

RL: Policy Search

Policy Gradient Algorithms

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Likelihood Ratio / Score Function Policy Gradient

$$\nabla_{\theta} V(\theta) = \frac{1}{m} \sum_{i=1}^m R(\tau^{(i)}) \sum_{t=0}^{T-1} \nabla_{\theta} \log \pi_{\theta}(a_t^{(i)} | s_t^{(i)})$$

- ▶ Unbiased but very noisy
- ▶ Fixes that can make it practical
 - ▶ Temporal structure
 - ▶ Baseline
 - ▶ (and some more)

Policy Gradient: Use Temporal Structure

$$\nabla_{\theta} \mathbb{E}_{\tau}[R] = \mathbb{E}_{\tau} \left[\left(\sum_{t=0}^{T-1} r_t \right) \left(\sum_{t=0}^{T-1} \nabla_{\theta} \log \pi_{\theta}(a_t | s_t) \right) \right]$$

We can repeat the same argument to derive the gradient estimator for a single reward term $r_{t'}$

$$\nabla_{\theta} \mathbb{E}[r_{t'}] = \mathbb{E} \left[r_{t'} \sum_{t=0}^{t'} \nabla_{\theta} \log \pi_{\theta}(a_t | s_t) \right]$$

Summing this formula over t , we obtain:

$$\begin{aligned} V(\theta) = \nabla_{\theta} \mathbb{E}[R] &= \left[\sum_{t'=0}^{T-1} r_{t'} \sum_{t=0}^{t'} \nabla_{\theta} \log \pi_{\theta}(a_t | s_t) \right] \\ &= \left[\sum_{t=0}^{T-1} \nabla_{\theta} \log \pi_{\theta}(a_t | s_t) \sum_{t'=t}^{T-1} r_{t'} \right] \end{aligned}$$

Policy Gradient: Use Temporal Structure

- Recall for a particular trajectory $\tau^{(i)}$, $\sum_{t'=t}^{T-1} r_{t'}^{(i)}$ is the return $G_t^{(i)}$

$$\nabla_{\theta} \mathbb{E}[R] \approx \frac{1}{m} \sum_{i=1}^m \sum_{t=0}^{T-1} \nabla_{\theta} \log \pi_{\theta}(a_t, s_t) G_t^{(i)}$$

Monte-Carlo Policy Gradient (REINFORCE)

Leverages likelihood ratio / score function and temporal structure

$$\Delta\theta_t = \alpha \nabla_{\theta} \log \pi_{\theta}(s_t, a_t) G_t$$

REINFORCE:

1. Initialize policy parameters θ arbitrarily
2. for each episode $\{s_1, a_1, r_2, \dots, s_{T-1}, a_{T-1}, r_T\} \sim \pi_{\theta}$ do
 - ▶ for $t = 1$ to $T - 1$ do
 - ▶ $\theta := \theta + \alpha \nabla_{\theta} \log \pi_{\theta}(s_t, a_t) G_t$
3. return θ

Policy Gradient: Introduce Baseline

- ▶ Reduce variance by introducing a baseline $b(s)$

$$\nabla_{\theta} \mathbb{E}_{\tau}[R] = \mathbb{E}_{\tau} \left[\sum_{t=0}^{T-1} \nabla_{\theta} \log \pi(a_t | s_t; \theta) \left(\sum_{t'=t}^{T-1} r_{t'} - b(s_t) \right) \right]$$

- ▶ For any choice of b , gradient estimator is unbiased
- ▶ Near optimal choice is the expected return

$$b(s_t) \approx \mathbb{E}[r_t + r_{t+1} + \dots + r_{T-1}]$$

- ▶ Interpretation: increase logprob of action a_t proportionally to how much returns $\sum_{t'=t}^{T-1} r_{t'}$ are better than expected

"Vanilla" Policy Gradient Algorithm

- ▶ Initialize policy parameters θ and baseline b
- ▶ for iteration = 1, 2, ... do
 - ▶ Collect a set of trajectories by executing the current policy
 - ▶ At each time step t in each trajectory τ^i , compute
 - ▶ Return $G_t^i = \sum_{t'=t}^{T-1} r_{t'}^i$, and
 - ▶ Advantage estimate $\hat{A}_t^i = G_t^i - b(s_t)$
 - ▶ Re-fit the baseline by minimizing $\sum_i \sum_t ||b(s_t) - G_t^i||^2$
 - ▶ Update the policy, using a policy gradient estimate \hat{g}
 - ▶ which is a sum of terms $\nabla_{\theta} \log \pi(a_t | s_t; \theta) \hat{A}_t^i$
 - ▶ Apply gradient \hat{g} by any DL-optimizer (e.g., SGD or ADAM)

Choosing the Baseline: Value Functions

- ▶ Recall Q -function:

$$Q^\pi(s, a) = \mathbb{E}_\pi[r_0 + \gamma r_1 + \gamma^2 r_2 + \dots \mid s_0 = s, a_0 = a]$$

- ▶ State-value function can serve as a great baseline

$$\begin{aligned} V^\pi(s) &= \mathbb{E}_\pi[r_0 + \gamma r_1 + \gamma^2 r_2 + \dots \mid s_0 = s] \\ &= \mathbb{E}_{a \sim \pi}[Q^\pi(s, a)] \end{aligned}$$

- ▶ Advantage function: Combining Q with baseline V :

$$A^\pi(s, a) = Q^\pi(s, a) - V^\pi(s)$$