

RL @ PicsArt

Day 2, part 3

Model-based RL, planning



Yandex
Data Factory

LAMBDA



**British Hedgehog
Preservation Society**

Learning Vs planning

Learning

- Black box environment
- Explore through trial and error
- Minimize regret

Planning

- Got environment model
- Search for optimal behavior
- Then act optimally

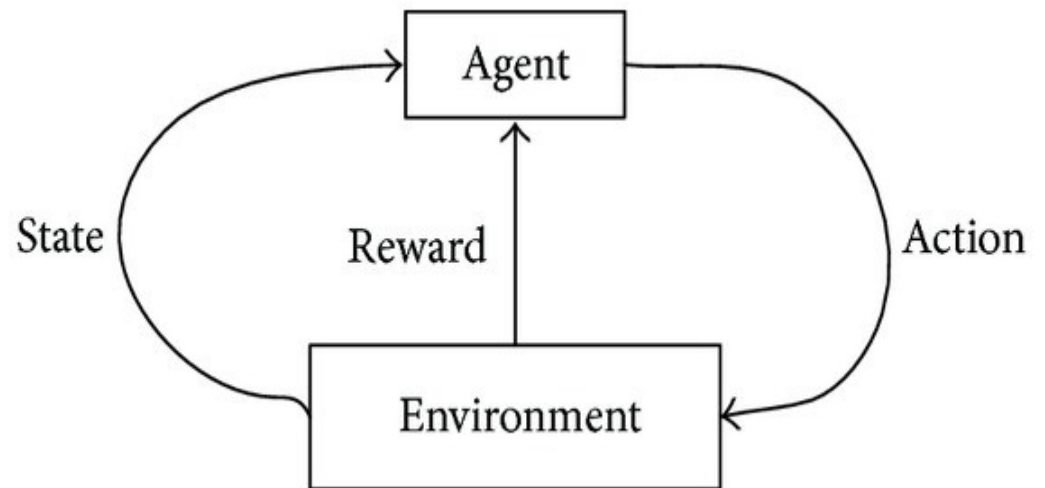
Model-based setup

What we know

- State transitions

$$P(s_{next}|s, a) \quad \text{or} \quad s_{next} = T(s, a)$$

- Rewards $r(s_t, a_t)$



Model-based setup

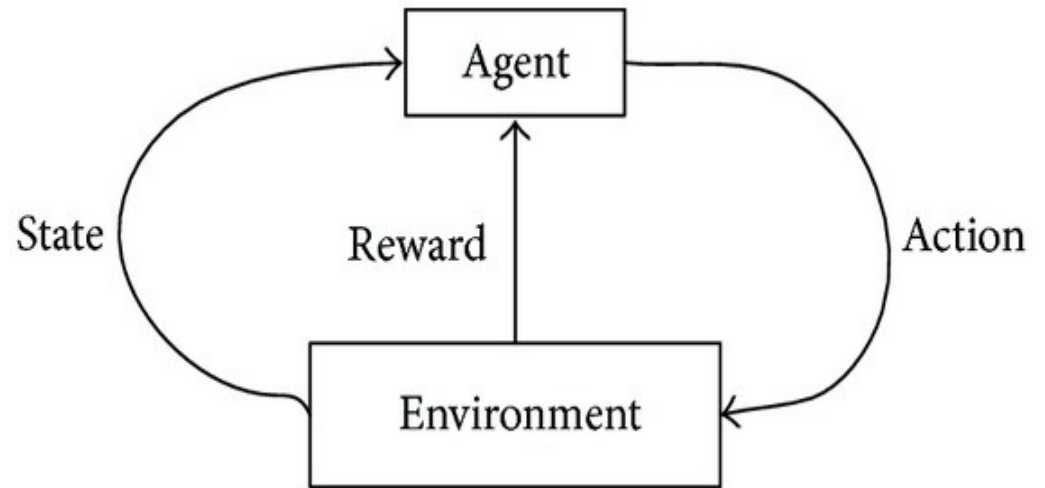
What we know

- State transitions

$$P(s_{next}|s, a) \quad \text{or} \quad s_{next} = T(s, a)$$

Weaker version: we can only
sample from $P(s'|s, a)$

- Rewards $r(s_t, a_t)$



Planning: pathfinding

Further limitations:

- Deterministic $s_{next} = T(s, a)$
- Pay $c(s1, s2)$ for moving $s1 \rightarrow s2$
- Find shortest route from state A to state B

Trivia: how do we do that?

Planning: pathfinding

Further limitations:

- Deterministic $s_{next} = T(s, a)$

- Pay $c(s1, s2)$ for moving $s1 \rightarrow s2$

Consider $c(s1, s2)$ as a negative reward
 $-r(s1, go_to_s2)$

- Find shortest route from state A to state B

Trivia: how do we do that?

