

Algorithms on the road to Monte Carlo Tree Search

Nathan R. Sturtevant

University of Denver

Twitter: @nathansttt

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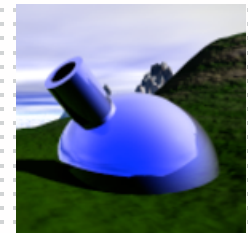


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AI ARTIFICIAL INTELLIGENCE
SUMMIT

GAME DEVELOPERS CONFERENCE

SAN FRANCISCO, CA
MARCH 17-21, 2014
EXPO DATES: MARCH 19-21

2014

Talk Goals

- Why Monte Carlo Tree Search (MCTS)?
- Understand at a high-level:
 - Regret Matching, UCB1, MCTS
- Prepare for next two lectures
- Demos on <http://movingai.com/gdc14/>

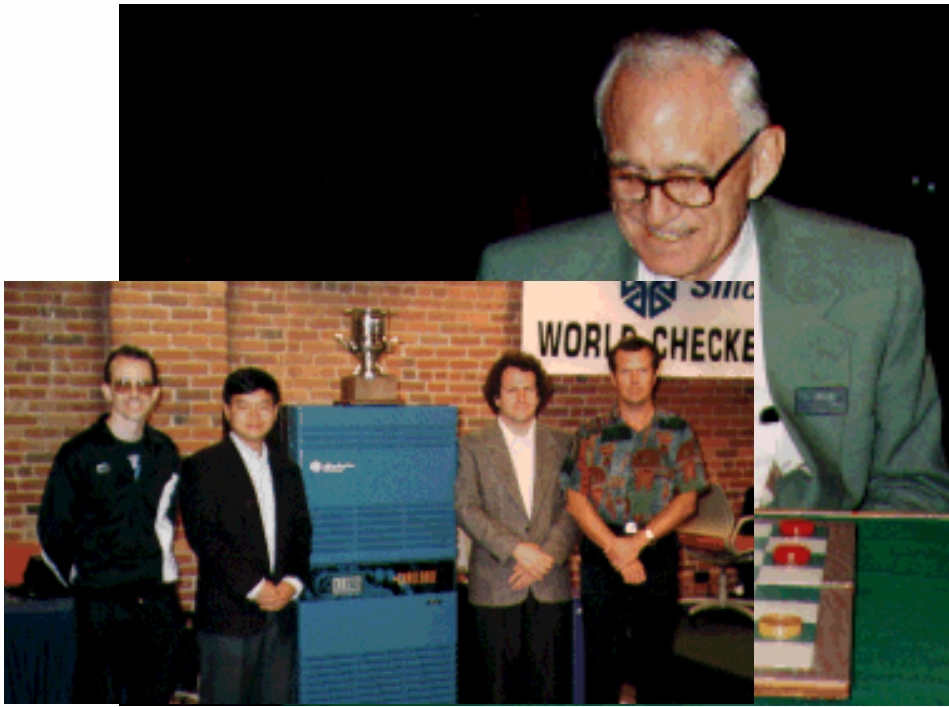
A Short History of Board Game AI



1990s: Checkers & Chess

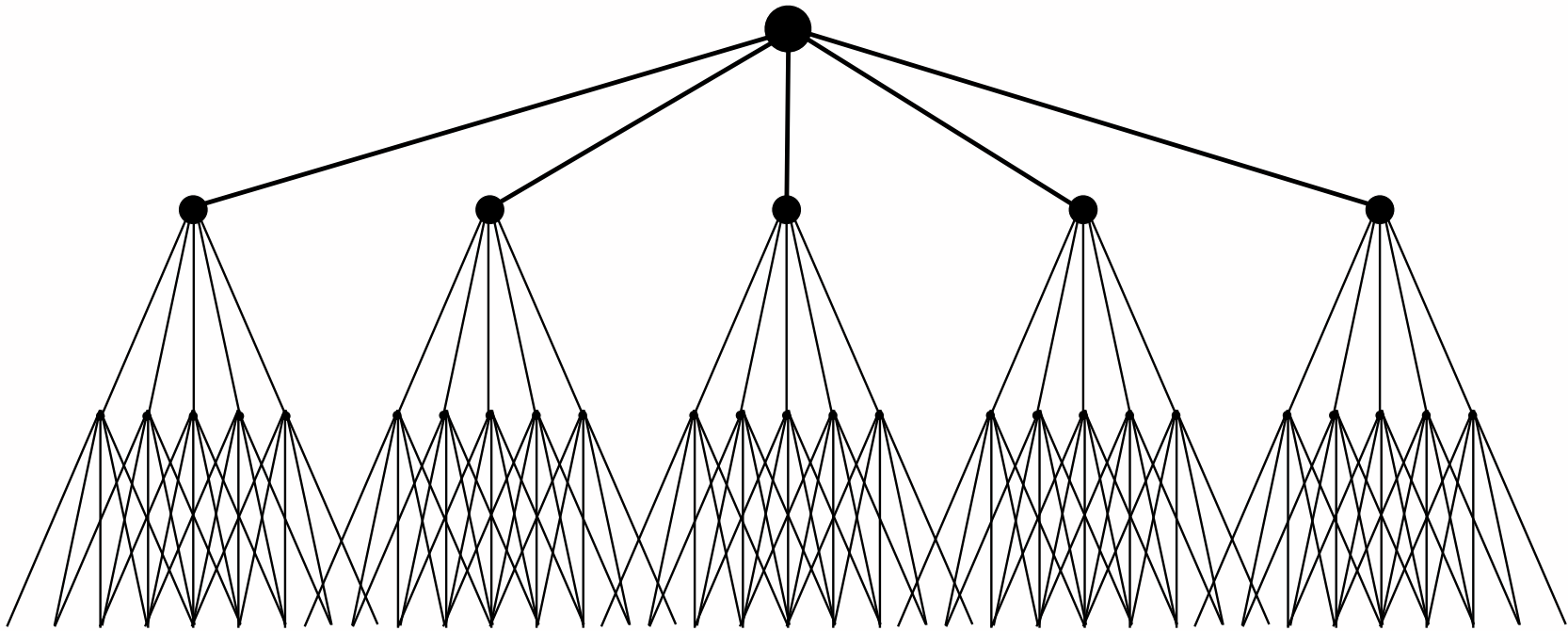


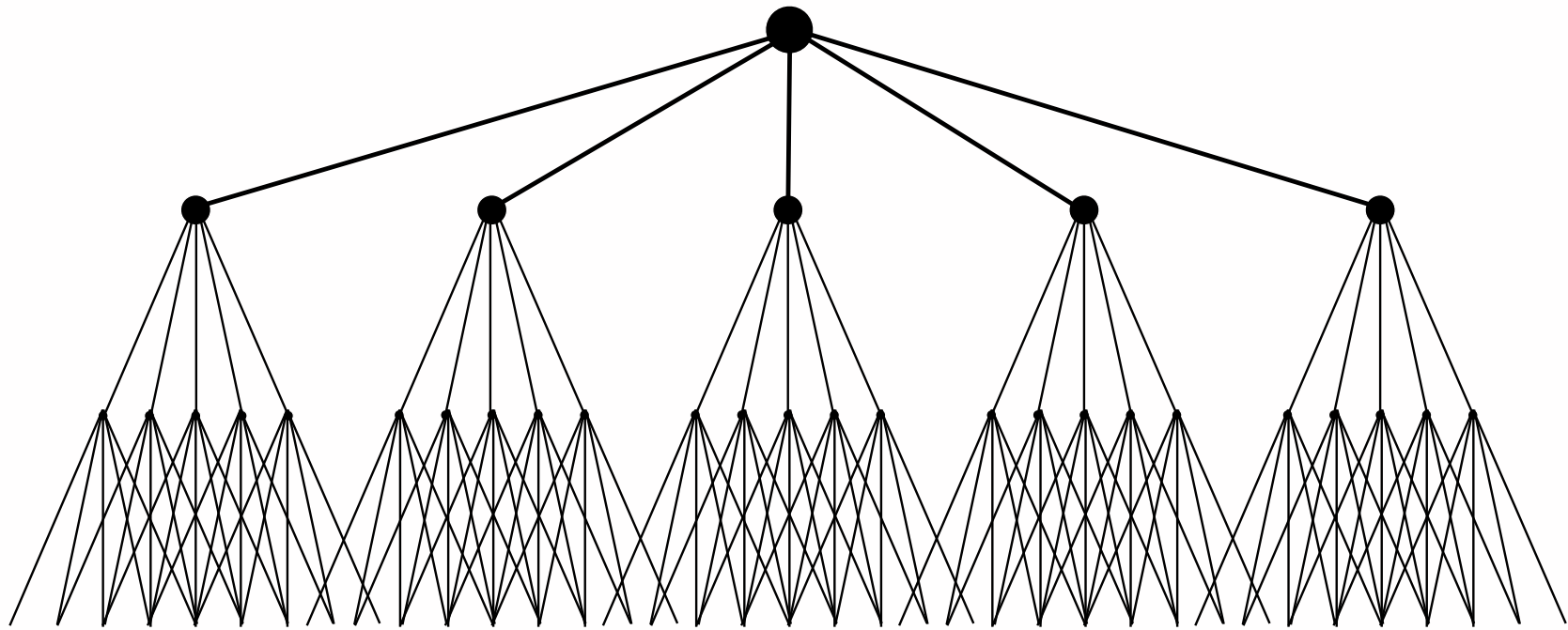
A Short History of Board Game AI



1990s: Checkers & Chess

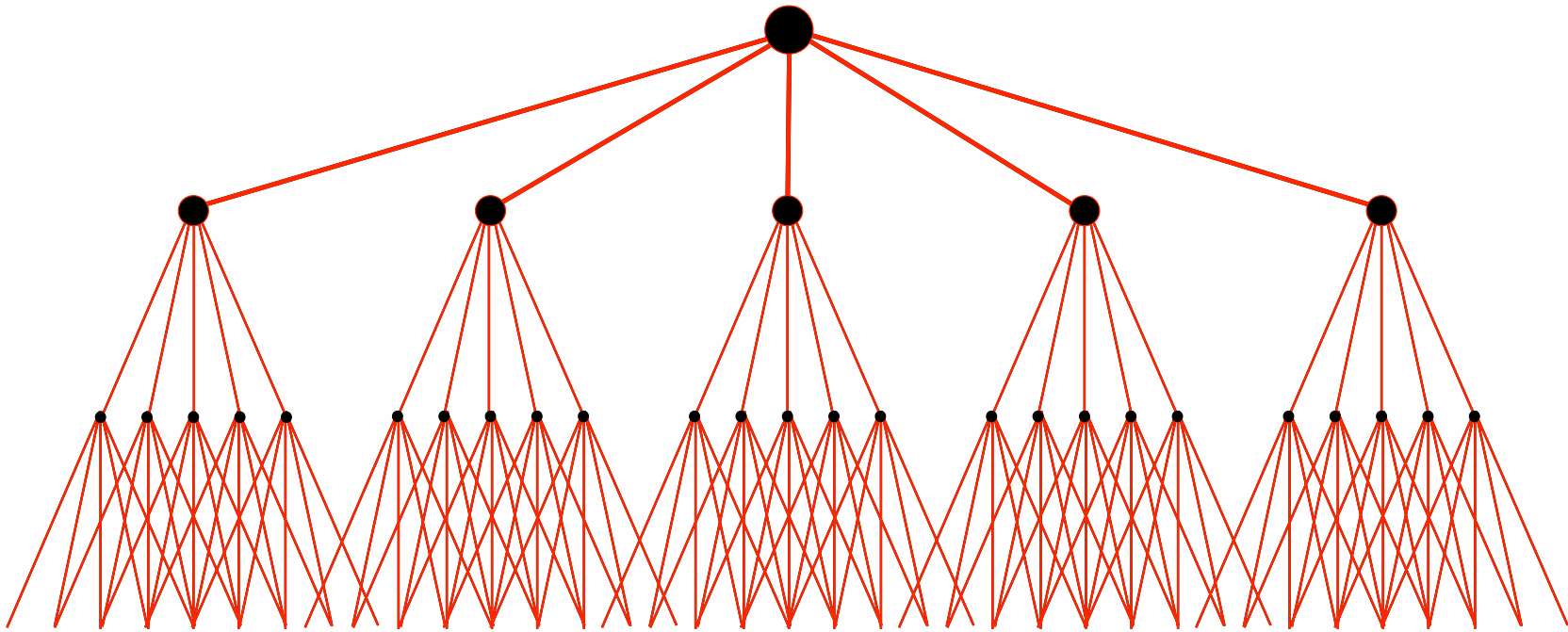






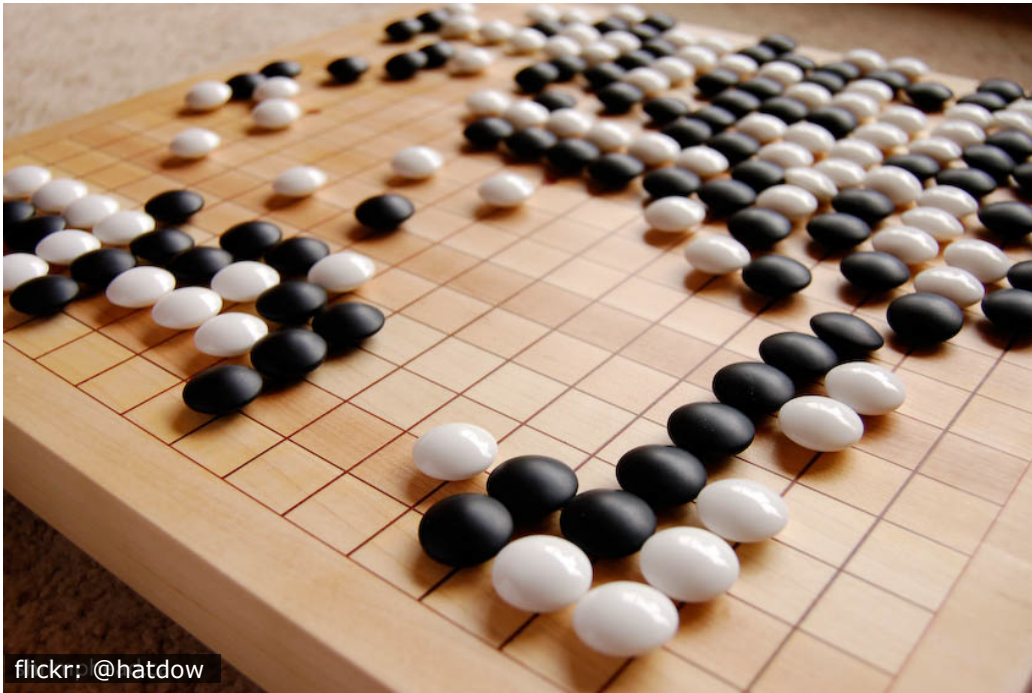
High Quality Evaluation Function

minimax/alpha-beta



High Quality Evaluation Function

Go



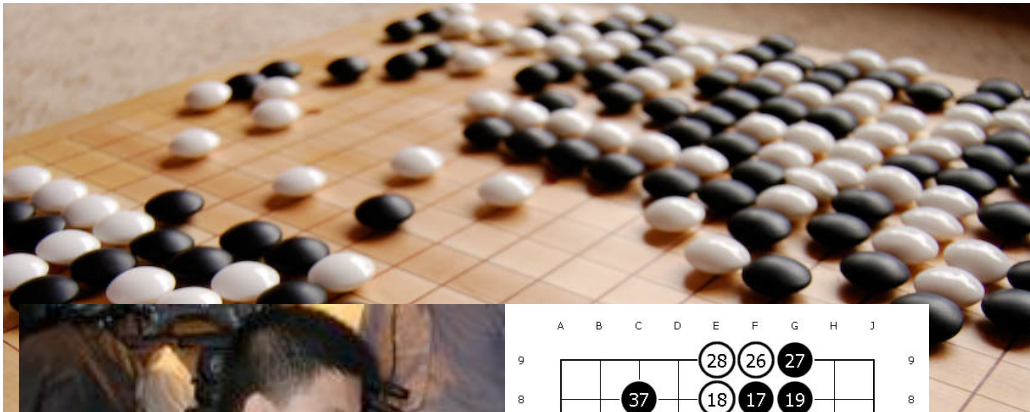
- Too many moves
- No good evaluation functions
- Lots of time to play

Go

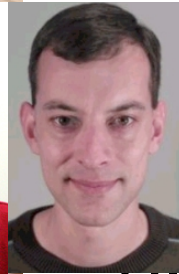
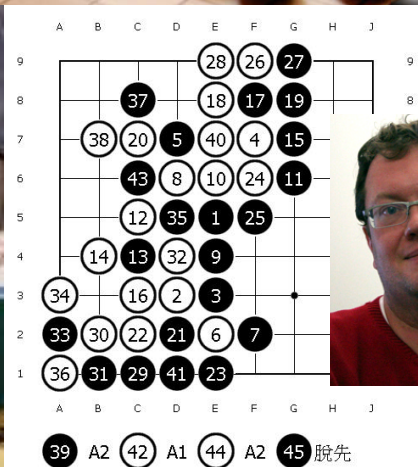


- Too many moves
- No good evaluation functions
- Lots of time to play

Go



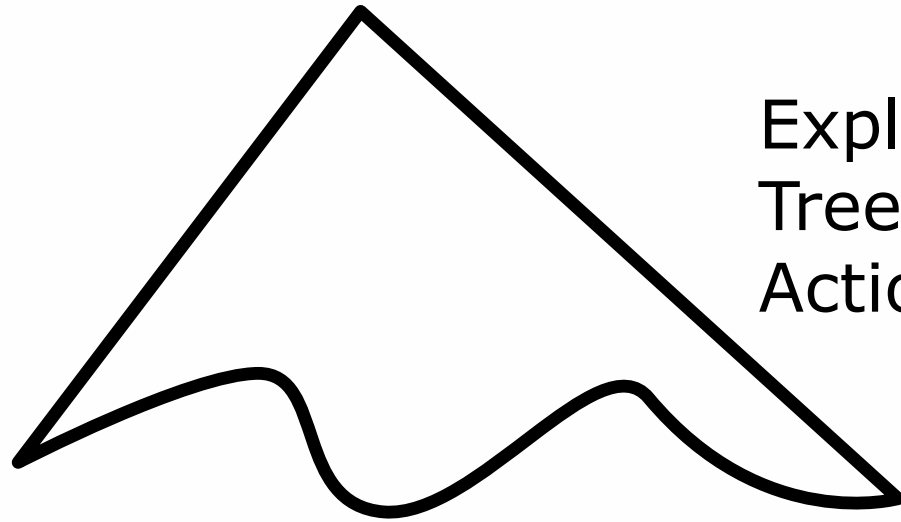
- Too many moves
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lots of time to play

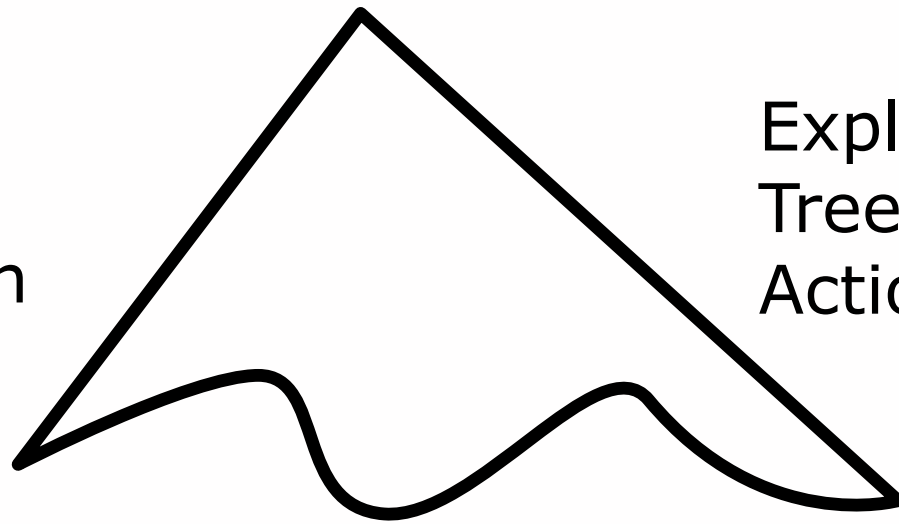
MCTS

Explicit
Tree of
Actions



MCTS

Tree Search

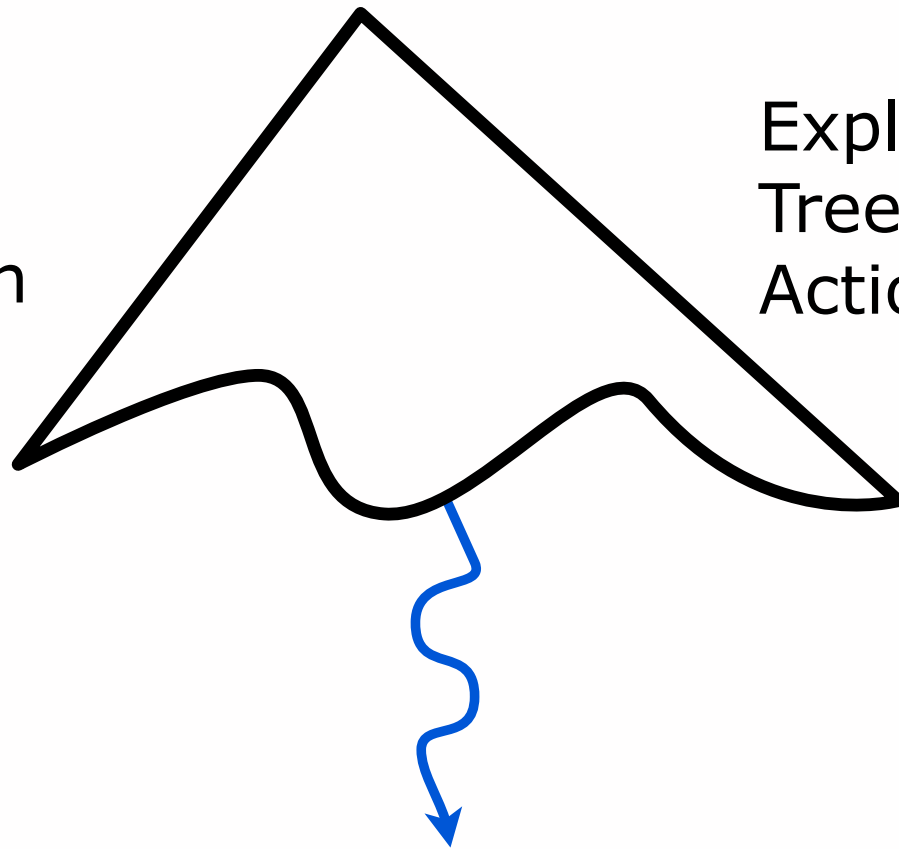


Explicit
Tree of
Actions

MCTS

Tree Search

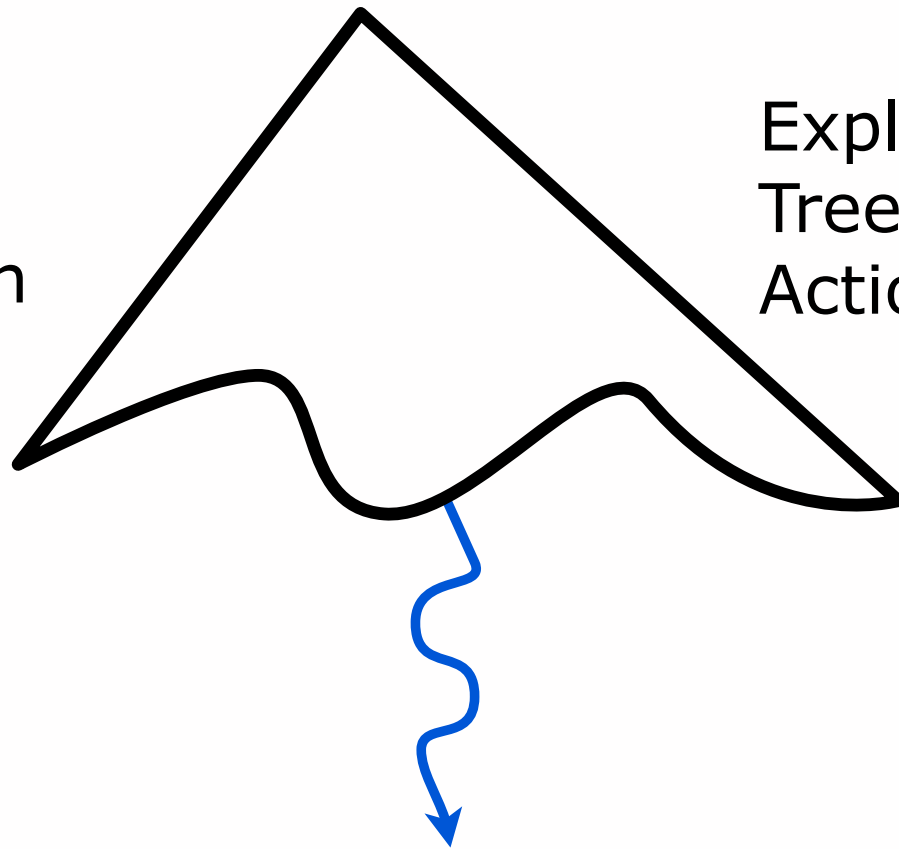
Explicit
Tree of
Actions



MCTS

Monte Carlo Tree Search

Explicit
Tree of
Actions



Utility

- Win = Max Utility
- Design Task
 - High Utility = Fun



Classification

Dynamic

Static

Regret Matching

FSM, etc.

