1. **实验内容**

**题目：11-State ChainWalk MDP**

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AI 生成的内容可能不正确。](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAegAAADRCAYAAAAHUiHdAAAACXBIWXMAABJ0AAASdAHeZh94AAAgAElEQVR4AQCxgU5+AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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要求：计算并画出利用bellman最优算子以及优势学习算子情况下迭代策略的性能界以及动作间隔（action gap）的变化？

1. **实验环境定义与提示**

环境特点：

1. 智能体在每个状态下执行“向左”或“向右”动作，按照动作指令转移一个状态的概率为0.7，按动作指令相反方向转移一个状态的概率为0.3；左（右）端点状态向左（右）转移状态时保持端点位置不变；
2. 奖励跟所处状态有关，中间状态s5奖励为0，右半部分状态s6-s10奖励均为1；左半部分状态，除左端点s0状态的奖励为3，其余状态s1-s4奖励为-1；

提示：

1. 算子形式

最优算子：

优势学习算子：



取值和

1. 初始Q值随机生成，如 10 \* np.random.random();
2. 策略的V值函数，而是根据第k次迭代Q值诱导的贪婪策略；

真实最优策略为“在任何状态下都执行‘向左’的动作”，那么Action gap定义为

1. **分步解析与代码解析**
2. 定义状态，定义奖励函数，定义转移函数
3. 实现最优算子：，也就是当前的状态价值为当前的实时奖励,加上后续的所有可能转移到状态的最大状态价值的期望。注意到这个，对于每一个的更新，是对返回的一个期望（）两个方向的加权和

*# Bellman最优算子*

def bellman\_optimal\_operator(Q):

    """

    Bellman 最优算子: 给定当前 Q，返回对所有 Q(s,a) 的更新结果。

    """

    new\_Q = np.zeros((n\_states, n\_actions))

    for s in range(n\_states):

        for a in [0, 1]:

            total = 0.0

            for (s\_next, prob) in transition(s, a):

                r = reward(s\_next)

                total += prob \* (r + gamma \* np.max(Q[s\_next]))

            new\_Q[s, a] = total

    return new\_Q

1. 实现优势学习算子：，值得注意的是，就是在最优算子的基础上，增加了一个，那么这个项如何理解？当前的与这个当前的最优情况的一个差值，也就是一个优势项，当前动作是最优动作，那么就产生影响，否则，将会产生一个负数，降低次优动作的值。

*# 优势学习算子*

def advantage\_learning\_operator(Q):

    """

    优势学习更新: 给定当前 Q，返回对所有 Q(s,a) 的更新结果。

    按照公式: T\_AL Q(s,a) = r(s,a) + α(Q(s,a) - max\_a Q(s,a)) + γE[max\_a' Q(s',a')]

    """

    new\_Q = np.zeros((n\_states, n\_actions))

    for s in range(n\_states):

        for a in [0,1]:

*# 计算 r(s,a) 项*

            r\_sa = 0.0

            for (s\_next, prob) in transition(s, a):

                r\_sa += prob \* reward(s\_next)

*# 计算 γE[max\_a' Q(s',a')] 项*

            expected\_future = 0.0

            for (s\_next, prob) in transition(s, a):

                expected\_future += prob \* np.max(Q[s\_next])

            expected\_future \*= gamma

*# 计算 α(Q(s,a) - max\_a Q(s,a)) 项*

            advantage\_term = alpha \* (Q[s, a] - np.max(Q[s]))

*# 组合所有项*

            new\_Q[s, a] = r\_sa + advantage\_term + expected\_future

    return new\_Q

1. 预处理最优策略下的,由于已经知道最优策略是一直向左，也就是。

def compute\_optimal\_V(gamma=0.99, tol=1e-12):

    """

    对"永远向左"这一固定策略做策略评估，返回其状态价值 V^\*(s)。

    在题目中已给出该策略就是最优策略。

    """

    V = np.zeros(n\_states)

    while True:

        V\_old = V.copy()

        for s in range(n\_states):

*# 执行"向左"动作后，根据transition(s,0)计算下一步期望*

            val = 0.0

            for (s\_next, prob) in transition(s, 0):

                r = reward(s\_next)

                val += prob \* (r + gamma \* V\_old[s\_next])

            V[s] = val

*# 判断收敛*

        if np.max(np.abs(V - V\_old)) < tol:

            break

    return V

1. 策略评估，使用的是等式，，专门用于评估固定策略的状态-动作价值，就是的动作策略，我们需要使用等式对于这个固定的策略求解出收敛的策略的价值，而不是作为对应的策略的价值，这个是不对的。

def evaluate\_policy(policy, gamma=0.99, tol=1e-8, max\_iter=1000):

    V = np.zeros(n\_states)

    for \_ in range(max\_iter):

