

Reinforcement Learning: Deep Q-Learning

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Reinforcement Learning in PyTorch

This tutorial introduces reinforcement learning (RL) using PyTorch. We'll focus on Q-Learning with Deep Q-Networks (DQN) to teach an agent how to navigate a simple environment. For demonstration, we'll use the `CartPole-v1` environment from OpenAI's Gym.

What is Reinforcement Learning?

Reinforcement Learning is a framework where an agent interacts with an environment to learn a policy $\pi(s)$, mapping states (s) to actions (a), by maximizing cumulative rewards.

Key terms:

- **State:** The current representation of the environment.
 - **Action:** The agent's decision.
 - **Reward:** Feedback from the environment.
 - **Policy:** Strategy for choosing actions.
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Step-by-Step Implementation

1. Setup

Install required libraries:

```
pip install gymnasium[all] torch matplotlib
```

2. Imports

```
In [ ]: import gymnasium as gym
import torch
import torch.nn as nn
import torch.optim as optim
import torch.nn.functional as F
import numpy as np
from collections import deque
import random
import matplotlib.pyplot as plt
```

3. Create the Neural Network

The DQN approximates the Q-value function $Q(s, a)$.

```
In [ ]: class DQN(nn.Module):
    def __init__(self, state_dim, action_dim):
        super(DQN, self).__init__()
        self.fc1 = nn.Linear(state_dim, 128)
        self.fc2 = nn.Linear(128, 128)
        self.fc3 = nn.Linear(128, action_dim)

    def forward(self, x):
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x) # Q-values for all actions
        return x
```

4. Replay Buffer

Experience replay stores past transitions to improve sample efficiency.

```
In [ ]: class ReplayBuffer:
    def __init__(self, capacity):
        self.buffer = deque(maxlen=capacity)

    def push(self, state, action, reward, next_state, done):
        self.buffer.append((state, action, reward, next_state, done))

    def sample(self, batch_size):
        batch = random.sample(self.buffer, batch_size)
        states, actions, rewards, next_states, dones = zip(*batch)
        return (np.array(states), np.array(actions), np.array(rewards),
                np.array(next_states), np.array(dones))

    def __len__(self):
        return len(self.buffer)
```

5. Epsilon-Greedy Policy

The agent explores the environment while balancing exploration and exploitation.

```
In [ ]: def epsilon_greedy_policy(state, epsilon, model, action_dim):
    if random.random() < epsilon:
        return random.randint(0, action_dim - 1) # Explore
    state = torch.FloatTensor(state).unsqueeze(0)
    with torch.no_grad():
        q_values = model(state)
    return q_values.argmax().item() # Exploit
```

6. Train the Agent

Define the main training loop for DQN.

```
In [ ]: def train_dqn(env, num_episodes=500, batch_size=64, gamma=0.99, epsilon_d

state_dim = env.observation_space.shape[0]
action_dim = env.action_space.n

# Initialize DQN and target networks
dqn = DQN(state_dim, action_dim)
target_dqn = DQN(state_dim, action_dim)
target_dqn.load_state_dict(dqn.state_dict())
optimizer = optim.Adam(dqn.parameters(), lr=0.001)

replay_buffer = ReplayBuffer(capacity=10000)

epsilon = 1.0
rewards_per_episode = []

for episode in range(num_episodes):
    state, _ = env.reset()
    episode_reward = 0

    while True:
        # Choose an action using epsilon-greedy policy
        action = epsilon_greedy_policy(state, epsilon, dqn, action_dim)
        next_state, reward, terminated, truncated, _ = env.step(action)
        episode_reward += reward
        done = terminated or truncated

        # Store transition in replay buffer
        replay_buffer.push(state, action, reward, next_state, done)
        state = next_state

        # Train the model if enough data is available
        if len(replay_buffer) >= batch_size:
            states, actions, rewards, next_states, dones = replay_buffer

            states = torch.FloatTensor(states)
            actions = torch.LongTensor(actions).unsqueeze(1)
            rewards = torch.FloatTensor(rewards)
            next_states = torch.FloatTensor(next_states)
            dones = torch.FloatTensor(dones)

            # Compute target Q-values
            with torch.no_grad():
                target_q_values = rewards + gamma * (1 - dones) * tar

            # Compute current Q-values
            current_q_values = dqn(states).gather(1, actions).squeeze

            # Loss: MSE
            loss = F.mse_loss(current_q_values, target_q_values)

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

        if done:
            break
```

```
# Update target network periodically
if episode % 10 == 0:
    target_dqn.load_state_dict(dqn.state_dict())

# Decay epsilon
epsilon = max(min_epsilon, epsilon * epsilon_decay)

rewards_per_episode.append(episode_reward)
print(f"Episode {episode}, Reward: {episode_reward}, Epsilon: {ep

return rewards_per_episode, dqn
```

7. Visualize Training

```
In [ ]: # Train the model
env = gym.make('CartPole-v1')
rewards, trained_dqn = train_dqn(env, num_episodes=2000)

# Plot rewards
plt.plot(rewards)
plt.xlabel("Episode")
plt.ylabel("Reward")
plt.title("Training Rewards")
plt.show()
```