MCTS

UCB1



Classification

Act on History

Predict Future

Regret Matching

UCB1

MCTS

Classification

Act on History

Predict Future

Regret Matching

UCB1

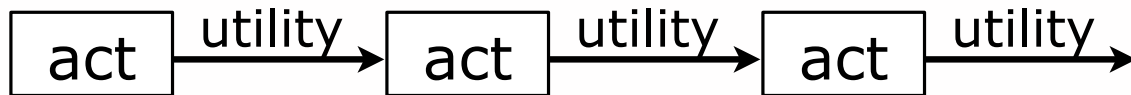
MCTS

Increasing Computation Cost

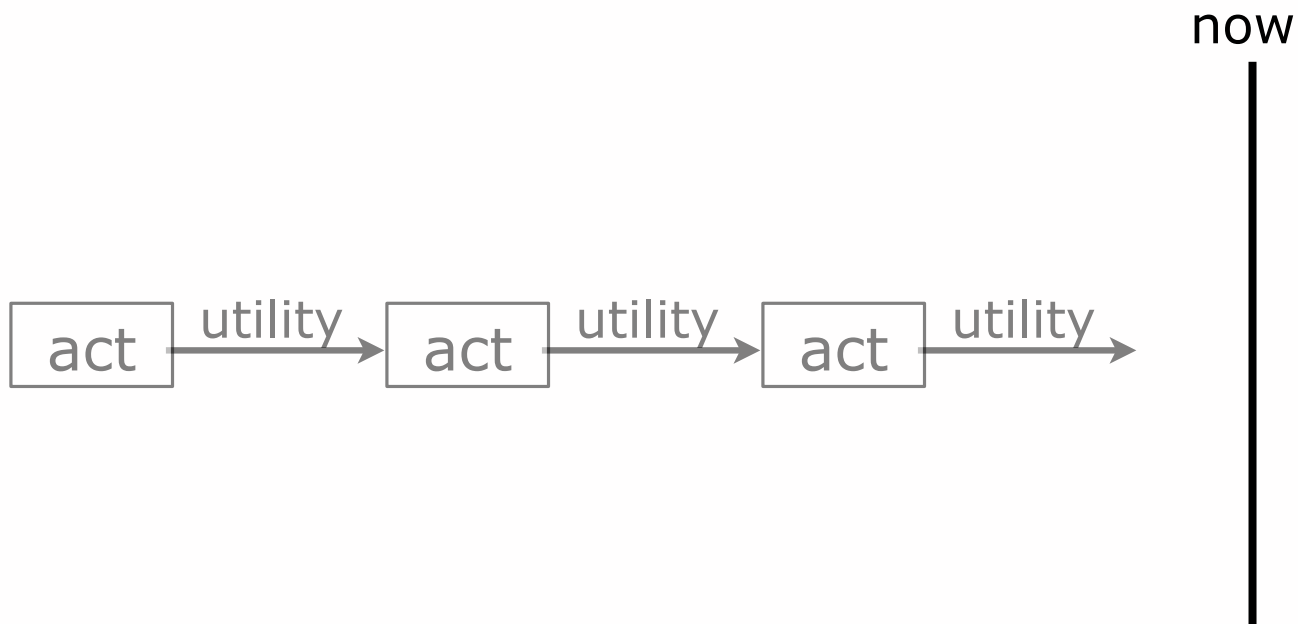


Act on History

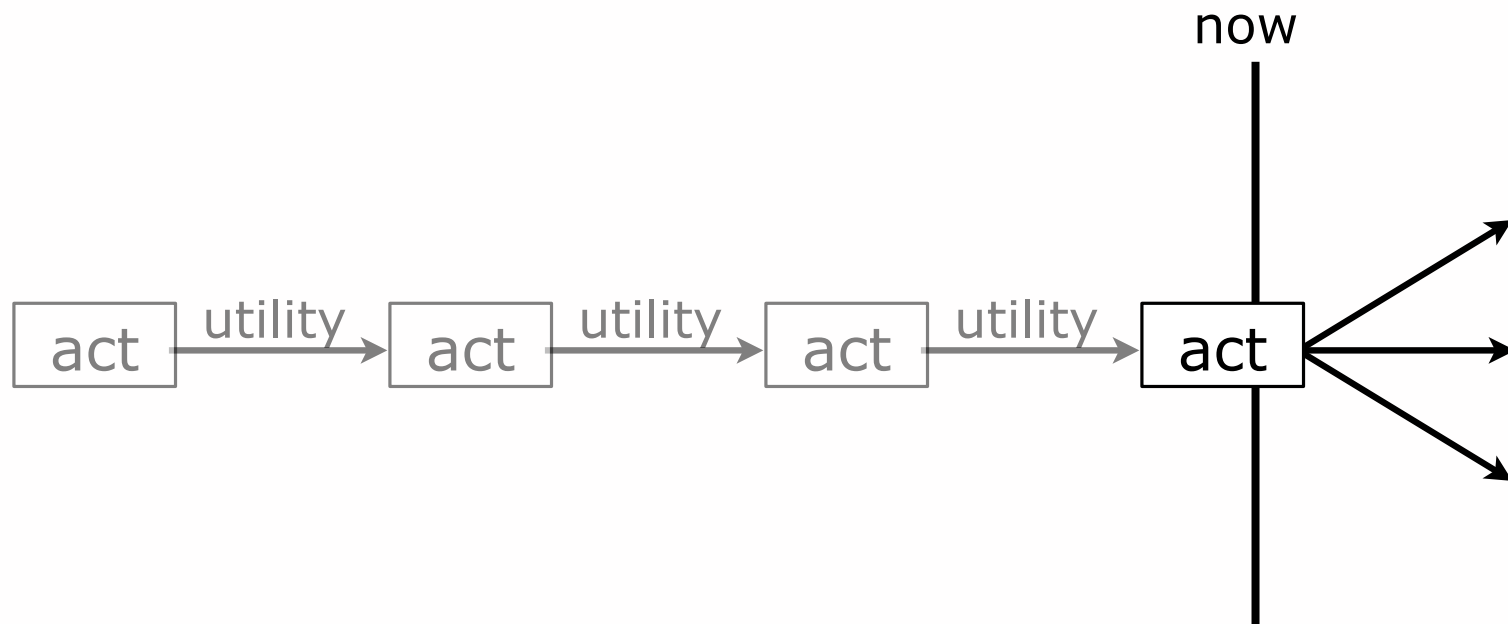
Act on History



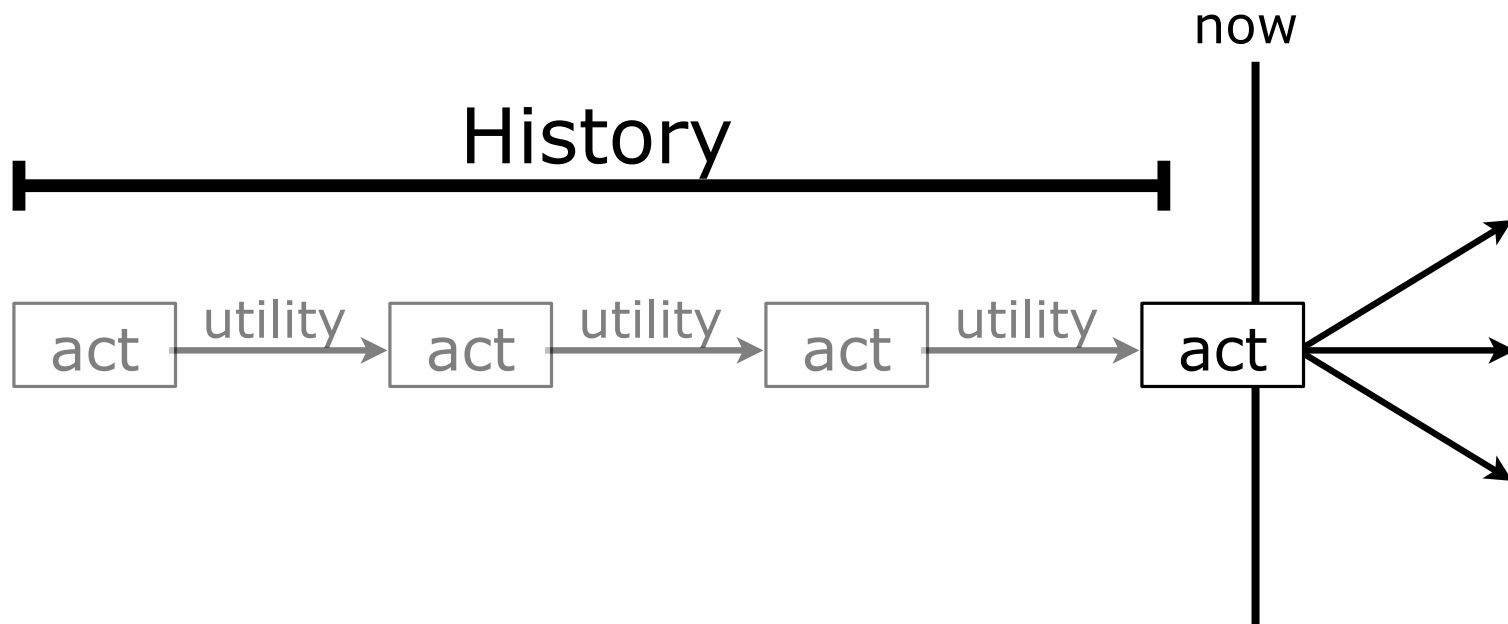
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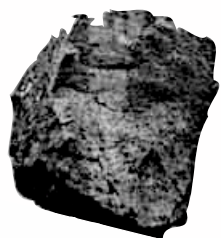


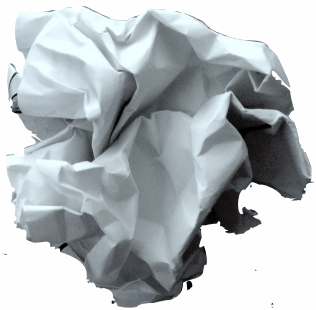
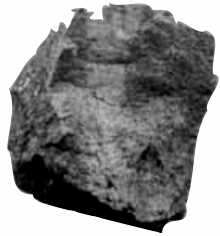
Act on History



Act on History

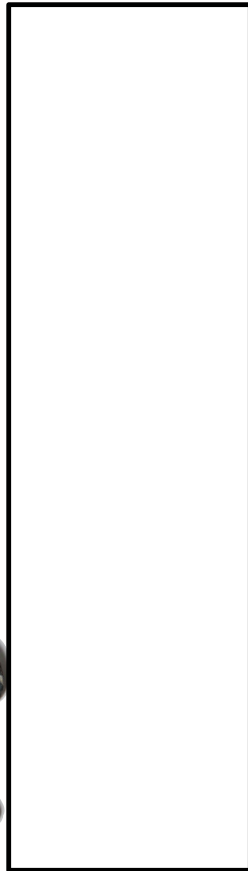
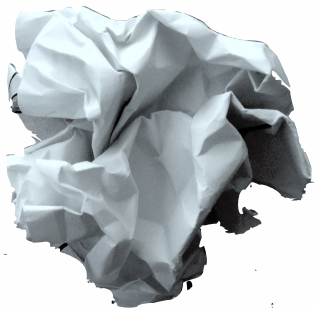
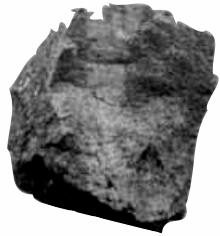






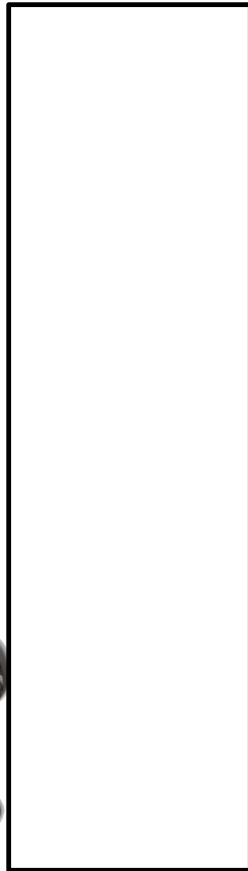
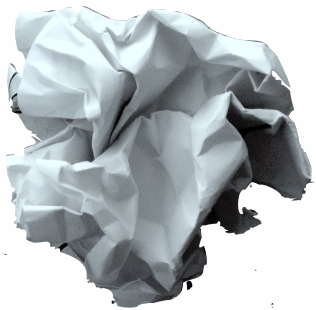
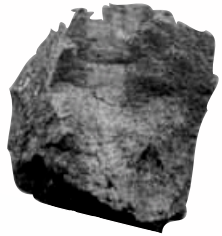
Regret Matching

Regret



Regret Matching

Regret



AI

Opponent

Round 1

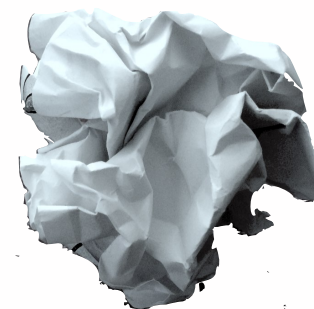
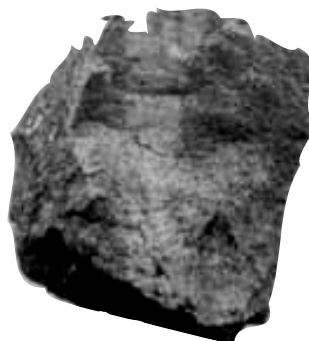
Regret Matching

Regret



AI

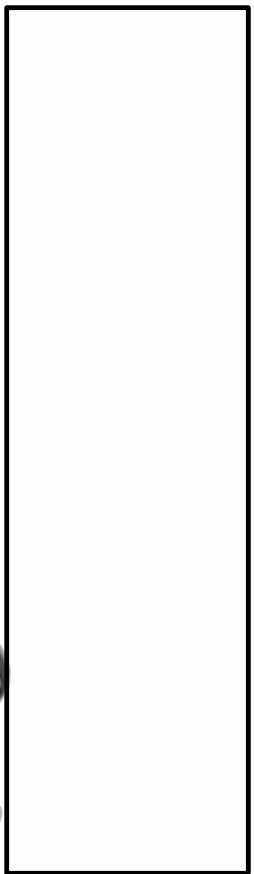
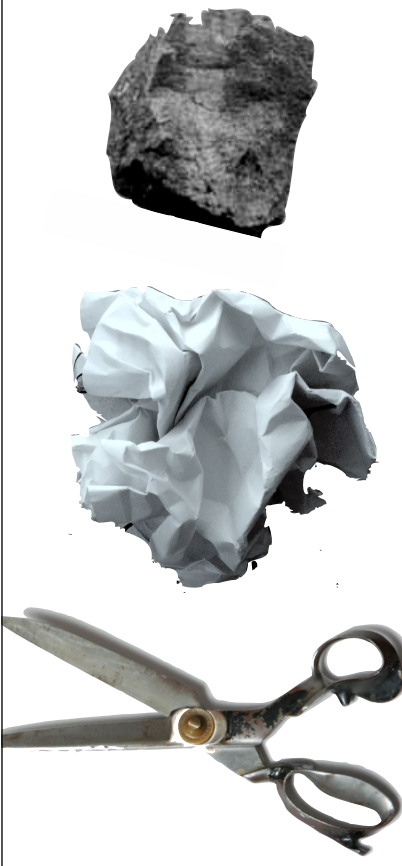
Opponent



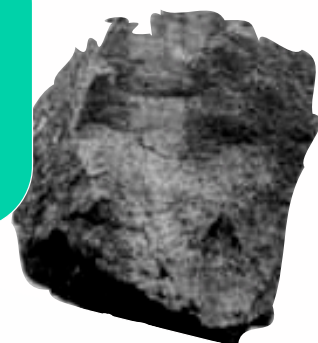
Round 1

Regret Matching

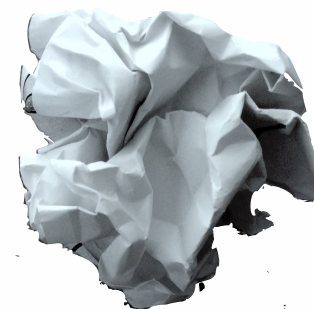
Regret



AI



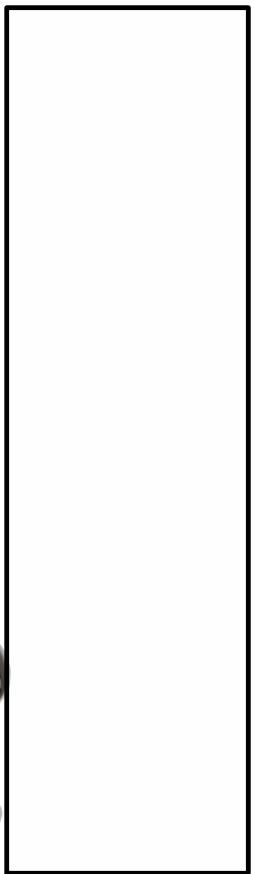
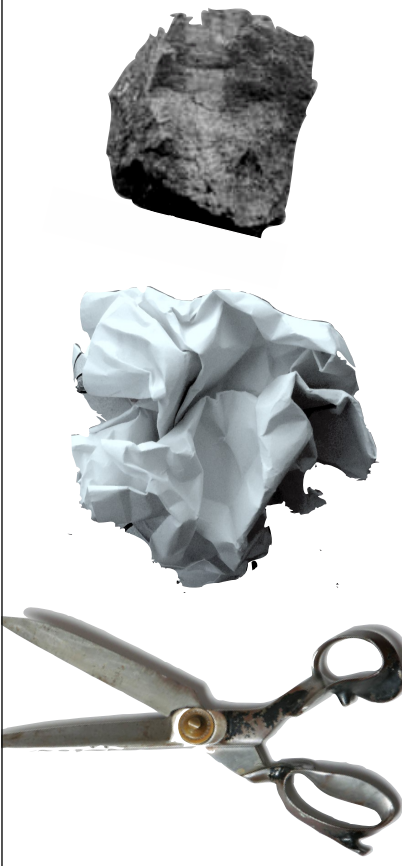
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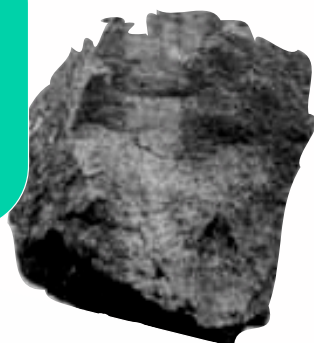
Round 1

Regret Matching

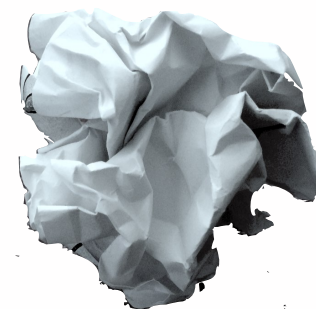
Regret



AI



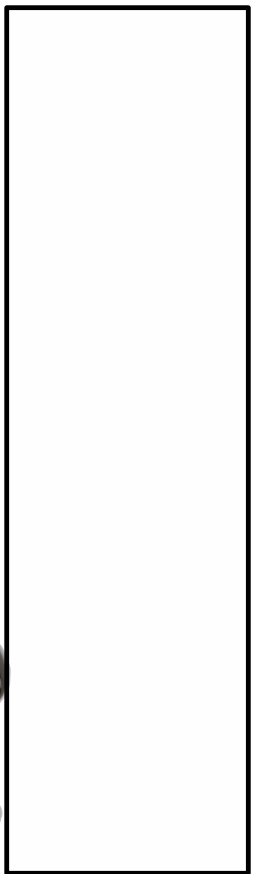
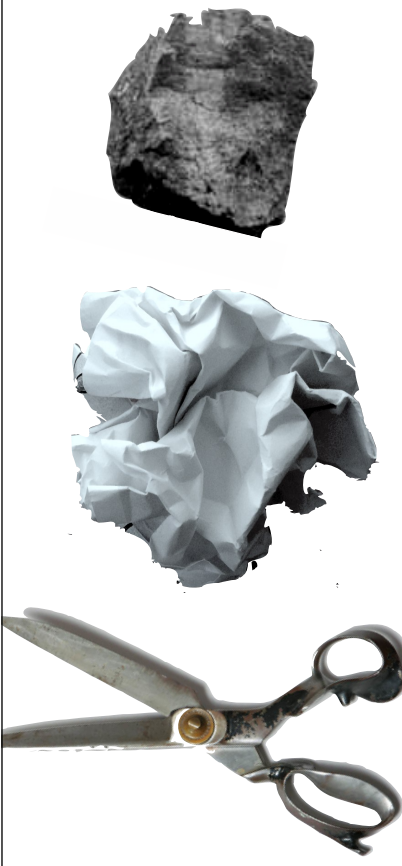
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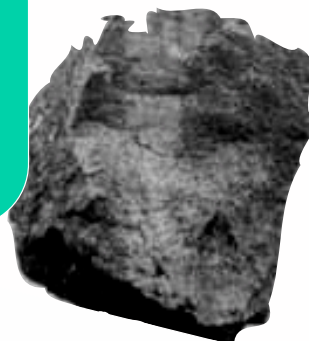
Round 1

Regret Matching

Regret



AI



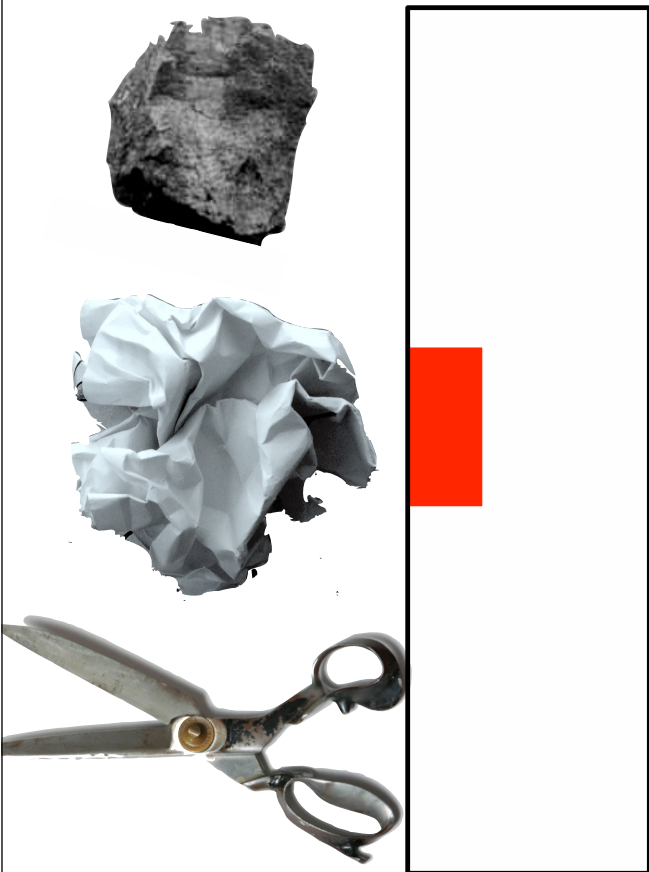
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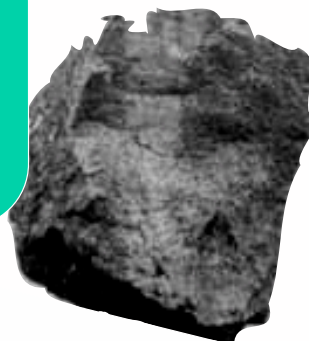
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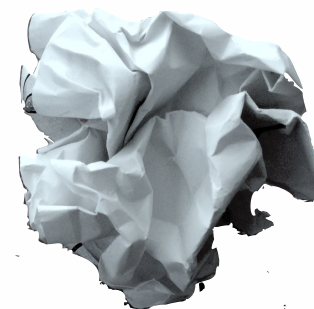
Regret



AI



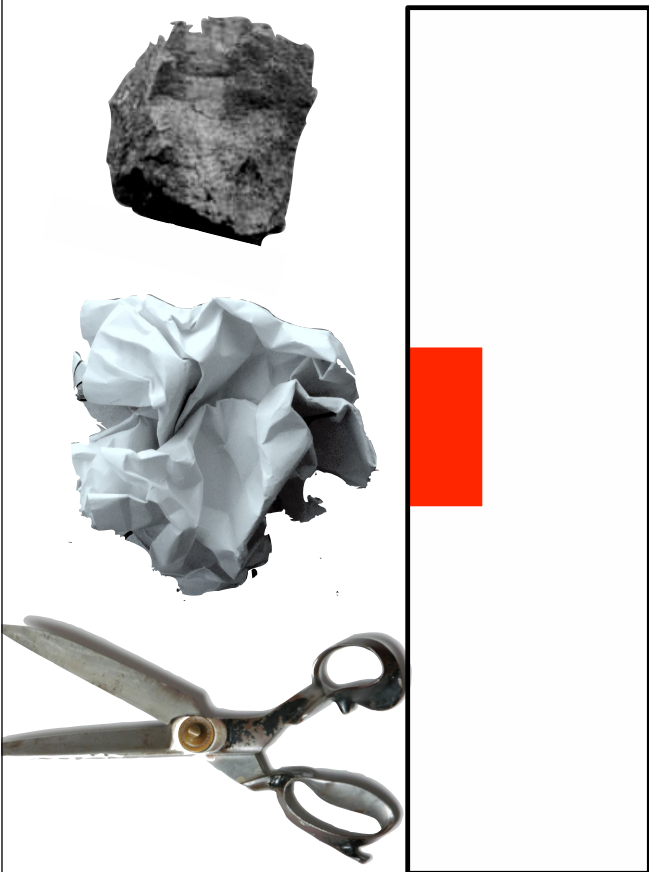
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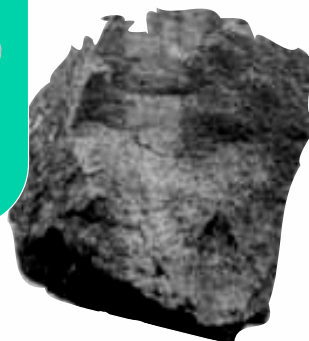
Round 1

Regret Matching

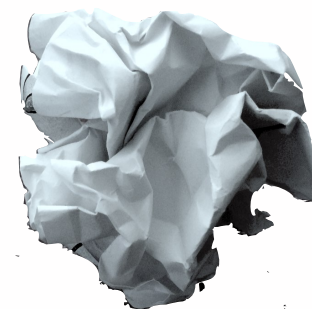
Regret



AI



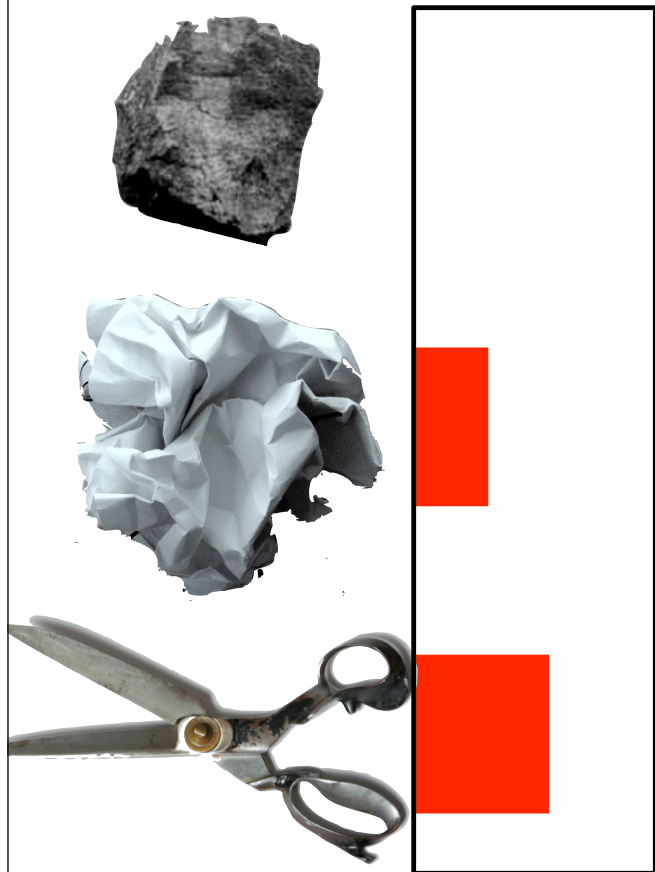
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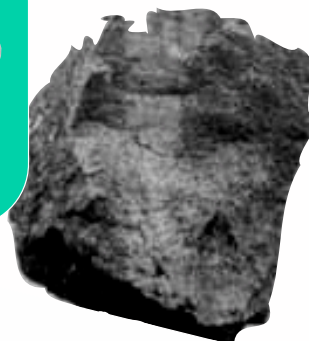
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Regret Matching