Dynamic programming

Compute following function

$$path(start, end)$$

$$path(a, b) = \min_v [path(a, v) + cost(v, b)]$$

Dijkstra's algorithm

- Computes the same function
- Maintains a queue of candidate nodes
- Expands the node with minimal distance to start

Pseudo-code

```
distance = {node:inf for each node} #distance to start

distance[start] = 0
fringe = [start]                    #nodes to explore

while True:
    node = fringe.pop_node_with_least_distance()
    if node == end: break

    for neighbor in neighbors(node):
        new_distance = distance[node] + cost(node, neighbor)

        #if we found a better path...
        if new_distance < distance[neighbor]:
            distance[neighbor] = new_distance
            fringe.add(neighbor)
```

Pseudo-code

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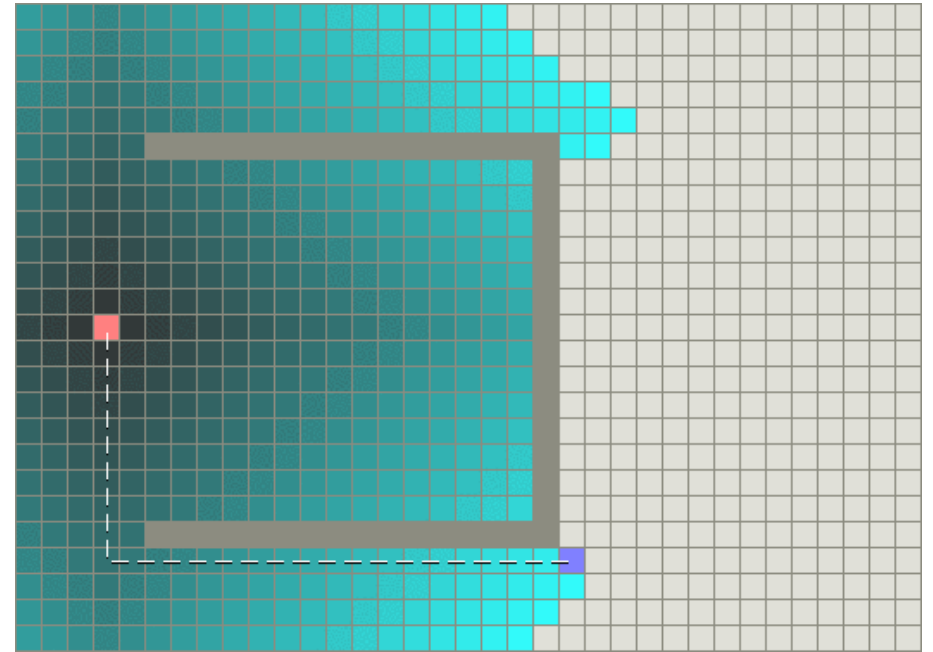
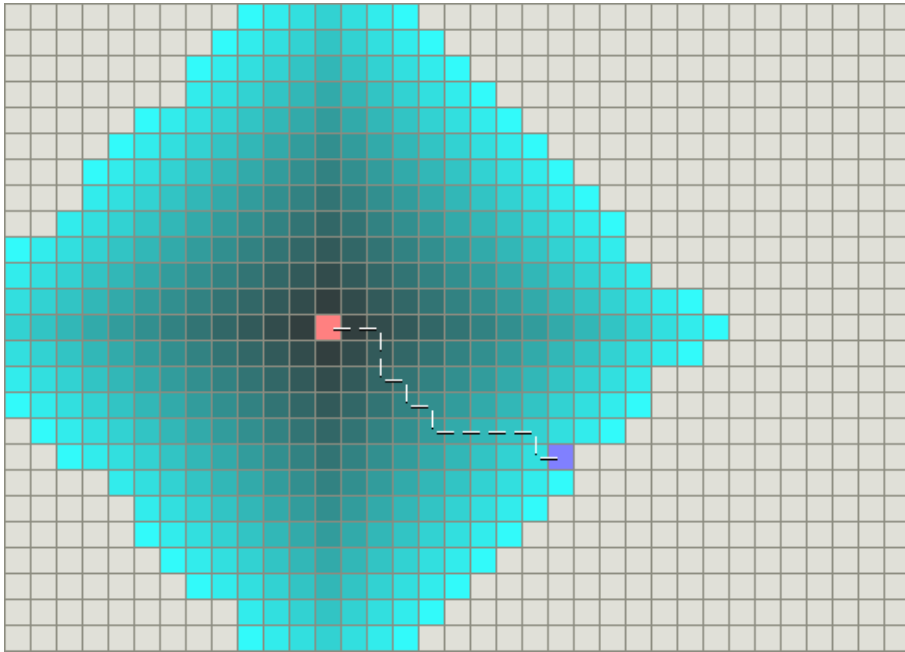
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```

Trivia: how do we get path(start,end)?

Examples



Blue: viewed nodes, red/violet = start/end, dark-grey = obstacle

A*, informed search

- Heuristic estimate of distance $h(a, b)$

$$h(a, b) \leq \text{Path}(a, b)$$

- Optimistic path estimate

$$\text{estimate}(v) = \text{Path}(\text{start}, v) + h(v, \text{end})$$

$$\forall v, \text{Path}(\text{start}, v) + h(v, \text{end}) \leq \text{Path}(\text{start}, \text{end})$$

- Pick nodes with least estimate(node)!

A*, informed search

- Heuristic estimate of distance $h(a, b)$

e.g. euclidian distance

$$h(a, b) \leq \text{Path}(a, b)$$

- Optimistic path estimate

$$\text{estimate}(v) = \text{Path}(\text{start}, v) + h(v, \text{end})$$

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- Pick nodes with least estimate(node)!

