More Tic-Tac-Toe and a Simple Robot Arm

For this assignment, you will use the reinforcement learning algorithm, Q learning, with a neural network to approximate the Q function. You will apply this to the game Tic-Tac-Toe and to the control of a simple robot arm.

Most of the code is provided. You are asked to make specific modifications and find parameter values that result in good performance on these tasks. The two tasks will probably require different parameter values.

Download necessary code from ttt_arm.zip.

```
%load_ext autoreload
%autoreload 2

import numpy as np
import matplotlib.pyplot as plt
from IPython.display import display, clear_output
import pandas as pd
import pickle
```

Tic Tac Toe

```
import tictactoe

class Game:

    def __init__(self, environment, agents):

        self.env = environment
        self.agents = agents

    def train(self, parms, verbose=True):

        n_batches = parms['n_batches']
        n_games_per_batch = parms['n_games_per_batch']
        n_epochs = parms['n_epochs']
        method = parms['method']
        learning_rate = parms['learning_rate']
        epsilon = parms['initial_epsilon']
        final_epsilon = parms['final_epsilon']

        ttt = self.env

        epsilon_decay =  np.exp((np.log(final_epsilon) -
np.log(epsilon)) / (n_batches)) # to produce this final value

        epsilon_trace = []
```

```
        outcomes = []

        for batch in range(n_batches):
            agents['X'].clear_samples()
            agents['O'].clear_samples()

            for gamei in range(n_games_per_batch):

                ttt.initialize()
                done = False

                while not done:

                    agent = agents[ttt.player]
                    obs = ttt.observe()
                    if len(self.env.valid_actions()) == 9:
                        action =
np.random.choice(self.env.valid_actions())
                        # print('picked random action at start of
game')
                    else:
                        action = agent.epsilon_greedy(epsilon)
                        # print('picked best action')

                    ttt.act(action)
                    r = ttt.reinforcement()
                    done = ttt.terminal_state()

                    agent.add_sample(obs, action, r, done)

                outcomes.append(r)

            # end n_trials_per_batch
            self.agents['X'].train(n_epochs, method, learning_rate)
            self.agents['O'].train(n_epochs, method, learning_rate)

            epsilon_trace.append(epsilon)
            epsilon *= epsilon_decay

            if verbose and (len(outcomes) % ((n_batches *
n_games_per_batch) // 20) == 0):
                print(f'{len(outcomes)}/{n_batches *
n_games_per_batch} games, {np.mean(outcomes):.2f} outcome mean')

        if verbose:
            plt.subplot(3, 1, 1)
            n_per = 10
            n_bins = len(outcomes) // n_per
            outcomes_binned = np.array(outcomes).reshape(-1, n_per)
            avgs = outcomes_binned.mean(1)
```

```
            xs = np.linspace(n_per, n_per * n_bins, len(avgs))
            plt.plot(xs, avgs)
            plt.axhline(y=0, color='orange', ls='--')
            plt.ylabel('R')

            plt.subplot(3, 1, 2)
            plt.plot(xs, np.sum(outcomes_binned == -1, axis=1), 'r-',
label='O Wins')
            plt.plot(xs, np.sum(outcomes_binned == 0, axis=1), 'b-',
label='Draws')
            plt.plot(xs, np.sum(outcomes_binned == 1, axis=1), 'g-',
label='X Wins')
            plt.legend(loc='center')
            plt.ylabel(f'Number of Games\nin Bins of {n_per:d}')

            plt.subplot(3, 1, 3)
            plt.plot(epsilon_trace)
            plt.ylabel(r'$\epsilon$')

        return outcomes, epsilon_trace


    def play_game(self, epsilon=0.0, verbose=True):
        ttt = self.env
        agents = self.agents
        ttt.initialize()
        while True:
            agent = agents[ttt.player]
            obs = ttt.observe()
            if len(ttt.valid_actions()) == 9:
                action = agent.epsilon_greedy(epsilon=1.0)
            else:
                action = agent.epsilon_greedy(epsilon)

            ttt.act(action)
            if verbose:
                print(ttt)
            if ttt.terminal_state():
                return ttt.reinforcement()

    def play_game_show_Q(self, epsilon=0.0):
        ttt = self.env
        agents = self.agents
        step = 0

        ttt.initialize()
        while True:
            agent = agents[ttt.player]
            obs = ttt.observe()
            actions = ttt.valid_actions()
```

```
            if len(ttt.valid_actions()) == 9:
                action = agent.epsilon_greedy(epsilon=1.0)
            else:
                action = agent.epsilon_greedy(epsilon)
            ttt.act(action)
            step += 1

            plt.subplot(5, 2, step)
            Qs = np.array([agent.use(np.hstack((obs, a))) for a in
actions])
            board_image = np.array([np.nan] * 9)
            for Q, a in zip(Qs, actions):
                board_image[a] = Q[0, 0]
            board_image = board_image.reshape(3, 3)
            maxmag = np.nanmax(np.abs(board_image))
            plt.imshow(board_image, cmap='coolwarm', vmin=-maxmag,
vmax=maxmag)
            plt.colorbar()
            obs = ttt.observe()
            i = -1
            for row in range(3):
                for col in range(3):
                    i += 1
                    if obs[i] == 1:
                        plt.text(col, row, 'X', ha='center',
                                 fontweight='bold', fontsize='large',
color='black')
                    elif obs[i] == -1:
                        plt.text(col, row, 'O', ha='center',
                                 fontweight='bold', fontsize='large',
color='black')
            plt.axis('off')
            if ttt.terminal_state():
                break

        plt.tight_layout()

ttt = tictactoe.TicTacToe()
nh = [10]
agents = {'X': tictactoe.QnetAgent(ttt, nh, 'max'),
          'O': tictactoe.QnetAgent(ttt, nh, 'min')}
game = Game(ttt, agents)
game.play_game(0)
```

```
     | |
    -----
     |X|
    ------
     | |
```

```
     | |
    -----
     |X|
    ------
     |O|

     | |
    -----
     |X|X
    ------
     |O|

    O| |
    -----
     |X|X
    ------
     |O|

    O| |
    -----
     |X|X
    ------
    X|O|

    O|O|
    -----
     |X|X
    ------
    X|O|

    O|O|
    -----
    X|X|X
    ------
    X|O|

1
```