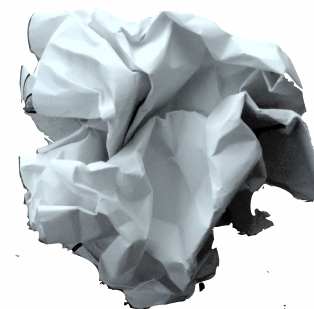
Regret



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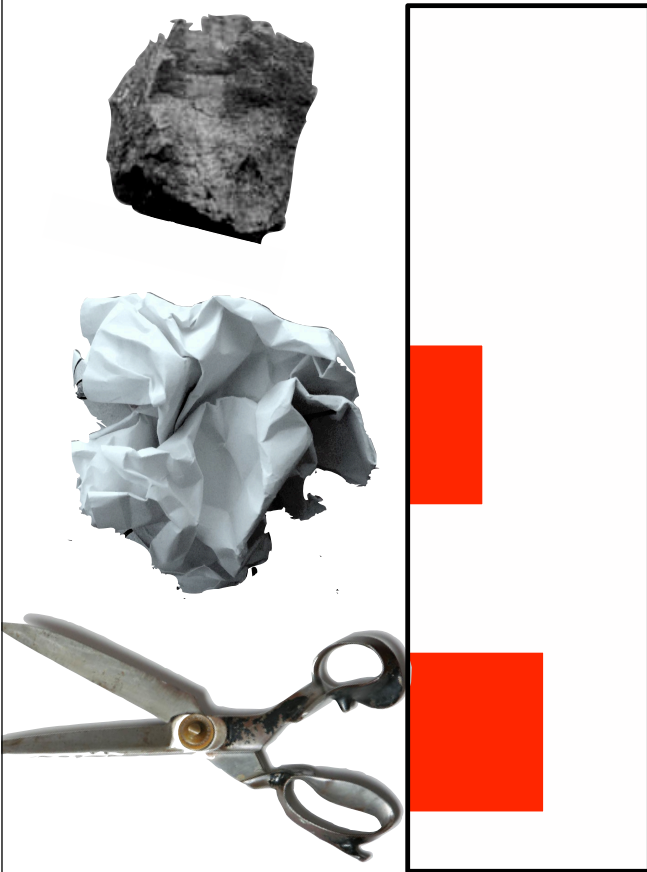
Opponent



Round 1

Regret Matching

Regret



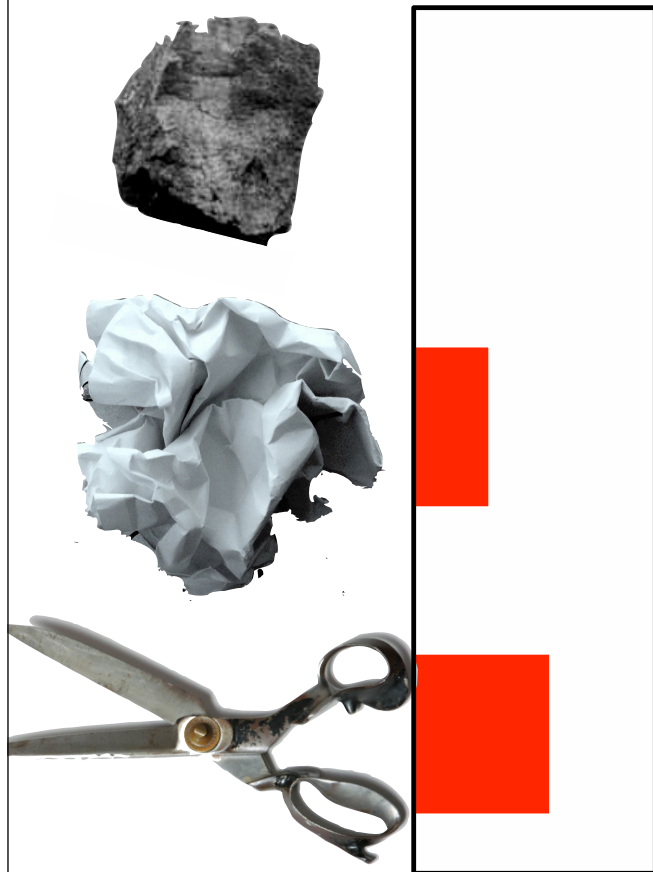
AI

Opponent

Round 2

Regret Matching

Regret



AI

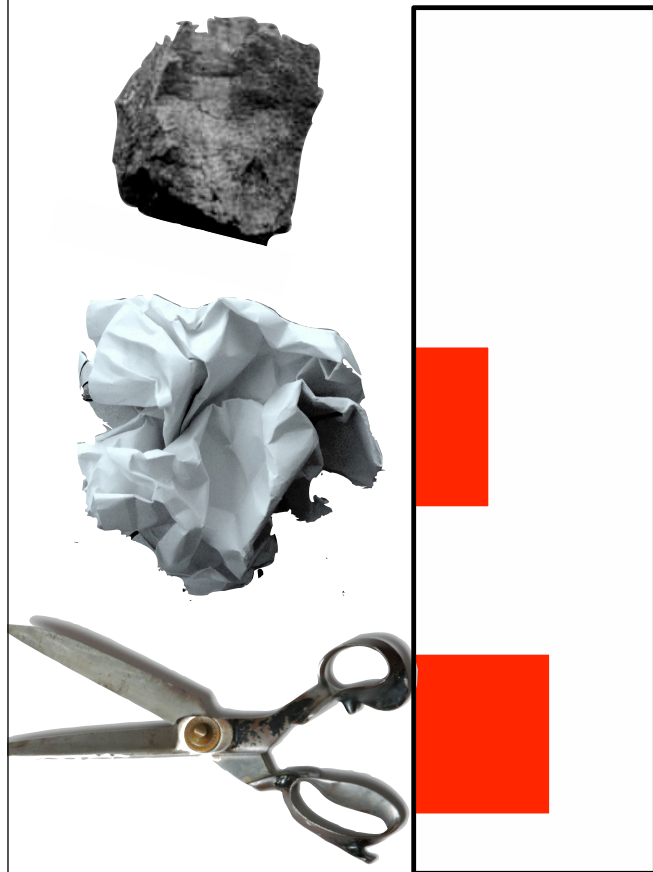
Opponent



Round 2

Regret Matching

Regret



AI



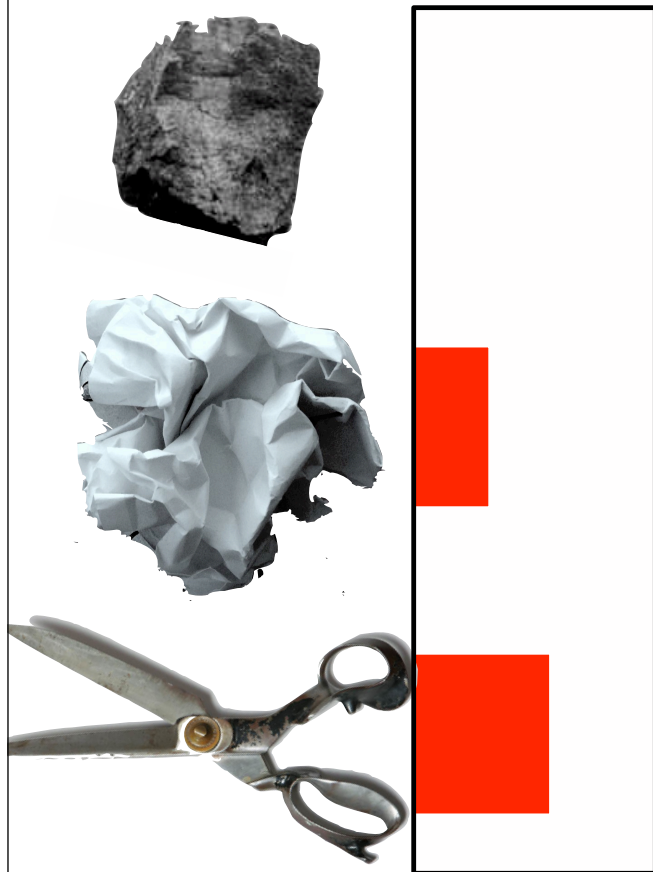
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Round 2

Regret Matching

Regret



AI



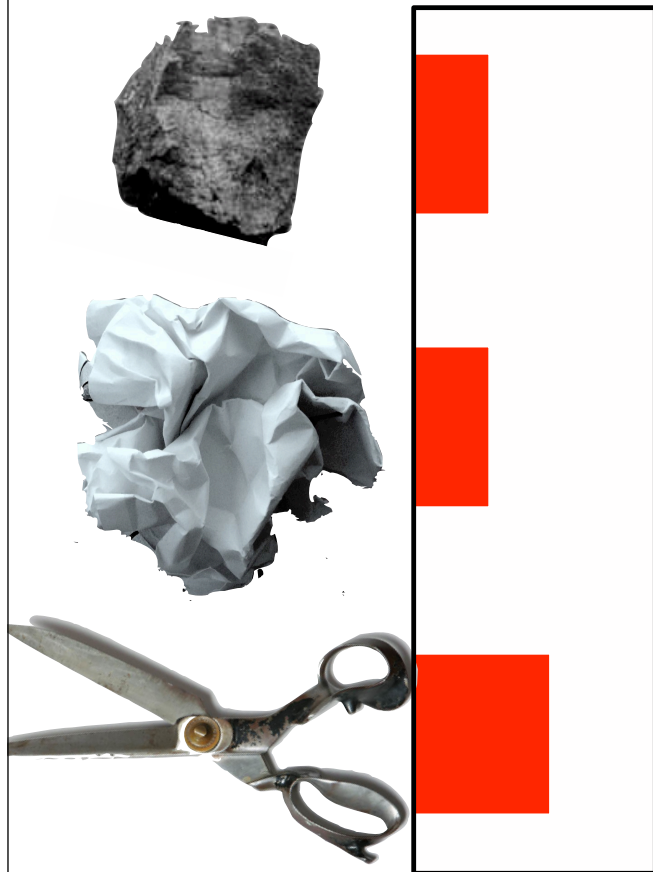
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Round 2

Regret Matching

Regret



AI



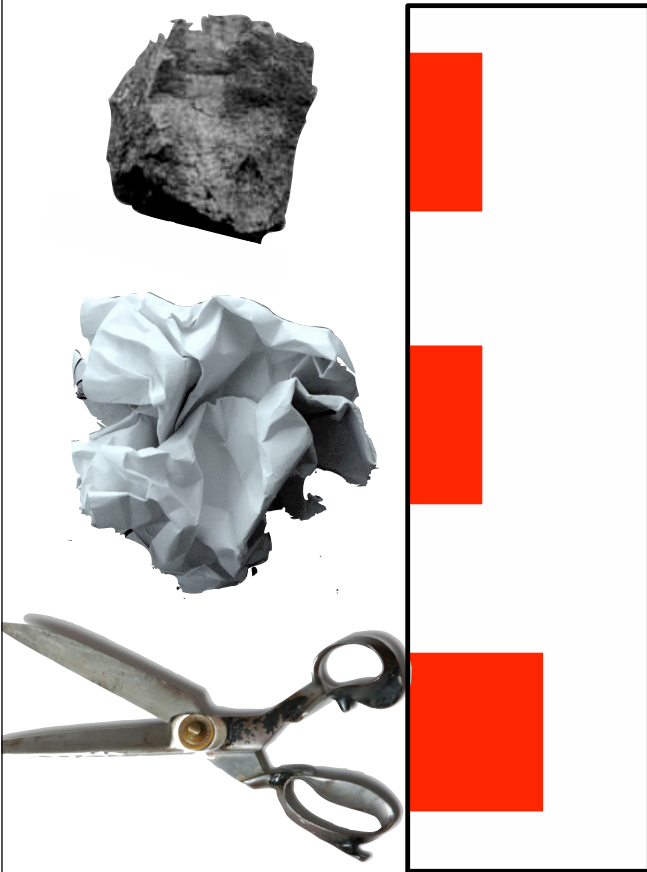
Opponent



Round 2

Regret Matching

Regret



AI



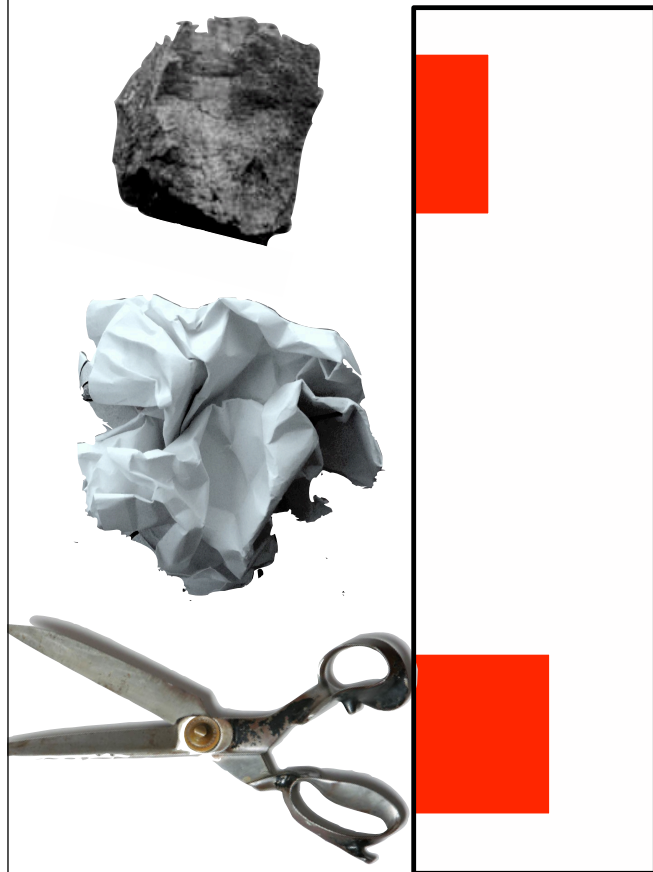
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Round 2

Regret Matching

Regret



AI



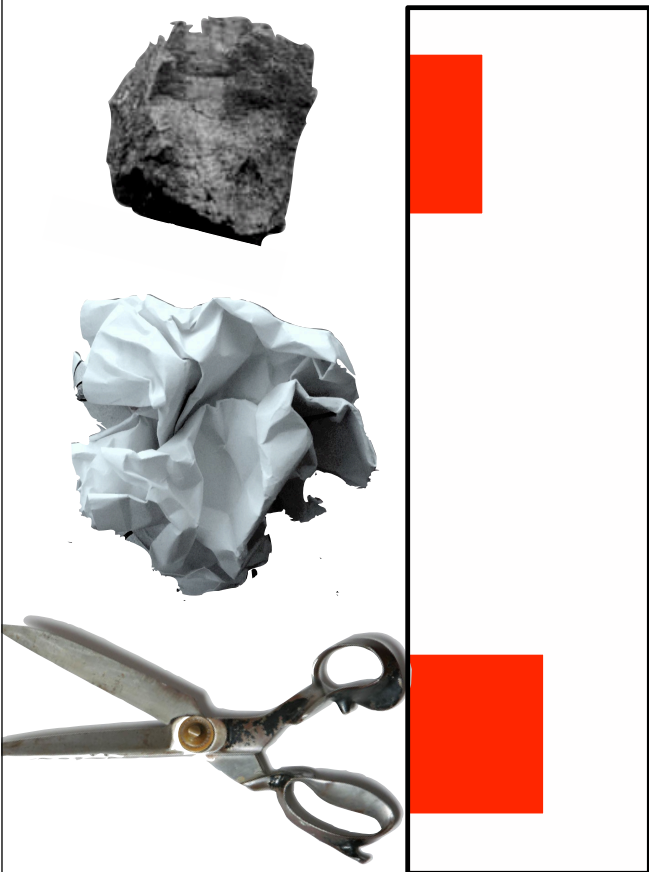
Opponent



Round 2

Regret Matching

Regret



AI



Opponent



Round 2

Regret Matching

Example: “Yomi” (David Sirlin)

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

Example: “Yomi” (David Sirlin)

Akira

Pai

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

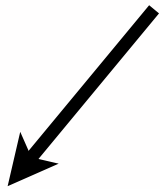
Example: “Yomi” (David Sirlin)

Akira knockdown Pai

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

Example: “Yomi” (David Sirlin)

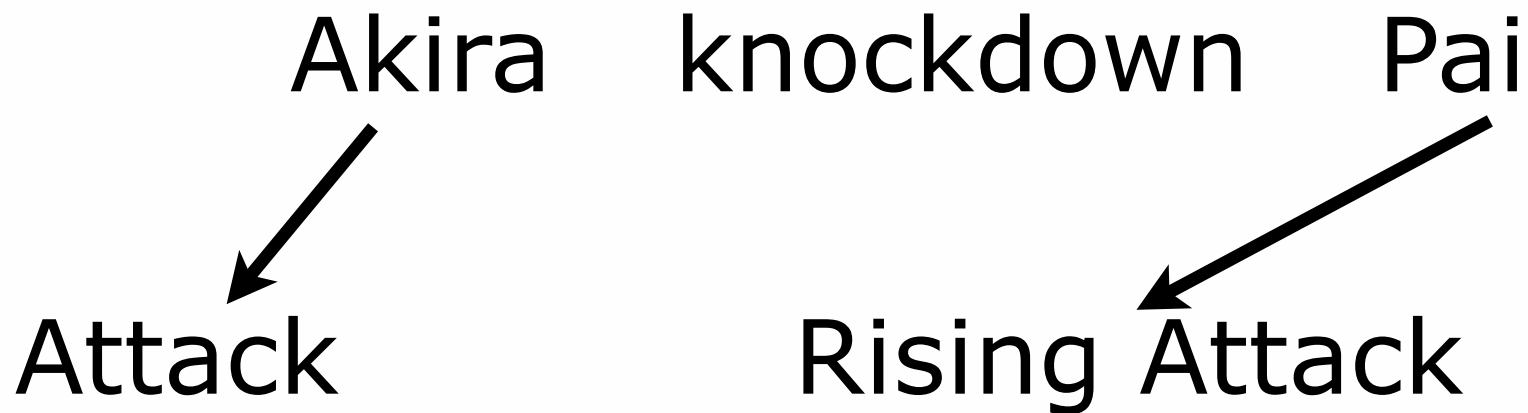
Akira knockdown Pai



Attack

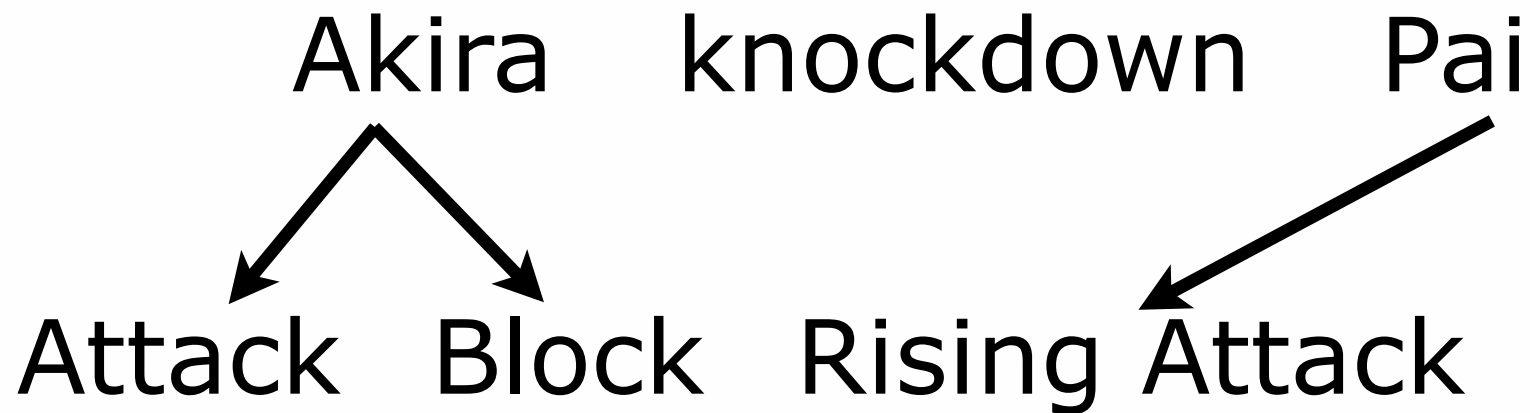
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Example: “Yomi” (David Sirlin)

Akira Block

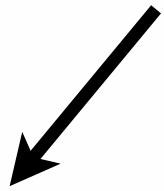
Pai Rising Attack

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

Example: "Yomi" (David Sirlin)

Akira Block

Pai Rising Attack

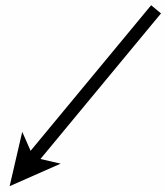


Throw

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

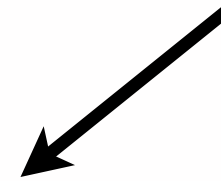
Example: "Yomi" (David Sirlin)

Akira Block



Throw

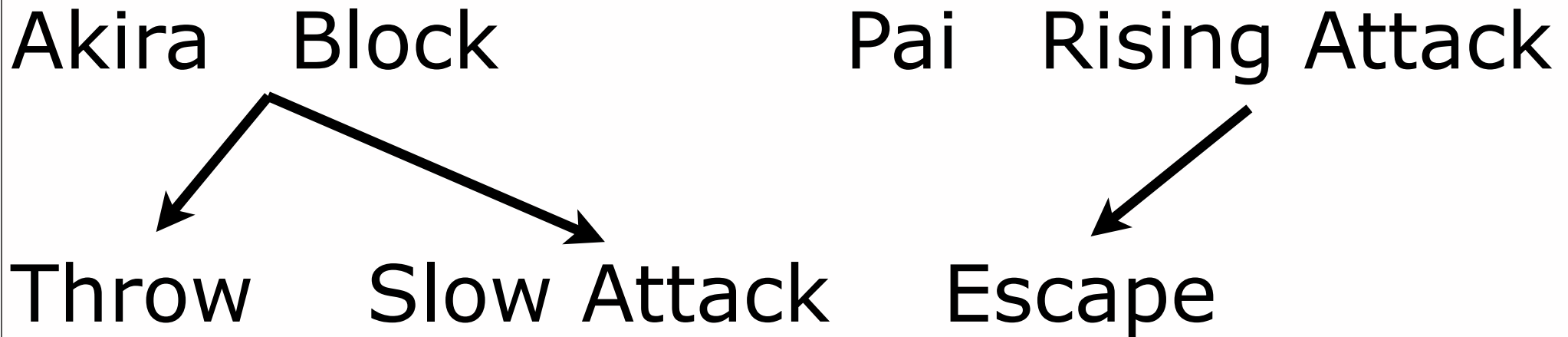
Pai Rising Attack



Escape

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

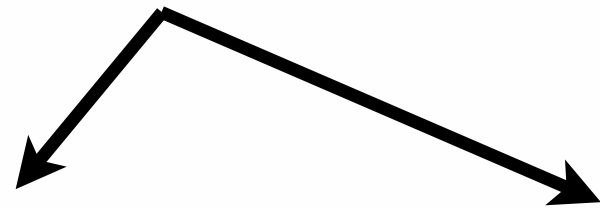
Example: "Yomi" (David Sirlin)



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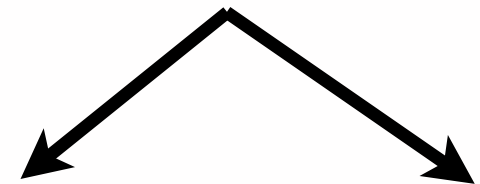
Example: "Yomi" (David Sirlin)

