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# Simple Monte Carlo Tree Search (MCTS) for Classic Control
Environments
# May 2025

import gymnasium as gym
import numpy as np
import random
import matplotlib.pyplot as plt
import time

# Use an environment that comes pre-installed with Gymnasium
# Classic control environments work well without additional
installations

class MCTSNode:
    """Node in the Monte Carlo Tree Search"""
    def __init__(self, state, done=False):
        self.state = state
        self.visits = 0
        self.value = 0.0
        self.children = {}  # action -> MCTSNode
        self.done = done

    def is_fully_expanded(self, action_space):
        """Check if all possible actions from this state have been
tried"""
        if hasattr(action_space, 'n'):  # Discrete action space
            return len(self.children) == action_space.n
        else:  # Continuous action space - we'll use a simplified
approach
            return len(self.children) >= 5  # Sample 5 different
actions

    def best_child(self, exploration_weight=1.0):
        """Select the best child node using UCB1 formula"""
        if not self.children:
            return None

        # UCB1 formula: value/visits + exploration_weight *
sqrt(log(parent_visits) / child_visits)
        def ucb1(child):
            exploitation = child.value / child.visits if child.visits
> 0 else 0
            exploration = exploration_weight *
np.sqrt(np.log(self.visits) / child.visits) if child.visits > 0 else
float('inf')
            return exploitation + exploration

        return max(self.children.items(), key=lambda x: ucb1(x[1]))
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    def select_unexplored_action(self, action_space):
        """Select an action that hasn't been tried yet"""
        if hasattr(action_space, 'n'):  # Discrete action space
            for action in range(action_space.n):
                if action not in self.children:
                    return action
        else:  # Continuous action space
            # Sample a random action not too close to existing ones
            while True:
                action = action_space.sample()
                # Convert to tuple for hashability if it's a numpy
array
                if isinstance(action, np.ndarray):
                    action = tuple(action)
                # Check if this action is sufficiently different from
existing ones
                if action not in self.children:
                    return action

        return None  # Should not happen if is_fully_expanded is
checked before

class SimpleMCTS:
    """Simplified Monte Carlo Tree Search implementation"""
    def __init__(self, env, simulation_steps=10,
exploration_weight=1.0):
        self.env = env
        self.simulation_steps = simulation_steps
        self.exploration_weight = exploration_weight

    def search(self, state, n_simulations=10):
        """Perform a simplified MCTS search"""
        # For environments where we can't easily clone the state,
        # we'll evaluate each action separately

        if hasattr(self.env.action_space, 'n'):  # Discrete action
space
            action_space = range(self.env.action_space.n)
        else:  # Continuous action space
            # Sample some discrete actions for evaluation
            action_space = [self.env.action_space.sample() for _ in
range(5)]

        best_action = None
        best_value = float('-inf')

        # Try each action multiple times
        for action in action_space:
            total_reward = 0
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            # Run multiple simulations for this action
            for _ in range(n_simulations):
                # Create a copy of the environment for simulation
                sim_env = gym.make(self.env.unwrapped.spec.id)
                sim_env.reset()

                # Try to match the state (simplified approach)
                if hasattr(state, 'shape') and len(state.shape) == 1:
                    # For environments with vector states, we can
reset and step a few times
                    # This is a crude approximation
                    sim_state, _ = sim_env.reset()

                # Take the action
                sim_state, reward, terminated, truncated, _ =
sim_env.step(action)
                done = terminated or truncated
                sim_reward = reward

                # Random rollout
                for _ in range(self.simulation_steps):
                    if done:
                        break

                    # Take random actions
                    random_action = sim_env.action_space.sample()
                    sim_state, reward, terminated, truncated, _ =
sim_env.step(random_action)
                    done = terminated or truncated
                    sim_reward += reward

