gamma, temp] = [1, 0.5, 0.99, 1]

                    Q_avgs, T_avgs, reward_avgs, steps_avgs = get_avg(env, algor
ithm, alpha = alpha, epsilon = epsilon , gamma = gamma, choose_action = choose_a
ction, temperature = temp, episodes=episodes)

                    #fig,axs = plt.subplots(2,2)
                    Q_avgs = Q_avgs[0]
                    T_avgs = T_avgs[0]
                    #print(T_avgs)
                    algoname = 'Q_Learning'
                    if(algorithm == sarsa):
                      algoname = 'Sarsa'

                    plot_Q(Q_avgs, "Q_Plot Configuration = {}  Algorithm = {}".f
ormat(str(config), str(algoname)))
                    plot_T(T_avgs,"T_Plot Configuration = {}  Algorithm = {}".fo
rmat(str(config), str(algoname)))
                    plot_reward(reward_avgs,"Rewards_Plot Configuration = {}  Al
gorithm = {}".format(str(config), str(algoname)))
                    plot_steps(steps_avgs,"Steps_Plot Configuration = {}  Algori
thm = {}".format(str(config), str(algoname)))

                config += 1
```

Best plots can be found in the report or
[https://drive.google.com/drive/folders/1AKkHsuAaeMEuRrNOpUuAOAA36SKIj4tZ (https://drive.google.com/drive/folders/1AKkHsuAaeMEuRrNOpUuAOAA36SKIj4tZ)](https://drive.google.com/drive/folders/1AKkHsuAaeMEuRrNOpUuAOAA36SKIj4tZ)