Akira Block



Throw Slow Attack

Pai Rising Attack



Escape Block

<http://www.sirlin.net/ptw-book/7-yomi-spies-of-the-mind.html>

Actions vs Strategies

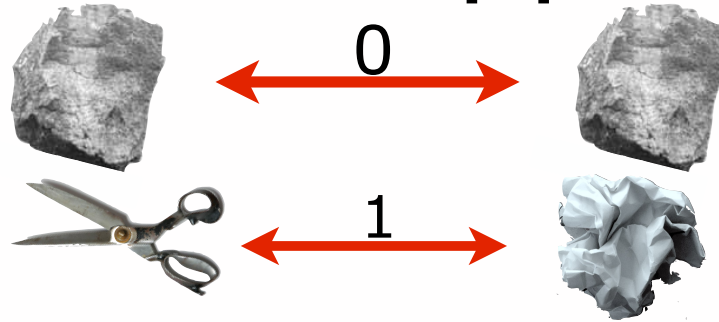


flickr: @helderjean

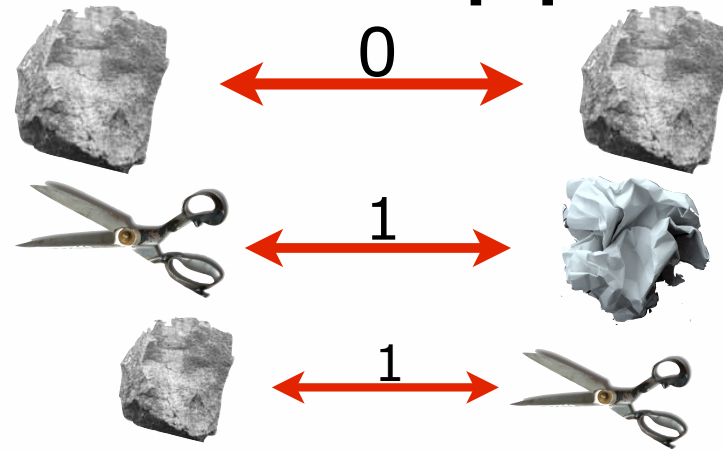
AI Opponent



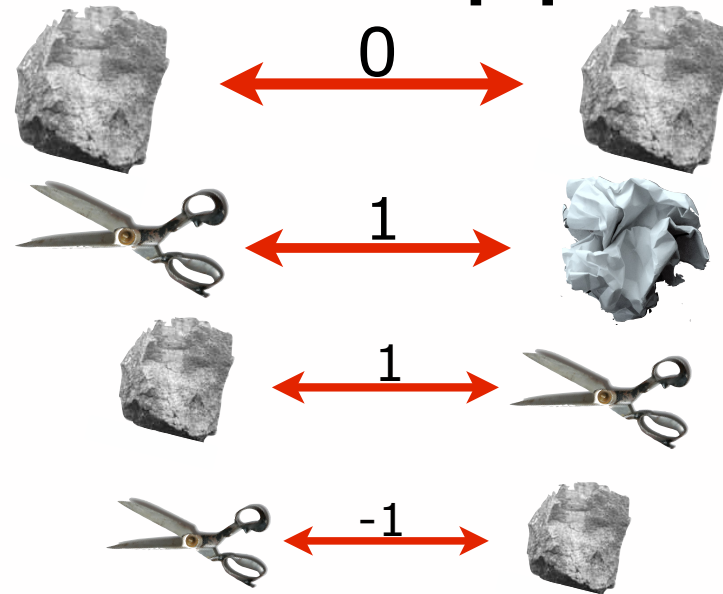
AI Opponent



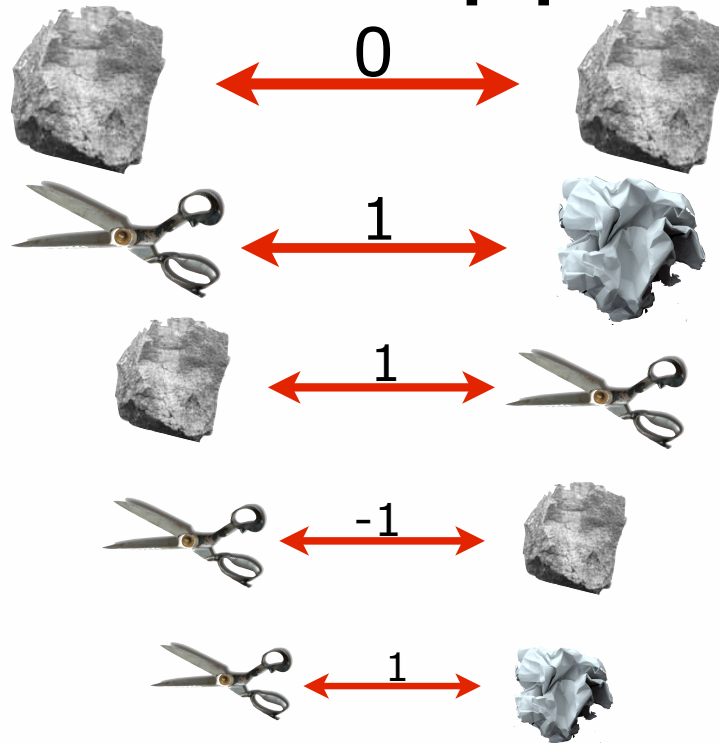
AI Opponent



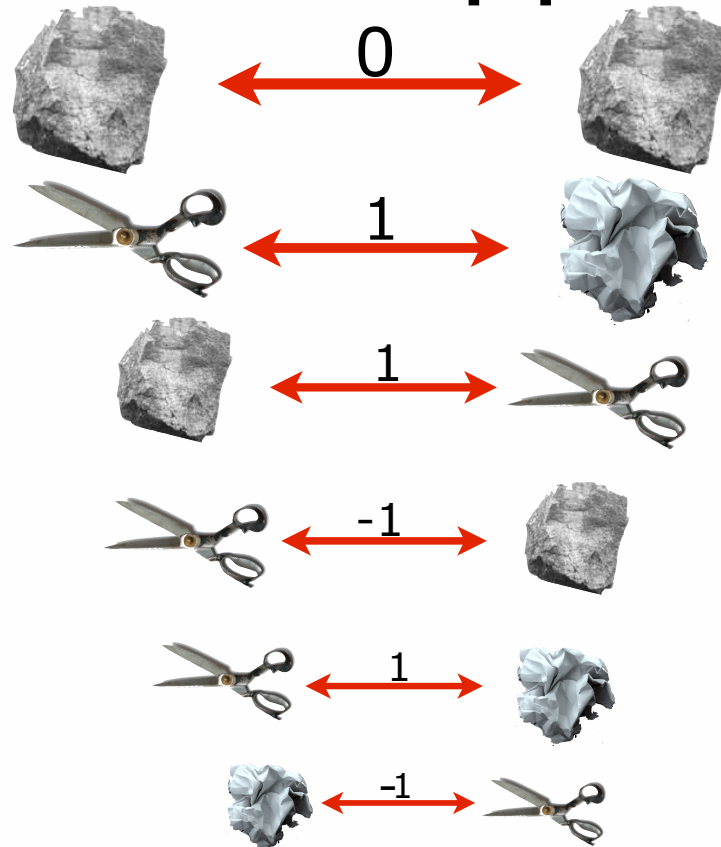
AI Opponent



AI Opponent

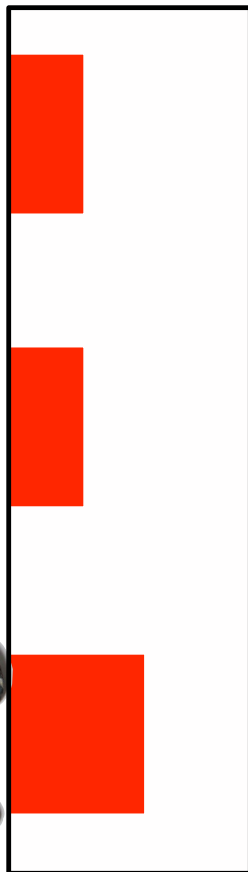
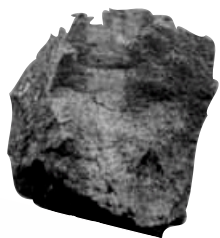


AI Opponent



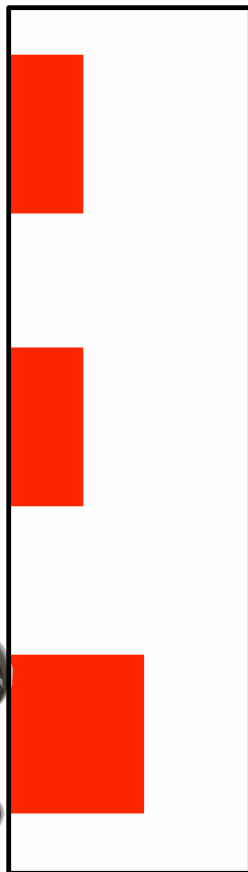
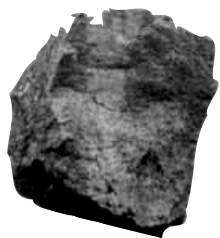
Action

Regret



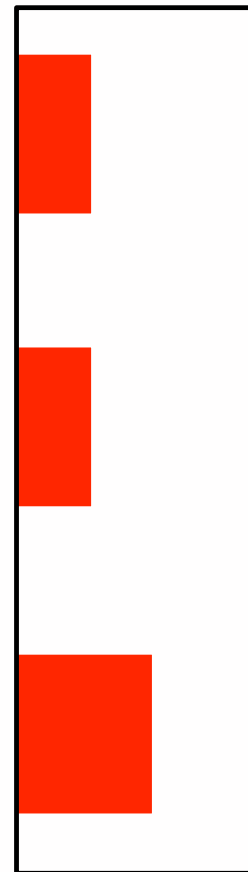
Action

Regret



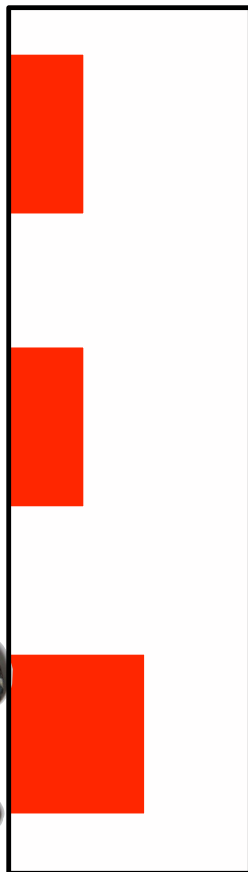
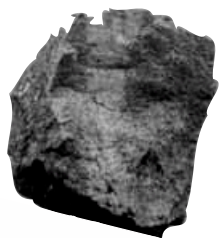
Strategy

Regret



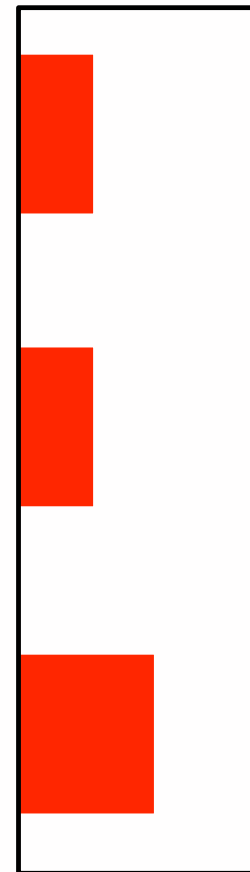
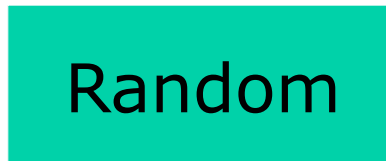
Action

Regret



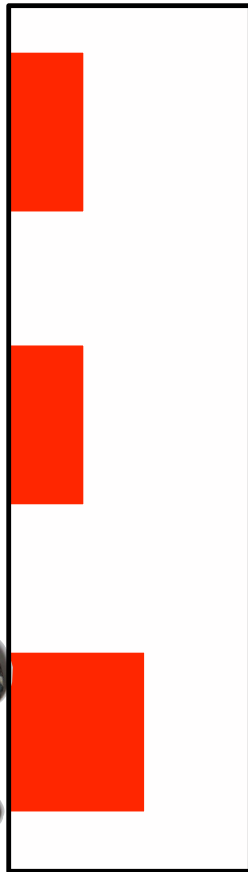
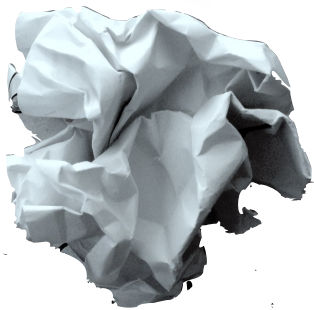
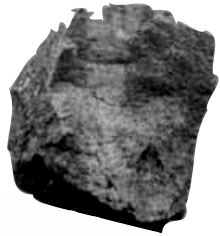
Strategy

Regret



Action

Regret

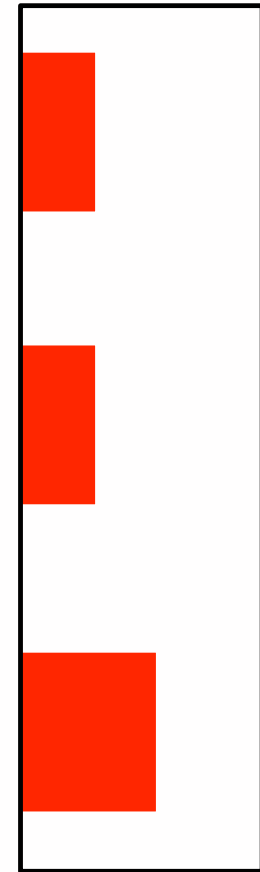


Strategy

Regret

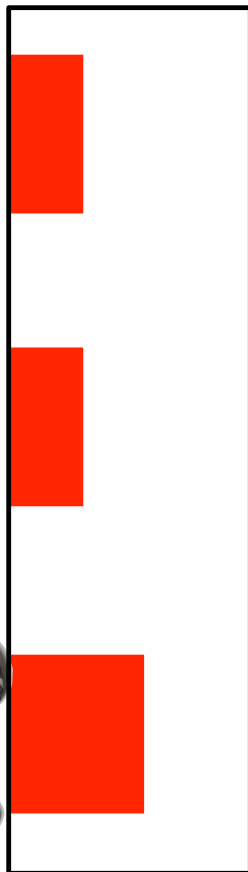
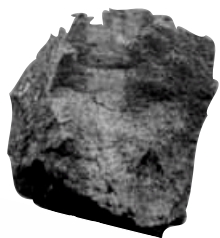
Random

Imitate Opponent



Action

Regret



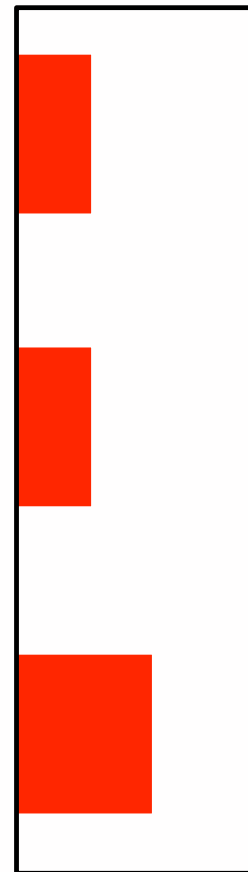
Strategy

Regret

Random

Imitate
Opponent

Beat
Imitator





Starcraft II



Armor Alley

Swords & Soldiers



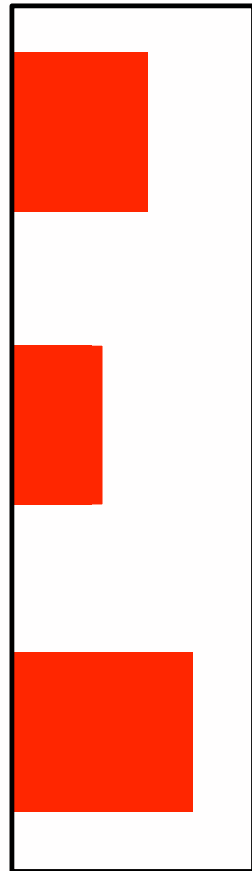
Strategy

Regret

Random

Imitate
Opponent

Beat
Imitator



Regret Matching

Strategy

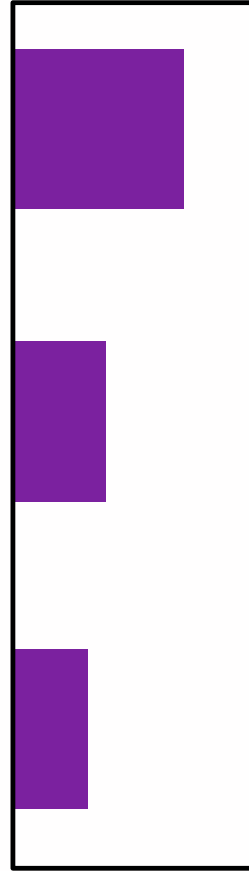
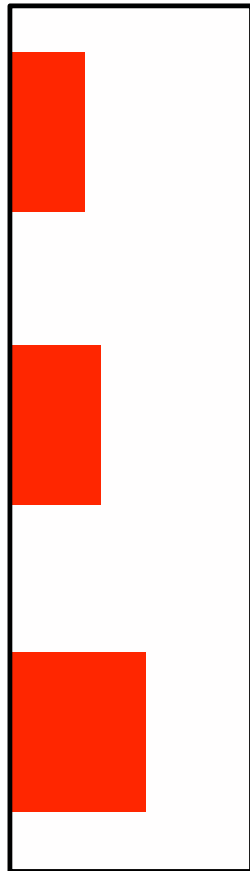
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

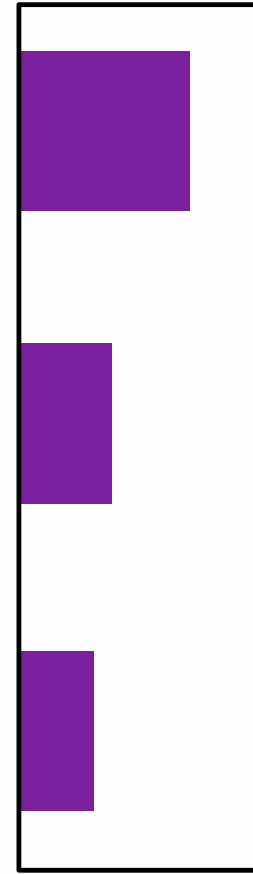
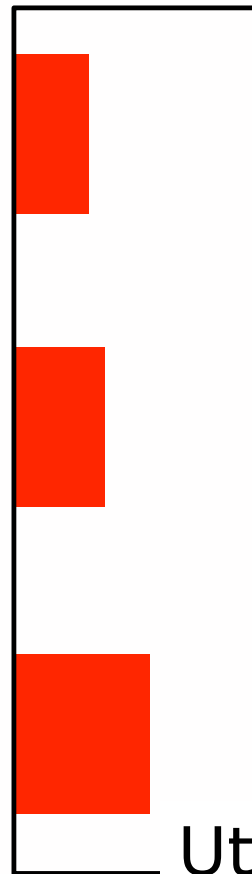
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



Utility

UCB1

Strategy

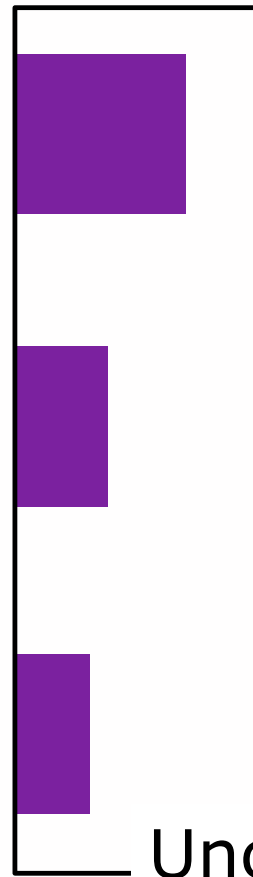
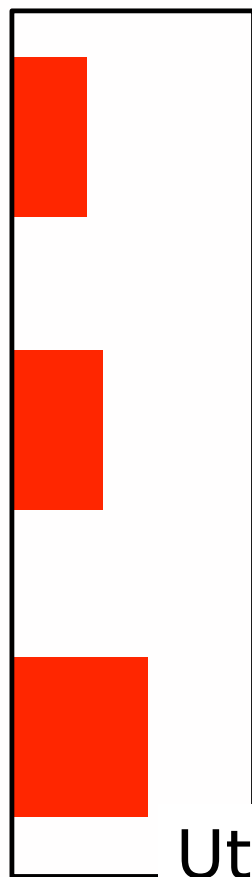
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

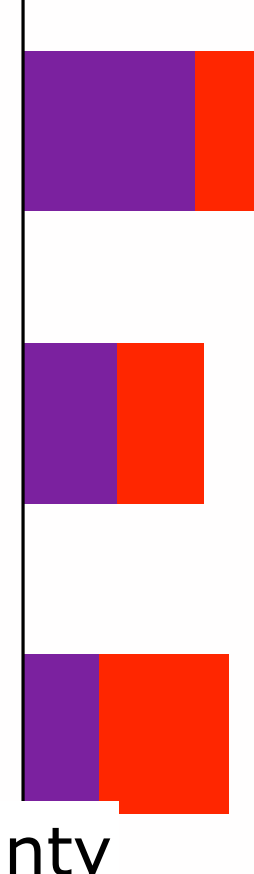
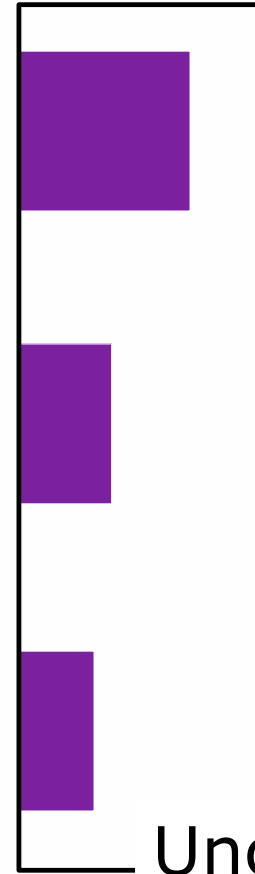
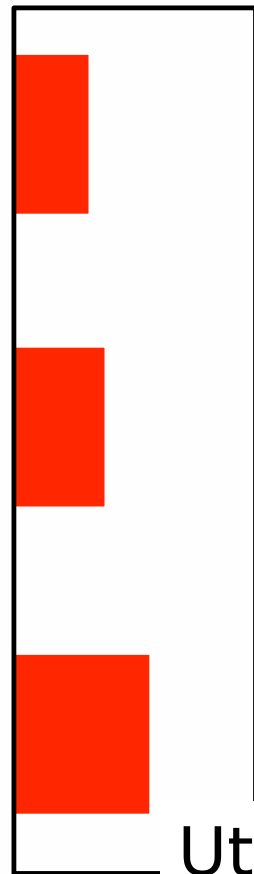
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

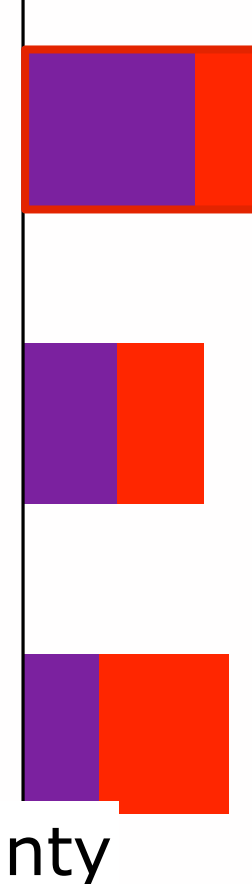
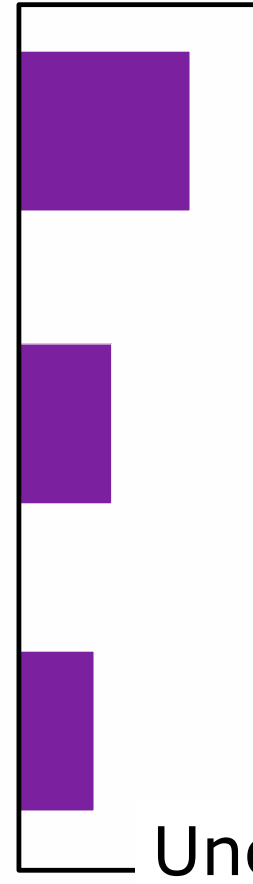
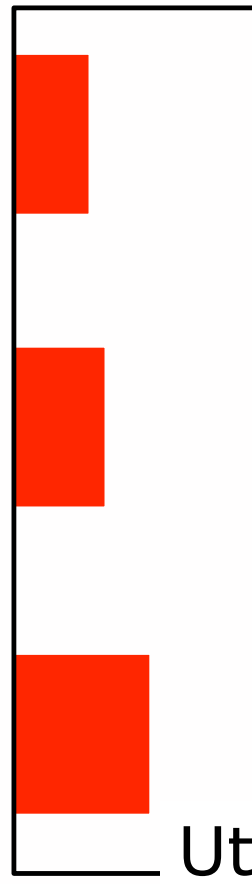
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

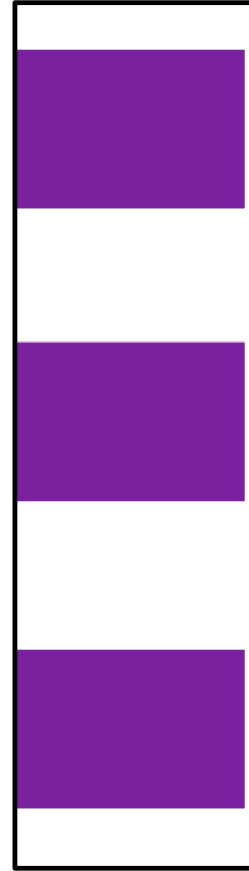
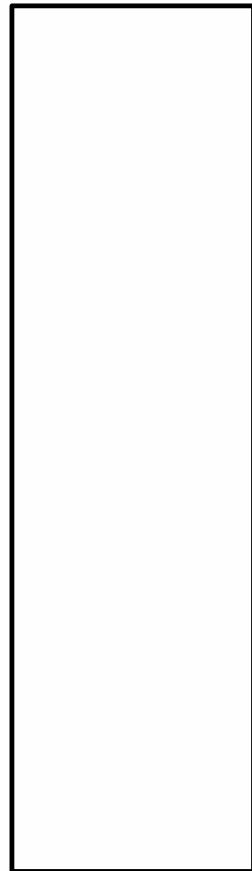
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

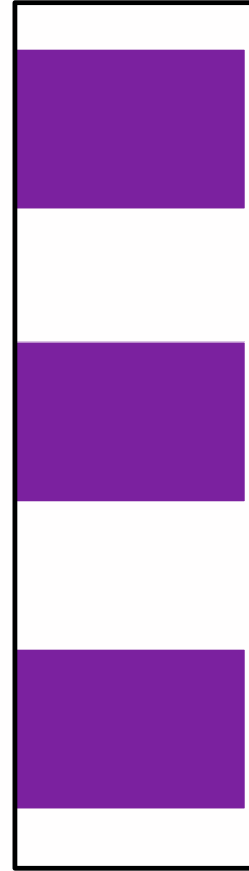
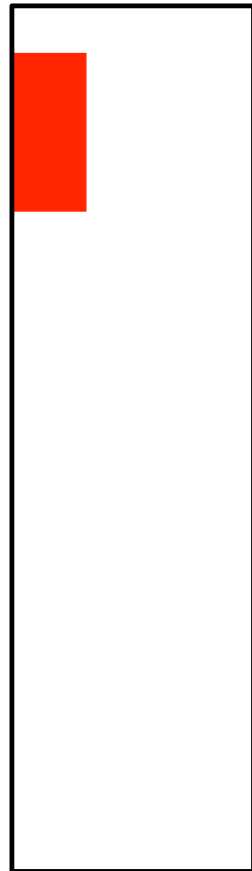
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

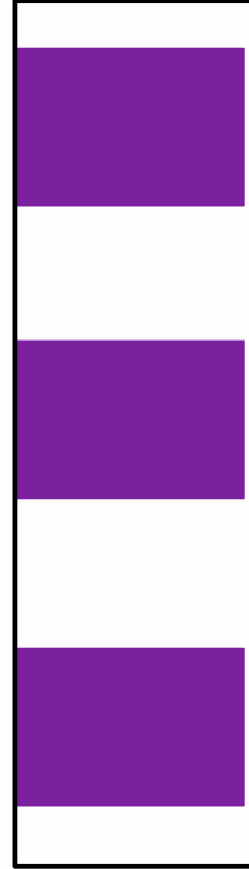
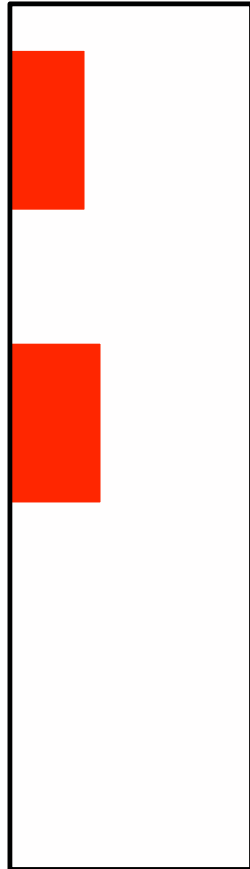
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

