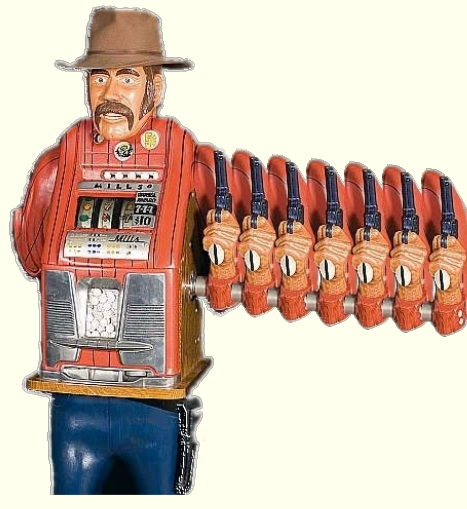


MULTI-ARMED BANDITS

- A set of K arms.
- Each arm can be pulled multiple times.
- When the i th arm is pulled, a random reward X_i is encountered.



Regret minimization:

- Simple regret (SR):** the reward of the last pull only is collected.
- Cumulative regret (CR):** all rewards are accumulated.

UCB AND UCT

- UCB(c)** pulls arm i that maximizes upper confidence bound b_i on the reward:
$$b_i = \bar{X}_i + \sqrt{\frac{c \log(n)}{n_i}}$$
- UCB is nearly optimal in minimizing the *cumulative regret*.
- UCT** extends UCB to MCTS by invoking UCB at every node of a rollout.

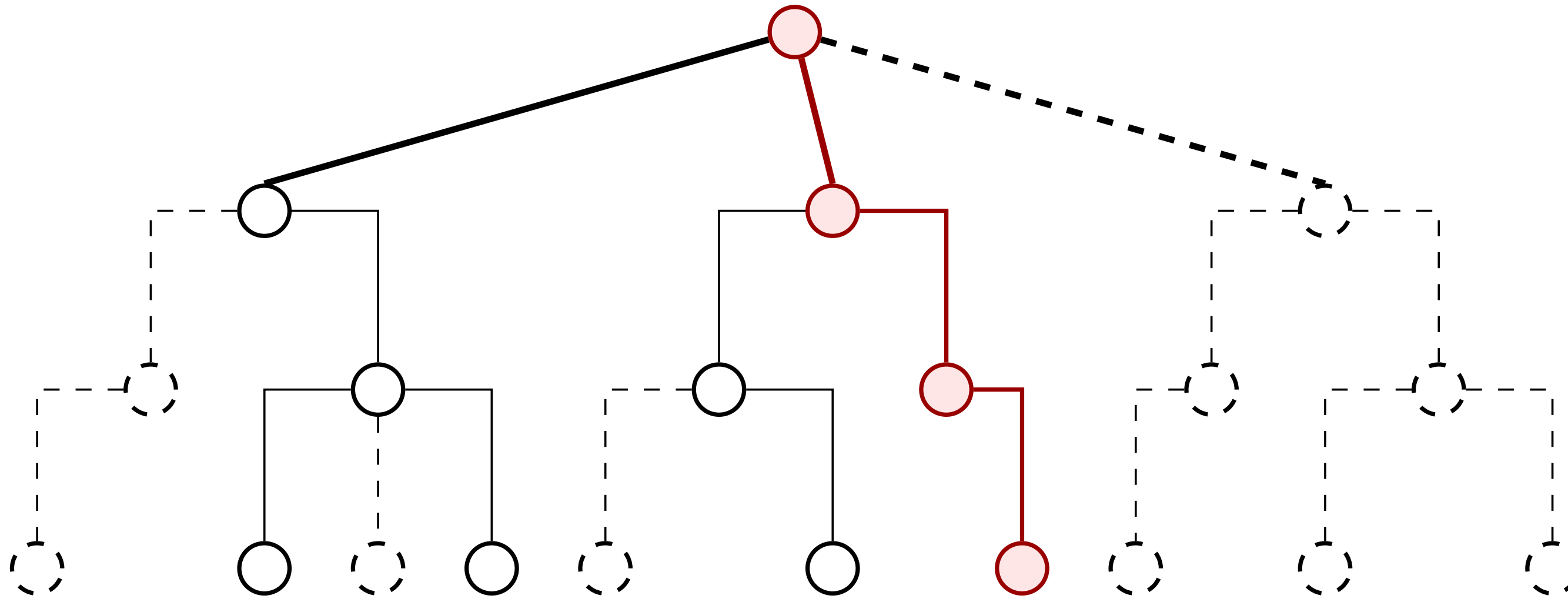
METAREASONING

- A problem-solving agent can perform *base-level* actions from a known set $\{A_i\}$.
- Before committing to an action, the agent may perform a sequence of *meta-level* deliberation actions from a set $\{S_j\}$.
- At any given time there is a base-level action A_α that maximizes the agent's *expected utility*.
- The **value of information** VOI_j is the expected difference between the expected utilities of the new and the old selected base-level action **after meta-level action S_j is taken.**
- The agent selects a meta-level action that **maximizes the VOI**, or A_α if no meta-level action has positive VOI.