A*, “informed” search

- Heuristic estimate of distance $h(a, b)$

$$\text{estimate}(v) = \text{Path}(\text{start}, v) + h(v, \text{end})$$

```
distance = {node:inf for each node} #distance to start

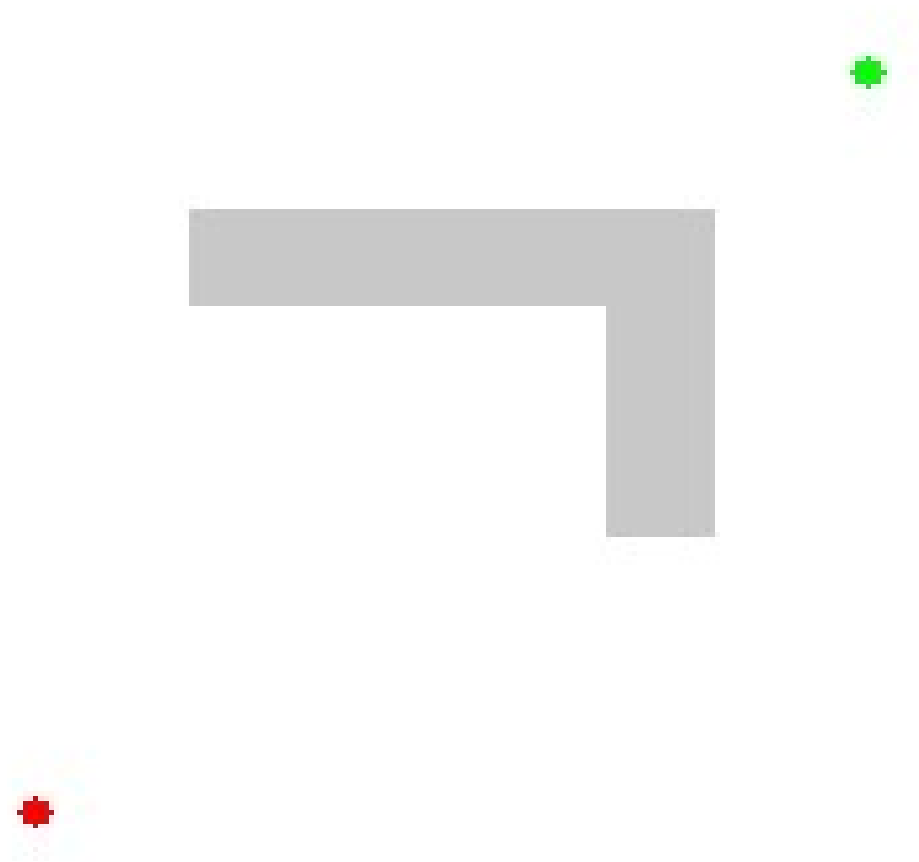
distance[start] = 0
fringe = [start] #nodes to explore

while True:    pop_node_with_least_estimate()
    node = fringe.pop_node_with_least_distance()
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        #if we found a better path...
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```

A* example



Blue: fringe, red/green= distance, dark-grey = obstacle

Adversarial setup