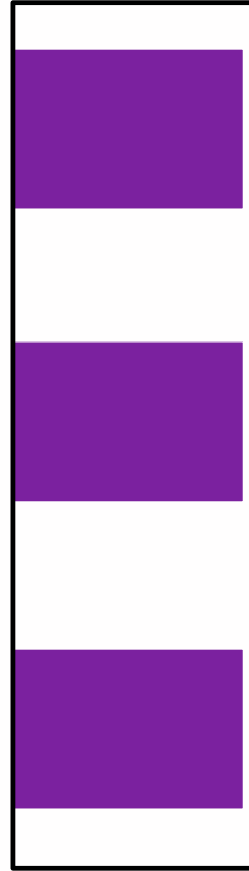
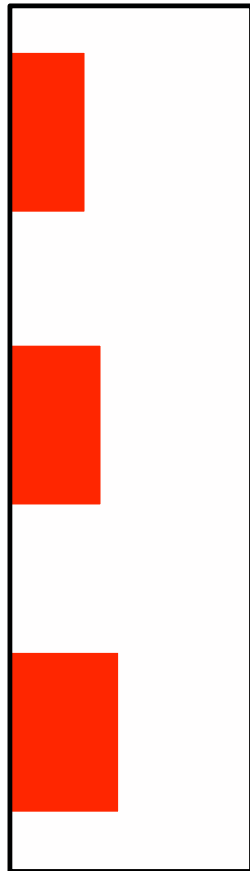
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



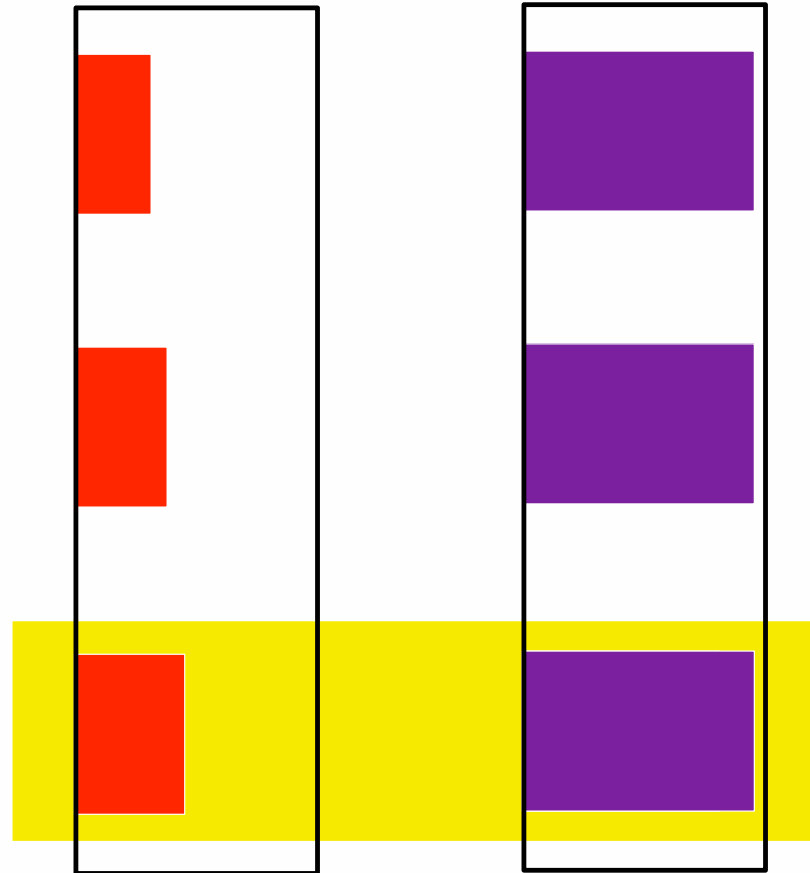
UCB1

Strategy

Exploit

Explore

Random

Imitate
OpponentBeat
Imitator

UCB1

Strategy

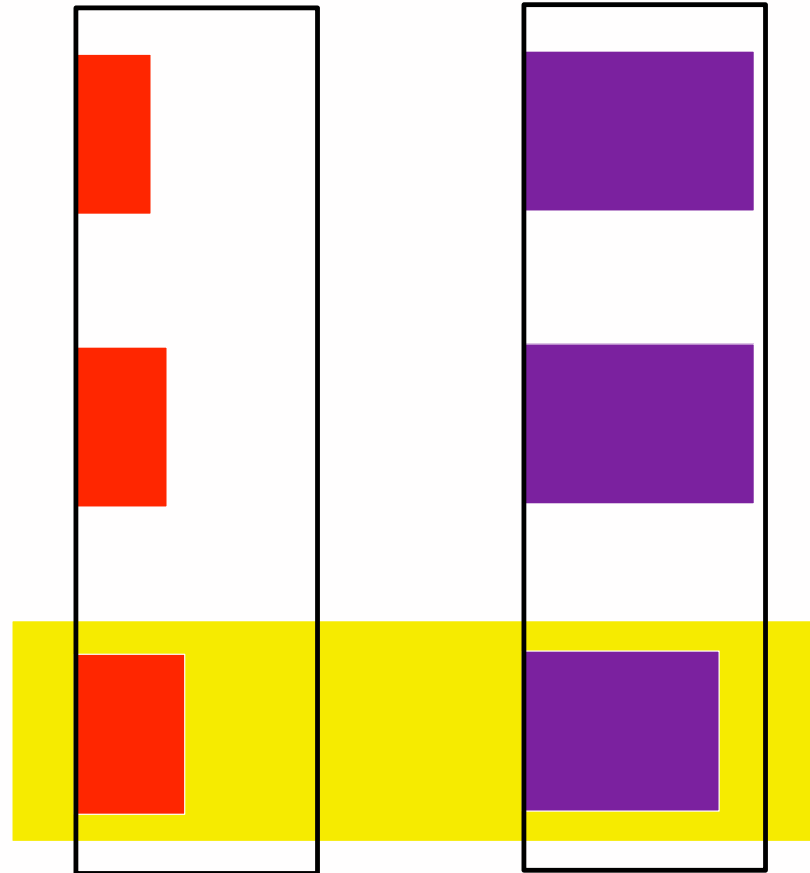
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

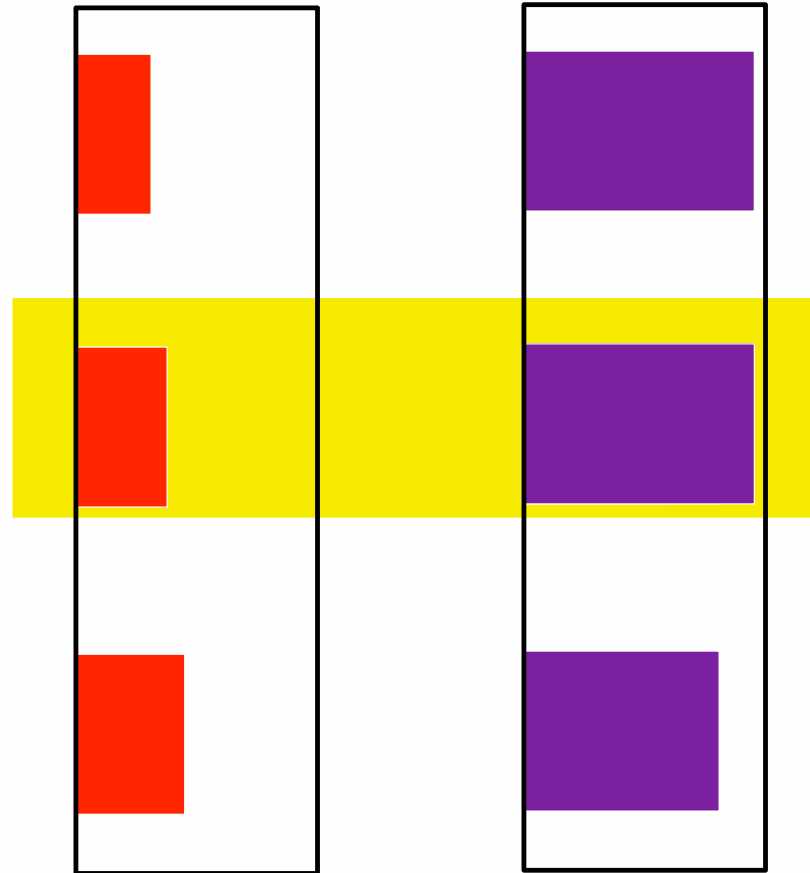
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

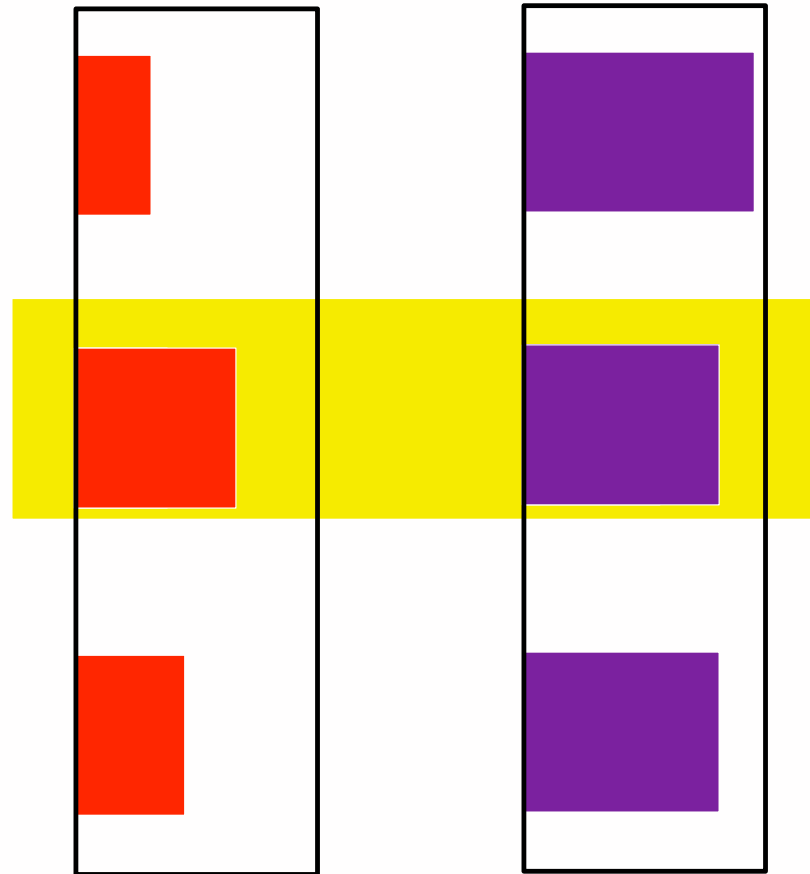
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator



UCB1

Strategy

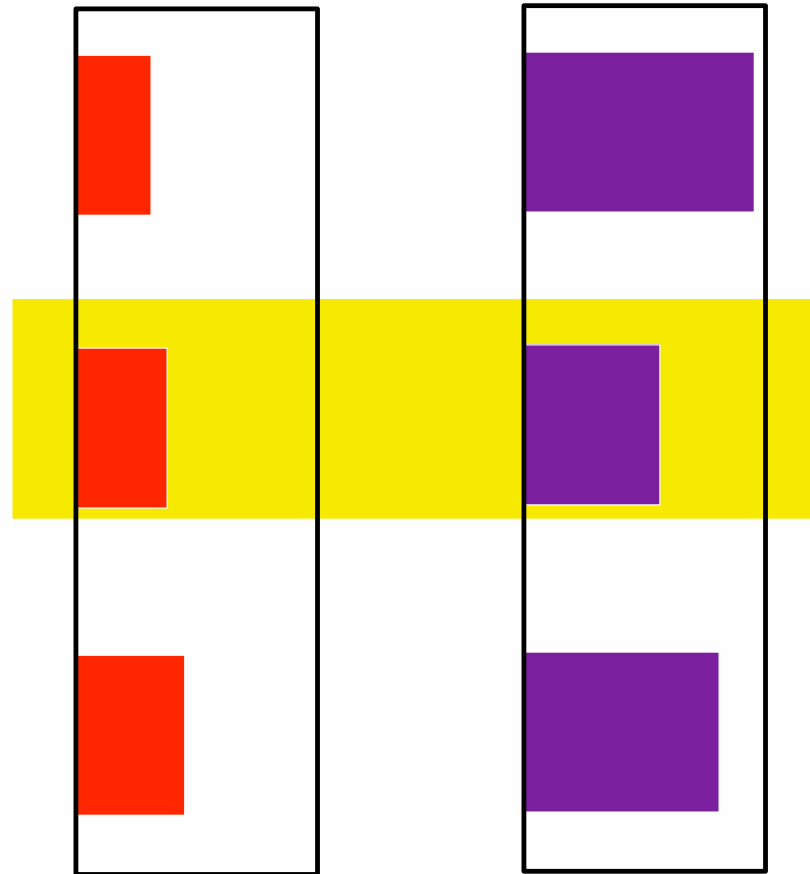
Exploit

Explore

Random

Imitate
Opponent

Beat
Imitator

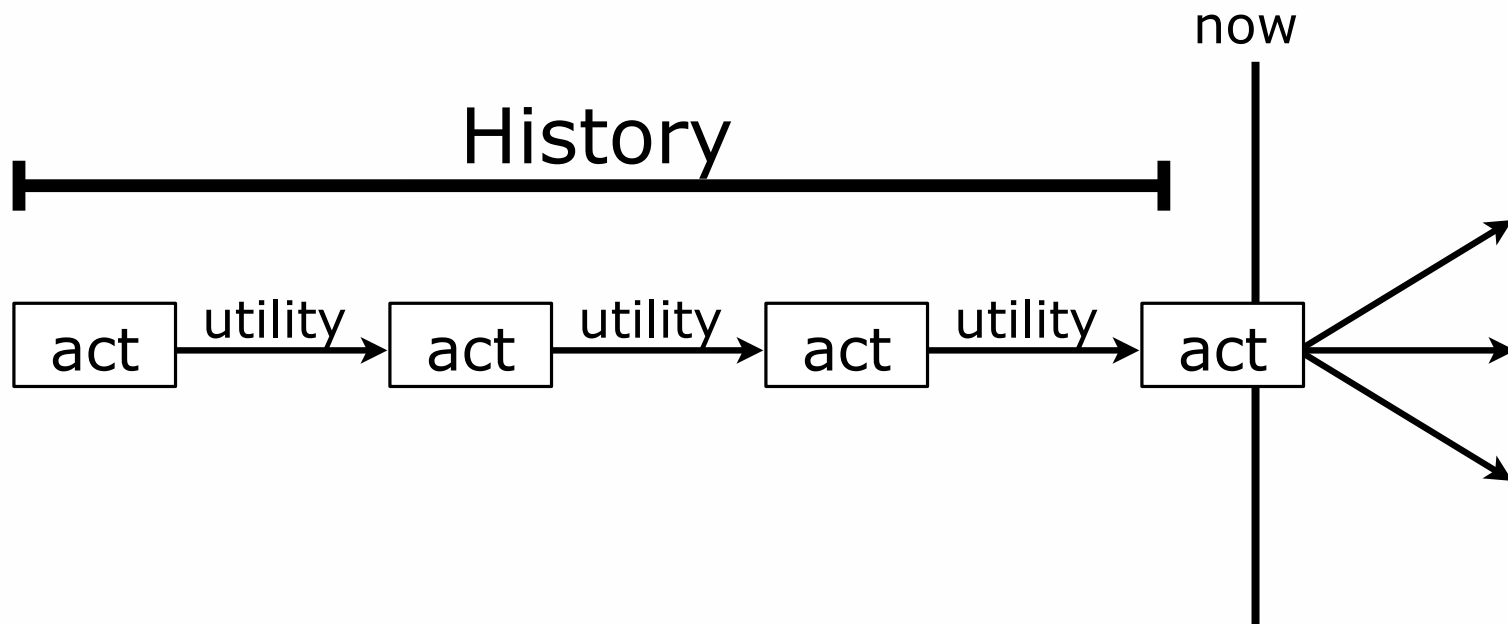


UCB1

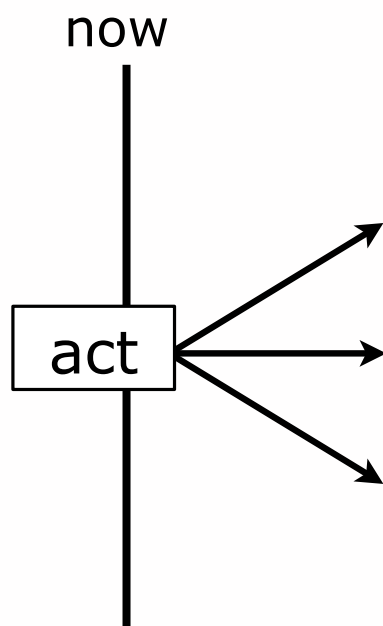


Prince of Persia

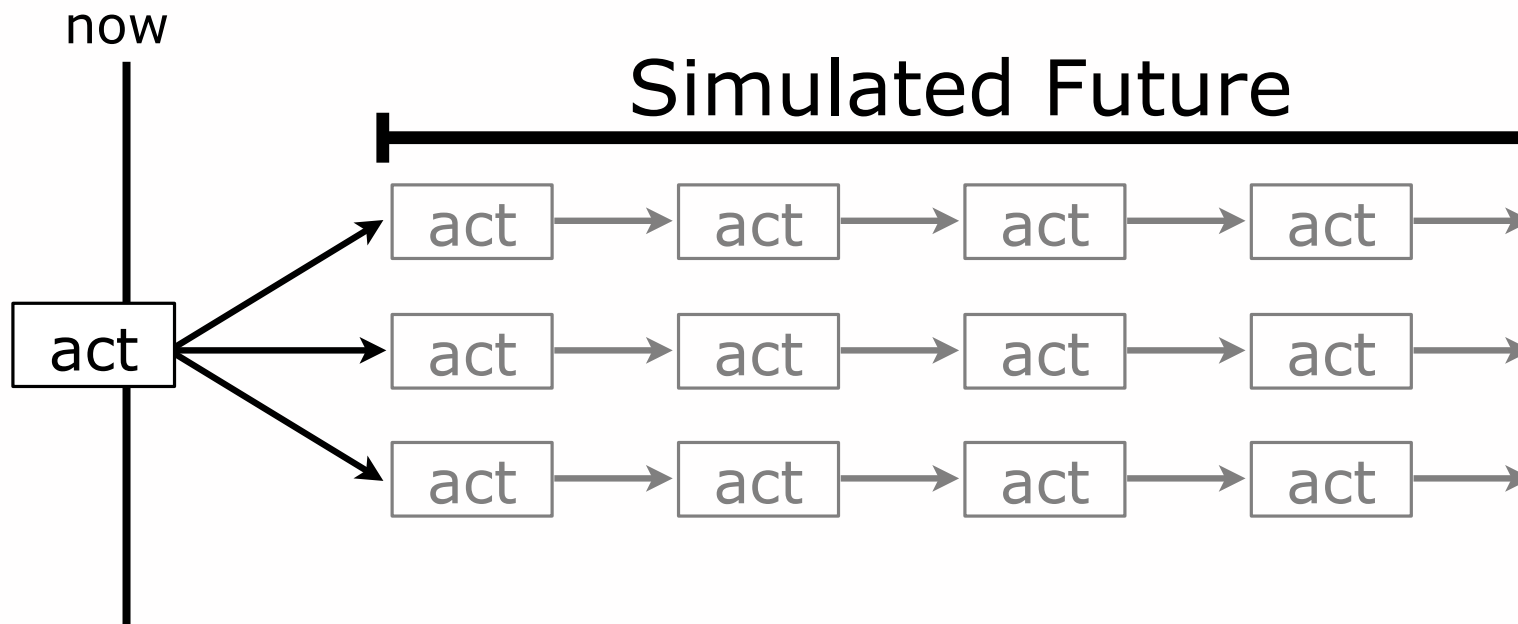
Act on History



Act on History



Act on History



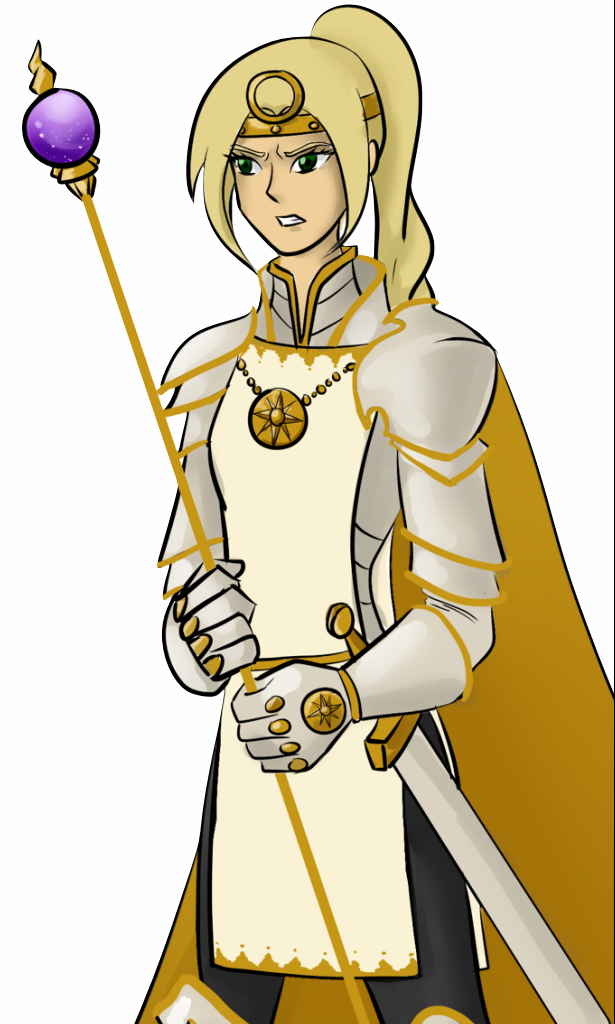
RPG Example

Paladin NPC

Melee Attack

Lightning Spell

Healing Spell



RPG Example

Paladin NPC

Melee Attack

Lightning Spell

Healing Spell

Offense
Strategy

Lightning

Attack

Attack

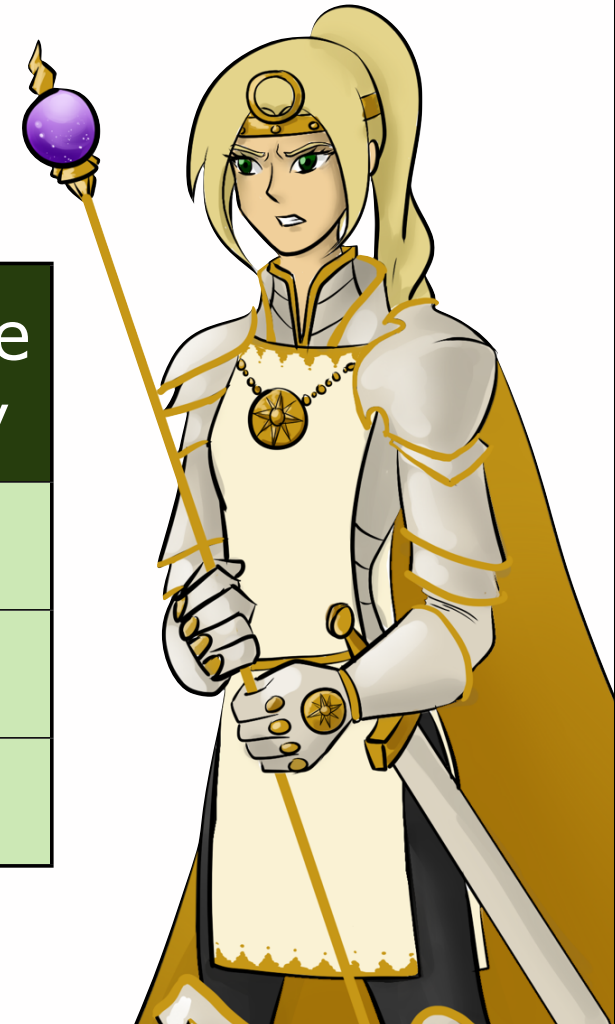


RPG Example

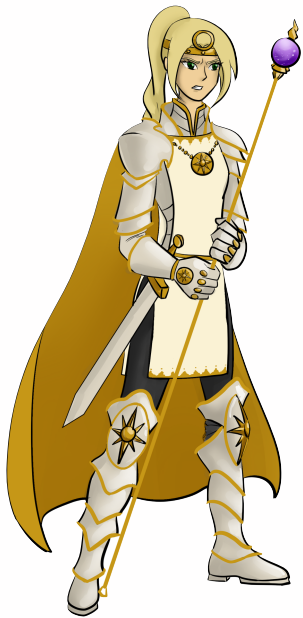
Paladin NPC
Melee Attack
Lightning Spell
Healing Spell

Offense Strategy
Lightning
Attack
Attack

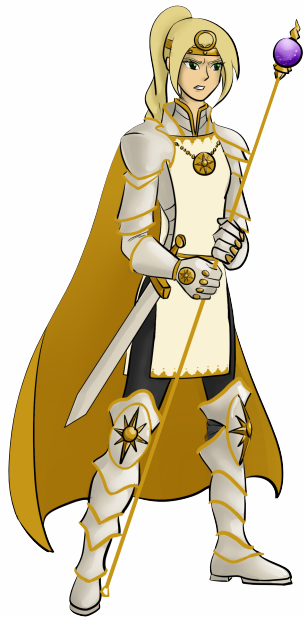
Defensive Strategy
Attack
Attack
Heal



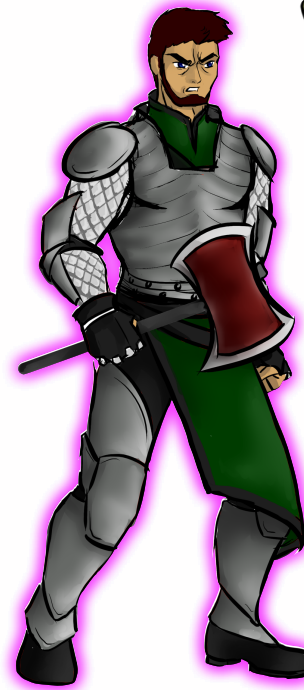
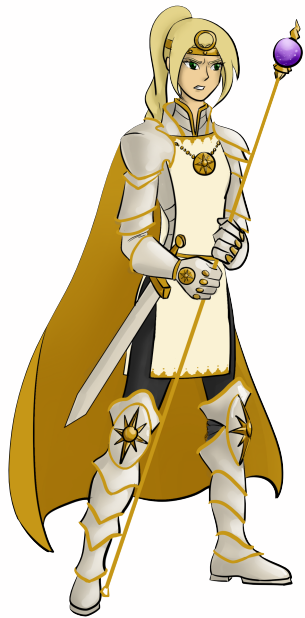
RPG example



