

MCTS Based on Simple Regret

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Hard to solve search problems

Search problems are often hard too solve in practice when:

- ▶ search space is extremely large;
- ▶ *and* good heuristics are unknown.

Easier to solve:

- ▶ Chess — search space size is manageable (10^{50}).
- ▶ Timetabling — good heuristics.

Hard to solve:

- ▶ Compute Go (10^{180}), Poker (10^{70}).
- ▶ Canadian Traveller Problem.

MCTS

Monte Carlo Tree Search helps in large search spaces.

- ▶ Starts with the root only.

Adaptive MCTS samples ‘good’ moves more frequently, but sometimes **explores** new directions.

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 4. **Backpropagation:** values of each stored node are updated.

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Multi-armed Bandit Problem and UCB

Multi-armed Bandit Problem:

- ▶ We are given a set of K arms.
- ▶ Each arm can be pulled multiple times.
- ▶ The reward is drawn from an **unknown** (but normally *stationary* and *bounded*) distribution.
- ▶ The **total reward** must be maximized.

UCB is near-optimal for MAB — solves *exploration/exploitation* tradeoff.

- ▶ pulls an arm that maximizes **Upper Confidence Bound**:
$$b_i = \bar{X}_i + \sqrt{\frac{c \log(n)}{n_i}}$$
- ▶ the cumulative regret is $O(\log n)$.

UCT

UCT (**U**pper **C**onfidence Bounds applied to **T**rees) is based on UCB.

- ▶ Adaptive MCTS.
- ▶ Applies the UCB selection scheme at each step of the rollout.
- ▶ Demonstrated good performance in Computer Go (MoGo, CrazyStone, Fuego, Pachi, ...) as well as in other domains.

However, the first step of a rollout is different:

- ▶ The purpose of MCTS is to choose an action with the greatest utility.
- ▶ Therefore, the **simple regret** must be minimized.

Simple **R**egret followed by **C**umulative **R**egret.

- ▶ Minimizes **simple regret** at the **first step**.
- ▶ Continues with UCT from the **second step on**.

```

1: procedure ROLLOUT(node, depth=1)
2:   if ISLEAF(node, depth) then
3:     return 0
4:   else
5:     if depth=1 then action  $\leftarrow$  FIRSTACTION(node)
6:     else action  $\leftarrow$  NEXTACTION(node)
7:     next-node  $\leftarrow$  NEXTSTATE(node, action)
8:     reward  $\leftarrow$  REWARD(node, action, next-node)
9:               + ROLLOUT(next-node, depth+1)
10:    UPDATESTATS(node, action, reward)

```

Sampling for Simple Regret

Sampling schemes for minimizing the simple regret:

1. ϵ -greedy sampling.
2. a modified version of UCB (worse for cumulative, better for simple regret).
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- ▶ 1, 2 — heuristic selection criterion, theoretical upper bounds can be obtained.
 - ▶ 3 — based on principles of *Rational Metareasoning*, but harder to analyze.

Heuristic sampling schemes

ε -greedy:

- ▶ Pulls the empirically best arm with probability ε .
- ▶ Any other arm with probability $\frac{1-\varepsilon}{K-1}$.
- ▶ Exhibits exponentially decreasing simple regret.
- ▶ Uniform sampling when $\varepsilon = \frac{1}{K}$, much better when $\varepsilon = \frac{1}{2}$.

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$UCB_{\sqrt{\cdot}}$ ($\sqrt{\cdot}$ instead of \log):

- ▶ Pulls arm i that maximizes $b_i = \bar{X}_i + \sqrt{\frac{c\sqrt{n}}{n_i}}$.
- ▶ Exhibits superpolynomially decreasing simple regret.

VOI-aware sampling

- ▶ Chooses an action with the maximum VOI estimate.
- ▶ Estimates the VOI based on bounds on:
 - ▶ the probability that one or more rollouts will make another action appear better than the current best;
 - ▶ the gain that may be incurred if such a change occurs.

$$VOI_{\alpha} \approx \frac{\bar{X}_{\beta}}{n_{\alpha} + 1} \exp(-2(\bar{X}_{\alpha} - \bar{X}_{\beta})^2 n_{\alpha})$$

$$VOI_i \approx \frac{1 - \bar{X}_{\alpha}}{n_i + 1} \exp(-2(\bar{X}_{\alpha} - \bar{X}_i)^2 n_i), \quad i \neq \alpha$$

where $\alpha = \arg \max_i \bar{X}_i, \quad \beta = \arg \max_{i, i \neq \alpha} \bar{X}_i$