        V\_old = V.copy()

        for s in range(n\_states):

            a = policy[s]

            val = 0.0

            for (s\_next, prob) in transition(s, a):

                r = reward(s\_next)

                val += prob \* (r + gamma \* V\_old[s\_next])

            V[s] = val

        if np.max(np.abs(V - V\_old)) < tol:

            break

    return V

1. **完整代码**

import numpy as np

import matplotlib.pyplot as plt

import copy

*# 环境参数*

n\_states = 11  *# 一共有11个状态*

n\_actions = 2  *# 0: 左, 1: 右*

gamma = 0.99  *# 折扣因子*

alpha = 0.99  *# 优势学习算子中的学习率*

*# 设置随机种子，确保结果可重复*

np.random.seed(0)

*# 奖励函数*

def reward(state):

    """到达状态 state 时获得的奖励。"""

    if state == 0:

        return 3.0

    elif 1 <= state <= 4:

        return -1.0

    elif state == 5:

        return 0.0

    elif 6 <= state <= 10:

        return 1.0

    else:

        raise ValueError("Invalid state")

*# 转移函数*

def transition(state, action):

*# action: 0=left, 1=right*

*# 如果向左走*

    if action == 0:  *# left*

*# intended: 期望状态,opposite: 相反状态*

        intended = state - 1

        opposite = state + 1

*# 如果向右走*

    else:  *# right*

        intended = state + 1

        opposite = state - 1

*# 处理边界情况*

    intended = max(0, min(n\_states-1, intended))

    opposite = max(0, min(n\_states-1, opposite))

*# return [(0.7, intended), (0.3, opposite)]*

    return [(intended, 0.7), (opposite, 0.3)]

*# 计算真实最优价值函数 V^\**

def compute\_optimal\_V(gamma=0.99, tol=1e-12):

    """

    对"永远向左"这一固定策略做策略评估，返回其状态价值 V^\*(s)。

    在题目中已给出该策略就是最优策略。

    """

    V = np.zeros(n\_states)

    while True:

        V\_old = V.copy()

        for s in range(n\_states):

*# 执行"向左"动作后，根据transition(s,0)计算下一步期望*

            val = 0.0

            for (s\_next, prob) in transition(s, 0):

                r = reward(s\_next)

                val += prob \* (r + gamma \* V\_old[s\_next])

            V[s] = val

*# 判断收敛*

        if np.max(np.abs(V - V\_old)) < tol:

            break

    return V

*# 计算真实最优V值*

optimal\_V = compute\_optimal\_V(gamma=gamma)

*# Bellman最优算子*

def bellman\_optimal\_operator(Q):

    """

    Bellman 最优算子: 给定当前 Q，返回对所有 Q(s,a) 的更新结果。

    """

    new\_Q = np.zeros((n\_states, n\_actions))

    for s in range(n\_states):

        for a in [0, 1]:

            total = 0.0

            for (s\_next, prob) in transition(s, a):

                r = reward(s\_next)

                total += prob \* (r + gamma \* np.max(Q[s\_next]))

            new\_Q[s, a] = total

    return new\_Q

*# 优势学习算子*

def advantage\_learning\_operator(Q):

    """

    优势学习更新: 给定当前 Q，返回对所有 Q(s,a) 的更新结果。

    按照公式: T\_AL Q(s,a) = r(s,a) + α(Q(s,a) - max\_a Q(s,a)) + γE[max\_a' Q(s',a')]

    """

    new\_Q = np.zeros((n\_states, n\_actions))

    for s in range(n\_states):

        for a in [0,1]:

*# 计算 r(s,a) 项*

            r\_sa = 0.0

            for (s\_next, prob) in transition(s, a):

                r\_sa += prob \* reward(s\_next)

*# 计算 γE[max\_a' Q(s',a')] 项*

            expected\_future = 0.0

            for (s\_next, prob) in transition(s, a):

                expected\_future += prob \* np.max(Q[s\_next])

            expected\_future \*= gamma

*# 计算 α(Q(s,a) - max\_a Q(s,a)) 项*

            advantage\_term = alpha \* (Q[s, a] - np.max(Q[s]))

*# 组合所有项*

            new\_Q[s, a] = r\_sa + advantage\_term + expected\_future

    return new\_Q

def evaluate\_policy(policy, gamma=0.99, tol=1e-8, max\_iter=1000):

    V = np.zeros(n\_states)

    for \_ in range(max\_iter):

        V\_old = V.copy()

        for s in range(n\_states):

            a = policy[s]

            val = 0.0

            for (s\_next, prob) in transition(s, a):

                r = reward(s\_next)

                val += prob \* (r + gamma \* V\_old[s\_next])

            V[s] = val

        if np.max(np.abs(V - V\_old)) < tol:

            break

    return V

*# 计算V值函数*

def compute\_V(Q):

