

5B_Reinforcement_Learning_Assignment

August 10, 2024

1 PyTorch Assignment: Reinforcement Learning (RL)

Duke Community Standard: By typing your name below, you are certifying that you have adhered to the Duke Community Standard in completing this assignment.

Name:

1.0.1 Short answer

1. One of the fundamental challenges of reinforcement learning is balancing *exploration* versus *exploitation*. What do these two terms mean, and why do they present a challenge?

In reinforcement learning, exploration and exploitation are two key strategies that agents must balance to effectively learn and optimize their behavior in an environment. Here's what each term means and why balancing them presents a challenge:

1.0.2 Exploration

Exploration refers to the agent's strategy of trying out new actions that it hasn't taken before, or actions it has taken infrequently. The goal of exploration is to discover potentially better strategies or actions that might yield higher rewards in the long run. Exploration helps the agent learn more about the environment and the consequences of various actions.

1.0.3 Exploitation

Exploitation involves the agent choosing actions that it already knows will yield high rewards based on its current knowledge. It leverages its existing knowledge to maximize immediate rewards by sticking to actions that have been proven effective in the past.

1.0.4 Why Balancing Exploration and Exploitation is a Challenge

Risk of Suboptimal Decisions:

1.0.5 Exploration:

If an agent focuses too much on exploration, it may waste time and resources on actions that are not immediately beneficial, potentially leading to suboptimal performance in the short term. Exploitation: On the other hand, if the agent focuses too much on exploitation, it might miss out on discovering better actions or strategies that could lead to higher rewards in the future.

1.0.6 Dynamic Environments:

In environments where the conditions or rewards change over time, excessive exploitation might lead the agent to stick to outdated strategies. Exploration is necessary to adapt to new or changing environments.

1.0.7 Incomplete Knowledge:

Initially, the agent might have limited knowledge about the environment. Exploration is crucial for gathering information about different states and actions, but as the agent learns more, it needs to transition towards exploitation to maximize rewards.

1.0.8 Trade-off Decisions:

Finding the right balance between exploration and exploitation is a complex decision. Too much exploration can lead to inefficiencies and wasted effort, while too much exploitation can prevent the agent from discovering potentially better strategies. Practical Approaches Epsilon-Greedy Strategy:

This strategy involves choosing a random action with probability ϵ (exploration) and choosing the best-known action with probability $1 - \epsilon$ (exploitation). ϵ is often decayed over time to balance exploration and exploitation effectively. Upper Confidence Bound (UCB):

This approach balances exploration and exploitation by considering both the estimated value of actions and the uncertainty or confidence in those estimates.

1.0.9 Softmax Action Selection:

Actions are selected based on a probability distribution derived from their estimated values, allowing for both exploration and exploitation in a probabilistic manner. Balancing exploration and exploitation is fundamental to achieving long-term success in reinforcement learning, as it enables the agent to learn and adapt effectively while optimizing its performance in the environment.

2. Another fundamental reinforcement learning challenge is what is known as the *credit assignment problem*, especially when rewards are sparse. What do we mean by the phrase, and why does it make learning especially difficult?

1.1 Credit Assignment Problem in Reinforcement Learning

The **credit assignment problem** in reinforcement learning refers to the challenge of determining which actions or decisions in a sequence are responsible for a particular outcome or reward. This issue becomes especially challenging when rewards are sparse, meaning that feedback on actions (i.e., rewards) is infrequent or delayed.

1.1.1 What is the Credit Assignment Problem?

1. Definition:

- The credit assignment problem involves figuring out how to allocate the credit (or blame) for the outcomes to the individual actions that led to those outcomes. Essentially, it's about determining which actions in a sequence contributed to a final reward or punishment.

2. Sparse Rewards:

- In many real-world scenarios, rewards are not provided after every action but rather at the end of a long sequence of actions or intermittently. For instance, in a game, a reward might be given only at the end of the game, regardless of the individual actions taken throughout.

1.1.2 Why Does It Make Learning Difficult?

1. Delayed Feedback:

- When rewards are sparse, it can be difficult to associate the reward with specific actions that led to it. If an agent receives a reward only after completing a long sequence of actions, it needs to figure out which of those actions were responsible for the reward. This can be challenging because the agent has to backtrack through the sequence of actions and determine their individual contributions to the outcome.

2. Long-Term Dependencies:

- In tasks where rewards are sparse, actions taken early in the sequence might influence the outcome significantly, but the feedback is received only much later. The agent needs to learn how early actions affect future rewards, which involves understanding and managing long-term dependencies.

