Lab 13: Reinforcement Learning (RL)

In [50]:

```
import importlib
from collections import defaultdict
import torch
import numpy

game_name = 'tictactoe'
game_module = importlib.import_module("games." + game_name)
env = game_module.Game()

env.reset()

# defining epsilon-greedy policy
def gen_epsilon_greedy_policy(n_action, epsilon):
    def policy_function(state, Q, available_actions):
        probs = torch.ones(n_action) * epsilon / n_action
        # print(probs)
        # print(state)
        # print(Q[state])
        best_action = torch.argmax(Q[state]).item()
        if not(best_action in available_actions):
            best_action = -1
            Q_max = -800000000
            for i in range(n_action):
                if i in available_actions and Q_max < Q[state][i]:
                    Q_max = Q[state][i]
                    best_action = i
        probs[best_action] += 1.0 - epsilon
        action = torch.multinomial(probs, 1).item()
        return action
    return policy_function

def q_learning(env, gamma, n_episode, alpha, player):
    """
    Obtain the optimal policy with off-policy Q-learning method
    @param env: OpenAI Gym environment
    @param gamma: discount factor
    @param n_episode: number of episodes
    @return: the optimal Q-function, and the optimal policy
    """
    n_action = 9
    Q = defaultdict(lambda: torch.zeros(n_action))
    for episode in range(n_episode):
        if episode % 10000 == 9999:
            print("episode: ", episode + 1)
        state = env.reset()
        state = hash(tuple(state.reshape(-1)))

        is_done = False
        while not is_done:
            if env.to_play() == player:
                available_action = env.legal_actions()
                action = epsilon_greedy_policy(state, Q, available_action)
                next_state, reward, is_done = env.step(action)
                next_state = hash(tuple(next_state.reshape(-1)))
                td_delta = reward + gamma * torch.max(Q[next_state]) - Q[state][
action]
                Q[state][action] += alpha * td_delta
            else:
                action = env.expert_agent()
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                next_state, reward, is_done = env.step(action)
                next_state = hash(tuple(next_state.reshape(-1)))

                if is_done:
                    reward = -reward
                    td_delta = reward + gamma * torch.max(Q[next_state]) - Q[sta
te][action]
                    Q[state][action] += alpha * td_delta

            length_episode[episode] += 1
            total_reward_episode[episode] += reward

            if is_done:
                break
            state = next_state

    policy = {}
    for state, actions in Q.items():
        policy[state] = torch.argmax(actions).item()
    return Q, policy

gamma = 1

n_episode = 1000000

alpha = 0.4

epsilon = 0.1

available_action = env.legal_actions()
epsilon_greedy_policy = gen_epsilon_greedy_policy(9, epsilon)

length_episode = [0] * n_episode
total_reward_episode = [0] * n_episode

# agent play first
optimal_Q, optimal_policy = q_learning(env, gamma, n_episode, alpha, 1)


print('The optimal policy:\n', optimal_policy)
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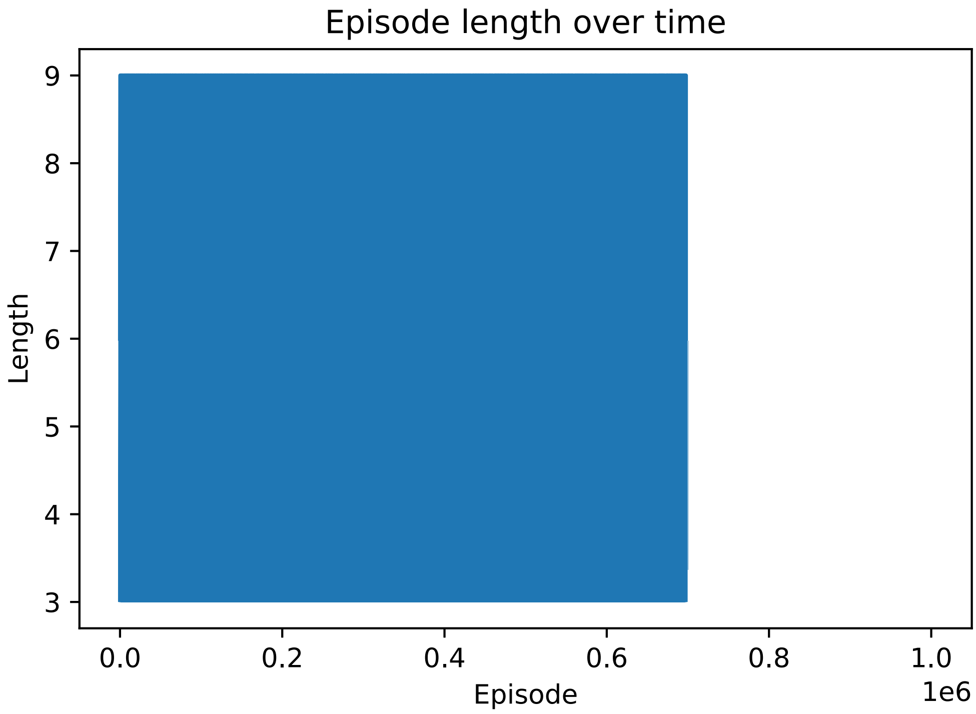
In [56]:

```python
import matplotlib.pyplot as plt

plt.plot(length_episode)
plt.title('Episode length over time')
plt.xlabel('Episode')
plt.ylabel('Length')
plt.show()


plt.plot(total_reward_episode)
print(total_reward_episode[-100:])
plt.title('Episode reward over time')
plt.xlabel('Episode')
plt.ylabel('Total reward')
plt.show()
```




```
[-1, -1, -1, -1, 1, -1, -1, -1, -1, -1, -1, 0, -1, -1, 1, -1, -1, -
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1, -1, -1, 1, 0, -1, -1, 1, 1, -1, -1, -1, -1, -1]
```

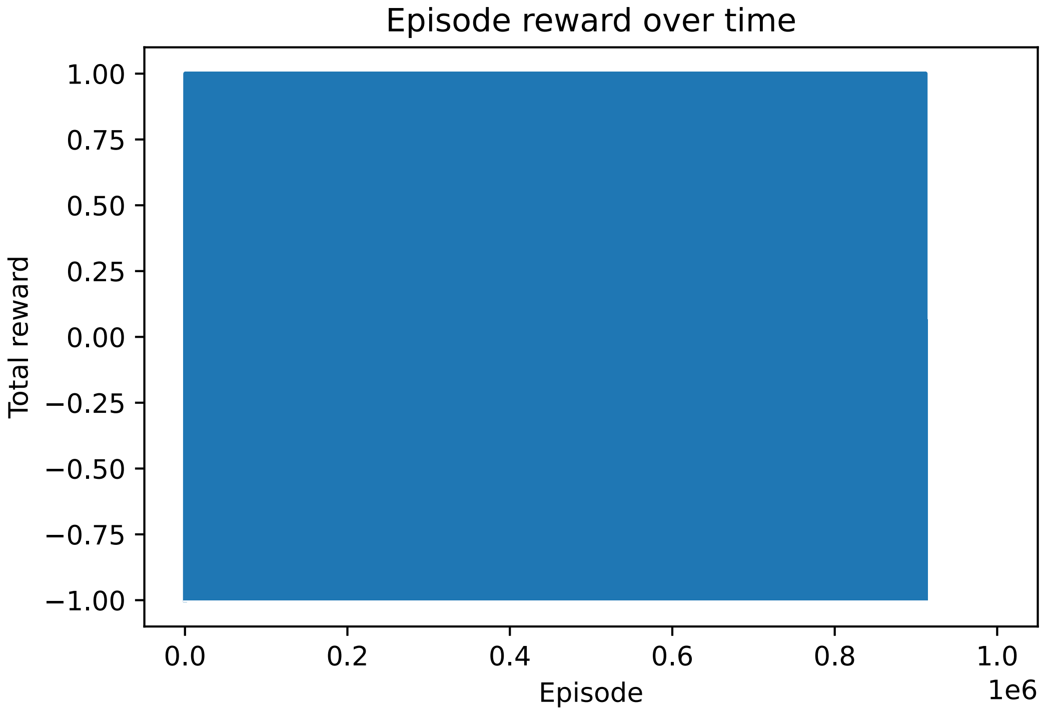

In [53]:

```
state = env.reset()
state = hash(tuple(state.reshape(-1)))

player = 1
is_done = False
while not is_done:
    if env.to_play() == player:
        available_action = env.legal_actions()
        print("available action:",available_action)
        action = epsilon_greedy_policy(state, optimal_Q, available_action)
        next_state, reward, is_done = env.step(action)
        next_state = hash(tuple(next_state.reshape(-1)))
        print("RL agent")
        print(env.action_to_string(action))
    else:
        action = env.expert_agent()
        next_state, reward, is_done = env.step(action)
        next_state = hash(tuple(next_state.reshape(-1)))
        print("Expert agent")
        print(env.action_to_string(action))