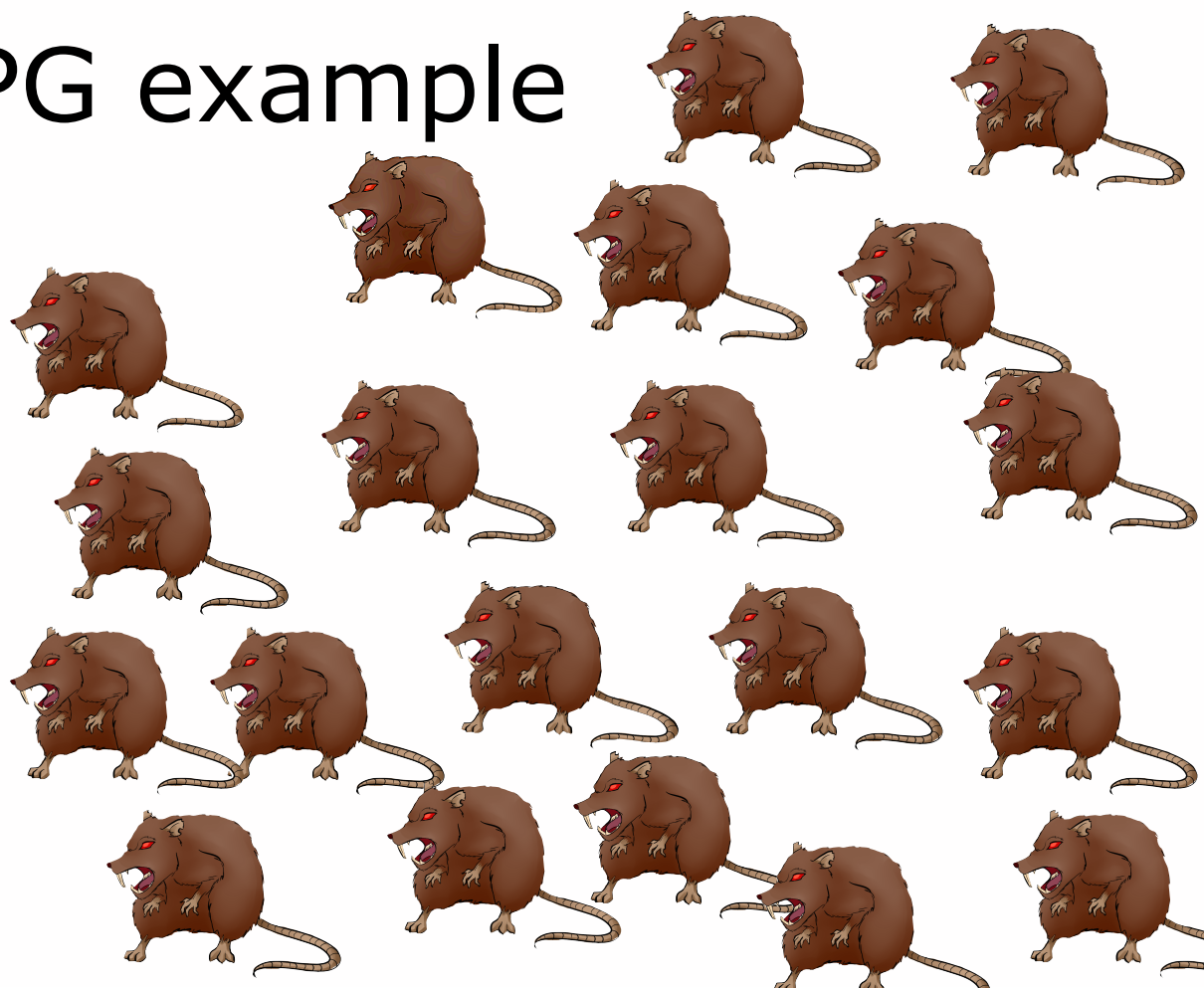
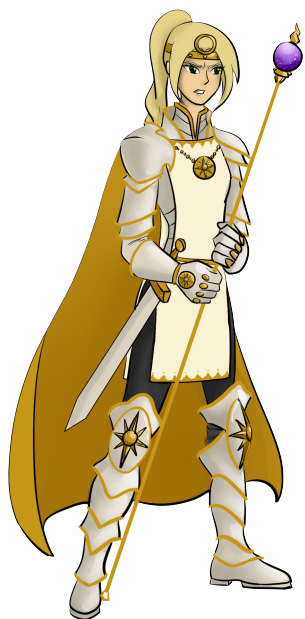
RPG example



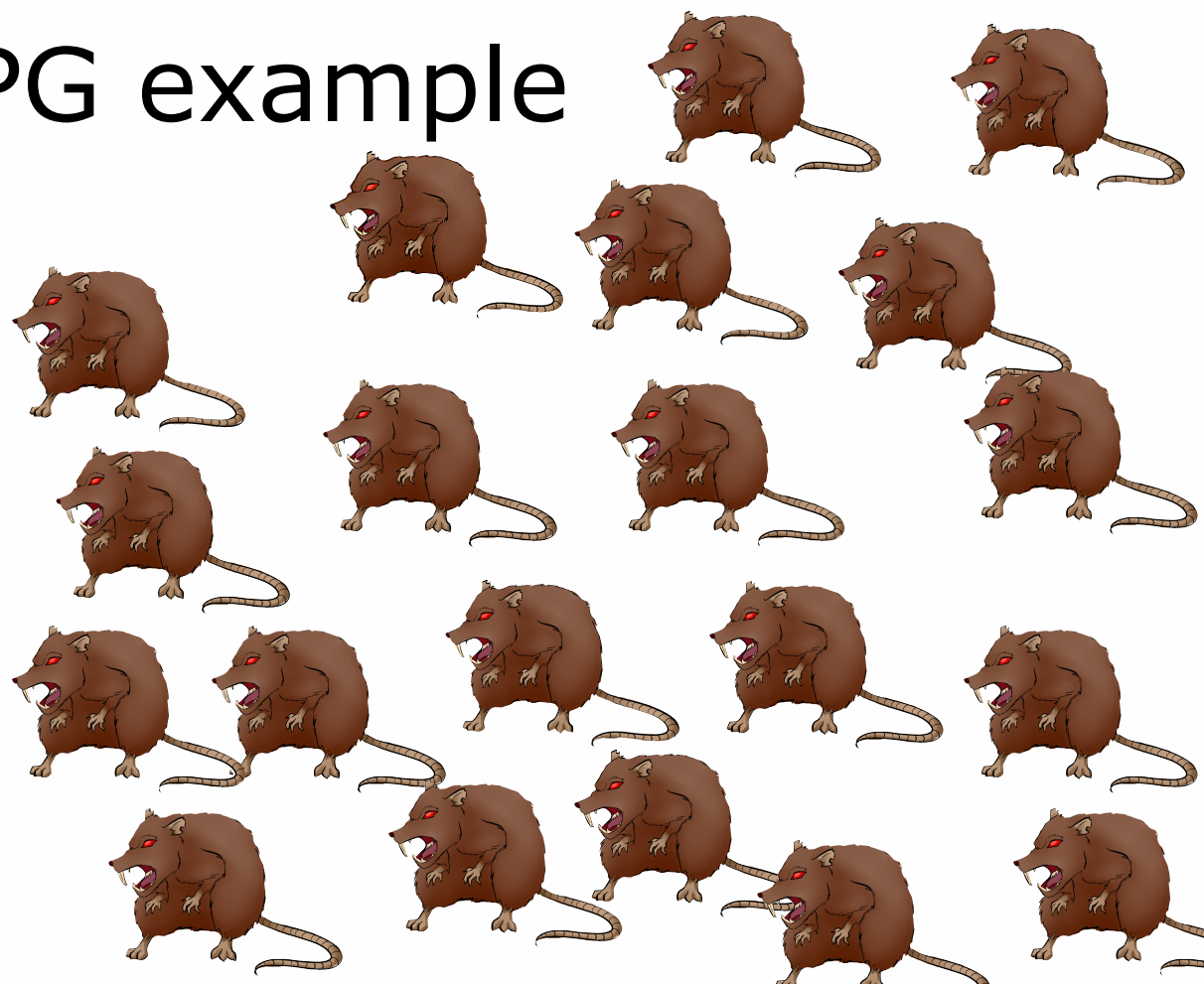
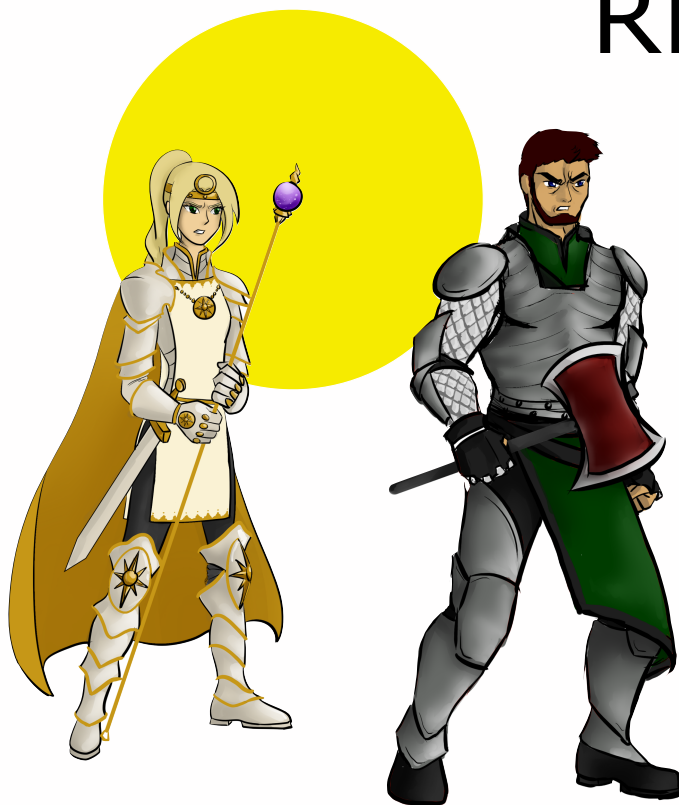
RPG example