3. Difficulty in Learning Effective Policies:

- The agent might struggle to learn effective policies because it lacks immediate feedback on the effectiveness of its actions. Without clear and frequent feedback, it's hard for the agent to understand which actions are beneficial or detrimental, leading to slower learning and potentially suboptimal policies.

4. Exploration Challenges:

- Sparse rewards make exploration more challenging. The agent might need to explore many different sequences of actions before receiving any feedback, making it harder to identify successful strategies and increasing the time required to learn an optimal policy.

1.1.3 Approaches to Address the Credit Assignment Problem

1. Temporal Difference Learning:

- Methods like Q-learning and SARSA help in credit assignment by updating the value of actions based on temporal differences between consecutive states and actions, even if rewards are sparse.
2. **Reward Shaping:**
 - This technique involves modifying the reward function to provide intermediate rewards or feedback to guide the learning process. For example, providing small rewards for achieving subgoals can help in assigning credit more effectively.
 3. **Monte Carlo Methods:**
 - Monte Carlo methods use episodes of complete experience to update value estimates, helping in assigning credit over the entire episode based on the final outcome.
 4. **Eligibility Traces:**
 - Eligibility traces combine the benefits of Monte Carlo methods and temporal difference learning by maintaining a trace of recently visited states and actions, allowing the agent to update values based on past actions even if rewards are received later.

1.1.4 Summary

The credit assignment problem is crucial in reinforcement learning because it affects how an agent learns to make decisions and improve its performance based on feedback. Sparse rewards exacerbate this problem by making it harder to link individual actions to the eventual outcomes, complicating the learning process and requiring sophisticated techniques to manage and mitigate the issue.

1.1.5 Deep SARSA Cart Pole

SARSA (state-action-reward-state-action) is another Q value algorithm that resembles Q-learning quite closely:

Q-learning update rule:

$$Q_{\pi}(s_t, a_t) \leftarrow (1 - \alpha) \cdot Q_{\pi}(s_t, a_t) + \alpha \cdot (r_t + \gamma \max_a Q_{\pi}(s_{t+1}, a)) \quad (1)$$

SARSA update rule:

$$Q_{\pi}(s_t, a_t) \leftarrow (1 - \alpha) \cdot Q_{\pi}(s_t, a_t) + \alpha \cdot (r_t + \gamma Q_{\pi}(s_{t+1}, a_{t+1})) \quad (2)$$

Unlike Q-learning, which is considered an *off-policy* network, SARSA is an *on-policy* algorithm. When Q-learning calculates the estimated future reward, it must “guess” the future, starting with the next action the agent will take. In Q-learning, we assume the agent will take the best possible action: $\max_a Q_{\pi}(s_{t+1}, a)$. SARSA, on the other hand, uses the action that was actually taken next in the episode we are learning from: $Q_{\pi}(s_{t+1}, a_{t+1})$. In other words, SARSA learns from the next action he actually took (on policy), as opposed to what the max possible Q value for the next state was (off policy).

Build an RL agent that uses SARSA to solve the Cart Pole problem.

Hint: You can and should reuse the Q-Learning agent we went over earlier. In fact, if you know what you're doing, it's possible to finish this assignment in about 30 seconds.

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[3]: ### YOUR CODE HERE ###
!pip install gym numpy
```

```
WARNING: pip is being invoked by an old script wrapper. This will fail in a
future version of pip.
Please see https://github.com/pypa/pip/issues/5599 for advice on fixing the
underlying issue.
To avoid this problem you can invoke Python with '-m pip' instead of running pip
directly.
Requirement already satisfied: gym in /opt/conda/lib/python3.7/site-packages
(0.15.7)
Requirement already satisfied: numpy in /opt/conda/lib/python3.7/site-packages
(1.18.1)
Requirement already satisfied: cloudpickle~=1.2.0 in
/opt/conda/lib/python3.7/site-packages (from gym) (1.2.2)
Requirement already satisfied: pygame<=1.5.0,>=1.4.0 in
/opt/conda/lib/python3.7/site-packages (from gym) (1.4.10)
Requirement already satisfied: scipy in /opt/conda/lib/python3.7/site-packages
(from gym) (1.4.1)
Requirement already satisfied: six in /opt/conda/lib/python3.7/site-packages
(from gym) (1.14.0)
Requirement already satisfied: future in /opt/conda/lib/python3.7/site-packages
(from pygame<=1.5.0,>=1.4.0->gym) (0.18.2)
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```
[4]: import numpy as np
import gym