Episode 0, Reward: 11.0, Epsilon: 0.99
Episode 1, Reward: 10.0, Epsilon: 0.99
Episode 2, Reward: 30.0, Epsilon: 0.99
Episode 3, Reward: 22.0, Epsilon: 0.98
Episode 4, Reward: 16.0, Epsilon: 0.98
Episode 5, Reward: 51.0, Epsilon: 0.97
Episode 6, Reward: 26.0, Epsilon: 0.97
Episode 7, Reward: 18.0, Epsilon: 0.96
Episode 8, Reward: 23.0, Epsilon: 0.96
Episode 9, Reward: 16.0, Epsilon: 0.95
Episode 10, Reward: 17.0, Epsilon: 0.95
Episode 11, Reward: 26.0, Epsilon: 0.94
Episode 12, Reward: 22.0, Epsilon: 0.94
Episode 13, Reward: 32.0, Epsilon: 0.93
Episode 14, Reward: 13.0, Epsilon: 0.93
Episode 15, Reward: 25.0, Epsilon: 0.92
Episode 16, Reward: 37.0, Epsilon: 0.92
Episode 17, Reward: 22.0, Epsilon: 0.91
Episode 18, Reward: 22.0, Epsilon: 0.91
Episode 19, Reward: 20.0, Epsilon: 0.90
Episode 20, Reward: 14.0, Epsilon: 0.90
Episode 21, Reward: 24.0, Epsilon: 0.90
Episode 22, Reward: 15.0, Epsilon: 0.89
Episode 23, Reward: 36.0, Epsilon: 0.89
Episode 24, Reward: 12.0, Epsilon: 0.88
Episode 25, Reward: 13.0, Epsilon: 0.88
Episode 26, Reward: 20.0, Epsilon: 0.87
Episode 27, Reward: 12.0, Epsilon: 0.87
Episode 28, Reward: 18.0, Epsilon: 0.86
Episode 29, Reward: 26.0, Epsilon: 0.86
Episode 30, Reward: 21.0, Epsilon: 0.86
Episode 31, Reward: 11.0, Epsilon: 0.85
Episode 32, Reward: 16.0, Epsilon: 0.85
Episode 33, Reward: 18.0, Epsilon: 0.84
Episode 34, Reward: 20.0, Epsilon: 0.84
Episode 35, Reward: 12.0, Epsilon: 0.83
Episode 36, Reward: 21.0, Epsilon: 0.83
Episode 37, Reward: 20.0, Epsilon: 0.83
Episode 38, Reward: 63.0, Epsilon: 0.82
Episode 39, Reward: 16.0, Epsilon: 0.82
Episode 40, Reward: 64.0, Epsilon: 0.81
Episode 41, Reward: 19.0, Epsilon: 0.81
Episode 42, Reward: 47.0, Epsilon: 0.81
Episode 43, Reward: 17.0, Epsilon: 0.80
Episode 44, Reward: 23.0, Epsilon: 0.80
Episode 45, Reward: 26.0, Epsilon: 0.79
Episode 46, Reward: 22.0, Epsilon: 0.79
Episode 47, Reward: 35.0, Epsilon: 0.79
Episode 48, Reward: 13.0, Epsilon: 0.78
Episode 49, Reward: 39.0, Epsilon: 0.78
Episode 50, Reward: 13.0, Epsilon: 0.77
Episode 51, Reward: 11.0, Epsilon: 0.77
Episode 52, Reward: 21.0, Epsilon: 0.77
Episode 53, Reward: 18.0, Epsilon: 0.76
Episode 54, Reward: 50.0, Epsilon: 0.76
Episode 55, Reward: 37.0, Epsilon: 0.76
Episode 56, Reward: 16.0, Epsilon: 0.75
Episode 57, Reward: 73.0, Epsilon: 0.75
Episode 58, Reward: 18.0, Epsilon: 0.74
Episode 59, Reward: 30.0, Epsilon: 0.74

Episode 60, Reward: 19.0, Epsilon: 0.74
Episode 61, Reward: 28.0, Epsilon: 0.73
Episode 62, Reward: 25.0, Epsilon: 0.73
Episode 63, Reward: 55.0, Epsilon: 0.73
Episode 64, Reward: 12.0, Epsilon: 0.72
Episode 65, Reward: 27.0, Epsilon: 0.72
Episode 66, Reward: 65.0, Epsilon: 0.71
Episode 67, Reward: 40.0, Epsilon: 0.71
Episode 68, Reward: 39.0, Epsilon: 0.71
Episode 69, Reward: 37.0, Epsilon: 0.70
Episode 70, Reward: 78.0, Epsilon: 0.70
Episode 71, Reward: 11.0, Epsilon: 0.70
Episode 72, Reward: 57.0, Epsilon: 0.69
Episode 73, Reward: 32.0, Epsilon: 0.69
Episode 74, Reward: 25.0, Epsilon: 0.69
Episode 75, Reward: 30.0, Epsilon: 0.68
Episode 76, Reward: 37.0, Epsilon: 0.68
Episode 77, Reward: 48.0, Epsilon: 0.68
Episode 78, Reward: 19.0, Epsilon: 0.67
Episode 79, Reward: 30.0, Epsilon: 0.67
Episode 80, Reward: 19.0, Epsilon: 0.67
Episode 81, Reward: 81.0, Epsilon: 0.66
Episode 82, Reward: 114.0, Epsilon: 0.66
Episode 83, Reward: 13.0, Epsilon: 0.66
Episode 84, Reward: 26.0, Epsilon: 0.65
Episode 85, Reward: 30.0, Epsilon: 0.65
Episode 86, Reward: 38.0, Epsilon: 0.65
Episode 87, Reward: 21.0, Epsilon: 0.64
Episode 88, Reward: 76.0, Epsilon: 0.64
Episode 89, Reward: 45.0, Epsilon: 0.64
Episode 90, Reward: 12.0, Epsilon: 0.63
Episode 91, Reward: 43.0, Epsilon: 0.63
Episode 92, Reward: 95.0, Epsilon: 0.63
Episode 93, Reward: 37.0, Epsilon: 0.62
Episode 94, Reward: 19.0, Epsilon: 0.62
Episode 95, Reward: 33.0, Epsilon: 0.62
Episode 96, Reward: 38.0, Epsilon: 0.61
Episode 97, Reward: 91.0, Epsilon: 0.61
Episode 98, Reward: 23.0, Epsilon: 0.61
Episode 99, Reward: 82.0, Epsilon: 0.61
Episode 100, Reward: 22.0, Epsilon: 0.60
Episode 101, Reward: 40.0, Epsilon: 0.60
Episode 102, Reward: 26.0, Epsilon: 0.60
Episode 103, Reward: 81.0, Epsilon: 0.59
Episode 104, Reward: 30.0, Epsilon: 0.59
Episode 105, Reward: 19.0, Epsilon: 0.59
Episode 106, Reward: 116.0, Epsilon: 0.58
Episode 107, Reward: 42.0, Epsilon: 0.58
Episode 108, Reward: 43.0, Epsilon: 0.58
Episode 109, Reward: 119.0, Epsilon: 0.58
Episode 110, Reward: 109.0, Epsilon: 0.57
Episode 111, Reward: 127.0, Epsilon: 0.57
Episode 112, Reward: 57.0, Epsilon: 0.57
Episode 113, Reward: 37.0, Epsilon: 0.56
Episode 114, Reward: 113.0, Epsilon: 0.56
Episode 115, Reward: 74.0, Epsilon: 0.56
Episode 116, Reward: 152.0, Epsilon: 0.56
Episode 117, Reward: 33.0, Epsilon: 0.55
Episode 118, Reward: 155.0, Epsilon: 0.55
Episode 119, Reward: 107.0, Epsilon: 0.55