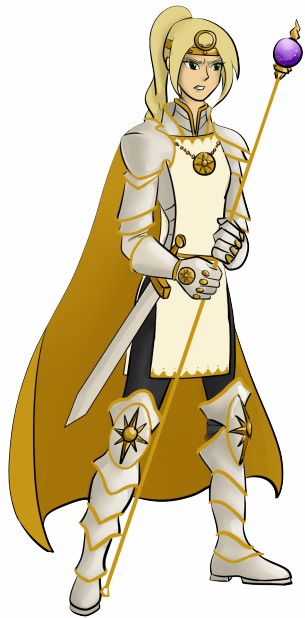
RPG example



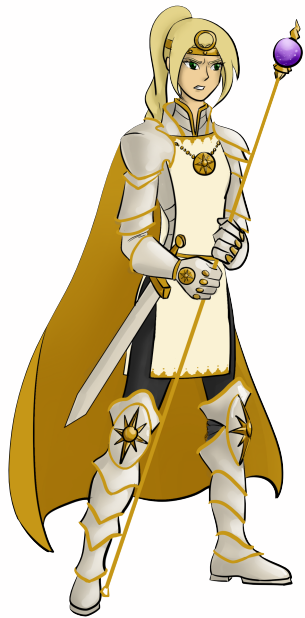
RPG example



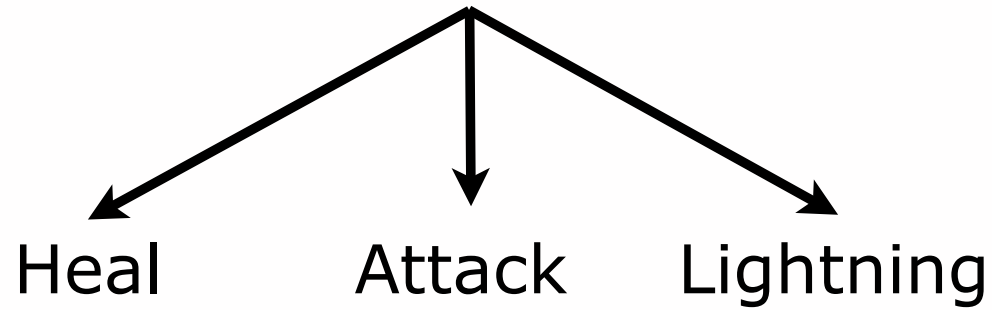
RPG example



RPG example

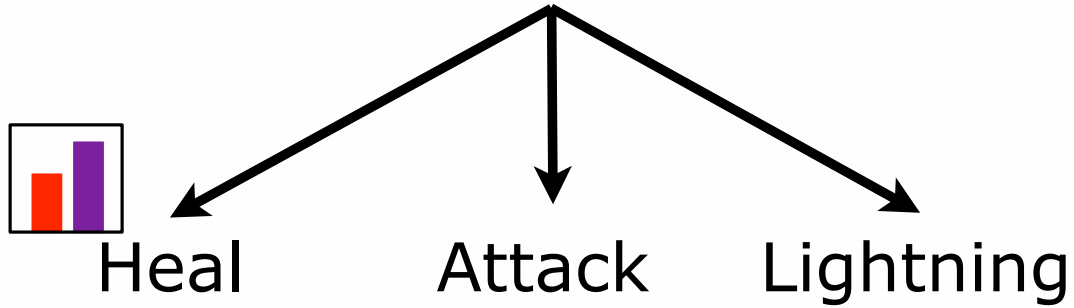


Next Action



Strategy

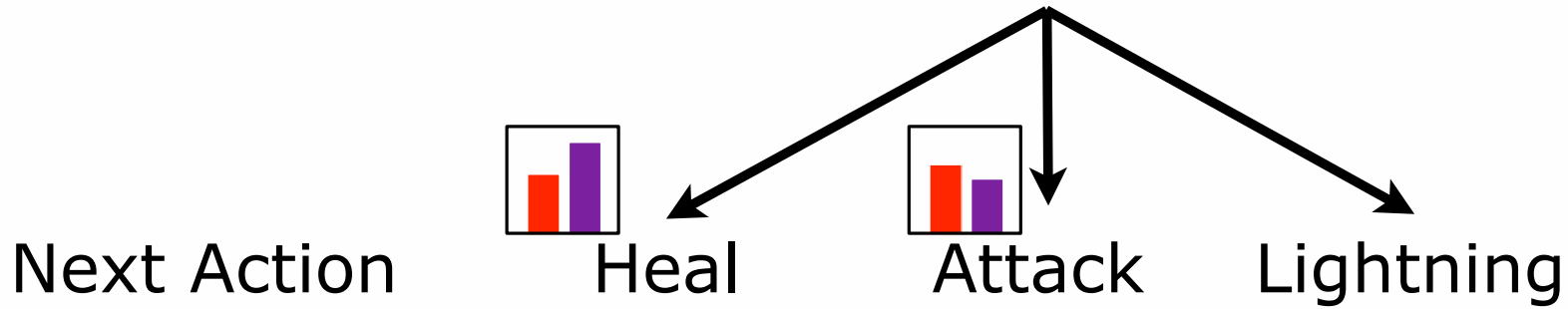
UCB1



Next Action

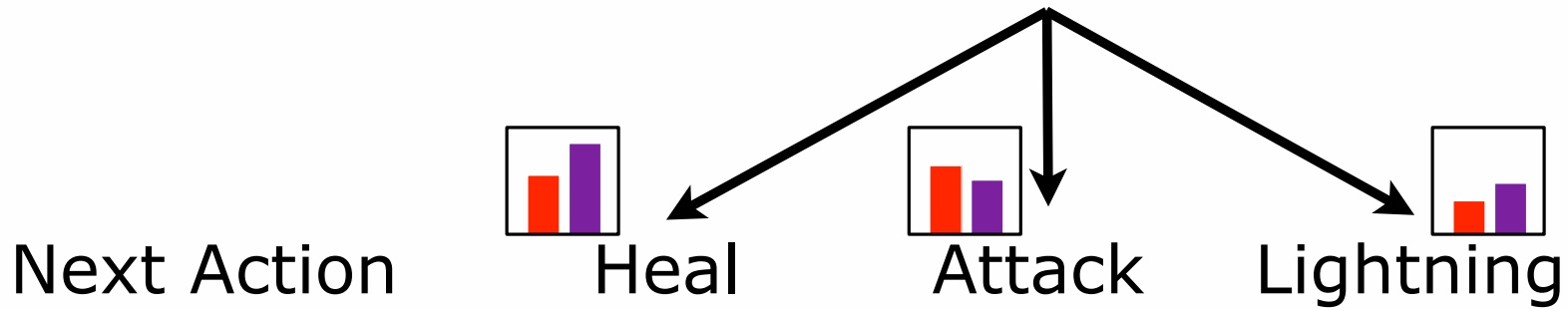
Strategy

UCB1



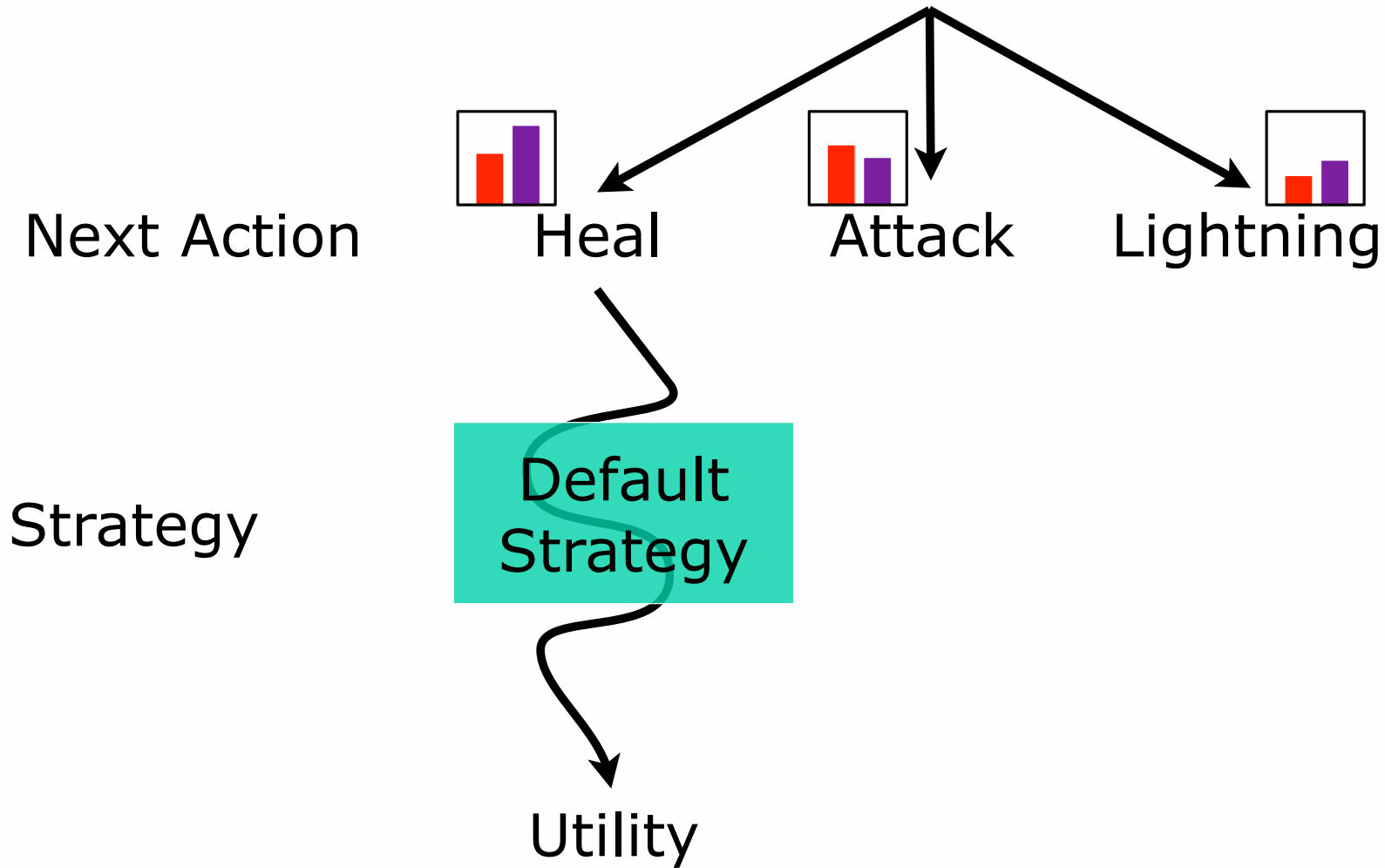
Strategy

UCB1

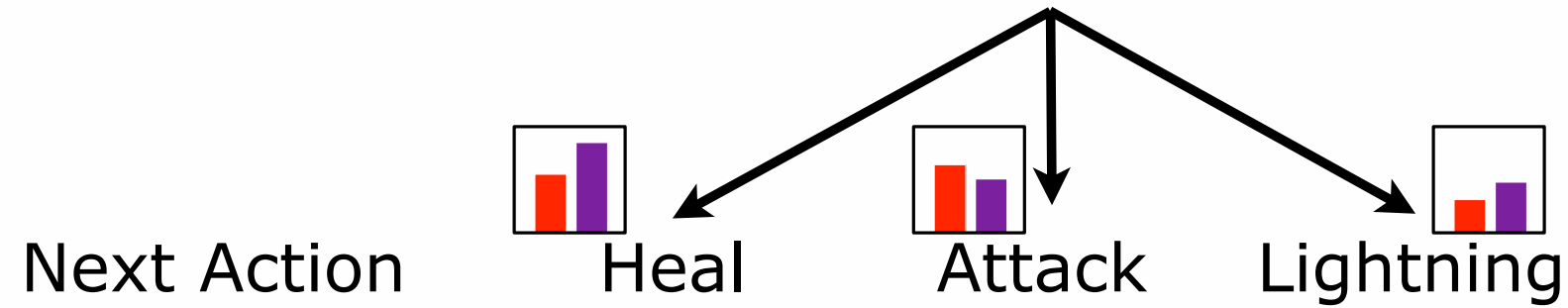


Strategy

UCB1



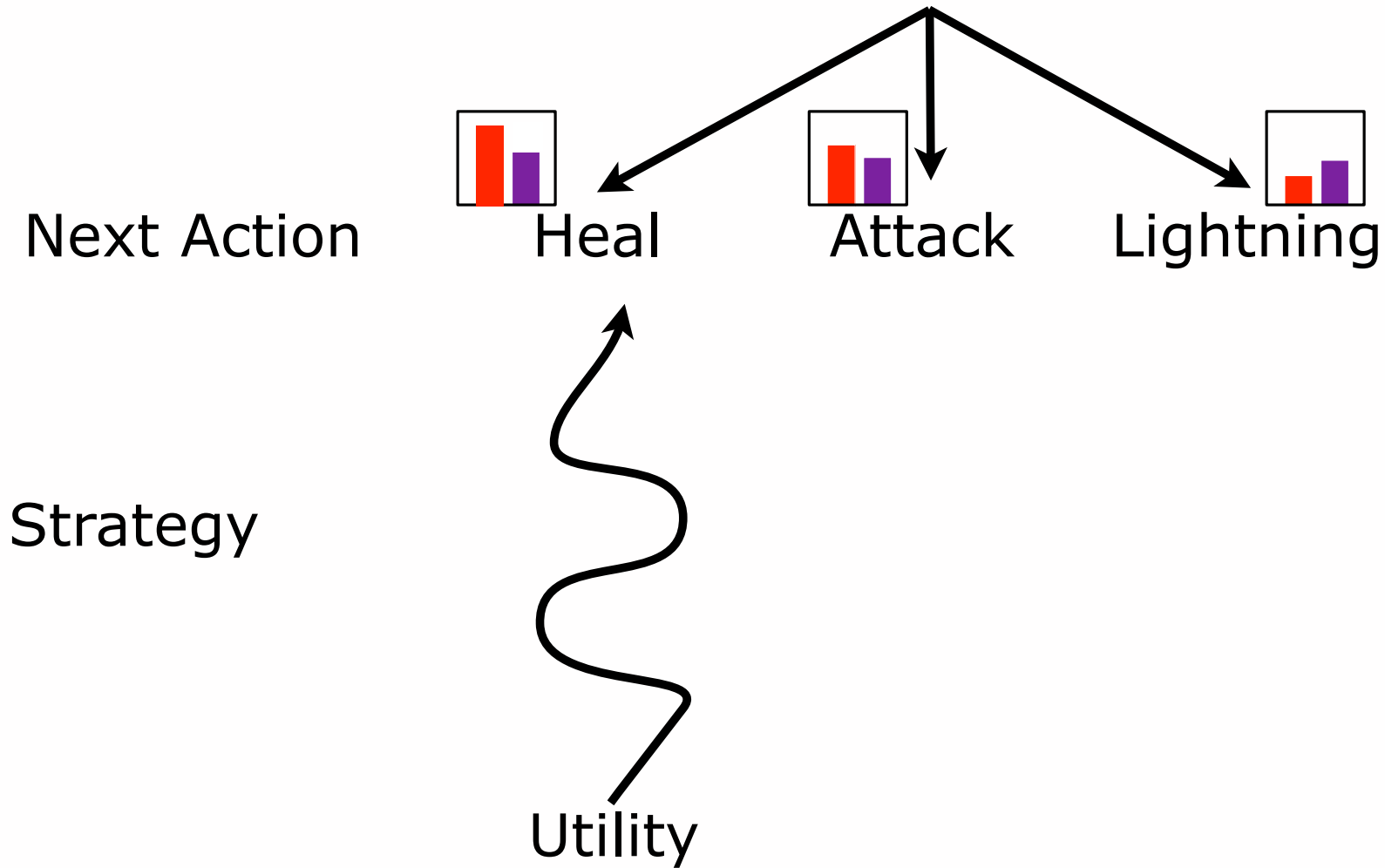
UCB1

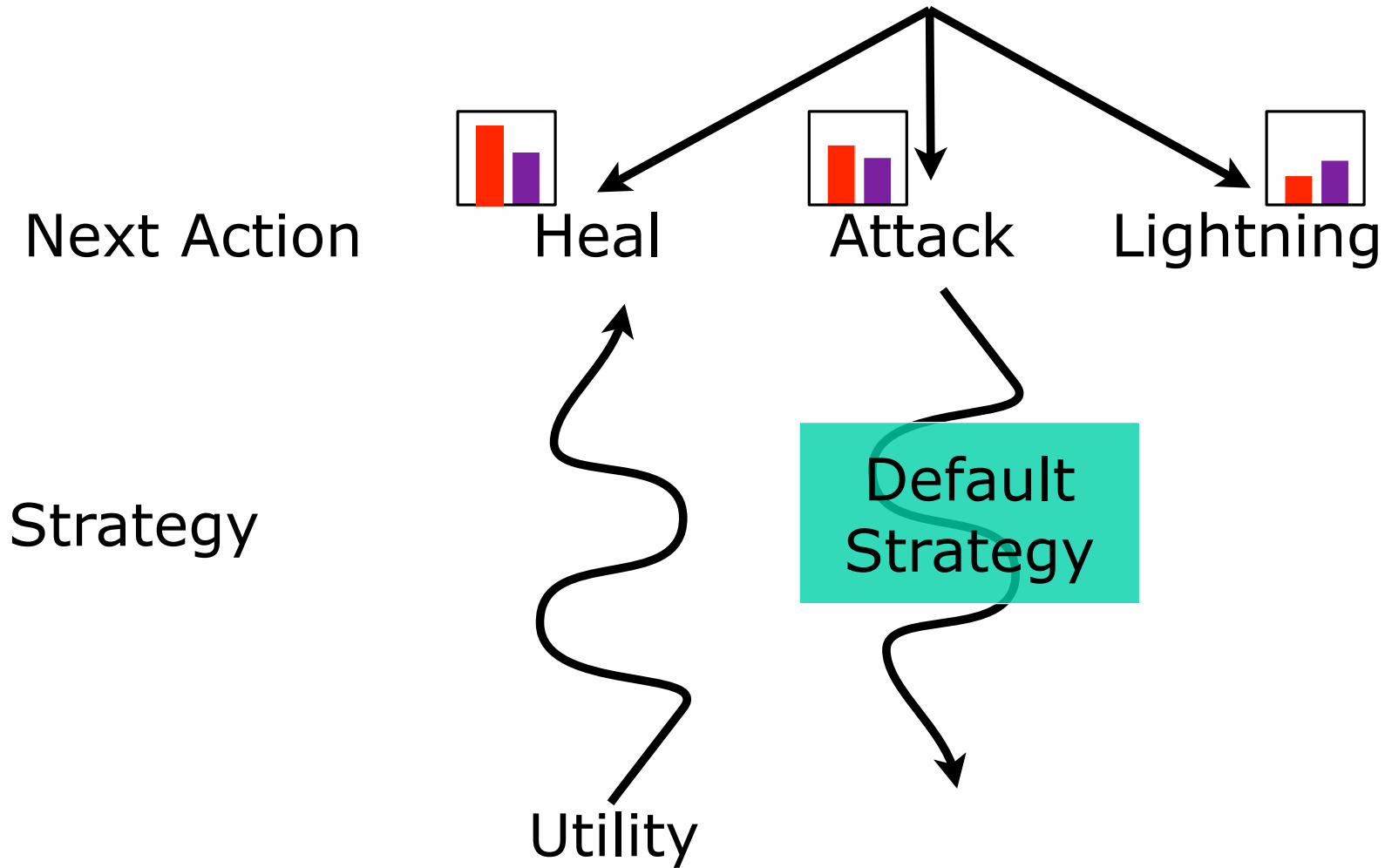


Strategy

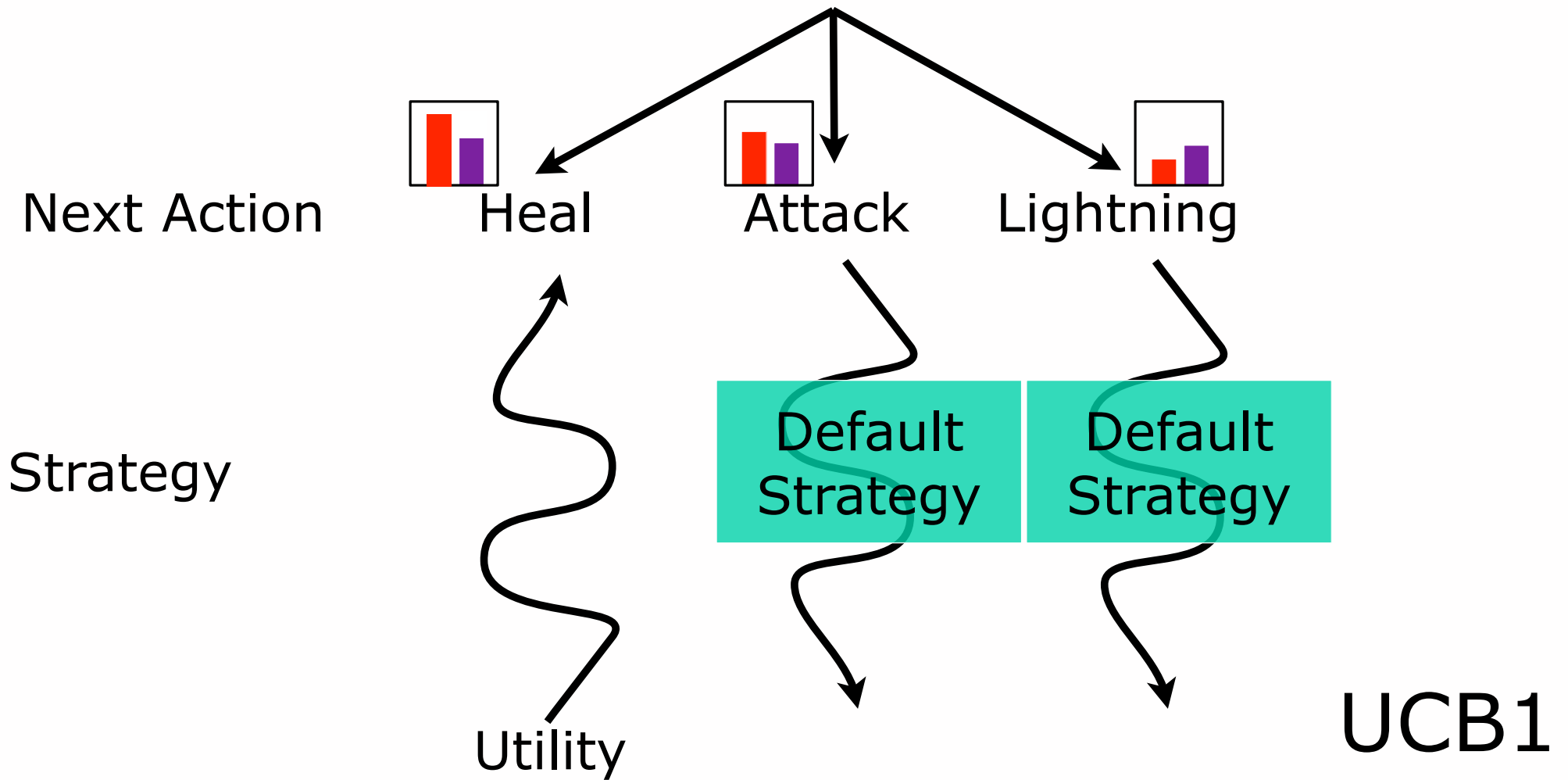
Utility

UCB1

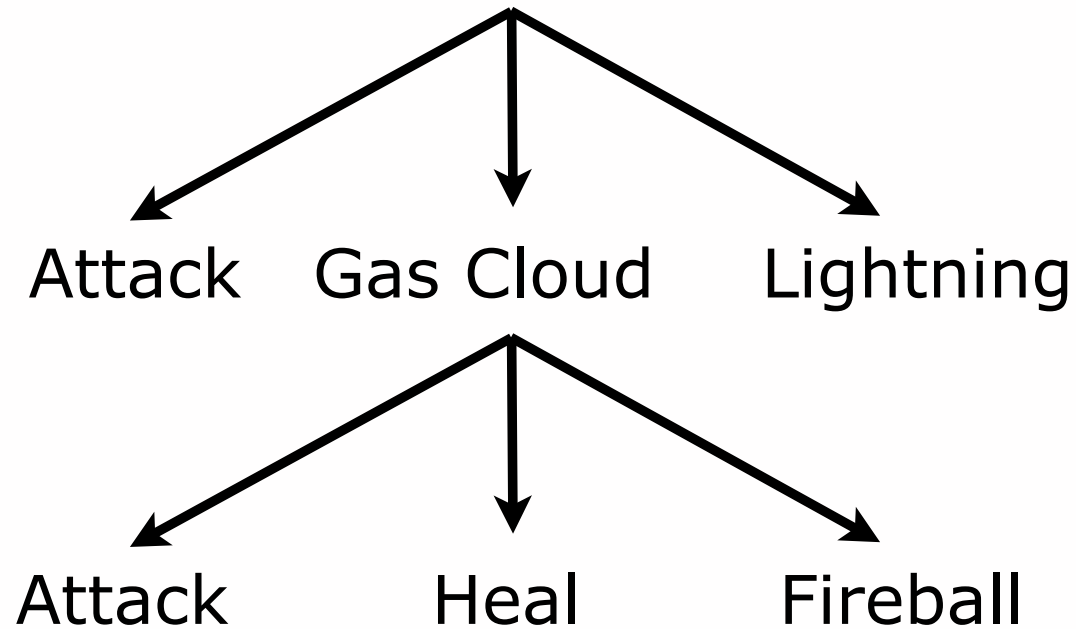




UCB1

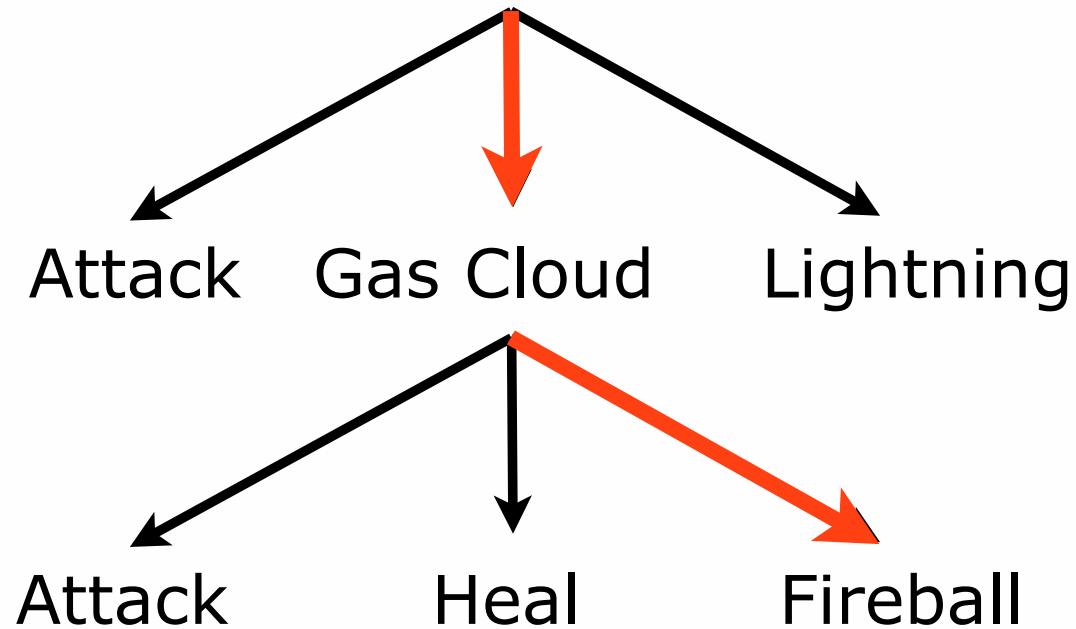


Next Action



UCB1 (UCT)

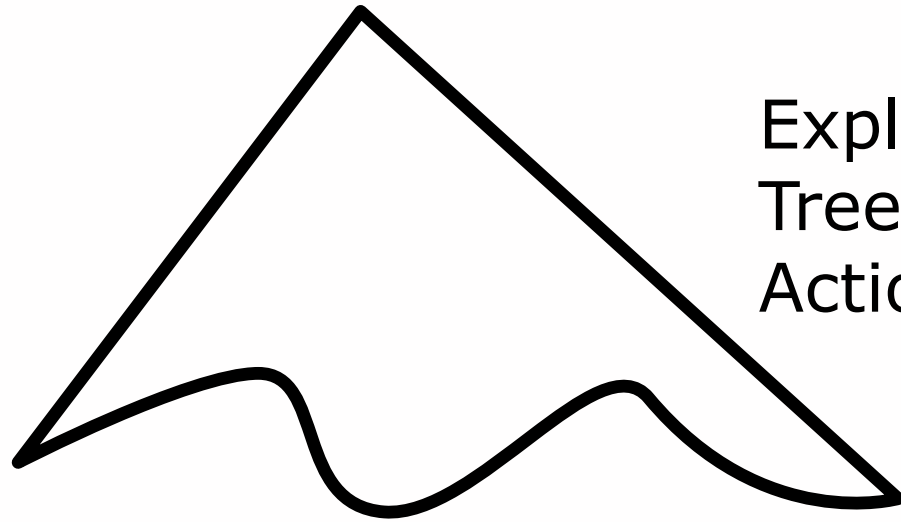
Next Action



UCB1 (UCT)

Full MCTS

Selection
Expansion
Simulation
Backpropagation



MCTS

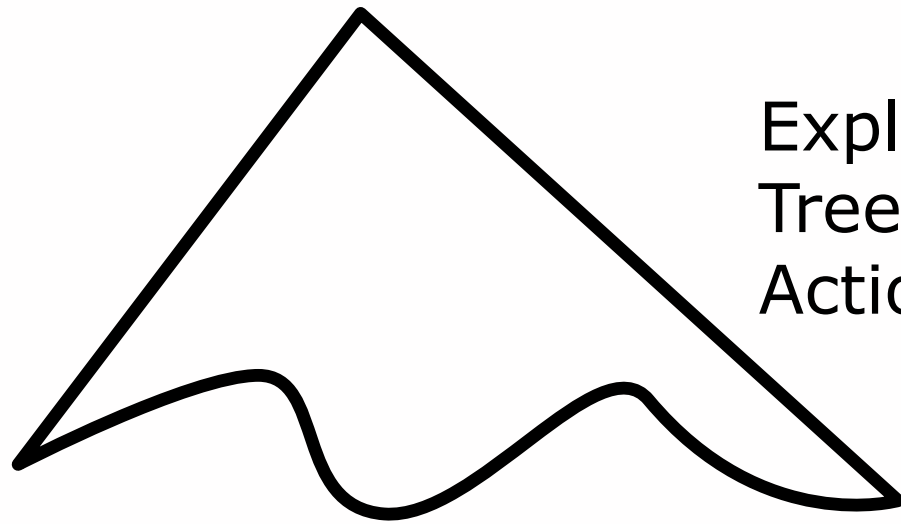
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

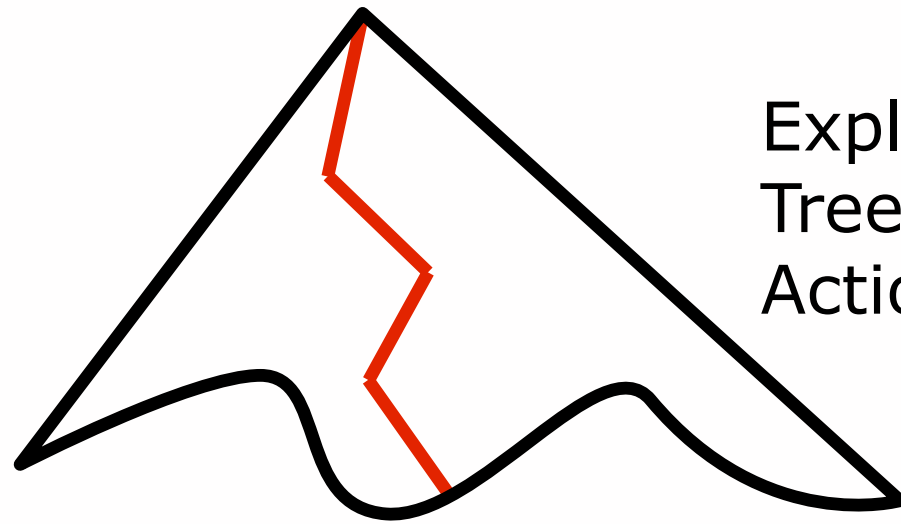
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

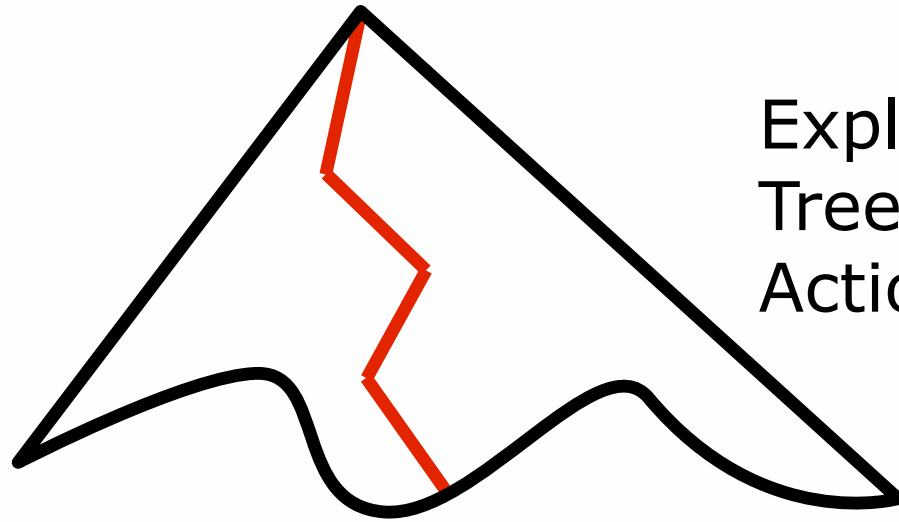
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

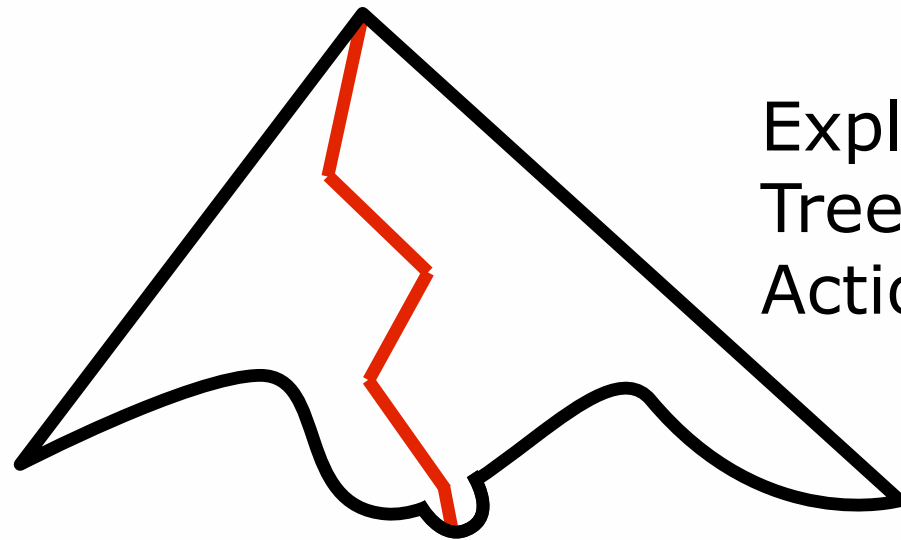
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

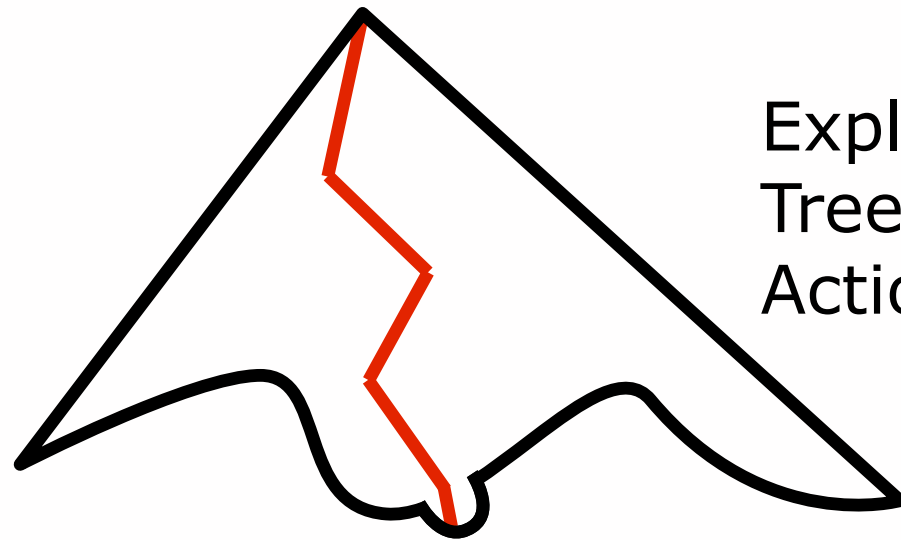
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

