In [2]:
```
import gymnasium as gym
from scipy.signal import savgol_filter
import matplotlib.pyplot as plt
import numpy as np
import time
import pickle
```

Setup

In [ ]:
```
# Training hyperparameters
learning_rate = 0.1  # alpha
discount_factor = 0.95  # gamma
episodes = 25000  # Number of training episodes
show_every = 1000  # How often to print progress
render = False
epsilon = 1.0  # Initial exploration rate
min_epsilon = 0.01  # Minimum exploration rate
epsilon_decay_rate = 0.9995  # epsilon decay rate

# State discretization (number of buckets for each observation dimension)
# (Cart Position, Cart Velocity, Pole Angle, Pole Velocity)
num_buckets = (10, 10, 12, 12)

# State bounds (limits)
# (Cart Position, Cart Velocity, Pole Angle, Pole Velocity)
state_bounds = [
    (-4.8, 4.8),
    (-4., 4.),
    (-0.418, 0.418),  # 24 deg
    (-4., 4.),
]
# ^these are for binning; these are not actual limits on the environment
```

In [4]:
```
# Environment initialization
env = gym.make("CartPole-v1", render_mode="human" if render else None)
print(f"Action Space: {env.action_space}")  # 0: push left, 1: push right
print(f"Observation Space: {env.observation_space}")
```

```
Action Space: Discrete(2)
Observation Space: Box([-4.8000002e+00 -3.4028235e+38 -4.1887903e-01 -3.4028235e+38], [4.8000002e+00 3.4028
235e+38 4.1887903e-01 3.4028235e+38], (4,), float32)
```

In [5]:
```
# Q-Table initialization
q_table_shape = num_buckets + (env.action_space.n,)
q_table = np.zeros(q_table_shape)
print(f"Q Table shape: {q_table.shape}")
```

```
Q Table shape: (10, 10, 12, 12, 2)
```

In [6]:
```
def discretize_state(observation, state_bounds, num_buckets):
    """Convert a continuous observation into a discrete state using bucketing."""
    discrete_state = []
    for i, (obs_val, (low, high), num_b) in enumerate(zip(observation, state_bounds, num_buckets)):
        bucket_size = (high - low) / num_b
        bucket_index = int((obs_val - low) / bucket_size)
        if bucket_index not in range(num_buckets[i]):
            bucket_index = max(0, min(bucket_index, num_buckets[i] - 1))  # Clamp to valid range
        discrete_state.append(bucket_index)
    return tuple(discrete_state)
```

Training Loop

In [ ]:
```
total_rewards = []
highest_reward = 0

for episode in range(episodes):
    # Initialize
    observation, info = env.reset()
    current_discrete_state = discretize_state(observation, state_bounds, num_buckets)
    total_reward = 0
    terminated = False
```