Same as deterministic case, but there's a second agent...

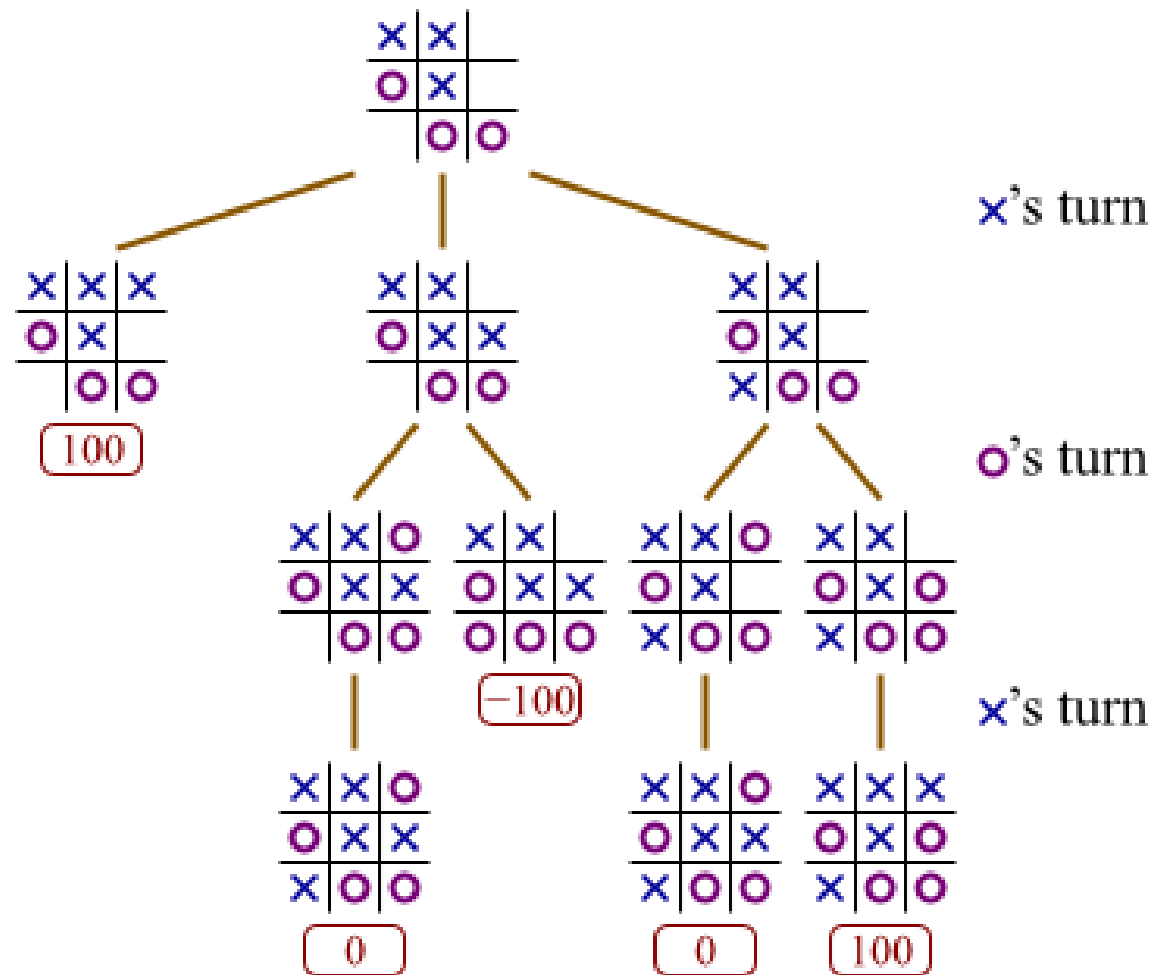
And he's playing against us!

We want highest expected reward.

Examples:

- Any board game: chess, checkers, go
- Pong :)

Adversarial search trees



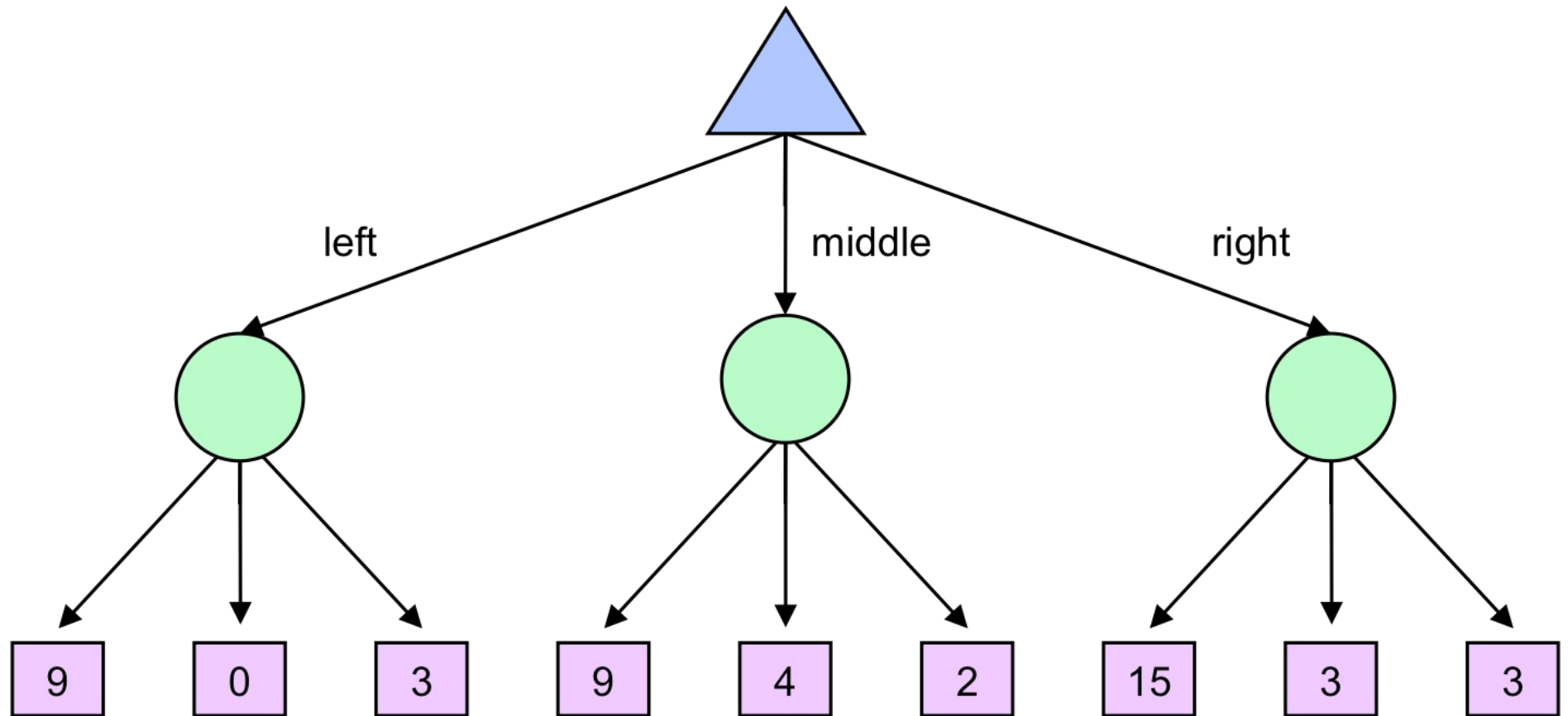
Stochastic setup

Stochastic environment,

$$s \sim P(s_{next} | s, a)$$

We want highest expected reward
or least expected cost

Stochastic search trees



How to evaluate action value?

Large/continuous state space

We can't explore all the nodes.

Need to pick most interesting ones!

Examples:

- ~any practical use case :)