class SARSAAgent:
    def __init__(self, state_space, action_space, alpha=0.1, gamma=0.99,
        epsilon=0.1):
        self.state_space = state_space
        self.action_space = action_space
        self.alpha = alpha
        self.gamma = gamma
        self.epsilon = epsilon
        self.q_table = np.zeros(state_space + (action_space,))

    def choose_action(self, state):
        if np.random.rand() < self.epsilon:
            return np.random.randint(self.action_space)
        else:
            return np.argmax(self.q_table[state])

    def update(self, state, action, reward, next_state, next_action):
        best_q = self.q_table[next_state][next_action]
        td_target = reward + self.gamma * best_q
        td_error = td_target - self.q_table[state][action]
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        self.q_table[state][action] += self.alpha * td_error

def discretize_state(state, bins):
    state_indices = []
    for i in range(len(state)):
        state_indices.append(np.digitize(state[i], bins[i]))
    return tuple(state_indices)

def main():
    env = gym.make('CartPole-v1')
    n_bins = 24
    bins = [np.linspace(-x, x, n_bins) for x in env.observation_space.high]

    agent = SARSAgent(
        state_space=(n_bins,) * len(env.observation_space.high),
        action_space=env.action_space.n
    )

    episodes = 1000
    for episode in range(episodes):
        state = discretize_state(env.reset(), bins)
        action = agent.choose_action(state)
        total_reward = 0

        done = False
        while not done:
            next_state, reward, done, _ = env.step(action)
            next_state = discretize_state(next_state, bins)
            next_action = agent.choose_action(next_state)

            agent.update(state, action, reward, next_state, next_action)

            state = next_state
            action = next_action
            total_reward += reward

        print(f'Episode {episode + 1}/{episodes}, Total Reward: {total_reward}')

    env.close()

if __name__ == "__main__":
    main()

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Episode 1/1000, Total Reward: 9.0
Episode 2/1000, Total Reward: 10.0
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Episode 866/1000, Total Reward: 23.0
Episode 867/1000, Total Reward: 56.0
Episode 868/1000, Total Reward: 13.0

Episode 869/1000, Total Reward: 25.0
Episode 870/1000, Total Reward: 31.0
Episode 871/1000, Total Reward: 46.0
Episode 872/1000, Total Reward: 12.0
Episode 873/1000, Total Reward: 17.0
Episode 874/1000, Total Reward: 25.0
Episode 875/1000, Total Reward: 12.0
Episode 876/1000, Total Reward: 27.0
Episode 877/1000, Total Reward: 51.0
Episode 878/1000, Total Reward: 14.0
Episode 879/1000, Total Reward: 24.0
Episode 880/1000, Total Reward: 28.0
Episode 881/1000, Total Reward: 37.0
Episode 882/1000, Total Reward: 22.0
Episode 883/1000, Total Reward: 18.0
Episode 884/1000, Total Reward: 28.0
Episode 885/1000, Total Reward: 50.0
Episode 886/1000, Total Reward: 31.0
Episode 887/1000, Total Reward: 56.0
Episode 888/1000, Total Reward: 16.0
Episode 889/1000, Total Reward: 38.0
Episode 890/1000, Total Reward: 14.0
Episode 891/1000, Total Reward: 39.0
Episode 892/1000, Total Reward: 23.0
Episode 893/1000, Total Reward: 15.0
Episode 894/1000, Total Reward: 45.0
Episode 895/1000, Total Reward: 14.0
Episode 896/1000, Total Reward: 18.0
Episode 897/1000, Total Reward: 15.0
Episode 898/1000, Total Reward: 14.0
Episode 899/1000, Total Reward: 10.0
Episode 900/1000, Total Reward: 10.0
Episode 901/1000, Total Reward: 10.0
Episode 902/1000, Total Reward: 10.0
Episode 903/1000, Total Reward: 11.0
Episode 904/1000, Total Reward: 10.0
Episode 905/1000, Total Reward: 10.0
Episode 906/1000, Total Reward: 9.0
Episode 907/1000, Total Reward: 11.0
Episode 908/1000, Total Reward: 10.0
Episode 909/1000, Total Reward: 12.0
Episode 910/1000, Total Reward: 11.0
Episode 911/1000, Total Reward: 11.0
Episode 912/1000, Total Reward: 10.0
Episode 913/1000, Total Reward: 11.0
Episode 914/1000, Total Reward: 10.0
Episode 915/1000, Total Reward: 9.0
Episode 916/1000, Total Reward: 16.0