                # Close the simulation environment
                sim_env.close()

                # Accumulate reward
                total_reward += sim_reward

            # Average reward for this action
            avg_reward = total_reward / n_simulations

            # Update best action
            if avg_reward > best_value:
                best_value = avg_reward
                best_action = action

        return best_action

def discretize_state(state, bins=(10, 10, 10, 10)):
    """Discretize a continuous state for easier handling"""
    if isinstance(state, np.ndarray) and state.shape == (4,):  #
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CartPole-like
        # Define state bounds (position, velocity, angle, angular
velocity)
        state_bounds = [
            [-2.4, 2.4],  # Cart position
            [-3.0, 3.0],  # Cart velocity
            [-0.3, 0.3],  # Pole angle
            [-3.0, 3.0]   # Pole angular velocity
        ]

        # Discretize each dimension
        discrete_state = []
        for i, (s, bounds, b) in enumerate(zip(state, state_bounds,
bins)):
            s = max(bounds[0], min(s, bounds[1]))  # Clip to bounds
            idx = int((s - bounds[0]) / (bounds[1] - bounds[0]) * b)
            idx = max(0, min(idx, b-1))  # Ensure within bounds
            discrete_state.append(idx)

        return tuple(discrete_state)

    return state  # Return as is if we can't handle it

def run_mcts_agent(env_name='CartPole-v1', n_episodes=3, render=True):
    """Run MCTS agent on a gym environment"""
    # Create environment
    env = gym.make(env_name, render_mode='human' if render else None)

    rewards = []

    for episode in range(n_episodes):
        state, _ = env.reset()
        state_d = discretize_state(state)  # Discretize for MCTS
        episode_reward = 0
        done = False
        step = 0

        # Create agent
        agent = SimpleMCTS(env, simulation_steps=10,
exploration_weight=1.0)

        while not done and step < 500:  # Limit steps to avoid too
long episodes
            # Get action from MCTS
            action = agent.search(state_d, n_simulations=5)

            # Take action
            state, reward, terminated, truncated, _ = env.step(action)
            state_d = discretize_state(state)  # Discretize for MCTS
            done = terminated or truncated
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            episode_reward += reward

            step += 1

            # Print progress
            if step % 10 == 0:
                print(f"Episode {episode+1}, Step {step}, Reward
{episode_reward}")

        rewards.append(episode_reward)
        print(f"Episode {episode+1} finished with reward
{episode_reward}")

    env.close()
    return rewards

# Simple random agent for comparison
def run_random_agent(env_name='CartPole-v1', n_episodes=3,
render=True):
    """Run a random agent for comparison"""
    env = gym.make(env_name, render_mode='human' if render else None)
    rewards = []

    for episode in range(n_episodes):
        state, _ = env.reset()
        episode_reward = 0
        done = False
        step = 0

        while not done and step < 500:
            action = env.action_space.sample()
            state, reward, terminated, truncated, _ = env.step(action)
            done = terminated or truncated
            episode_reward += reward
            step += 1

            if step % 50 == 0:
                print(f"Random agent - Episode {episode+1}, Step
{step}, Reward {episode_reward}")

        rewards.append(episode_reward)
        print(f"Random agent - Episode {episode+1} finished with
reward {episode_reward}")

    env.close()
    return rewards

if __name__ == "__main__":
    # List available environments
    from gymnasium.envs.registration import registry
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    classic_envs = [env_id for env_id in registry.keys() if 'CartPole'
in env_id or 'Pendulum' in env_id or 'MountainCar' in env_id]
    print(f"Available classic environments: {classic_envs}")

    # Run MCTS on CartPole
    print("\nRunning MCTS on CartPole...")
    mcts_rewards = run_mcts_agent(env_name='CartPole-v1',
n_episodes=2, render=True)

    # Run random agent for comparison
    print("\nRunning random agent on CartPole...")
    random_rewards = run_random_agent(env_name='CartPole-v1',
n_episodes=1, render=True)