Episode 120, Reward: 130.0, Epsilon: 0.55
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Episode 136, Reward: 93.0, Epsilon: 0.50
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Episode 267, Reward: 138.0, Epsilon: 0.26
Episode 268, Reward: 200.0, Epsilon: 0.26
Episode 269, Reward: 137.0, Epsilon: 0.26
Episode 270, Reward: 73.0, Epsilon: 0.26
Episode 271, Reward: 155.0, Epsilon: 0.26
Episode 272, Reward: 274.0, Epsilon: 0.25
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Episode 287, Reward: 11.0, Epsilon: 0.24
Episode 288, Reward: 226.0, Epsilon: 0.23
Episode 289, Reward: 203.0, Epsilon: 0.23
Episode 290, Reward: 248.0, Epsilon: 0.23
Episode 291, Reward: 251.0, Epsilon: 0.23
Episode 292, Reward: 69.0, Epsilon: 0.23
Episode 293, Reward: 100.0, Epsilon: 0.23
Episode 294, Reward: 96.0, Epsilon: 0.23
Episode 295, Reward: 68.0, Epsilon: 0.23
Episode 296, Reward: 188.0, Epsilon: 0.23
Episode 297, Reward: 452.0, Epsilon: 0.22
Episode 298, Reward: 23.0, Epsilon: 0.22
Episode 299, Reward: 369.0, Epsilon: 0.22

Episode 300, Reward: 126.0, Epsilon: 0.22
Episode 301, Reward: 156.0, Epsilon: 0.22
Episode 302, Reward: 444.0, Epsilon: 0.22
Episode 303, Reward: 254.0, Epsilon: 0.22
Episode 304, Reward: 118.0, Epsilon: 0.22
Episode 305, Reward: 12.0, Epsilon: 0.22
Episode 306, Reward: 80.0, Epsilon: 0.21
Episode 307, Reward: 25.0, Epsilon: 0.21
Episode 308, Reward: 185.0, Epsilon: 0.21
Episode 309, Reward: 365.0, Epsilon: 0.21
Episode 310, Reward: 277.0, Epsilon: 0.21
Episode 311, Reward: 175.0, Epsilon: 0.21
Episode 312, Reward: 176.0, Epsilon: 0.21
Episode 313, Reward: 147.0, Epsilon: 0.21
Episode 314, Reward: 36.0, Epsilon: 0.21
Episode 315, Reward: 286.0, Epsilon: 0.21
Episode 316, Reward: 13.0, Epsilon: 0.20
Episode 317, Reward: 78.0, Epsilon: 0.20
Episode 318, Reward: 32.0, Epsilon: 0.20
Episode 319, Reward: 153.0, Epsilon: 0.20
Episode 320, Reward: 64.0, Epsilon: 0.20
Episode 321, Reward: 188.0, Epsilon: 0.20
Episode 322, Reward: 81.0, Epsilon: 0.20
Episode 323, Reward: 210.0, Epsilon: 0.20
Episode 324, Reward: 159.0, Epsilon: 0.20
Episode 325, Reward: 249.0, Epsilon: 0.20
Episode 326, Reward: 72.0, Epsilon: 0.19
Episode 327, Reward: 469.0, Epsilon: 0.19
Episode 328, Reward: 96.0, Epsilon: 0.19
Episode 329, Reward: 178.0, Epsilon: 0.19
Episode 330, Reward: 125.0, Epsilon: 0.19
Episode 331, Reward: 209.0, Epsilon: 0.19
Episode 332, Reward: 115.0, Epsilon: 0.19
Episode 333, Reward: 494.0, Epsilon: 0.19
Episode 334, Reward: 337.0, Epsilon: 0.19
Episode 335, Reward: 177.0, Epsilon: 0.19
Episode 336, Reward: 408.0, Epsilon: 0.18
Episode 337, Reward: 282.0, Epsilon: 0.18
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Episode 350, Reward: 293.0, Epsilon: 0.17
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Episode 353, Reward: 199.0, Epsilon: 0.17
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Episode 355, Reward: 142.0, Epsilon: 0.17
Episode 356, Reward: 158.0, Epsilon: 0.17
Episode 357, Reward: 139.0, Epsilon: 0.17
Episode 358, Reward: 160.0, Epsilon: 0.17
Episode 359, Reward: 194.0, Epsilon: 0.16

Episode 360, Reward: 150.0, Epsilon: 0.16
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Episode 362, Reward: 144.0, Epsilon: 0.16
Episode 363, Reward: 13.0, Epsilon: 0.16
Episode 364, Reward: 138.0, Epsilon: 0.16
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Episode 382, Reward: 35.0, Epsilon: 0.15
Episode 383, Reward: 108.0, Epsilon: 0.15
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Episode 403, Reward: 109.0, Epsilon: 0.13
Episode 404, Reward: 108.0, Epsilon: 0.13
Episode 405, Reward: 95.0, Epsilon: 0.13
Episode 406, Reward: 11.0, Epsilon: 0.13
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Episode 488, Reward: 154.0, Epsilon: 0.09
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Episode 490, Reward: 202.0, Epsilon: 0.09
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Episode 492, Reward: 137.0, Epsilon: 0.08
Episode 493, Reward: 183.0, Epsilon: 0.08
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Episode 500, Reward: 215.0, Epsilon: 0.08
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Episode 520, Reward: 500.0, Epsilon: 0.07
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Episode 531, Reward: 48.0, Epsilon: 0.07
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Episode 549, Reward: 500.0, Epsilon: 0.06
Episode 550, Reward: 500.0, Epsilon: 0.06
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Episode 582, Reward: 500.0, Epsilon: 0.05
Episode 583, Reward: 500.0, Epsilon: 0.05
Episode 584, Reward: 500.0, Epsilon: 0.05
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Episode 624, Reward: 500.0, Epsilon: 0.04
Episode 625, Reward: 420.0, Epsilon: 0.04
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Episode 632, Reward: 228.0, Epsilon: 0.04
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Episode 635, Reward: 500.0, Epsilon: 0.04
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Episode 652, Reward: 500.0, Epsilon: 0.04
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Episode 658, Reward: 500.0, Epsilon: 0.04
Episode 659, Reward: 47.0, Epsilon: 0.04