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MONTE-CARLO SAMPLING IN TREES



- MCTS performs multiple *rollouts* to partially explore the search space.
- At the current root node, the sampling is aimed at finding the **first move** to perform: minimizing the **simple regret** is more appropriate at the root node.
- Deeper in the tree, minimizing **cumulative regret** results in a better estimate of the value of the state.
- An improvement over UCT can be achieved by **combining different sampling schemes** on the first step and during the rest of a rollout.

MAIN RESULTS

The **SR+CR** MCTS Scheme

- Selects an action at **the current root** suitable for minimizing the **simple regret (FIRSTACTION)**.
- Deeper down**, selects actions according to UCB, that approximately minimizes the **cumulative regret (NEXTACTION)**.

```

1 ROLLOUT(node, depth=1)
2   if ISLEAF(node, depth)
3     return 0
4   else
5     if depth=1 then action ← FIRSTACTION(node)
6     else action ← NEXTACTION(node)
7     next ← NEXTSTATE(node, action)
8     reward ← REWARD(node, action, next)
9              + ROLLOUT(next, depth+1)
10    UPDATESTATS(node, action, reward)
11    return reward
    
```

Sampling for Simple Regret

- ε -greedy sampling ($\varepsilon = \frac{1}{2}$).
- Modified version of **UCB** (optimized for *simple regret*).
- VOI-aware** sampling:

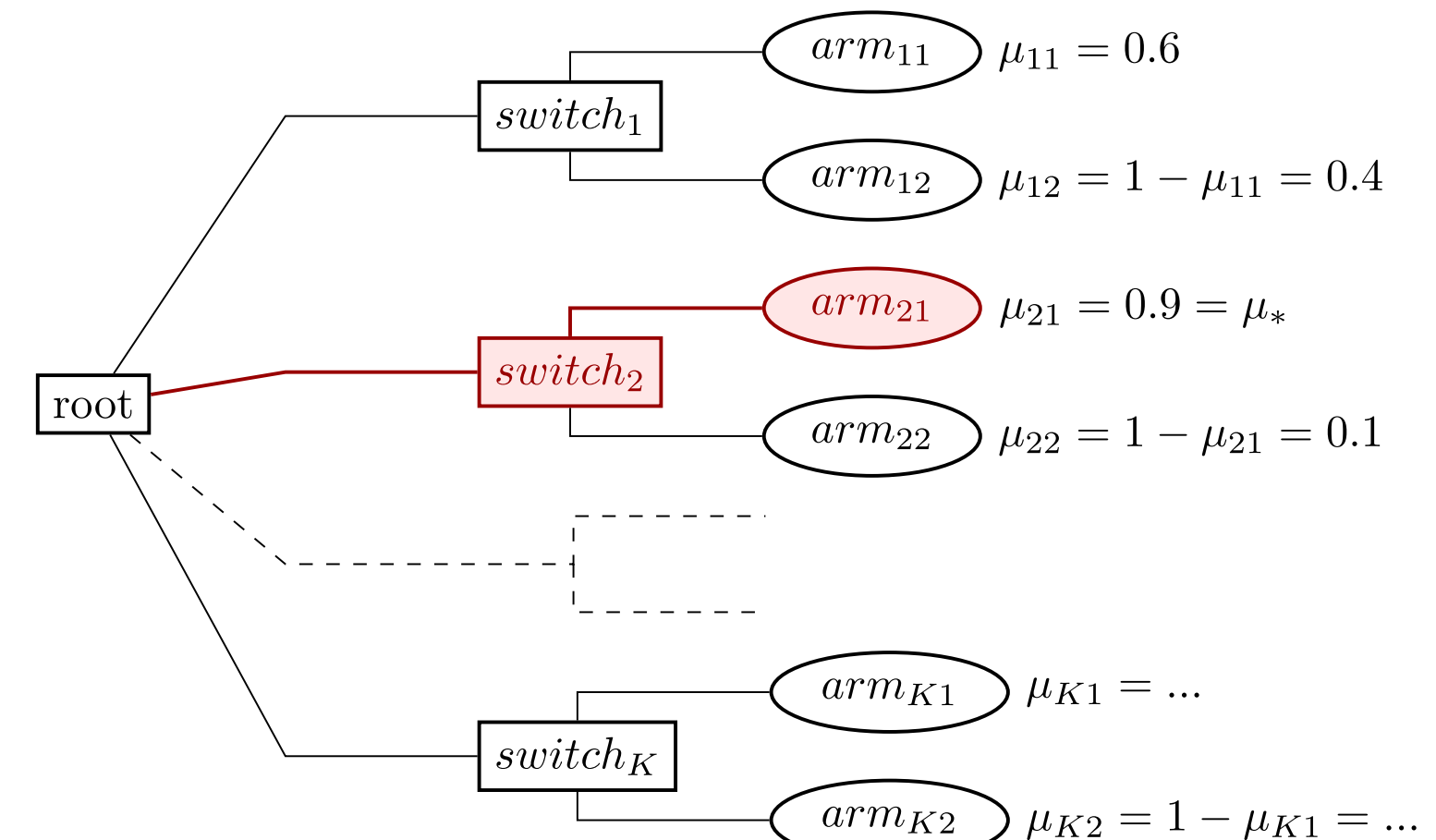
$$VOI_\alpha \approx \frac{\bar{X}_\beta}{n_\alpha + 1} \exp\left(-2(\bar{X}_\alpha - \bar{X}_\beta)^2 n_\alpha\right)$$