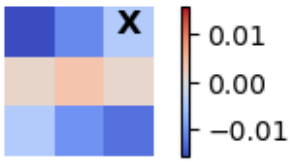
```
previous_best = -np.inf
results = []
for nb in [100, 500]:
    for ng in [5, 10, 20]:
        for ne in [2, 5, 10, 20]:
            for nh in [ [], [50], [50, 50, 50] ]:
                parms = {
                    'n_batches': nb,
                    'n_games_per_batch': ng,
                    'n_epochs': ne,
                    'method': 'scg',
```

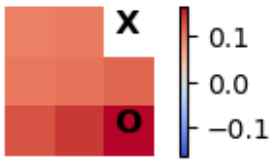
```
                    'learning_rate': 0.01,
                    'initial_epsilon': 1.0,
                    'final_epsilon': 0.01,
                    'gamma': 1.0
                }
                agents = {'X': tictactoe.QnetAgent(ttt, nh, 'max'),
                          'O': tictactoe.QnetAgent(ttt, nh, 'min')}
                game = Game(ttt, agents)

                outcomes, _ = game.train(parms, verbose=False)
                mean_outcomes = np.mean(outcomes)
                results.append([nh, nb, ng, ne, mean_outcomes])
                clear_output()
                df = pd.DataFrame(results,
                                  columns=('hiddens', 'batches',
'games',
                                           'epochs', 'mean r'))
                print(df.sort_values(by='mean r', ascending=False))

                if mean_outcomes > previous_best:
                    previous_best = mean_outcomes
                    with open('best_ttt_agents.pkl', 'wb') as f:
                        pickle.dump(agents, f)
```

