Exploration in RL

Traditional Exploration Strategies for MDPs

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Recap: Bandit Exploration

- Optimistic initialization
- Optimism in the face of uncertainty (Upper Confidence bounds)
- Probability matching (Thompson Sampling)

Optimistic Initialization: Model-free RL

- Initialize action-value function $Q(s,a)$ to $\frac{r_{max}}{1-\gamma}$
- Run favorite model-free RL algorithm
  - Monte-carlo method
  - Sarsa
  - Q-Learning
- Encourages systematic exploration of states and actions

Upper Confidence Bounds: Model-free RL

- Maximize UCB on action-value function $Q^\pi(s, a)$

$$a_t \in \arg\max_{a \in A} Q(s_t, a) + U(s_t, a)$$

  - Estimate uncertainty in policy evaluation (easy)
  - Ignores uncertainty from policy improvement
- Maximize UCB on optimal action-value function $Q^*(s, a)$

$$a_t \in \arg\max_{a \in A} Q(s_t, a) + U_1(s_t, a) + U_2(s_t, a)$$

  - Estimate uncertainty in policy evaluation (easy)
  - plus uncertainty from policy improvement (hard)

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Bayesian Model-based RL

- Maintain posterior distribution over MDP models
- Estimate both transitions and rewards $\mathbb{P}[P, R \mid h_t]$
  - where $h_t = s_1, a_1, r_2, \dots, s_t$ is the history
- Use posterior to guide exploration
  - Upper confidence bounds (Bayesian UCB)
  - Probability matching (Thompson sampling)

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Thompson Sampling: Model-based RL

- Thompson sampling implements probability matching

$$
\begin{aligned}
\pi(s, a \mid h_t) &= \mathbb{P}[Q^*(s,a) > Q^*(s,a'), \forall a' \neq a \mid h_t] \\
&= \mathbb{E}_{P,R \mid h_t}\left[\mathbf{1}(a \in \operatorname*{arg\,max}_{a \in A} Q^*(s,a))\right]
\end{aligned}
$$

1. Use Bayes law to compute posterior $\mathbb{P}[P, R \mid h_t]$
2. Sample an MDP P, R from posterior
3. Solve MDP using favorite planning algorithm to get $Q^*(s,a)$
4. Select optimal action for sample MDP: $a_t \in \arg\max_{a \in A} Q^*(s_t, a)$

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