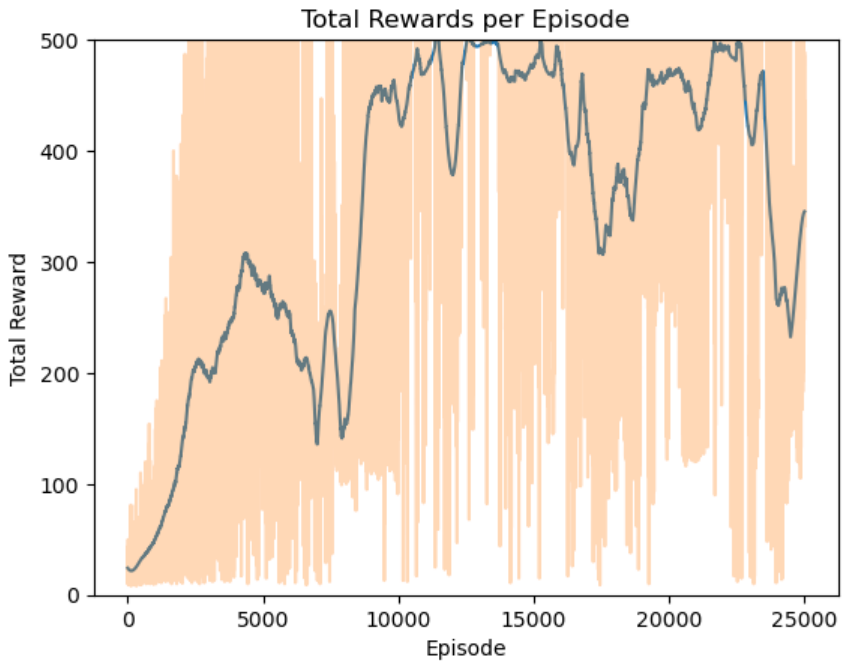
```
    truncated = False

    # Decide whether to render this episode
    render_this_episode = episode % show_every == 0

    while not terminated and not truncated:
        # Render
        if render_this_episode and render:
            try:
                env.render()
                time.sleep(0.01)  # 100 FPS maximum
            except Exception as e:
                print(f"Could not render: {e}")
                pass

        # Epsilon-greedy action selection
        if np.random.random() > epsilon:
            action = np.argmax(q_table[current_discrete_state])  # Exploit
        else:
            action = env.action_space.sample()  # Explore

        # Take action and time step
        next_observation, reward, terminated, truncated, info = env.step(action)
        next_discrete_state = discretize_state(next_observation, state_bounds, num_buckets)

        # Update Q table
        if not terminated:
            # Estimate maximum Q-value @ t+1
            max_future_q = np.max(q_table[next_discrete_state])

            # Current Q-value
            current_q = q_table[current_discrete_state + (action,)]

            # New Q from Bellman equation
            new_q = current_q + learning_rate * (
                reward + discount_factor * max_future_q - current_q
            )

            # Update
            q_table[current_discrete_state + (action,)] = new_q

        elif terminated:
            q_table[current_discrete_state + (action,)] = 0

        # State transition
        current_discrete_state = next_discrete_state
        total_reward += reward

    # Decay epsilon after episode
    epsilon = max(min_epsilon, epsilon * epsilon_decay_rate)

    # Track rewards and print progress
    total_rewards.append(total_reward)
    if total_reward > highest_reward:
        highest_reward = total_reward

    if episode % show_every == 0:
        avg_reward = sum(total_rewards[-show_every:]) / len(
            total_rewards[-show_every:]
        )
        print(
            f"Episode: {episode:5} | Avg Reward (last {show_every}): {avg_reward:6.2f} | Epsilon: {epsilon
        )
```

In [ ]:
```
# Save trained model
data = {
    "q_table": q_table,
    "total_rewards": total_rewards
    }
with open("data_QL.pkl", "wb") as f:
    pickle.dump(data, f)
```

Postprocessing

In [7]:
```
# Load trained model
with open("data_QL.pkl", "rb") as f:
    data = pickle.load(f)
    q_table = data["q_table"]
    total_rewards = data["total_rewards"]
```

In [10]:
```
# Plot
plt.plot(savgol_filter(total_rewards, 1001, 3), label="filtered")
plt.plot(total_rewards, alpha=0.3, label="raw")
plt.title("Total Rewards per Episode")
plt.xlabel("Episode")
plt.ylabel("Total Reward")
plt.ylim([0, 500])
plt.show()
```



In [9]:
```
# Render a single episode using the trained Q-table
env = gym.make("CartPole-v1", render_mode="human")
observation, info = env.reset()
discrete_state = discretize_state(observation, state_bounds, num_buckets)
terminated = False
truncated = False

while not terminated and not truncated:
    action = np.argmax(q_table[discrete_state])
    next_observation, reward, terminated, truncated, info = env.step(action)
    discrete_state = discretize_state(next_observation, state_bounds, num_buckets)
    time.sleep(0.02)  # 50 FPS max

env.close()
```

```
<frozen importlib._bootstrap>:488: RuntimeWarning: Your system is avx2 capable but pygame was not built wit
h support for it. The performance of some of your blits could be adversely affected. Consider enabling comp
ile time detection with environment variables like PYGAME_DETECT_AVX2=1 if you are compiling without cross
compilation.
```