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

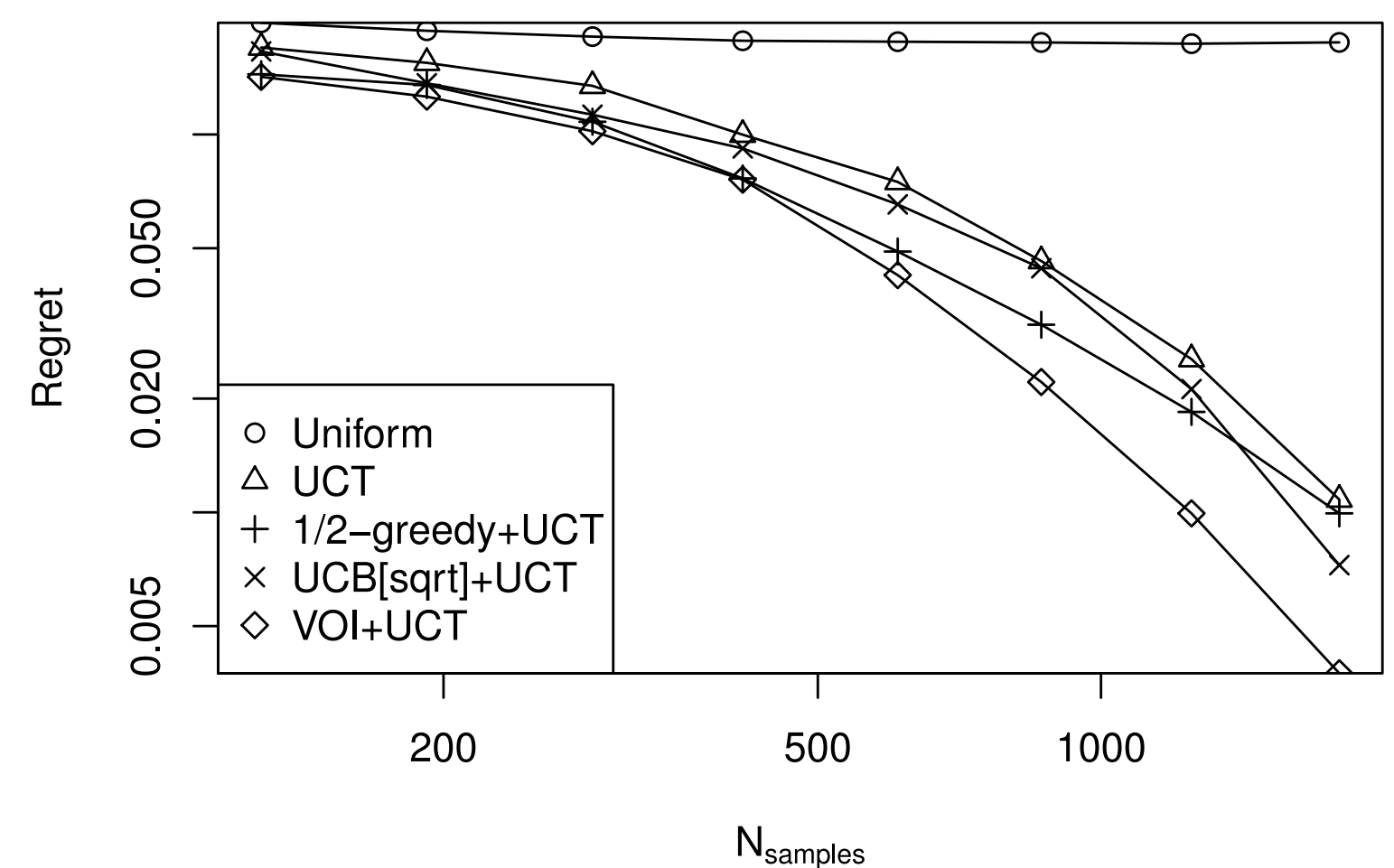
EXPERIMENTS

- SR+CR **outperforms UCT**.
- SR+UCT(c) is **less dependent on tuning** of the exploration factor c .