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Episode 673, Reward: 500.0, Epsilon: 0.03
Episode 674, Reward: 500.0, Epsilon: 0.03
Episode 675, Reward: 339.0, Epsilon: 0.03
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Episode 680, Reward: 500.0, Epsilon: 0.03
Episode 681, Reward: 500.0, Epsilon: 0.03
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Episode 683, Reward: 160.0, Epsilon: 0.03
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Episode 686, Reward: 500.0, Epsilon: 0.03
Episode 687, Reward: 476.0, Epsilon: 0.03
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Episode 703, Reward: 176.0, Epsilon: 0.03
Episode 704, Reward: 420.0, Epsilon: 0.03
Episode 705, Reward: 289.0, Epsilon: 0.03
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Episode 707, Reward: 500.0, Epsilon: 0.03
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Episode 709, Reward: 175.0, Epsilon: 0.03
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Episode 713, Reward: 113.0, Epsilon: 0.03
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Episode 719, Reward: 136.0, Epsilon: 0.03

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Episode 759, Reward: 56.0, Epsilon: 0.02
Episode 760, Reward: 242.0, Epsilon: 0.02
Episode 761, Reward: 11.0, Epsilon: 0.02
Episode 762, Reward: 37.0, Epsilon: 0.02
Episode 763, Reward: 36.0, Epsilon: 0.02
Episode 764, Reward: 32.0, Epsilon: 0.02
Episode 765, Reward: 58.0, Epsilon: 0.02
Episode 766, Reward: 293.0, Epsilon: 0.02
Episode 767, Reward: 500.0, Epsilon: 0.02
Episode 768, Reward: 349.0, Epsilon: 0.02
Episode 769, Reward: 45.0, Epsilon: 0.02
Episode 770, Reward: 231.0, Epsilon: 0.02
Episode 771, Reward: 152.0, Epsilon: 0.02
Episode 772, Reward: 228.0, Epsilon: 0.02
Episode 773, Reward: 52.0, Epsilon: 0.02
Episode 774, Reward: 309.0, Epsilon: 0.02
Episode 775, Reward: 67.0, Epsilon: 0.02
Episode 776, Reward: 41.0, Epsilon: 0.02
Episode 777, Reward: 24.0, Epsilon: 0.02
Episode 778, Reward: 47.0, Epsilon: 0.02
Episode 779, Reward: 44.0, Epsilon: 0.02

Episode 780, Reward: 37.0, Epsilon: 0.02
Episode 781, Reward: 16.0, Epsilon: 0.02
Episode 782, Reward: 33.0, Epsilon: 0.02
Episode 783, Reward: 205.0, Epsilon: 0.02
Episode 784, Reward: 47.0, Epsilon: 0.02
Episode 785, Reward: 11.0, Epsilon: 0.02
Episode 786, Reward: 213.0, Epsilon: 0.02
Episode 787, Reward: 500.0, Epsilon: 0.02
Episode 788, Reward: 11.0, Epsilon: 0.02
Episode 789, Reward: 12.0, Epsilon: 0.02
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Episode 792, Reward: 84.0, Epsilon: 0.02
Episode 793, Reward: 32.0, Epsilon: 0.02
Episode 794, Reward: 58.0, Epsilon: 0.02
Episode 795, Reward: 500.0, Epsilon: 0.02
Episode 796, Reward: 500.0, Epsilon: 0.02
Episode 797, Reward: 141.0, Epsilon: 0.02
Episode 798, Reward: 128.0, Epsilon: 0.02
Episode 799, Reward: 433.0, Epsilon: 0.02
Episode 800, Reward: 427.0, Epsilon: 0.02
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Episode 802, Reward: 71.0, Epsilon: 0.02
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Episode 804, Reward: 268.0, Epsilon: 0.02
Episode 805, Reward: 485.0, Epsilon: 0.02
Episode 806, Reward: 50.0, Epsilon: 0.02
Episode 807, Reward: 500.0, Epsilon: 0.02
Episode 808, Reward: 75.0, Epsilon: 0.02
Episode 809, Reward: 203.0, Epsilon: 0.02
Episode 810, Reward: 213.0, Epsilon: 0.02
Episode 811, Reward: 217.0, Epsilon: 0.02
Episode 812, Reward: 500.0, Epsilon: 0.02
Episode 813, Reward: 171.0, Epsilon: 0.02
Episode 814, Reward: 471.0, Epsilon: 0.02
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Episode 816, Reward: 479.0, Epsilon: 0.02
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Episode 819, Reward: 500.0, Epsilon: 0.02
Episode 820, Reward: 266.0, Epsilon: 0.02
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Episode 822, Reward: 497.0, Epsilon: 0.02
Episode 823, Reward: 500.0, Epsilon: 0.02
Episode 824, Reward: 109.0, Epsilon: 0.02
Episode 825, Reward: 500.0, Epsilon: 0.02
Episode 826, Reward: 500.0, Epsilon: 0.02
Episode 827, Reward: 441.0, Epsilon: 0.02
Episode 828, Reward: 500.0, Epsilon: 0.02
Episode 829, Reward: 420.0, Epsilon: 0.02
Episode 830, Reward: 350.0, Epsilon: 0.02
Episode 831, Reward: 455.0, Epsilon: 0.02
Episode 832, Reward: 391.0, Epsilon: 0.02
Episode 833, Reward: 500.0, Epsilon: 0.02
Episode 834, Reward: 500.0, Epsilon: 0.02
Episode 835, Reward: 334.0, Epsilon: 0.02
Episode 836, Reward: 395.0, Epsilon: 0.02
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Episode 844, Reward: 316.0, Epsilon: 0.01
Episode 845, Reward: 424.0, Epsilon: 0.01
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Episode 848, Reward: 361.0, Epsilon: 0.01
Episode 849, Reward: 431.0, Epsilon: 0.01
Episode 850, Reward: 382.0, Epsilon: 0.01
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Episode 854, Reward: 202.0, Epsilon: 0.01
Episode 855, Reward: 245.0, Epsilon: 0.01
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Episode 860, Reward: 195.0, Epsilon: 0.01
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Episode 863, Reward: 174.0, Epsilon: 0.01
Episode 864, Reward: 179.0, Epsilon: 0.01
Episode 865, Reward: 160.0, Epsilon: 0.01
Episode 866, Reward: 141.0, Epsilon: 0.01
Episode 867, Reward: 147.0, Epsilon: 0.01
Episode 868, Reward: 181.0, Epsilon: 0.01
Episode 869, Reward: 160.0, Epsilon: 0.01
Episode 870, Reward: 148.0, Epsilon: 0.01
Episode 871, Reward: 133.0, Epsilon: 0.01
Episode 872, Reward: 169.0, Epsilon: 0.01
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Episode 880, Reward: 155.0, Epsilon: 0.01
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Episode 883, Reward: 226.0, Epsilon: 0.01
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Episode 886, Reward: 159.0, Epsilon: 0.01
Episode 887, Reward: 136.0, Epsilon: 0.01
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Episode 893, Reward: 122.0, Epsilon: 0.01
Episode 894, Reward: 109.0, Epsilon: 0.01
Episode 895, Reward: 110.0, Epsilon: 0.01
Episode 896, Reward: 138.0, Epsilon: 0.01
Episode 897, Reward: 160.0, Epsilon: 0.01
Episode 898, Reward: 127.0, Epsilon: 0.01
Episode 899, Reward: 176.0, Epsilon: 0.01