    """计算当前诱导的 V^π(s) = max\_a Q(s,a)"""

    return np.max(Q, axis=1)

*# 计算性能界 ||V\* - V^{π\_k}||∞*

def compute\_performance\_bound(optimal\_V, current\_V):

    """计算与 V^\* 的无穷范数差"""

    return np.max(np.abs(optimal\_V - current\_V))

*# 计算动作间隔*

def compute\_action\_gap(Q):

    """计算动作间隔 (Action Gap): 每个状态下左右动作的Q值差异，然后取平均"""

    gaps = np.zeros(n\_states)

    for s in range(n\_states):

        gaps[s] = Q[s, 0] - Q[s, 1]  *# 左(0) - 右(1)*

    return np.mean(gaps)

*# 主实验函数*

def run\_experiment(operator, n\_iterations=400):

*# 初始化Q值*

    np.random.seed(0)

    Q = 10 \* np.random.rand(n\_states, n\_actions)

    performance\_bounds = []

    action\_gaps = []

    for \_ in range(n\_iterations):

*# 应用算子更新Q值*

        Q = operator(Q)

*# 获取当前贪婪策略*

        current\_policy = np.argmax(Q, axis=1)

*# 评估当前策略的真实价值函数*

        current\_V = evaluate\_policy(current\_policy)

*# 计算性能界*

        bound = compute\_performance\_bound(optimal\_V, current\_V)

        performance\_bounds.append(bound)

*# 计算动作间隔*

        gap = compute\_action\_gap(Q)

        action\_gaps.append(gap)

    return performance\_bounds, action\_gaps, Q

*# 运行实验*

n\_iterations = 200

np.random.seed(0)  *# 重置随机种子，确保两次实验使用相同的初始Q值*

bellman\_bounds, bellman\_gaps, Q\_bellman = run\_experiment(bellman\_optimal\_operator, n\_iterations)

np.random.seed(0)  *# 重置随机种子，确保两次实验使用相同的初始Q值*

al\_bounds, al\_gaps, Q\_adv = run\_experiment(advantage\_learning\_operator, n\_iterations)

fig, axs = plt.subplots(1, 2, figsize=(14, 5), sharey=False, sharex=True)

iters = np.arange(n\_iterations)

*# 左图: 性能界 ||V^\* - V^π||∞*

axs[0].plot(iters, bellman\_bounds, label="Bellman Optimal", lw=2)

axs[0].plot(iters, al\_bounds, label="Advantage Learning", lw=2)

axs[0].set\_xlabel("Iterations")

axs[0].set\_ylabel(r"Performance Bound ||V\* - V^{π\_k}||∞")

axs[0].set\_title("Performance Bound over Iterations")

axs[0].grid(True)

axs[0].legend()

*# 右图: 动作间隔 (Action Gap)*

axs[1].semilogy(iters, np.abs(bellman\_gaps), label="Bellman optimal")  *# 使用对数坐标*

axs[1].semilogy(iters, np.abs(al\_gaps), label="Advantage Learning")  *# 使用对数坐标*

axs[1].set\_xlabel("Iterations")

axs[1].set\_ylabel("Action Gap")

axs[1].set\_title("Action Gap over Iterations")

axs[1].grid(True)

axs[1].legend()

plt.tight\_layout()

plt.show()

1. **评价指标**
2. 评价指标：优势性能，衡量的是当前策略与最优策略的价值函数接近程度，如收敛于0，说明策略已经收敛至最优，下降速度放映的是算子逼近最优策略的效率
3. 动作间隔：衡量策略的动作选择正确性，间隔越大，策略越倾向于固定动作，间隔大的策略对环境扰动更不敏感。
4. **结果分析**
5. :参数设置

时，结果如下图：

* 图中，优势学习（橙色）后期优势性能值更低，最终策略更接近理论最优，（蓝色）初期下降更快，说明它短期收敛的效率更高；优势学习（橙色）间隔显著更高，因为显著放大了最优动作优势，（蓝色）间隔平稳增长，因为依赖环境反馈自然形成差异。
* 对应来说，如果需要快速原型开发，优先选择最优算子，因为初期收敛快，如果需要部署高可靠性策略，选择优势学习算子，因为最终精度高，动作确定性更强。