- Atari

Count-based exploration

UCB-1 for bandits

Idea:

Prioritize actions with uncertain outcomes!

Less times visited = more uncertain.

Math: add upper confidence bond to reward.

Count-based exploration

UCB-1 for bandits

Take actions in proportion to \tilde{v}_a

$$\tilde{v}_a = v_a + \sqrt{\frac{2 \log N}{n_a}}$$

Upper conf. bound
for r in $[0,1]$

- N number of time-steps so far
- n_a times action **a** is taken

Count-based exploration

UCB-1 for bandits

Take actions in proportion to \tilde{v}_a

$$\tilde{v}_a = v_a + \sqrt{\frac{2 \log N}{n_a}}$$

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Count-based exploration

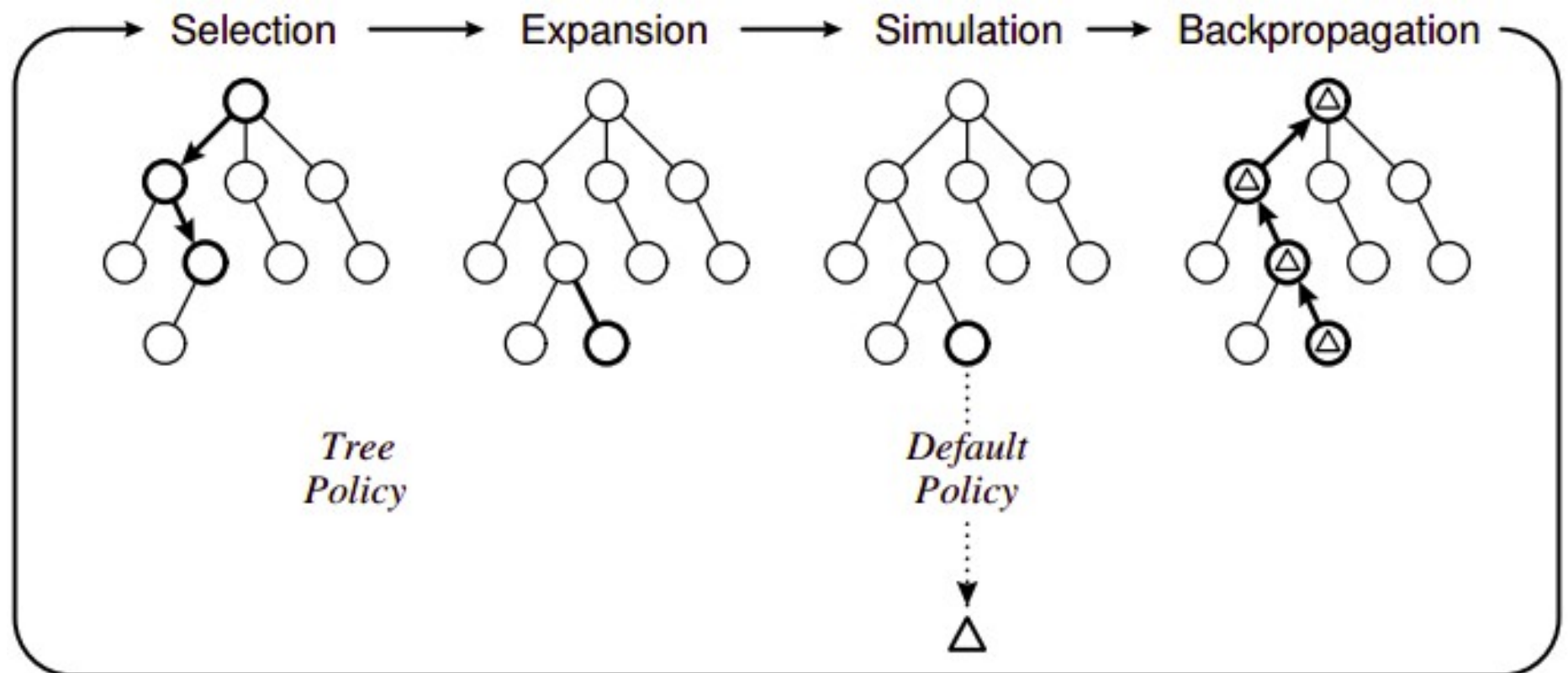
UCB generalized for multiple states

$$\tilde{Q}(s, a) = Q(s, a) + \alpha \cdot \sqrt{\frac{2 \log N_s}{n_{s,a}}}$$

where

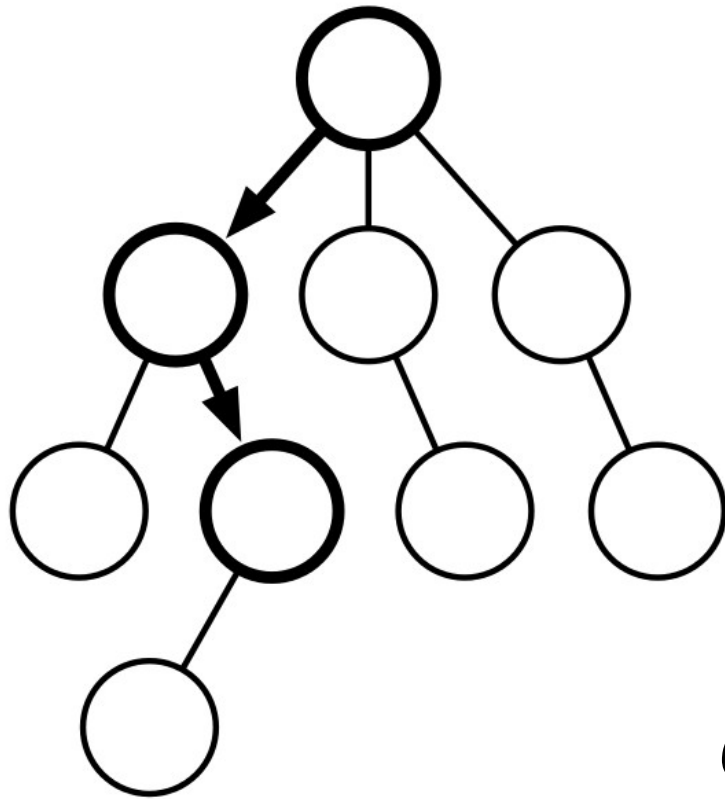
- N_s visits to state **s**
- $n_{s,a}$ times action **a** is taken from state **s**

MCTS



MCTS: selection

Selection

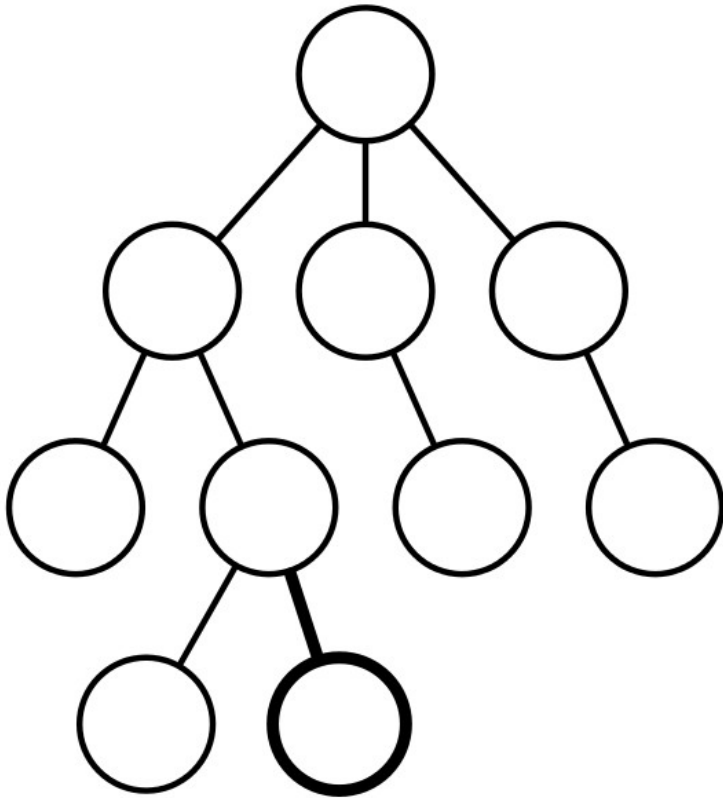


Starting from the root,
recursively select node
with highest ucb-1 score

$$\tilde{Q}(s, a) = Q(s, a) + \alpha \cdot \sqrt{\frac{2 \log N_s}{n_{s,a}}}$$

MCTS: Expansion

Expansion



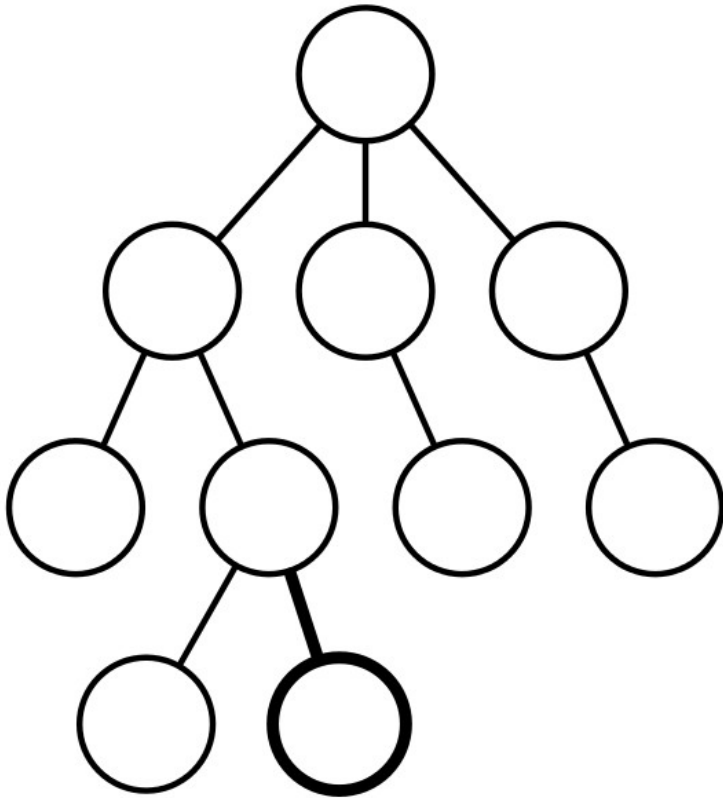