Episode 900, Reward: 108.0, Epsilon: 0.01
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Episode 902, Reward: 110.0, Epsilon: 0.01
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Episode 917, Reward: 105.0, Epsilon: 0.01
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Episode 953, Reward: 116.0, Epsilon: 0.01
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Episode 956, Reward: 122.0, Epsilon: 0.01
Episode 957, Reward: 112.0, Epsilon: 0.01
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Episode 1006, Reward: 110.0, Epsilon: 0.01
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Episode 1009, Reward: 23.0, Epsilon: 0.01
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Episode 1014, Reward: 408.0, Epsilon: 0.01
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Episode 1016, Reward: 454.0, Epsilon: 0.01
Episode 1017, Reward: 256.0, Epsilon: 0.01
Episode 1018, Reward: 407.0, Epsilon: 0.01
Episode 1019, Reward: 444.0, Epsilon: 0.01

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Episode 1024, Reward: 500.0, Epsilon: 0.01
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Episode 1077, Reward: 500.0, Epsilon: 0.01
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Episode 1080, Reward: 223.0, Epsilon: 0.01
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Episode 1090, Reward: 500.0, Epsilon: 0.01
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Episode 1098, Reward: 274.0, Epsilon: 0.01
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Episode 1101, Reward: 222.0, Epsilon: 0.01
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Episode 1105, Reward: 243.0, Epsilon: 0.01
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Episode 1109, Reward: 500.0, Epsilon: 0.01
Episode 1110, Reward: 500.0, Epsilon: 0.01
Episode 1111, Reward: 500.0, Epsilon: 0.01
Episode 1112, Reward: 500.0, Epsilon: 0.01
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Episode 1117, Reward: 99.0, Epsilon: 0.01
Episode 1118, Reward: 500.0, Epsilon: 0.01
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Episode 1121, Reward: 500.0, Epsilon: 0.01
Episode 1122, Reward: 500.0, Epsilon: 0.01
Episode 1123, Reward: 500.0, Epsilon: 0.01
Episode 1124, Reward: 500.0, Epsilon: 0.01
Episode 1125, Reward: 500.0, Epsilon: 0.01
Episode 1126, Reward: 500.0, Epsilon: 0.01
Episode 1127, Reward: 500.0, Epsilon: 0.01
Episode 1128, Reward: 209.0, Epsilon: 0.01
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Episode 1133, Reward: 500.0, Epsilon: 0.01
Episode 1134, Reward: 500.0, Epsilon: 0.01
Episode 1135, Reward: 500.0, Epsilon: 0.01
Episode 1136, Reward: 498.0, Epsilon: 0.01
Episode 1137, Reward: 500.0, Epsilon: 0.01
Episode 1138, Reward: 500.0, Epsilon: 0.01
Episode 1139, Reward: 500.0, Epsilon: 0.01

Episode 1140, Reward: 500.0, Epsilon: 0.01
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Episode 1143, Reward: 500.0, Epsilon: 0.01
Episode 1144, Reward: 500.0, Epsilon: 0.01
Episode 1145, Reward: 500.0, Epsilon: 0.01
Episode 1146, Reward: 500.0, Epsilon: 0.01
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Episode 1149, Reward: 500.0, Epsilon: 0.01
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Episode 1163, Reward: 500.0, Epsilon: 0.01
Episode 1164, Reward: 500.0, Epsilon: 0.01
Episode 1165, Reward: 500.0, Epsilon: 0.01
Episode 1166, Reward: 500.0, Epsilon: 0.01
Episode 1167, Reward: 500.0, Epsilon: 0.01
Episode 1168, Reward: 500.0, Epsilon: 0.01
Episode 1169, Reward: 500.0, Epsilon: 0.01
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Episode 1173, Reward: 316.0, Epsilon: 0.01
Episode 1174, Reward: 500.0, Epsilon: 0.01
Episode 1175, Reward: 500.0, Epsilon: 0.01
Episode 1176, Reward: 500.0, Epsilon: 0.01
Episode 1177, Reward: 500.0, Epsilon: 0.01
Episode 1178, Reward: 500.0, Epsilon: 0.01
Episode 1179, Reward: 219.0, Epsilon: 0.01
Episode 1180, Reward: 500.0, Epsilon: 0.01
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Episode 1182, Reward: 446.0, Epsilon: 0.01
Episode 1183, Reward: 251.0, Epsilon: 0.01
Episode 1184, Reward: 500.0, Epsilon: 0.01
Episode 1185, Reward: 174.0, Epsilon: 0.01
Episode 1186, Reward: 133.0, Epsilon: 0.01
Episode 1187, Reward: 130.0, Epsilon: 0.01
Episode 1188, Reward: 141.0, Epsilon: 0.01
Episode 1189, Reward: 126.0, Epsilon: 0.01
Episode 1190, Reward: 120.0, Epsilon: 0.01
Episode 1191, Reward: 111.0, Epsilon: 0.01
Episode 1192, Reward: 111.0, Epsilon: 0.01
Episode 1193, Reward: 326.0, Epsilon: 0.01
Episode 1194, Reward: 181.0, Epsilon: 0.01
Episode 1195, Reward: 181.0, Epsilon: 0.01
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Episode 1197, Reward: 152.0, Epsilon: 0.01
Episode 1198, Reward: 183.0, Epsilon: 0.01
Episode 1199, Reward: 234.0, Epsilon: 0.01