    # Plot results
    plt.figure(figsize=(10, 5))
    plt.plot(mcts_rewards, 'b-', label='MCTS Agent')
    plt.plot(range(len(mcts_rewards), len(mcts_rewards) +
len(random_rewards)), random_rewards, 'r--', label='Random Agent')
    plt.title('Agent Performance on CartPole')
    plt.xlabel('Episode')
    plt.ylabel('Total Reward')
    plt.legend()
    plt.grid(True)
    plt.show()

    print("\nAverage MCTS reward:", np.mean(mcts_rewards))
    print("Average random reward:", np.mean(random_rewards))
```

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Available classic environments: ['CartPole-v0', 'CartPole-v1',
'MountainCar-v0', 'MountainCarContinuous-v0', 'Pendulum-v1',
'phys2d/CartPole-v0', 'phys2d/CartPole-v1', 'phys2d/Pendulum-v0',
'InvertedPendulum-v2', 'InvertedPendulum-v4', 'InvertedPendulum-v5',
'InvertedDoublePendulum-v2', 'InvertedDoublePendulum-v4',
'InvertedDoublePendulum-v5']

Running MCTS on CartPole...
Episode 1 finished with reward 9.0
Episode 2, Step 10, Reward 10.0
Episode 2 finished with reward 18.0

Running random agent on CartPole...
Random agent - Episode 1 finished with reward 26.0
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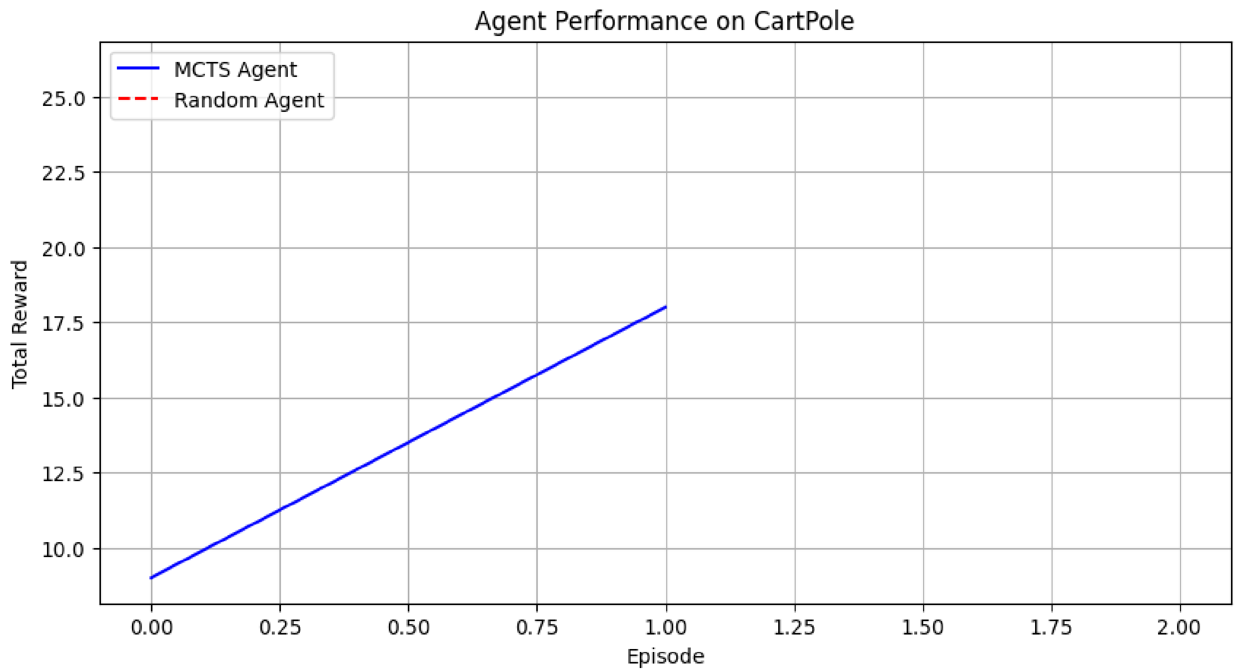


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Average MCTS reward: 13.5
Average random reward: 26.0
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