Add one or more children from the chosen node.

Each child is a one-step simulation $\mathbf{s} \rightarrow \mathbf{s}', \mathbf{a}, \mathbf{r}$

Simple case: add one node per action.

MCTS: Expansion

Expansion



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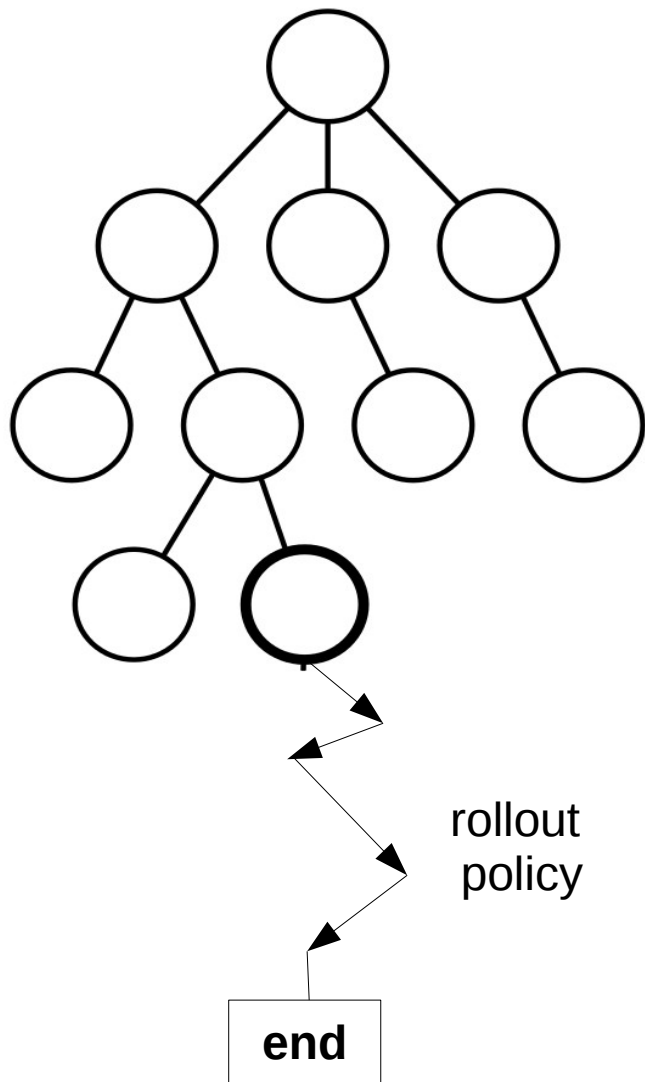
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Simple case: add one node per action.

Any ideas when this is won't work?

MCTS: Rollout (sampling)

Sampling



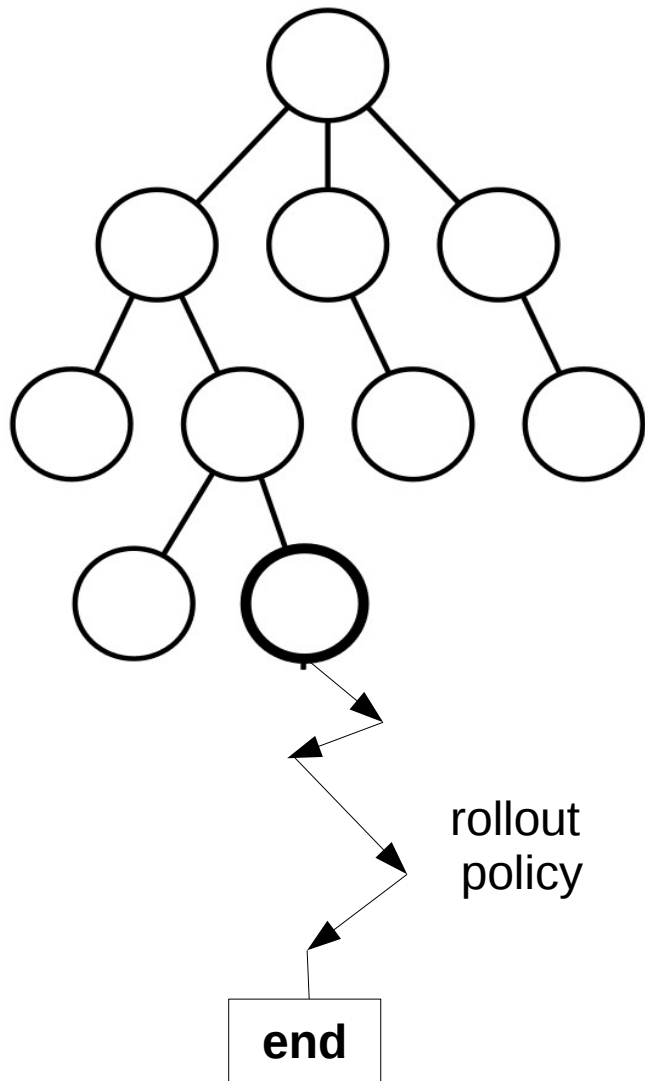
Estimate node value by playing game from that state till the end with simple policy.

e.g. random actions