Episode 1200, Reward: 157.0, Epsilon: 0.01
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Episode 1204, Reward: 291.0, Epsilon: 0.01
Episode 1205, Reward: 255.0, Epsilon: 0.01
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Episode 1213, Reward: 252.0, Epsilon: 0.01
Episode 1214, Reward: 225.0, Epsilon: 0.01
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Episode 1240, Reward: 109.0, Epsilon: 0.01
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Episode 1242, Reward: 113.0, Epsilon: 0.01
Episode 1243, Reward: 107.0, Epsilon: 0.01
Episode 1244, Reward: 103.0, Epsilon: 0.01
Episode 1245, Reward: 111.0, Epsilon: 0.01
Episode 1246, Reward: 107.0, Epsilon: 0.01
Episode 1247, Reward: 114.0, Epsilon: 0.01
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Episode 1249, Reward: 117.0, Epsilon: 0.01
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Episode 1252, Reward: 329.0, Epsilon: 0.01
Episode 1253, Reward: 132.0, Epsilon: 0.01
Episode 1254, Reward: 441.0, Epsilon: 0.01
Episode 1255, Reward: 134.0, Epsilon: 0.01
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Episode 1258, Reward: 333.0, Epsilon: 0.01
Episode 1259, Reward: 351.0, Epsilon: 0.01

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Episode 1300, Reward: 500.0, Epsilon: 0.01
Episode 1301, Reward: 500.0, Epsilon: 0.01
Episode 1302, Reward: 102.0, Epsilon: 0.01
Episode 1303, Reward: 124.0, Epsilon: 0.01
Episode 1304, Reward: 141.0, Epsilon: 0.01
Episode 1305, Reward: 500.0, Epsilon: 0.01
Episode 1306, Reward: 95.0, Epsilon: 0.01
Episode 1307, Reward: 118.0, Epsilon: 0.01
Episode 1308, Reward: 109.0, Epsilon: 0.01
Episode 1309, Reward: 97.0, Epsilon: 0.01
Episode 1310, Reward: 121.0, Epsilon: 0.01
Episode 1311, Reward: 106.0, Epsilon: 0.01
Episode 1312, Reward: 96.0, Epsilon: 0.01
Episode 1313, Reward: 96.0, Epsilon: 0.01
Episode 1314, Reward: 92.0, Epsilon: 0.01
Episode 1315, Reward: 97.0, Epsilon: 0.01
Episode 1316, Reward: 18.0, Epsilon: 0.01
Episode 1317, Reward: 107.0, Epsilon: 0.01
Episode 1318, Reward: 26.0, Epsilon: 0.01
Episode 1319, Reward: 106.0, Epsilon: 0.01