Episode 917/1000, Total Reward: 10.0
Episode 918/1000, Total Reward: 11.0
Episode 919/1000, Total Reward: 9.0
Episode 920/1000, Total Reward: 14.0
Episode 921/1000, Total Reward: 11.0
Episode 922/1000, Total Reward: 13.0
Episode 923/1000, Total Reward: 11.0
Episode 924/1000, Total Reward: 10.0
Episode 925/1000, Total Reward: 9.0
Episode 926/1000, Total Reward: 11.0
Episode 927/1000, Total Reward: 9.0
Episode 928/1000, Total Reward: 28.0
Episode 929/1000, Total Reward: 11.0
Episode 930/1000, Total Reward: 13.0
Episode 931/1000, Total Reward: 8.0
Episode 932/1000, Total Reward: 10.0
Episode 933/1000, Total Reward: 11.0
Episode 934/1000, Total Reward: 12.0
Episode 935/1000, Total Reward: 10.0
Episode 936/1000, Total Reward: 12.0
Episode 937/1000, Total Reward: 11.0
Episode 938/1000, Total Reward: 14.0
Episode 939/1000, Total Reward: 9.0
Episode 940/1000, Total Reward: 13.0
Episode 941/1000, Total Reward: 13.0
Episode 942/1000, Total Reward: 16.0
Episode 943/1000, Total Reward: 9.0
Episode 944/1000, Total Reward: 13.0
Episode 945/1000, Total Reward: 24.0
Episode 946/1000, Total Reward: 19.0
Episode 947/1000, Total Reward: 25.0
Episode 948/1000, Total Reward: 32.0
Episode 949/1000, Total Reward: 14.0
Episode 950/1000, Total Reward: 41.0
Episode 951/1000, Total Reward: 12.0
Episode 952/1000, Total Reward: 33.0
Episode 953/1000, Total Reward: 15.0
Episode 954/1000, Total Reward: 20.0
Episode 955/1000, Total Reward: 44.0
Episode 956/1000, Total Reward: 16.0
Episode 957/1000, Total Reward: 12.0
Episode 958/1000, Total Reward: 15.0
Episode 959/1000, Total Reward: 38.0
Episode 960/1000, Total Reward: 12.0
Episode 961/1000, Total Reward: 22.0
Episode 962/1000, Total Reward: 15.0
Episode 963/1000, Total Reward: 11.0
Episode 964/1000, Total Reward: 31.0

Episode 965/1000, Total Reward: 24.0
Episode 966/1000, Total Reward: 23.0
Episode 967/1000, Total Reward: 36.0
Episode 968/1000, Total Reward: 26.0
Episode 969/1000, Total Reward: 21.0
Episode 970/1000, Total Reward: 25.0
Episode 971/1000, Total Reward: 17.0
Episode 972/1000, Total Reward: 15.0
Episode 973/1000, Total Reward: 15.0
Episode 974/1000, Total Reward: 21.0
Episode 975/1000, Total Reward: 26.0
Episode 976/1000, Total Reward: 23.0
Episode 977/1000, Total Reward: 14.0
Episode 978/1000, Total Reward: 13.0
Episode 979/1000, Total Reward: 55.0
Episode 980/1000, Total Reward: 33.0
Episode 981/1000, Total Reward: 32.0
Episode 982/1000, Total Reward: 13.0
Episode 983/1000, Total Reward: 21.0
Episode 984/1000, Total Reward: 24.0
Episode 985/1000, Total Reward: 40.0
Episode 986/1000, Total Reward: 27.0
Episode 987/1000, Total Reward: 26.0
Episode 988/1000, Total Reward: 23.0
Episode 989/1000, Total Reward: 24.0
Episode 990/1000, Total Reward: 37.0
Episode 991/1000, Total Reward: 38.0
Episode 992/1000, Total Reward: 45.0
Episode 993/1000, Total Reward: 51.0
Episode 994/1000, Total Reward: 28.0
Episode 995/1000, Total Reward: 72.0
Episode 996/1000, Total Reward: 11.0
Episode 997/1000, Total Reward: 39.0
Episode 998/1000, Total Reward: 10.0
Episode 999/1000, Total Reward: 11.0
Episode 1000/1000, Total Reward: 35.0

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