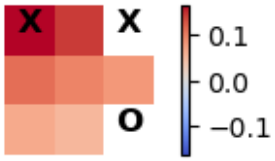
	hiddens	batches	games	epochs	mean r
41	[50, 50, 50]	500	5	5	0.3980
22	[50]	100	10	20	0.3970
10	[50]	100	5	20	0.3920
58	[50]	500	10	20	0.3716
32	[50, 50, 50]	100	20	10	0.3705
55	[50]	500	10	10	0.3696
56	[50, 50, 50]	500	10	10	0.3644
23	[50, 50, 50]	100	10	20	0.3500
19	[50]	100	10	10	0.3490
44	[50, 50, 50]	500	5	10	0.3472
47	[50, 50, 50]	500	5	20	0.3376
38	[50, 50, 50]	500	5	2	0.3320
7	[50]	100	5	10	0.3300
20	[50, 50, 50]	100	10	10	0.3290
43	[50]	500	5	10	0.3280
3	[]	100	5	5	0.3240
46	[50]	500	5	20	0.3208
26	[50, 50, 50]	100	20	2	0.3175
2	[50, 50, 50]	100	5	2	0.3160
35	[50, 50, 50]	100	20	20	0.3045
53	[50, 50, 50]	500	10	5	0.3002
11	[50, 50, 50]	100	5	20	0.3000
34	[50]	100	20	20	0.2985
24	[]	100	20	2	0.2950
29	[50, 50, 50]	100	20	5	0.2905

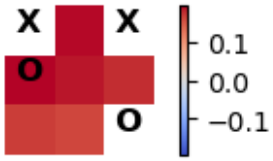
```
16           [50]      100     10        5  0.2890
49           [50]      500     10        2  0.2856
5    [50, 50, 50]      100      5        5  0.2820
52           [50]      500     10        5  0.2760
28           [50]      100     20        5  0.2735
40           [50]      500      5        5  0.2728
50   [50, 50, 50]      500     10        2  0.2696
8    [50, 50, 50]      100      5       10  0.2660
4            [50]      100      5        5  0.2600
14   [50, 50, 50]      100     10        2  0.2590
42             []      500      5       10  0.2440
37           [50]      500      5        2  0.2424
21             []      100     10       20  0.2400
39             []      500      5        5  0.2348
1            [50]      100      5        2  0.2340
15             []      100     10        5  0.2300
48             []      500     10        2  0.2210
36             []      500      5        2  0.2208
17   [50, 50, 50]      100     10        5  0.2170
31           [50]      100     20       10  0.2150
0              []      100      5        2  0.2120
54             []      500     10       10  0.2084
30             []      100     20       10  0.1995
33             []      100     20       20  0.1975
57             []      500     10       20  0.1970
27             []      100     20        5  0.1960
45             []      500      5       20  0.1928
51             []      500     10        5  0.1910
12             []      100     10        2  0.1860
25           [50]      100     20        2  0.1830
9              []      100      5       20  0.1800
18             []      100     10       10  0.1760
13           [50]      100     10        2  0.1740
6              []      100      5       10  0.1740
```

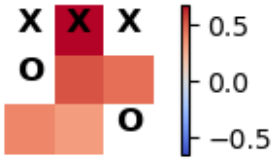
```
with open('best_ttt_agents.pkl', 'rb') as f:
    agents = pickle.load(f)

ttt = agents['X'].env
game = Game(ttt, agents)

rs = []
for n_games in range(100):
    rs.append(game.play_game(epsilon=0.05, verbose=False))

print(f'mean of final outcomes {np.mean(rs)}')

game.play_game_show_Q()
```