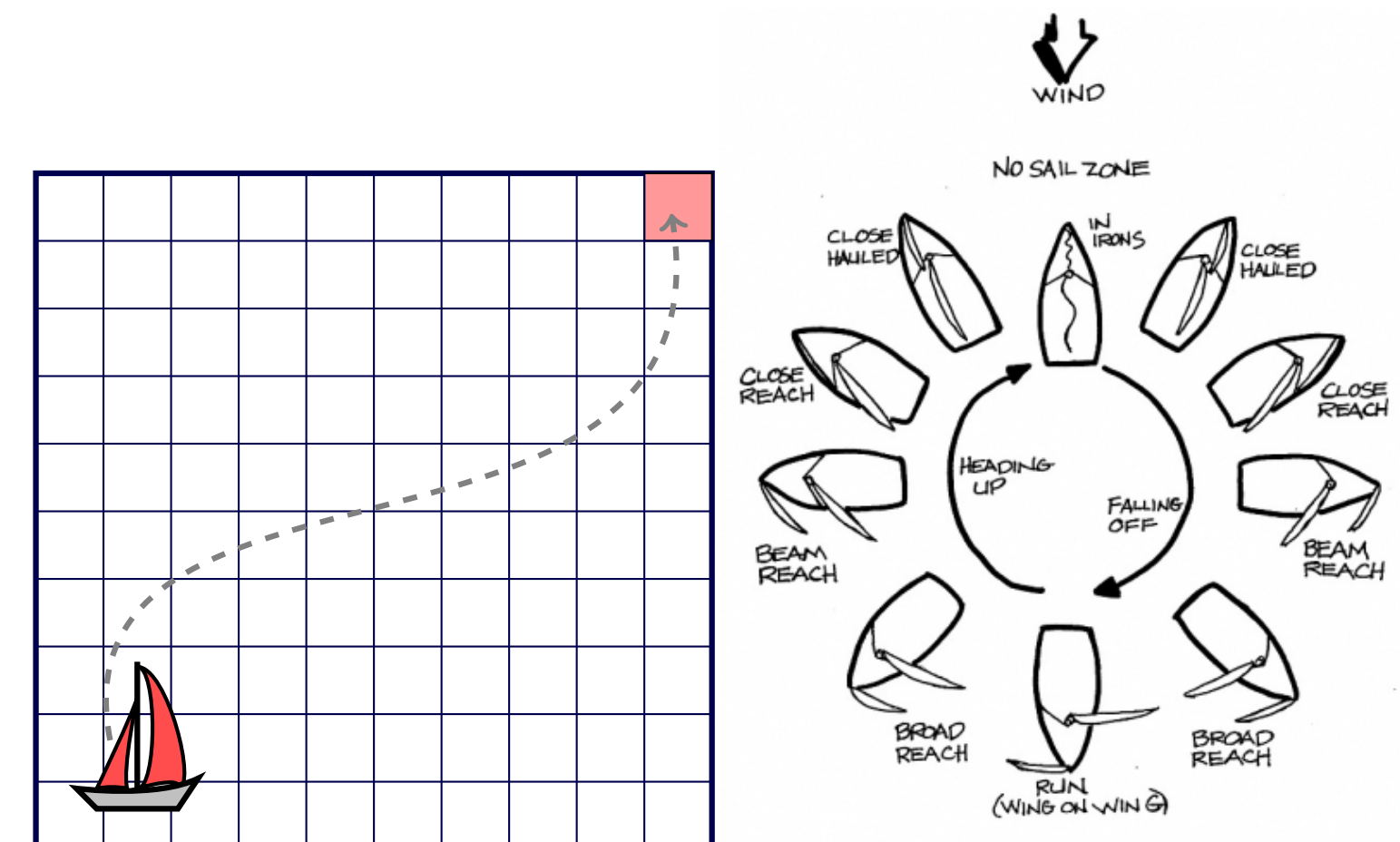
Random Trees