Simple regret in MAB

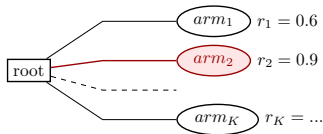


Fig. 1: Search tree

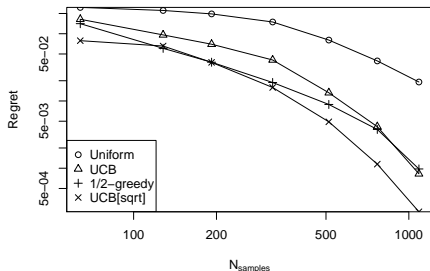


Fig. 2: Regret vs # of samples
(32 arms)

- ▶ For smaller numbers of samples, $\frac{1}{2}$ -greedy achieves the best performance.
- ▶ For larger numbers of samples, $UCB_{\sqrt{\cdot}}$ outperforms $\frac{1}{2}$ -greedy.
- ▶ A combination of $\frac{1}{2}$ -greedy and $UCB_{\sqrt{\cdot}}$ dominates UCB over the whole range.

Monte Carlo tree search

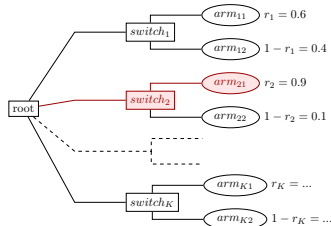


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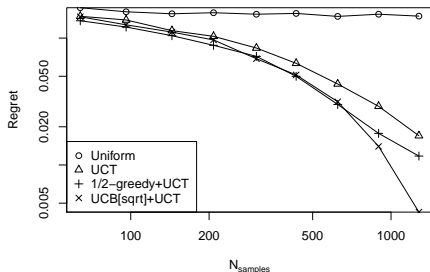


Fig. 2: Regret vs # of samples
(16 switches)

- ▶ Either $\frac{1}{2}$ -greedy+UCT or $\text{UCB}_{\sqrt{\cdot}}$ +UCT gives the lowest regret.
- ▶ $\text{UCB}_{\sqrt{\cdot}}$ +UCT dominates UCT everywhere except for small numbers of instances.
- ▶ The advantage of both $\frac{1}{2}$ -greedy+UCT and $\text{UCB}_{\sqrt{\cdot}}$ +UCT grows with the number of arms.

Sailing domain

- ▶ A square lake.
- ▶ A sailboat has to find the shortest path between corners.
- ▶ The wind changes randomly.

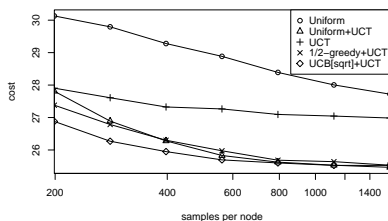


Fig. 1: Median cost

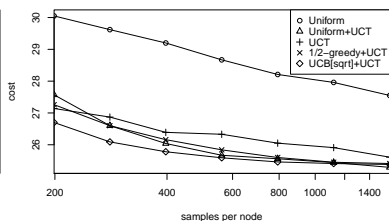
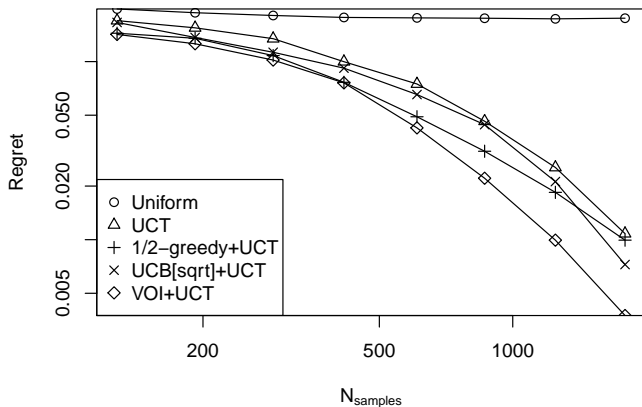


Fig. 2: Minimum cost

- ▶ UCT is always worse than $\frac{1}{2}$ -greedy+UCT or $UCB_{\sqrt{\cdot}}$ +UCT.
- ▶ UCT is sensitive to the value of c : the median cost is much higher than the minimum cost.

VOI-aware MCTS



- ▶ The experiments were performed on randomly generated trees.
- ▶ VOI+UCT, the scheme based on a VOI estimate, outperforms all other sampling schemes in this example.

Summary

Done:

- ▶ Improved MCTS scheme, SRCR, introduced.
- ▶ SRCR performs better than unmodified UCT.
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TODO:

- ▶ Better sampling schemes can be developed based on principles of Rational Metareasoning.
- ▶ UCT is not well understood. Better understanding will help in developing efficient MCTS schemes and adapting to different domains.

Thank you!