Episode 1320, Reward: 100.0, Epsilon: 0.01
Episode 1321, Reward: 117.0, Epsilon: 0.01
Episode 1322, Reward: 160.0, Epsilon: 0.01
Episode 1323, Reward: 500.0, Epsilon: 0.01
Episode 1324, Reward: 500.0, Epsilon: 0.01
Episode 1325, Reward: 175.0, Epsilon: 0.01
Episode 1326, Reward: 349.0, Epsilon: 0.01
Episode 1327, Reward: 215.0, Epsilon: 0.01
Episode 1328, Reward: 403.0, Epsilon: 0.01
Episode 1329, Reward: 122.0, Epsilon: 0.01
Episode 1330, Reward: 143.0, Epsilon: 0.01
Episode 1331, Reward: 114.0, Epsilon: 0.01
Episode 1332, Reward: 110.0, Epsilon: 0.01
Episode 1333, Reward: 115.0, Epsilon: 0.01
Episode 1334, Reward: 13.0, Epsilon: 0.01
Episode 1335, Reward: 110.0, Epsilon: 0.01
Episode 1336, Reward: 113.0, Epsilon: 0.01
Episode 1337, Reward: 105.0, Epsilon: 0.01
Episode 1338, Reward: 108.0, Epsilon: 0.01
Episode 1339, Reward: 115.0, Epsilon: 0.01
Episode 1340, Reward: 107.0, Epsilon: 0.01
Episode 1341, Reward: 117.0, Epsilon: 0.01
Episode 1342, Reward: 112.0, Epsilon: 0.01
Episode 1343, Reward: 103.0, Epsilon: 0.01
Episode 1344, Reward: 106.0, Epsilon: 0.01
Episode 1345, Reward: 110.0, Epsilon: 0.01
Episode 1346, Reward: 109.0, Epsilon: 0.01
Episode 1347, Reward: 103.0, Epsilon: 0.01
Episode 1348, Reward: 101.0, Epsilon: 0.01
Episode 1349, Reward: 44.0, Epsilon: 0.01
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Episode 1351, Reward: 97.0, Epsilon: 0.01
Episode 1352, Reward: 113.0, Epsilon: 0.01
Episode 1353, Reward: 110.0, Epsilon: 0.01
Episode 1354, Reward: 114.0, Epsilon: 0.01
Episode 1355, Reward: 116.0, Epsilon: 0.01
Episode 1356, Reward: 130.0, Epsilon: 0.01
Episode 1357, Reward: 110.0, Epsilon: 0.01
Episode 1358, Reward: 142.0, Epsilon: 0.01
Episode 1359, Reward: 110.0, Epsilon: 0.01
Episode 1360, Reward: 121.0, Epsilon: 0.01
Episode 1361, Reward: 301.0, Epsilon: 0.01
Episode 1362, Reward: 150.0, Epsilon: 0.01
Episode 1363, Reward: 147.0, Epsilon: 0.01
Episode 1364, Reward: 223.0, Epsilon: 0.01
Episode 1365, Reward: 126.0, Epsilon: 0.01
Episode 1366, Reward: 162.0, Epsilon: 0.01
Episode 1367, Reward: 299.0, Epsilon: 0.01
Episode 1368, Reward: 500.0, Epsilon: 0.01
Episode 1369, Reward: 334.0, Epsilon: 0.01
Episode 1370, Reward: 450.0, Epsilon: 0.01
Episode 1371, Reward: 152.0, Epsilon: 0.01
Episode 1372, Reward: 69.0, Epsilon: 0.01
Episode 1373, Reward: 331.0, Epsilon: 0.01
Episode 1374, Reward: 139.0, Epsilon: 0.01
Episode 1375, Reward: 168.0, Epsilon: 0.01
Episode 1376, Reward: 130.0, Epsilon: 0.01
Episode 1377, Reward: 140.0, Epsilon: 0.01
Episode 1378, Reward: 140.0, Epsilon: 0.01
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Episode 1382, Reward: 157.0, Epsilon: 0.01
Episode 1383, Reward: 66.0, Epsilon: 0.01
Episode 1384, Reward: 68.0, Epsilon: 0.01
Episode 1385, Reward: 307.0, Epsilon: 0.01
Episode 1386, Reward: 69.0, Epsilon: 0.01
Episode 1387, Reward: 62.0, Epsilon: 0.01
Episode 1388, Reward: 373.0, Epsilon: 0.01
Episode 1389, Reward: 78.0, Epsilon: 0.01
Episode 1390, Reward: 68.0, Epsilon: 0.01
Episode 1391, Reward: 151.0, Epsilon: 0.01
Episode 1392, Reward: 174.0, Epsilon: 0.01
Episode 1393, Reward: 309.0, Epsilon: 0.01
Episode 1394, Reward: 188.0, Epsilon: 0.01
Episode 1395, Reward: 330.0, Epsilon: 0.01
Episode 1396, Reward: 190.0, Epsilon: 0.01
Episode 1397, Reward: 500.0, Epsilon: 0.01
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Episode 1404, Reward: 201.0, Epsilon: 0.01
Episode 1405, Reward: 218.0, Epsilon: 0.01
Episode 1406, Reward: 239.0, Epsilon: 0.01
Episode 1407, Reward: 231.0, Epsilon: 0.01
Episode 1408, Reward: 239.0, Epsilon: 0.01
Episode 1409, Reward: 210.0, Epsilon: 0.01
Episode 1410, Reward: 238.0, Epsilon: 0.01
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Episode 1412, Reward: 329.0, Epsilon: 0.01
Episode 1413, Reward: 258.0, Epsilon: 0.01
Episode 1414, Reward: 269.0, Epsilon: 0.01
Episode 1415, Reward: 276.0, Epsilon: 0.01
Episode 1416, Reward: 322.0, Epsilon: 0.01
Episode 1417, Reward: 261.0, Epsilon: 0.01
Episode 1418, Reward: 228.0, Epsilon: 0.01
Episode 1419, Reward: 364.0, Epsilon: 0.01
Episode 1420, Reward: 270.0, Epsilon: 0.01
Episode 1421, Reward: 500.0, Epsilon: 0.01
Episode 1422, Reward: 500.0, Epsilon: 0.01
Episode 1423, Reward: 195.0, Epsilon: 0.01
Episode 1424, Reward: 500.0, Epsilon: 0.01
Episode 1425, Reward: 352.0, Epsilon: 0.01
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Episode 1458, Reward: 500.0, Epsilon: 0.01
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Episode 1464, Reward: 500.0, Epsilon: 0.01
Episode 1465, Reward: 300.0, Epsilon: 0.01
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Episode 1537, Reward: 500.0, Epsilon: 0.01
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Episode 1540, Reward: 31.0, Epsilon: 0.01
Episode 1541, Reward: 110.0, Epsilon: 0.01
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Episode 1546, Reward: 500.0, Epsilon: 0.01
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Episode 1551, Reward: 500.0, Epsilon: 0.01
Episode 1552, Reward: 305.0, Epsilon: 0.01
Episode 1553, Reward: 274.0, Epsilon: 0.01
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Episode 1558, Reward: 248.0, Epsilon: 0.01
Episode 1559, Reward: 244.0, Epsilon: 0.01