Remember total reward.

MCTS: Rollout (sampling)

Sampling



Estimate node value by playing game from that state till the end with simple policy.

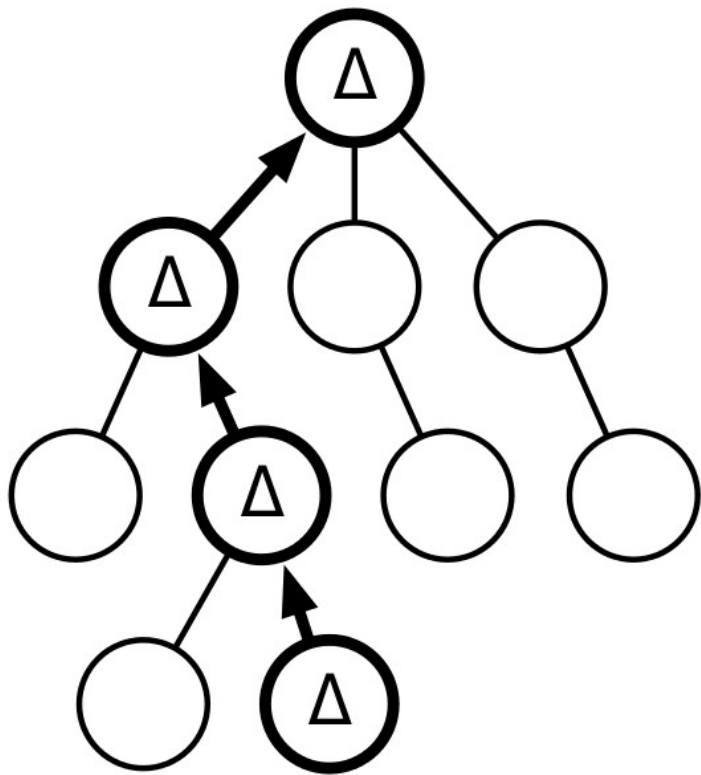
e.g. random actions

Remember total reward.

Can we do better than random?

MCTS: Backprop

Backpropagation

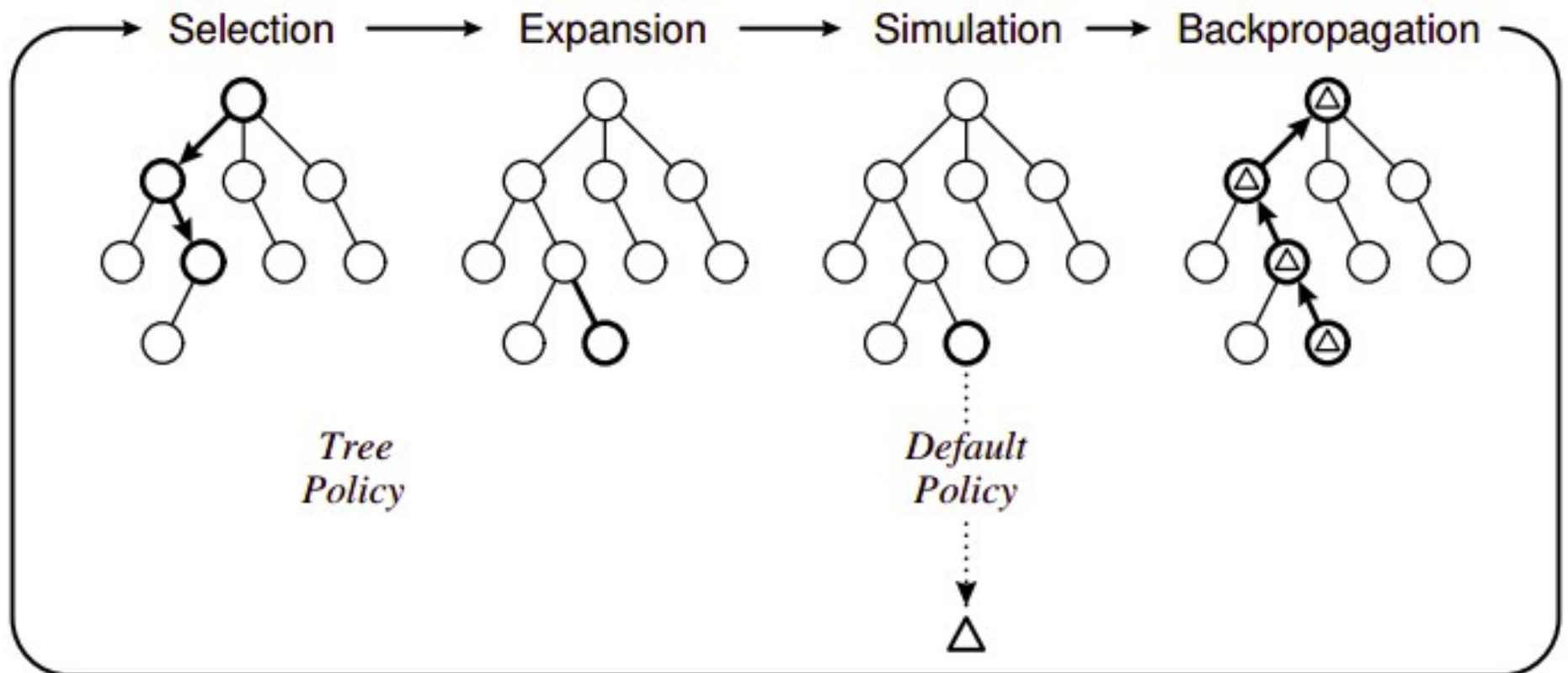


Given rollout reward,
update value of leaf and
all it's parents.

$$V(\text{parent}) = r + \gamma \cdot V(\text{child})$$

Also increment visit counts
(N and n_a for ucb-1)

MCTS



How do we pick action from root?

Brace yourselves



And now goes the part with actual cool stuff...³³