图表, 折线图

AI 生成的内容可能不正确。

1. 超参数敏感性测试：探索的值对性能界和动作间隔的影响？

：影响的公式部分项，影响的解释：控制下一个状态的最大值对当前值的更新的贡献程度！

设置四组实验，保持,开始设置四组,查看结果：

,没有收敛于0，收敛于110左右， 差值为45.48

图表

AI 生成的内容可能不正确。

*，*同时记录收敛时，的差值，此时为159.52

*图表

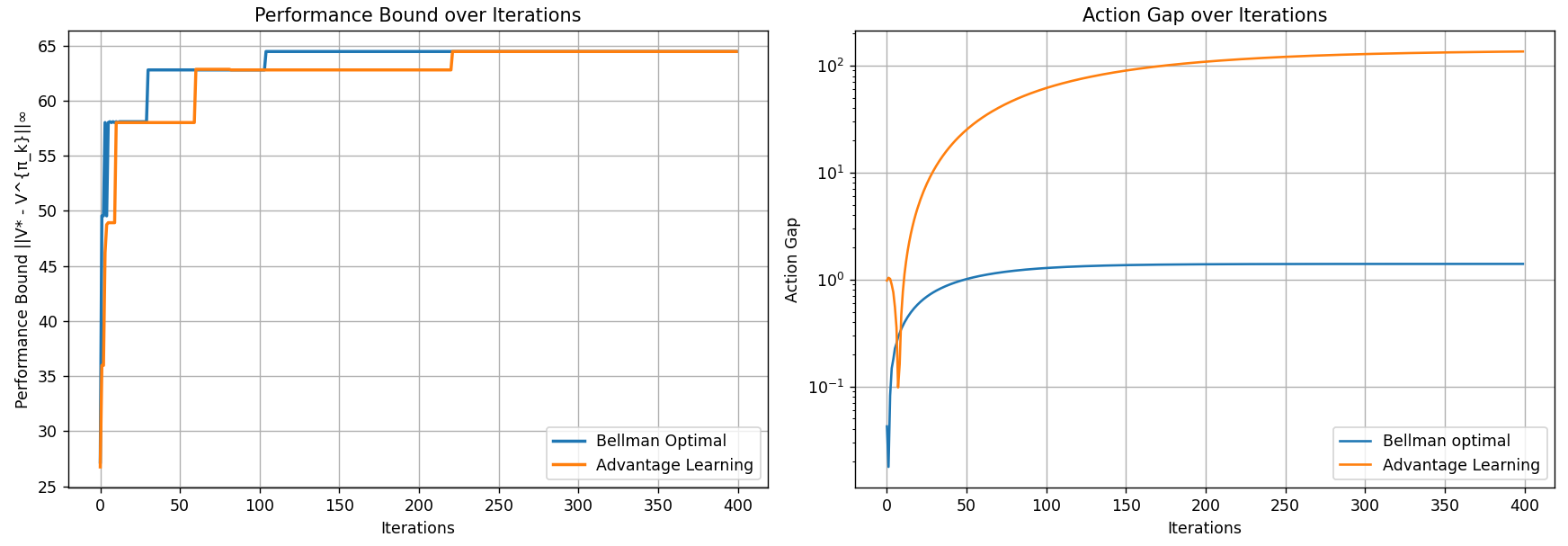
AI 生成的内容可能不正确。*

发现较小的时候，性能界是没有正确收敛于0的，所以的情况图片由于和的类似，将不展示，反思为什么会出现这种情况？

较小，性能边界收敛值大，因为长期回报信息被压缩，动作间隔小，因为未来奖励的惩罚力度不足，因为和的值是需要协同调节的。

下面继续给出和的情况：

,时，的差距值为134.12

**

,时，的差距值为149.51

图表, 折线图

AI 生成的内容可能不正确。

可以发现，随着的值越大，算子和优势学习算子更加注重未来的状态的情况，而不是局限于当前的状态的情况，同时随着这个值变大，动作间隔也在变大，说明在充分考虑这个未来的情况之后，动作的确定性也在变大!

:影响部分：影响优势学习算子中的，也就是对于当前动作与最优动作的修正，当当前的动作就是最优的动作的时候，没有影响，否则将产生一个负数项，会削弱当前状态的值。

参数设置与探讨：固定,探索的情况

,时，的差值为3.84

图表, 折线图, 直方图

AI 生成的内容可能不正确。

时，的差值为6.58

图表, 直方图

AI 生成的内容可能不正确。

时，的差值为14.81

图表, 直方图

AI 生成的内容可能不正确。

时，的差值为159.52

图表

AI 生成的内容可能不正确。

调整的时候，影响的是优势学习算子，可以看到，收敛之后的的差值随着的变大而逐渐变大，说明优势学习算子随着对于错误动作的惩罚力度的增加，会让决策过程中，动作趋向正确动作的确定性也增加！

1. **小结**

算子适合用于需要短期收敛较快的工作，但是综合性能来说，由于算子相较于优势学习算子，缺少了对于当前动作的惩罚，而导致这个的值会较小，也就是对于正确动作的确定性会较小，相比之下，优势学习算子的会随着的值变大，最后呈现一种指数级别的增加，也就是对错误动作的惩罚力度增大，会让策略动作更加确定的选择最优动作。