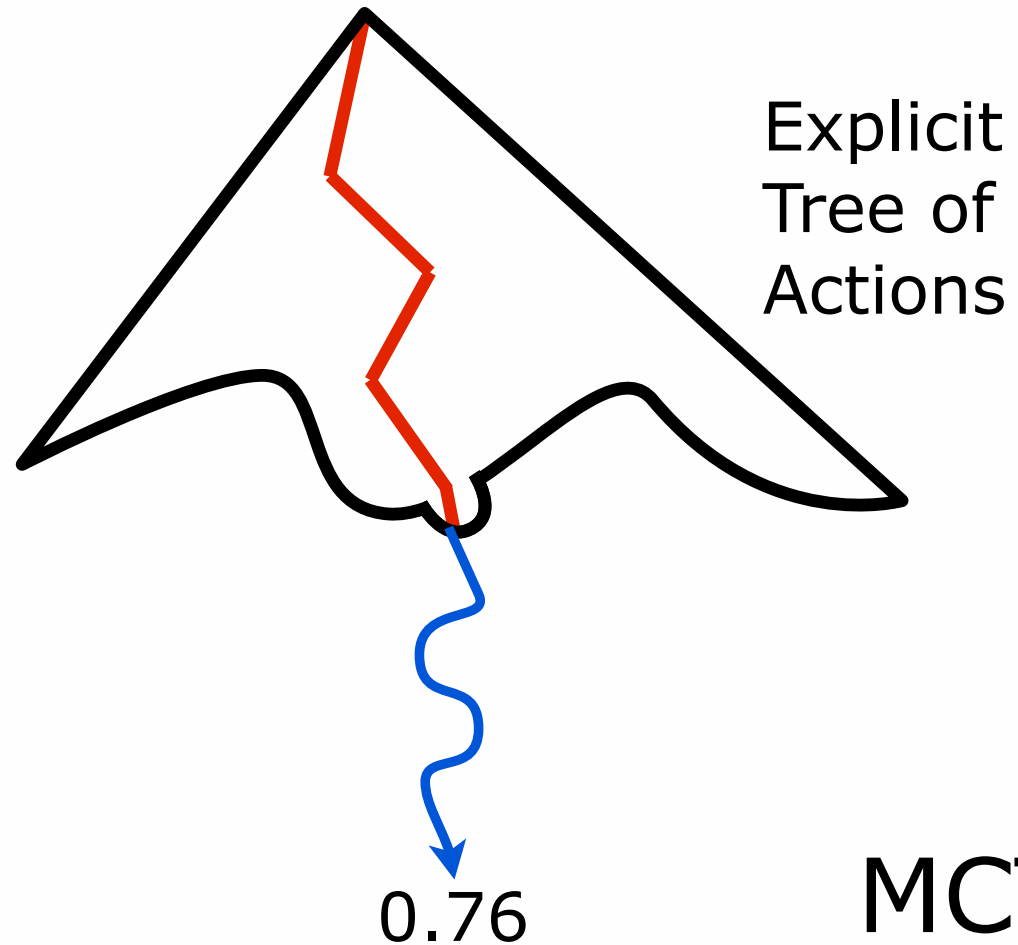
Full MCTS

Selection

Expansion

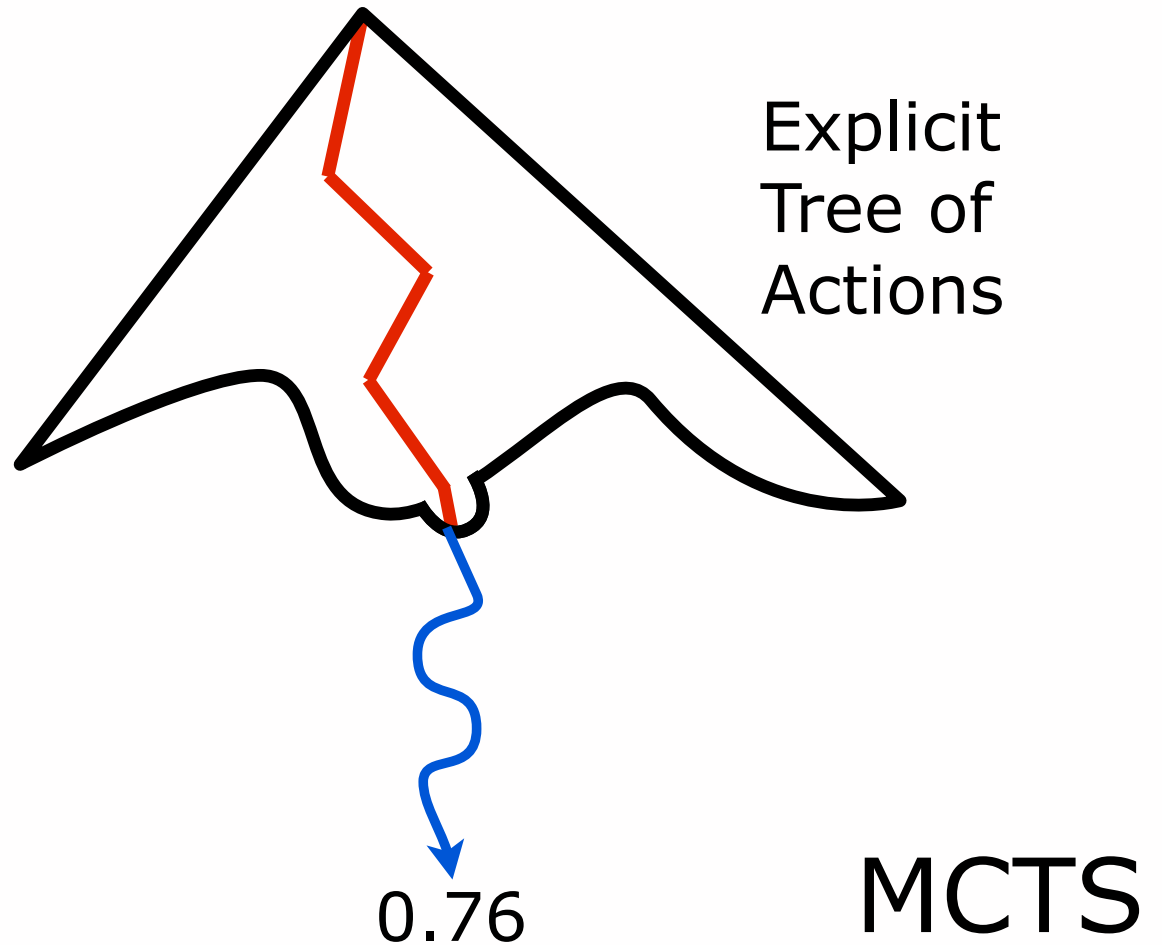
Simulation

Backpropagation



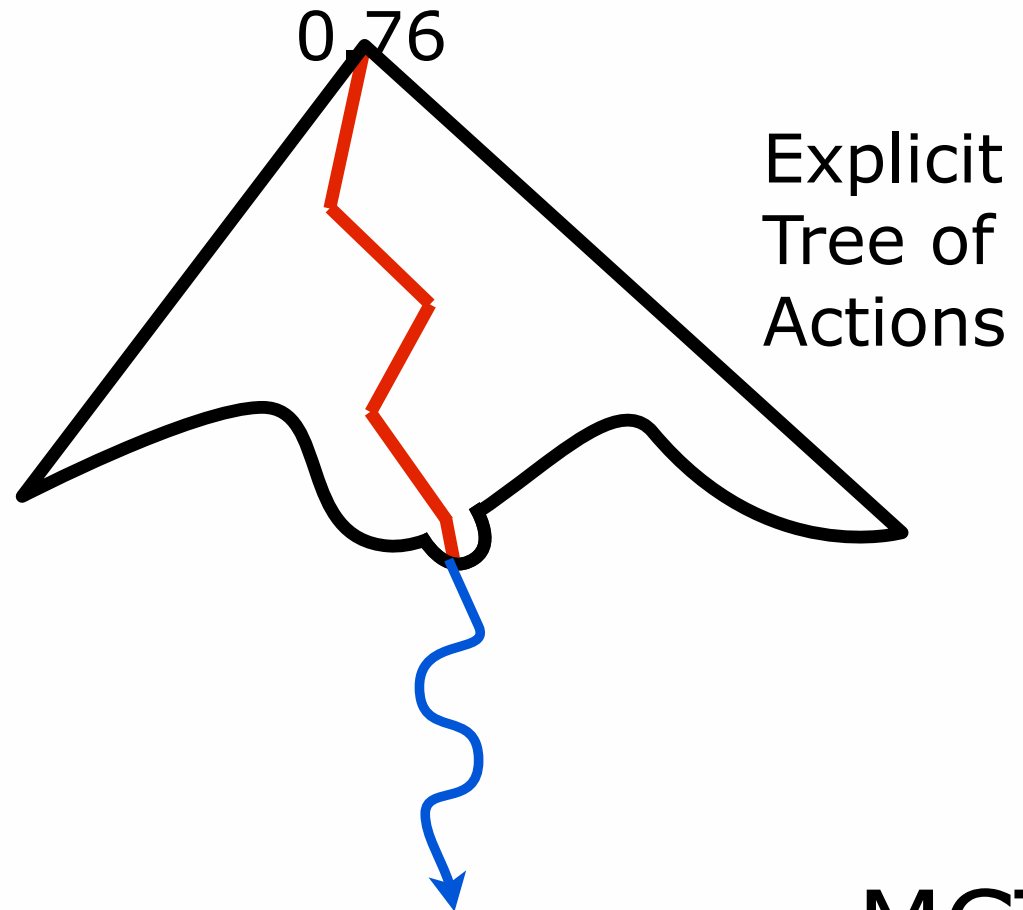
Full MCTS

Selection
Expansion
Simulation
Backpropagation



Full MCTS

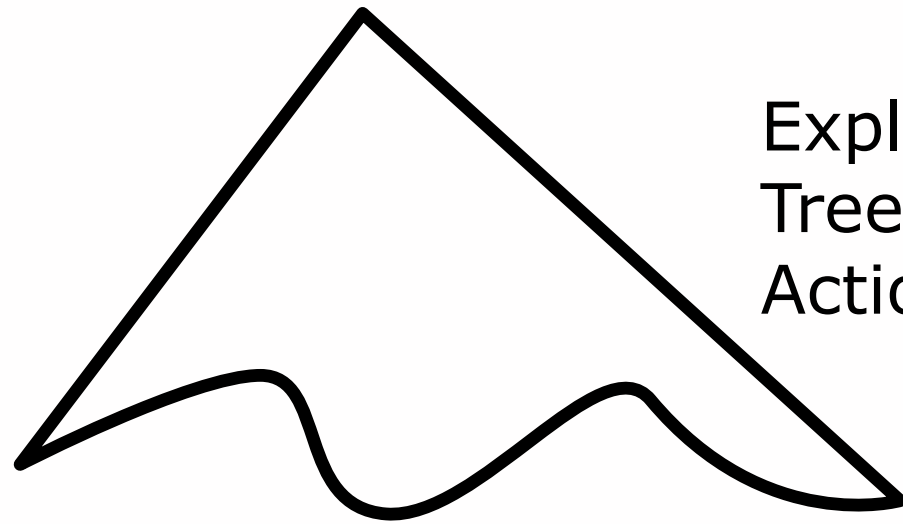
Selection
Expansion
Simulation
Backpropagation



MCTS

Full MCTS

Selection
Expansion
Simulation
Backpropagation



Explicit
Tree of
Actions

MCTS

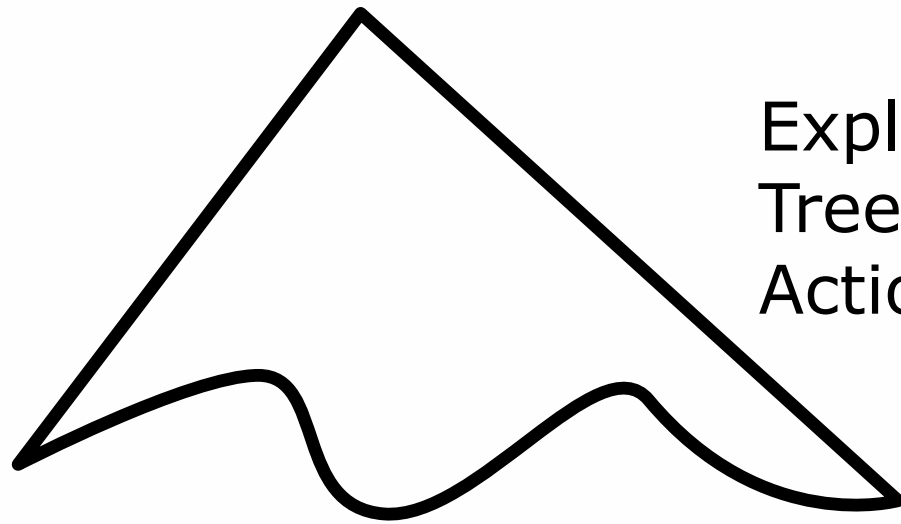
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

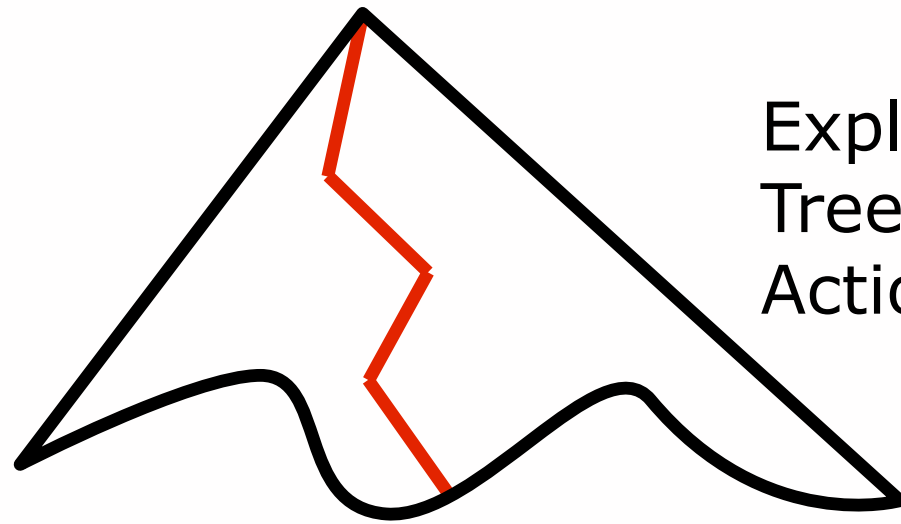
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

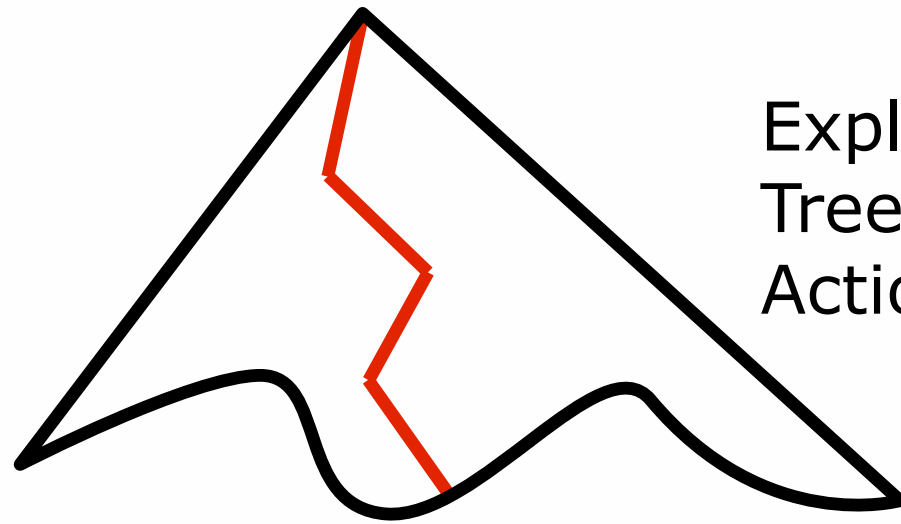
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

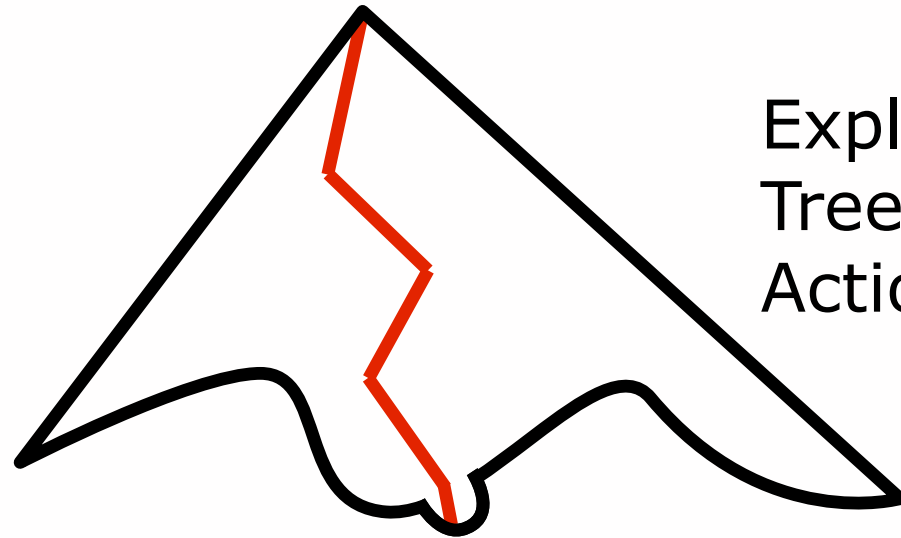
Full MCTS

Selection

Expansion

Simulation

Backpropagation



Explicit
Tree of
Actions

MCTS

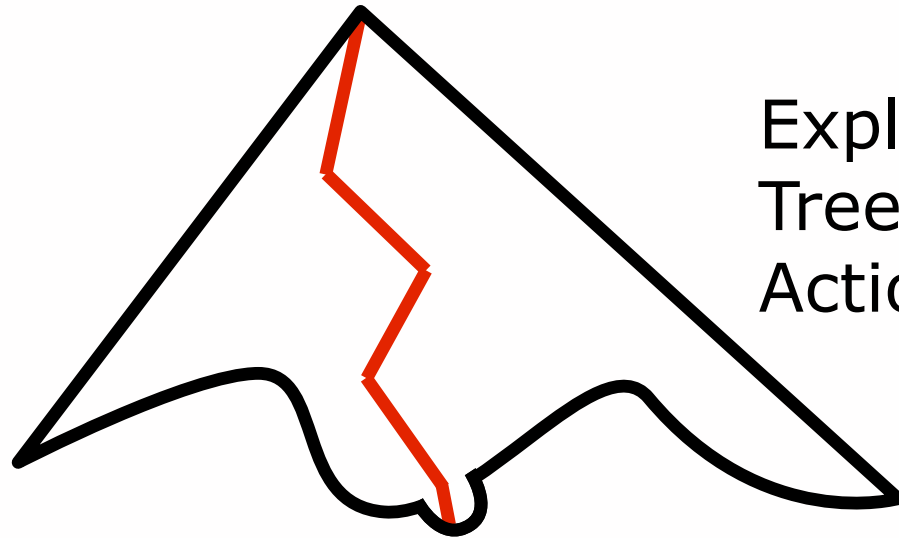
Full MCTS

Selection

Expansion

Simulation

Backpropagation

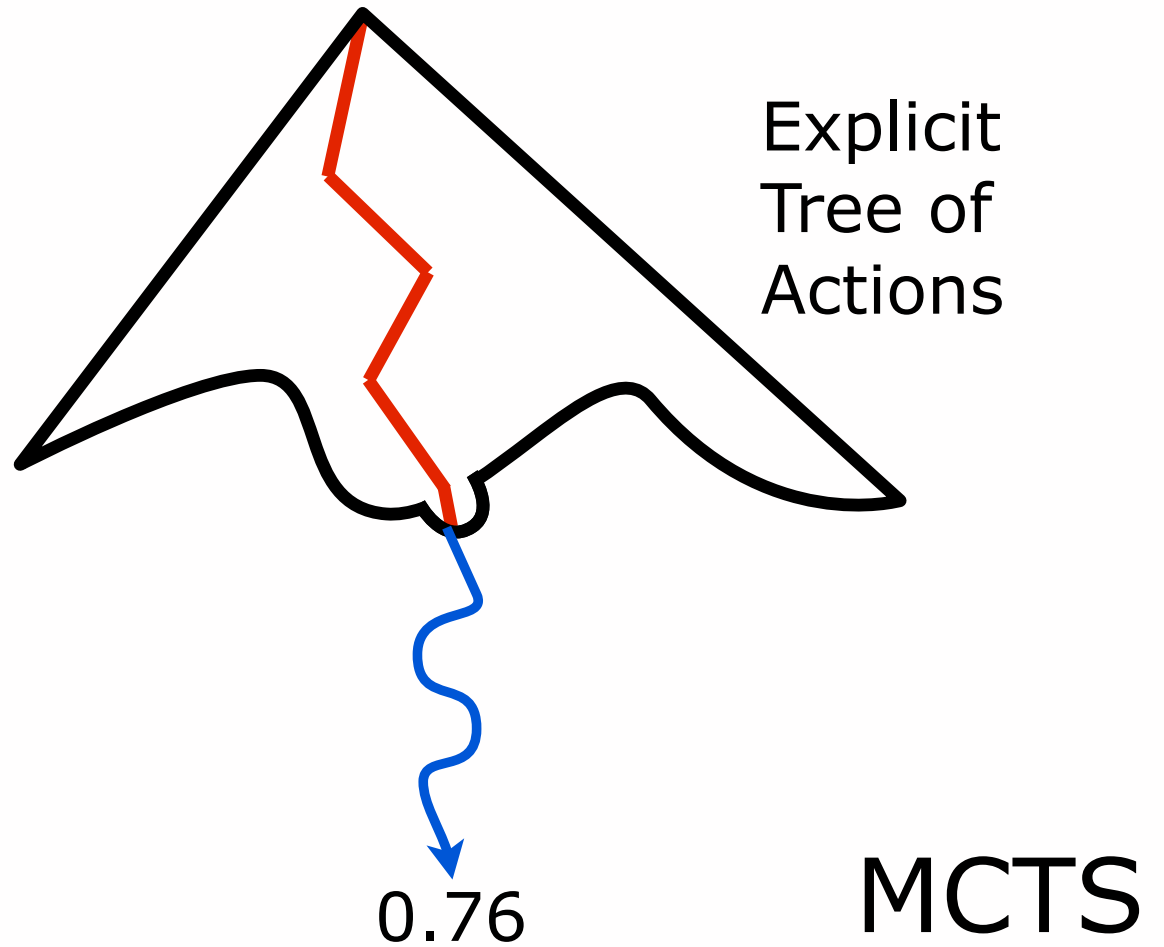


Explicit
Tree of
Actions

MCTS

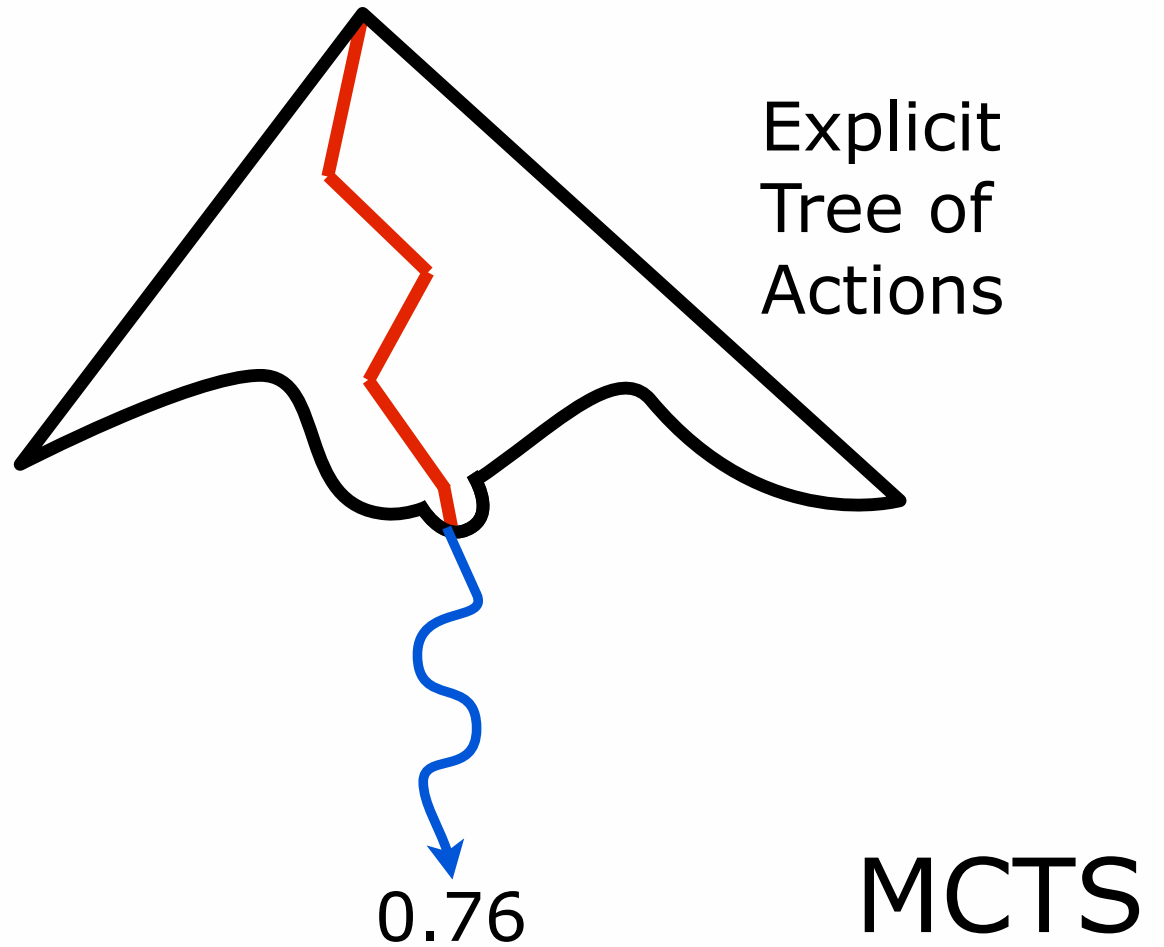
Full MCTS

- Selection
- Expansion
- Simulation
- Backpropagation



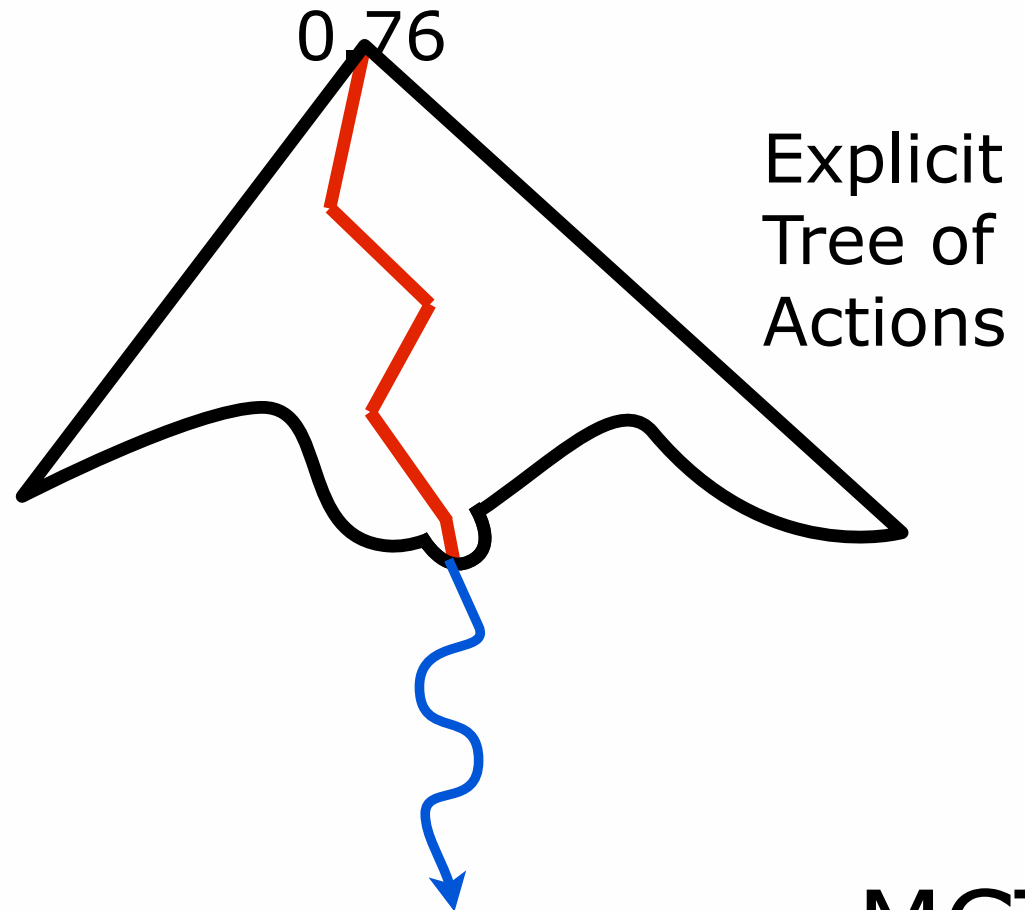
Full MCTS

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Full MCTS

Selection
Expansion
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Backpropagation



MCTS

MCTS Key Ideas

- The ability to query & apply moves
- Converging strategy/playouts
- Simple utility evaluation

- Can build more intelligent strategy

History Based

Regret Matching

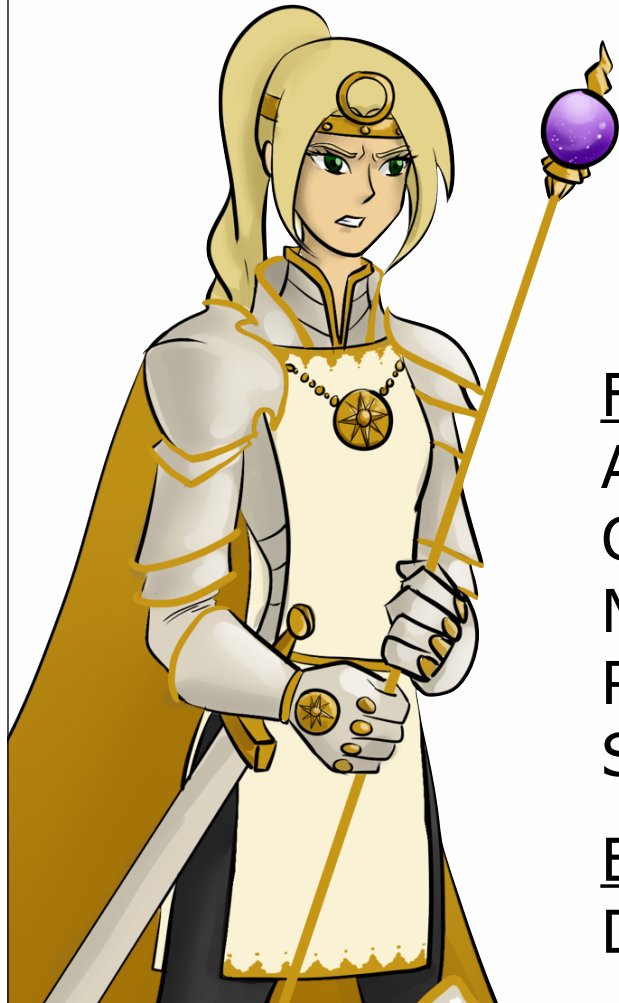
UCB1

- Good for Repeated Play
 - All strategies / actions should be reasonable
- Regret Matching
 - Randomizes strategy between good actions
- UCB1
 - Good when can't evaluate the utility of alternate strategies
 - Works better on strategies than actions

Simulation-Based

UCB1MCTS

- Use predictions of the future to decide what to play now
- Good when I can't afford to play bad strategies
- Full MCTS can find sets of actions which are not in any of our default policies



For more info:
movingai.com/gdc14/

Feedback:

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