Robot

```
import numpy as np
import matplotlib.pyplot as plt
from IPython.display import display, clear_output
import pandas as pd
import pickle

import robot

 class Experiment:

    def __init__(self, environment, agent):

        self.env = environment
        self.agent = agent

    def train(self, parms, verbose=True):

        n_batches = parms['n_batches']
        n_steps_per_batch = parms['n_steps_per_batch']
        n_epochs = parms['n_epochs']
        method = parms['method']
        learning_rate = parms['learning_rate']
        epsilon = parms['initial_epsilon']
        final_epsilon = parms['final_epsilon']
        gamma = parms['gamma']

        env = self.env

        epsilon_decay =  np.exp((np.log(final_epsilon) -
np.log(epsilon))/ (n_batches)) # to produce this final value

        epsilon_trace = []
```

```
        outcomes = []

        for batch in range(n_batches):
            agent.clear_samples()
            env.initialize()

            sum_rs = 0

            for step in range(n_steps_per_batch):

                obs = self.env.observe()
                action = agent.epsilon_greedy(epsilon)

                env.act(action)
                r = env.reinforcement()
                sum_rs += r

                done = step == n_steps_per_batch - 1
                agent.add_sample(obs, action, r, done)

            outcomes.append(sum_rs / n_steps_per_batch)

            self.agent.train(n_epochs, method, learning_rate, gamma)

            epsilon_trace.append(epsilon)
            epsilon *= epsilon_decay

            if verbose and (len(outcomes) % (n_batches // 20) == 0):
                print(f'{len(outcomes)}/{n_batches} batches,
{np.mean(outcomes):.4f} outcome mean')

        if verbose:
            plt.figure(1)
            plt.clf()
            plt.subplot(2, 1, 1)
            n_per = 10
            n_bins = len(outcomes) // n_per
            outcomes_binned = np.array(outcomes).reshape(-1, n_per)
            avgs = outcomes_binned.mean(1)
            xs = np.linspace(n_per, n_per * n_bins, len(avgs))
            plt.plot(xs, avgs)
            plt.axhline(y=0, color='orange', ls='--')
            plt.ylabel('R')

            plt.subplot(2, 1, 2)
            plt.plot(epsilon_trace)
            plt.ylabel(r'$\epsilon$')
            #plt.pause(0.1)

        return outcomes # , epsilon_trace
```

```
    def test(self, n_trials, n_steps, epsilon=0.0, graphics=True):
        if graphics:
            fig = plt.figure(figsize=(10, 10))
        robot = self.env
        sum_rs = 0
        for trial in range(n_trials):
            robot.initialize()
            agent = self.agent
            points = np.zeros((n_steps, robot.n_links + 1, 2))
            actions = np.zeros((n_steps, robot.n_links))
            Q_values = np.zeros((n_steps))

            for i in range(n_steps):
                action = agent.epsilon_greedy(epsilon)
                Q = agent.use(np.hstack((robot.observe(), action)))
                self.env.act(action)
                sum_rs += self.env.reinforcement()
                points[i] = robot.points
                actions[i] = action
                Q_values[i] = Q[0, 0]

            if graphics:
                Q_min, Q_max = np.min(Q_values), np.max(Q_values)
                print(Q_min, Q_max)
                for i in range(n_steps):
                    fig.clf()
                    plt.scatter(robot.goal[0], robot.goal[1], s=40,
c='blue')
                    action = actions[i]
                    robot.set_points(points[i])
                    robot.draw()  # alpha=(Q_values[i] - Q_min) /
(Q_max - Q_min))
                    clear_output(wait=True)
                    display(fig)

                clear_output(wait=True)
        return sum_rs / (n_trials * n_steps)

robbie = robot.Robot()
robbie.set_goal([5., 5.])

agent = robot.QnetAgent(robbie, [100, 100, 100])
experiment = Experiment(robbie, agent)

import pandas as pd

previous_best = -np.inf

results = []
```

```
for nb in [100, 200, 5000]:
    for ns in [50, 100]:
        for ne in [5, 10]:
            for nh in [ [], [50], [50, 50] ]:
                parms = {
                    'n_batches': nb,
                    'n_steps_per_batch': ns,
                    'n_epochs': ne,
                    'method': 'scg',
                    'learning_rate': 0.01,
                    'initial_epsilon': 1.0,
                    'final_epsilon': 0.001,
                    'gamma': 1.0
                }
                agent = robot.QnetAgent(robbie, nh)
                experiment = Experiment(robbie, agent)

                outcomes = experiment.train(parms, verbose=False)
                results.append([nh, nb, ns, ne, outcomes[-1]])
                clear_output()
                df = pd.DataFrame(results,
                                  columns=('hiddens', 'batches',
'steps',
                                           'epochs', 'dist'))
                print(df.sort_values(by='dist', ascending=False))

                if outcomes[-1] > previous_best:
                    previous_best = outcomes[-1]
                    with open('best_robot_agent.pkl', 'wb') as f:
                        pickle.dump(agent, f)

                print()
```