    state = next_state
    env.render()
```

```
available action: [0, 1, 2, 3, 4, 5, 6, 7, 8]
RL agent
Play row 1, column 1
 O |   |
---+---+---
   |   |
---+---+---
   |   |
Expert agent
Play row 2, column 1
 O |   |
---+---+---
 X |   |
---+---+---
   |   |
available action: [1, 2, 4, 5, 6, 7, 8]
RL agent
Play row 1, column 2
 O | O |
---+---+---
 X |   |
---+---+---
   |   |
Expert agent
Play row 1, column 3
 O | O | X
---+---+---
 X |   |
---+---+---
   |   |
available action: [4, 5, 6, 7, 8]
RL agent
Play row 2, column 2
 O | O | X
---+---+---
 X | O |
---+---+---
   |   |
Expert agent
Play row 3, column 3
 O | O | X
---+---+---
 X | O |
---+---+---
   |   | X
available action: [5, 6, 7]
RL agent
Play row 3, column 2
 O | O | X
---+---+---
 X | O |
---+---+---
   | O | X
```

In-lab exercise and homework: DQN

For any but trivial problems, tabular Q-Learning will fail due to the difficulty of storing the value of every state-action pair and the enormous amount of time it takes for every cell in the table to converge.

The first thing we'd like to do, then, is approximate Q[s,a] with a function q(s,a) using fewer than the 177,147 parameters we used with tabular Q-learning.

As a first attempt, we might convert the input state-action pairs to a binary representation and use a linear output for the Q value. We would use a one-hot representation for each of the 9 game cells in s (3 choices) and the 9 possible actions. This would give us 36 inputs. The neural network would be multi-layer. With two fully connected layers of 10 units each, we'd have 10x37+10x11+11=491 parameters. That's a lot less than tabular Q-learning!

However, take a look at DQN. Their model has a NN to process the input images from the Atari console and has one output for each possible action. With this approach, we would have just 27 inputs and 9 outputs. Two fully connected layers of 10 units each would give us 10x28+10x11+9x11=489 parameters, which is similar in size to the above and has the advantage of only having to be executed once to get the value of every action. We could go with this tiny network or make it a lot bigger and still beat the Q table's size by a wide margin.

So, the first step will be to replace the Q table with a Q network. Go ahead and write your network class in PyTorch. Deep Q-Learning

Alright, you have a neural network to replace the Q table, but how to learn its parameters?

Take a look again at Mnih et al. (2015). The method they recommend is experience replay in which they store recent state-action-reward tuples in a buffer and train on random subsamples from the buffer.

This is probably overkill for tic-tac-toe, but let's implement it anyway!

You'll have to decide some things, such as what to do if the agent samples an illegal move. Give a negative reward? Give a 0 reward? Think about it and try an approach.

Go ahead and write the DQN algorithm, using your simple fully connected network in place of the CNN. Get it learning!

Report on your experiments and results by next week.

In [1]:

```
import gym
import tensorflow as tf
import numpy as np
import math
import time
import torch
import torch.nn as nn
import torch.optim as optim
import torch.nn.functional as F
import torchvision.transforms as T
import random
device = torch.device("cuda" if torch.cuda.is_available() else "cpu ")
```

DQN

Note this DQN consists of two fully connected layers of 10 unit each

In [6]:

```
class DQN(nn.Module):

    def __init__(self, inputs, outputs):
        super(DQN, self).__init__()
        self.fc1 = nn.Linear(inputs, 10)
        self.fc2 = nn.Linear(10, outputs)
        self.relu = nn.ReLU()
        self.softmax = nn.Softmax()

    def forward(self, x):
        x = self.relu(self.fc1(x)) x = self.fc2(x)
        return x

    def act(self, state, epsilon):
        # Get an epsilon greedy action for given state
        if random.random() > epsilon: # Use argmax_a Q(s,a)
            state = autograd.Variable(torch.FloatTensor(state).unsqueeze(0), vol
atile=True).to(device)
            q_value = self.forward(state)
            q_value = q_value.cpu()
            action = q_value.max(1)[1].item()
        else: # get random action
            action = random.randrange(env.action_space.n)
        return action
```

Replay Memory

In [8]:

```
class ReplayMemory(object):
    def __init__(self, capacity):
        self.capacity = capacity
        self.memory = [] # Queue-like self.position = 0
    def push(self, experience):
        """Saves a experience."""
        if len(self.memory) < self.capacity:
            self.memory.append(None) # if we haven't reached full c apacity, we
 append a new transition
            self.memory[self.position] = experience
            self.position = (self.position + 1) % self.capacity # e.g i f the ca
pacity is 100, and our position is now 101, we don't append to
                       # position 101 (impossible), but to position 1 (its remai
nder), overwriting old data
    def sample(self, batch_size):
        return random.sample(self.memory, batch_size)
    def __len__(self):
        return len(self.memory)
```

Losses

In [ ]:

```python
def compute_td_loss(model, batch_size, gamma=0.99):

    # Get batch from replay buffer
    state, action, reward, next_state, done = replay_buffer.sample(batch_size)

    # Convert to tensors. Creating Variables is not necessary with more recent PyTorch versions.
    state      = autograd.Variable(torch.FloatTensor(np.float32(state))).to(device)
    next_state = autograd.Variable(torch.FloatTensor(np.float32(next_state)), volatile=True).to(device)
    action     = autograd.Variable(torch.LongTensor(action)).to(device)
    reward     = autograd.Variable(torch.FloatTensor(reward)).to(device)
    done       = autograd.Variable(torch.FloatTensor(done)).to(device)

    # Calculate Q(s) and Q(s')
    q_values      = model(state)
    next_q_values = model(next_state)

    # Get Q(s,a) and max_a' Q(s',a')
    q_value          = q_values.gather(1, action.unsqueeze(1)).squeeze(1)
    next_q_value     = next_q_values.max(1)[0]
    # Calculate target for Q(s,a): r + gamma max_a' Q(s',a')
    # Note that the done signal is used to terminate recursion at end of episode.
    expected_q_value = reward + gamma * next_q_value * (1 - done)

    # Calculate MSE loss. Variables are not needed in recent PyTorch versions.
    loss = (q_value - autograd.Variable(expected_q_value.data)).pow(2).mean()

    optimizer.zero_grad()
    loss.backward()
    optimizer.step()

    return loss
```

In [ ]:

```
def train(env, model, eps_by_episode, optimizer, replay_buffer, episodes = 10000
, batch_size=32, gamma = 0.99):
    losses = []
    all_rewards = []
    episode_reward = 0
    tot_reward = 0
    tr = trange(episodes+1, desc='Agent training', leave=True)

    # Get initial state input
    state = env.reset()

    # Execute episodes iterations
    for episode in tr:
        tr.set_description("Agent training (episode{}) Avg Reward {}".format(epi
sode+1,tot_reward/(episode+1)))
        tr.refresh()

        # Get initial epsilon greedy action
        epsilon = eps_by_episode(episode)
        action = model.act(state, epsilon)

        # Take a step
        next_state, reward, done, _ = env.step(action)

        # Append experience to replay buffer
        replay_buffer.push(state, action, reward, next_state, done)

        tot_reward += reward
        episode_reward += reward

        state = next_state

        # Start a new episode if done signal is received
        if done:
            state = env.reset()
            all_rewards.append(episode_reward)
            episode_reward = 0

        # Train on a batch if we've got enough experience
        if len(replay_buffer) > batch_size:
            loss = compute_td_loss(model, batch_size, gamma)
            losses.append(loss.item())

    plot(episode, all_rewards, losses)
    return model,all_rewards, losses
```

In [ ]:

```
import importlib
from collections import defaultdict
import torch
import numpy

game_name = 'tictactoe'
game_module = importlib.import_module("games." + game_name)
env = game_module.Game()
```

In [ ]:

```
state = env.reset()
available_action = env.legal_actions()
BATCH_SIZE = 5 # original = 128
GAMMA = 0.999 # original = 0.999
N_EPISODES = 50000 # total episodes to be run MEMORY_SIZE = 100000 # original =
 10000 EPS_START = 0.9 # original = 0.9
EPS_END = 0.01 # original = 0.05
EPS_DECAY = 3000 # original = 200
policy_net = DQN(state.flatten().shape[0], len(available_action)).t
o(device)
optimizer = optim.RMSprop(policy_net.parameters())
memory = ReplayMemory(MEMORY_SIZE)
player = 1

for episode in range(N_EPISODES):
    if episode % 10000 == 9999:
        print("episode: ", episode + 1)
    state = env.reset()
    state = torch.FloatTensor(state).view(27).to(device)
    is_done = False while not is_done:
    if env.to_play() == player:
        available_action = env.legal_actions()
        action = select_action(state)
        next_state, reward, is_done = env.step(action)
        next_state = torch.FloatTensor(next_state).view(27).to(device)
    else:
        action = env.expert_agent()
        next_state, reward, is_done = env.step(action)
        next_state = torch.FloatTensor(next_state).view(27).to(
    if is_done:
        reward = -reward
        optimize_model(state, False) if is_done:
        break
    memory.push((state, reward, is_done))
    state = next_state
print('Complete')
```

I found this lab to be difficult. I spent some time trying to understand it and started to get a gist of how it works.