Episode 1560, Reward: 69.0, Epsilon: 0.01
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Episode 1563, Reward: 500.0, Epsilon: 0.01
Episode 1564, Reward: 500.0, Epsilon: 0.01
Episode 1565, Reward: 500.0, Epsilon: 0.01
Episode 1566, Reward: 500.0, Epsilon: 0.01
Episode 1567, Reward: 500.0, Epsilon: 0.01
Episode 1568, Reward: 500.0, Epsilon: 0.01
Episode 1569, Reward: 432.0, Epsilon: 0.01
Episode 1570, Reward: 219.0, Epsilon: 0.01
Episode 1571, Reward: 500.0, Epsilon: 0.01
Episode 1572, Reward: 500.0, Epsilon: 0.01
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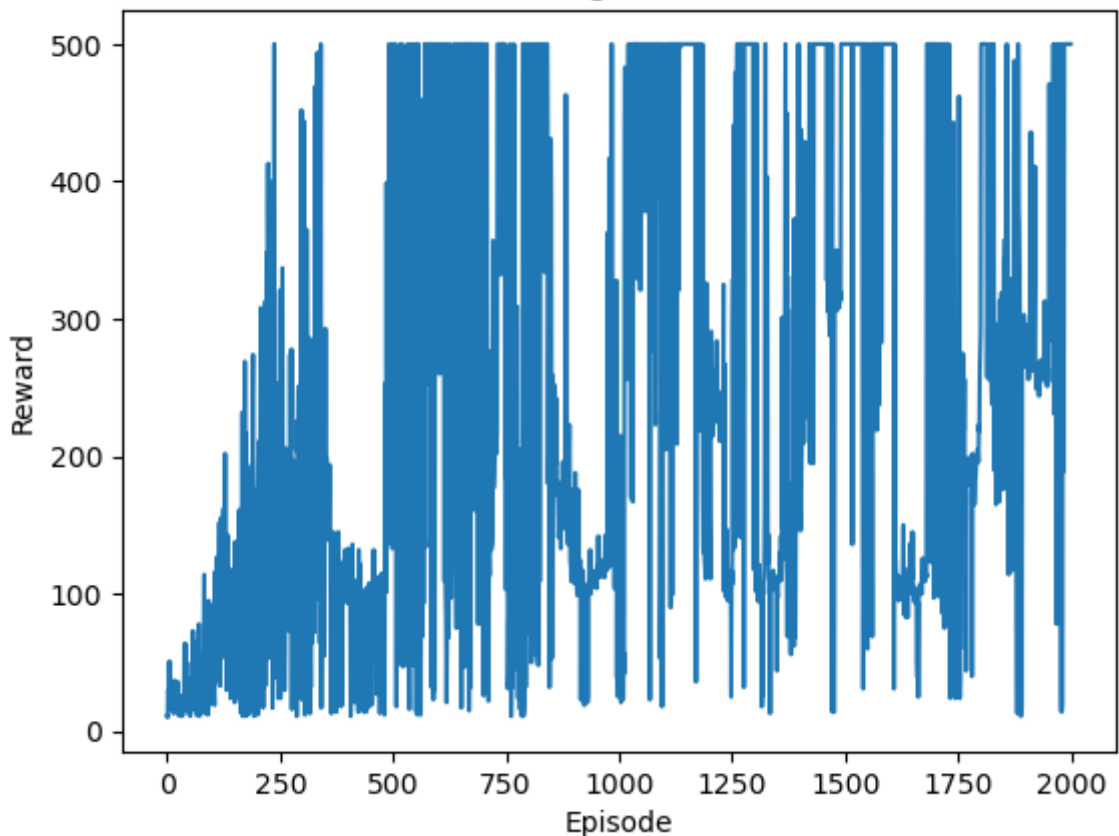
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Episode 1982, Reward: 500.0, Epsilon: 0.01
Episode 1983, Reward: 500.0, Epsilon: 0.01
Episode 1984, Reward: 189.0, Epsilon: 0.01
Episode 1985, Reward: 500.0, Epsilon: 0.01
Episode 1986, Reward: 500.0, Epsilon: 0.01
Episode 1987, Reward: 500.0, Epsilon: 0.01
Episode 1988, Reward: 500.0, Epsilon: 0.01
Episode 1989, Reward: 500.0, Epsilon: 0.01
Episode 1990, Reward: 500.0, Epsilon: 0.01
Episode 1991, Reward: 500.0, Epsilon: 0.01
Episode 1992, Reward: 500.0, Epsilon: 0.01
Episode 1993, Reward: 500.0, Epsilon: 0.01
Episode 1994, Reward: 500.0, Epsilon: 0.01
Episode 1995, Reward: 500.0, Epsilon: 0.01
Episode 1996, Reward: 500.0, Epsilon: 0.01
Episode 1997, Reward: 500.0, Epsilon: 0.01
Episode 1998, Reward: 500.0, Epsilon: 0.01
Episode 1999, Reward: 500.0, Epsilon: 0.01
```

Training Rewards



```
In [ ]: import cv2

def create_video(env, model, num_episodes=5, video_path="output.mp4"):
    """
    Visualize the agent's performance in the environment, overlay episode
    and save it as a single MP4 video.

    Parameters:
        env: Gym environment with render_mode="rgb_array".
        model: Trained DQN model.
        num_episodes: Number of episodes to record.
        video_path: Path to save the combined video.
```

```

"""
# Extract frame dimensions from the environment's render
state, _ = env.reset()
frame = env.render()
frame_height, frame_width, _ = frame.shape

# Set up video writer
fourcc = cv2.VideoWriter_fourcc(*"mp4v") # Codec for MP4
video_writer = cv2.VideoWriter(video_path, fourcc, 30, (frame_width,

# Text overlay settings
font = cv2.FONT_HERSHEY_SIMPLEX
font_scale = 1
font_color = (0, 0, 255) # White
font_thickness = 2

for episode in range(1, num_episodes + 1):
    state, _ = env.reset()
    episode_reward = 0

    while True:
        # Use the trained model to select an action
        state_tensor = torch.FloatTensor(state).unsqueeze(0)
        with torch.no_grad():
            action = model(state_tensor).argmax().item()

        # Take a step in the environment
        next_state, reward, terminated, truncated, _ = env.step(action)
        episode_reward += reward
        state = next_state

        # Render the current frame
        frame = env.render()

        # Overlay the episode number on the frame
        text = f"Episode: {episode}, Reward: {int(episode_reward)}"
        cv2.putText(
            frame,
            text,
            (10, 30), # Position (x, y)
            font,
            font_scale,
            font_color,
            font_thickness,
            lineType=cv2.LINE_AA,
        )

        # Write the frame to the video
        video_writer.write(cv2.cvtColor(frame, cv2.COLOR_RGB2BGR))

        if terminated or truncated:
            print(f"Episode {episode}: Reward = {episode_reward}")
            break

# Release resources
video_writer.release()
env.close()
print(f"Video saved to {video_path}")

# Create the environment with render_mode="rgb_array"

```

```
env = gym.make("CartPole-v1", render_mode="rgb_array")
create_video(env, trained_dqn, num_episodes=5, video_path="combined_episodes.mp4")
```

Episode 1: Reward = 500.0
Episode 2: Reward = 500.0
Episode 3: Reward = 500.0
Episode 4: Reward = 500.0
Episode 5: Reward = 500.0
Video saved to combined_episodes.mp4

Results

Observations:

- The graph of rewards improves over episodes.
 - The agent starts balancing the pole for increasing durations.
-

Exercises

1. Experiment with different network architectures.
 2. Change hyperparameters like learning rate or replay buffer size.
 3. Test the trained model in the environment using a greedy policy.
-

This tutorial introduced RL with a simple DQN implementation in PyTorch, laying the foundation for more complex algorithms like Double DQN or Policy Gradient methods.