	hiddens	batches	steps	epochs	dist
13	[50]	200	50	5	-1.814330
17	[50, 50]	200	50	10	-4.569909
1	[50]	100	50	5	-5.063843
16	[50]	200	50	10	-5.805537
5	[50, 50]	100	50	10	-5.866438
4	[50]	100	50	10	-7.114635
18	[]	200	100	5	-7.848883
7	[50]	100	100	5	-7.996590
6	[]	100	100	5	-8.317250
0	[]	100	50	5	-8.321376
3	[]	100	50	10	-8.546975
10	[50]	100	100	10	-8.749536
12	[]	200	50	5	-8.816075
2	[50, 50]	100	50	5	-8.881165
15	[]	200	50	10	-9.246151
9	[]	100	100	10	-9.302054

```
11  [50, 50]      100    100      10 -10.096282
8   [50, 50]      100    100       5 -10.254745
14  [50, 50]      200     50       5 -10.688630


---------------------------------------------------------------------------
-----
KeyboardInterrupt                         Traceback (most recent call
last)
Cell In[11], line 23
     20 agent = robot.QnetAgent(robbie, nh)
     21 experiment = Experiment(robbie, agent)
---> 23 outcomes = experiment.train(parms, verbose=False)
     24 results.append([nh, nb, ns, ne, outcomes[-1]])
     25 clear_output()

Cell In[2], line 35, in Experiment.train(self, parms, verbose)
     32 for step in range(n_steps_per_batch):
     34     obs = self.env.observe()
---> 35     action = agent.epsilon_greedy(epsilon)
     37     env.act(action)
     38     r = env.reinforcement()

File ~/public_html/cs545/notebooks/tmp/robot.py:119, in
QnetAgent.epsilon_greedy(self, epsilon)
    117     np.random.shuffle(actions)
    118     obs = self.env.observe()
--> 119     Qs = np.array([self.use(np.hstack((obs, a))) for a in
actions])
    120     action = actions[np.argmax(Qs)]  # Minimize sum of
distances to goal
    121 return action

File ~/public_html/cs545/notebooks/tmp/robot.py:126, in
QnetAgent.use(self, X)
    124 if X.ndim == 1:
    125     X = X.reshape(1, -1)
--> 126 return self.Qnet.use(X)

File ~/public_html/cs545/notebooks/tmp/neuralnetworksA4.py:410, in
NeuralNetwork.use(self, X)
    408 # Standardize X
    409 X = (X - self.X_means) / self.X_stds
--> 410 Zs = self._forward(X)
    411 # Unstandardize output Y before returning it
    412 return Zs[-1] * self.T_stds + self.T_means

File ~/public_html/cs545/notebooks/tmp/neuralnetworksA4.py:301, in
NeuralNetwork._forward(self, X)
    298 # Append output of each layer to list in self.Zs, then return
```

```
it.
    300 for W in self.Ws[:-1]:  # forward through all but last layer
--> 301     self.Zs.append(np.tanh(self._add_ones(self.Zs[-1]) @ W))
    302 last_W = self.Ws[-1]
    303 self.Zs.append(self._add_ones(self.Zs[-1]) @ last_W)

File ~/public_html/cs545/notebooks/tmp/neuralnetworksA4.py:282, in
NeuralNetwork._add_ones(self, X)
    281 def _add_ones(self, X):
--> 282     return np.insert(X, 0, 1, 1)

File
~/anaconda3/lib/python3.12/site-packages/numpy/lib/function_base.py:53
69, in insert(arr, obj, values, axis)
   5365 def _insert_dispatcher(arr, obj, values, axis=None):
   5366     return (arr, obj, values)
-> 5369 @array_function_dispatch(_insert_dispatcher)
   5370 def insert(arr, obj, values, axis=None):
   5371     """
   5372     Insert values along the given axis before the given
indices.
   5373
   (...)
   5456
   5457     """
   5458     wrap = None

KeyboardInterrupt:
```