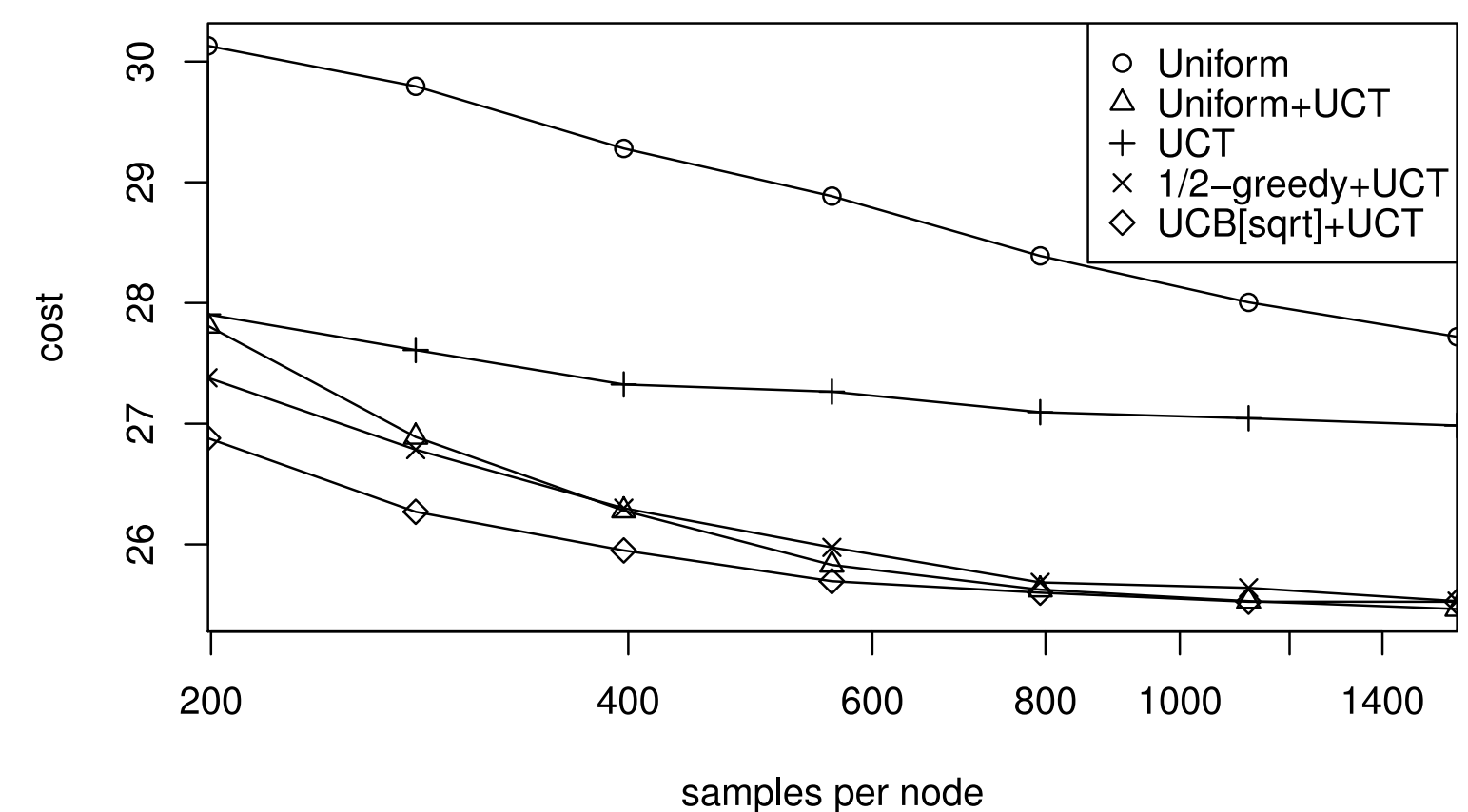
Regret vs. number of samples:



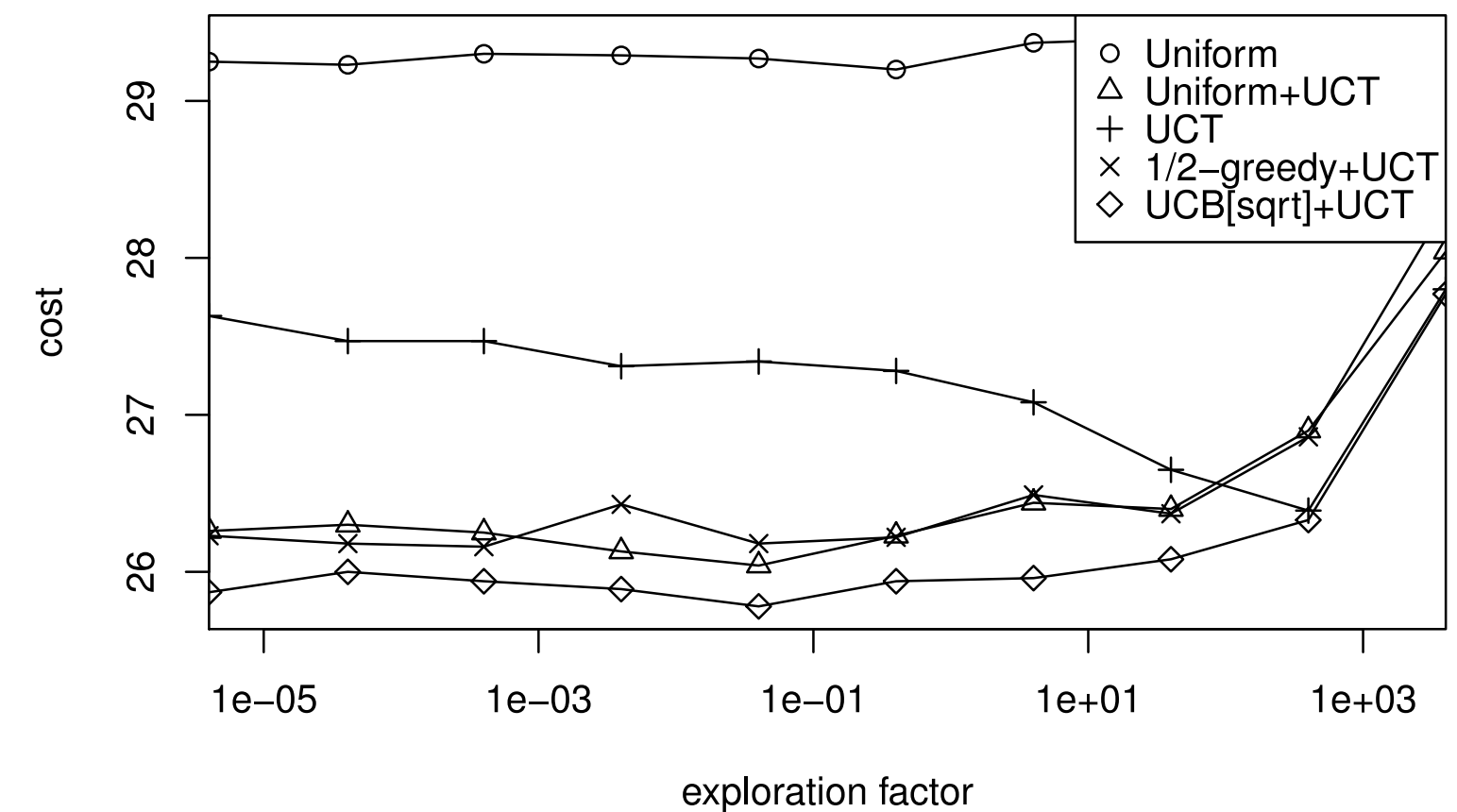
Sailing Domain



Path cost vs. number of samples:



Path cost vs. exploration factor:



CONTRIBUTIONS

- Improved MCTS scheme — **SR+CR**.
- SR+CR performs **better than unmodified UCT**.
- VOI-aware** sampling for minimizing *simple regret*.

FUTURE WORK

- Rational metareasoning** in MCTS: theory and VOI estimates.
- Better sampling for **non-root nodes**.
- Application to **Computer Go** and other complex domains.