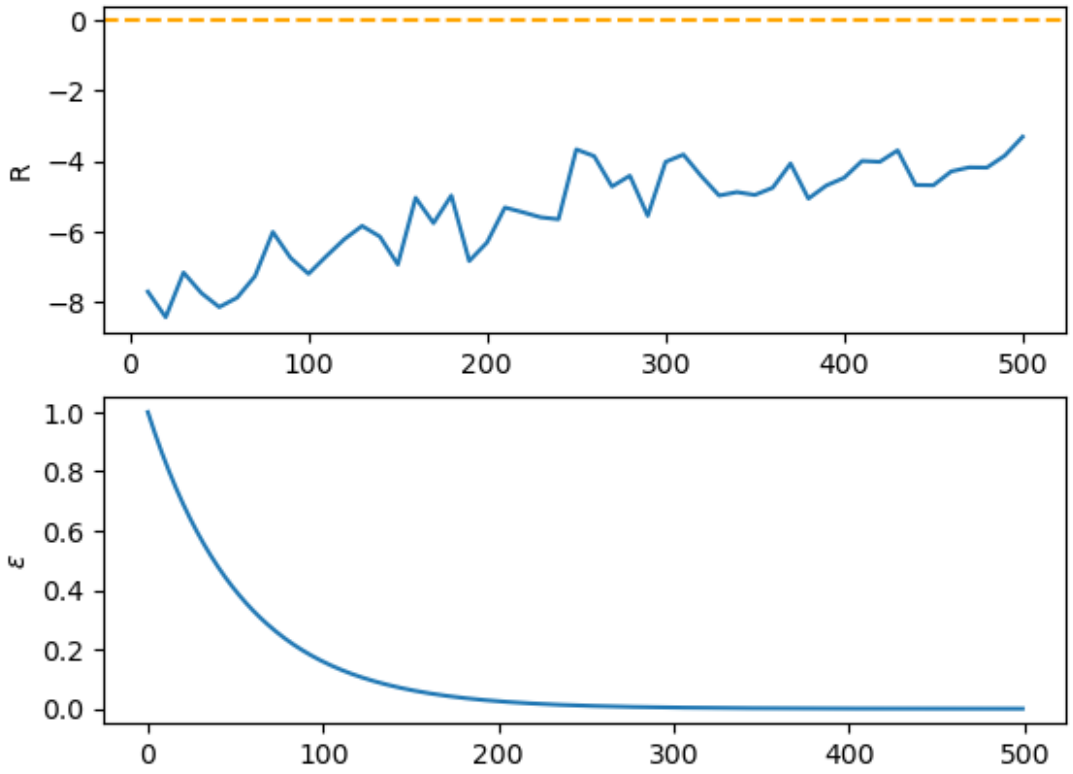
```
with open('best_robot_agent.pkl', 'rb') as f:
    agent = pickle.load(f)

robbie = agent.env
experiment = Experiment(robbie, agent)

mean_r = experiment.test(n_trials=10, n_steps=100, epsilon=0.0,
graphics=False)

print(f'mean of reinforcements {mean_r:.3f}')
```

```
mean of reinforcements -2.424
```

```
parms = {
    'n_batches': 500,
    'n_steps_per_batch': 50,
    'n_epochs': 5,
    'method': 'scg',
    'learning_rate': 0.01,
    'initial_epsilon': 1.0,
    'final_epsilon': 0.0001,
    'gamma': 1.0
```

```
}

agent = robot.QnetAgent(robbie, [50])
experiment = Experiment(robbie, agent)

outcomes = experiment.train(parms)
```

```
25/500 batches, -7.9906 outcome mean
50/500 batches, -7.8550 outcome mean
75/500 batches, -7.6936 outcome mean
100/500 batches, -7.4452 outcome mean
125/500 batches, -7.2722 outcome mean
150/500 batches, -7.0897 outcome mean
175/500 batches, -6.8215 outcome mean
200/500 batches, -6.7659 outcome mean
225/500 batches, -6.6292 outcome mean
250/500 batches, -6.4414 outcome mean
275/500 batches, -6.2562 outcome mean
300/500 batches, -6.1209 outcome mean
325/500 batches, -5.9951 outcome mean
350/500 batches, -5.9060 outcome mean
375/500 batches, -5.8354 outcome mean
400/500 batches, -5.7448 outcome mean
425/500 batches, -5.6290 outcome mean
450/500 batches, -5.5753 outcome mean
475/500 batches, -5.5057 outcome mean
500/500 batches, -5.4142 outcome mean
```




```
experiment.test(10, 100, epsilon=0.0, graphics=True)
```

```
-3.4894459784287455
```