Monte Carlo Search Tree and Its Applications

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Kasparov vs Deep Blue

Kasparov vs Deep Blue

Great display of artifical intelligence (AI)

Techniques employed by IBM

- Brute force deterministic approach
- human knowledge

Limitation

- scalability into larger search spaces

Monte Carlo tree search (MCTS) is an alternative method

Outline

Introduction

Naive MCTS Implementation

Applying MCTS to Go

Applying MCTS to Narrative Generation

Conclusion

Monte Carlo Tree Search (MCTS)

- Combines random sampling and game trees
- Probabilistic not deterministic
- Useful for problems with larger search spaces

Two MCTS Applications

Go

- Board game about positional advantage
- Game board for Chess: 8x8
- Possible games of Chess: 10^{120}
- Game board for Go: 19x19
- Possible games of Go: 10^{761}

Narrative generation

- Useful Applications
    - Video game replay value
    - educational applications
- The search space scales with the number of characters, items, locations, and actions

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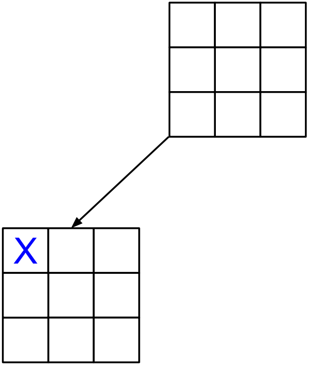
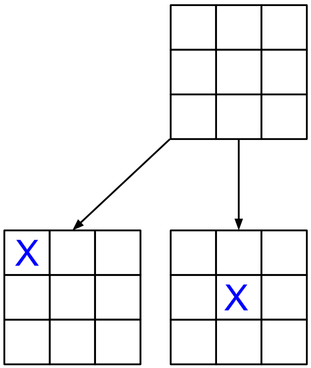
TicTacToe Diagram



TicTacToe Diagram



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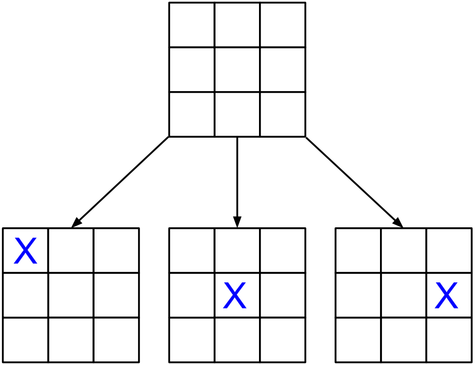
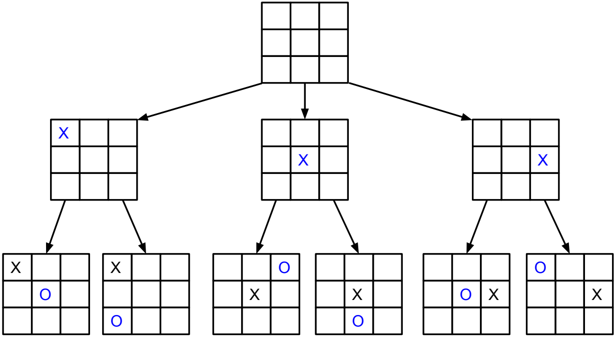


TicTacToe Diagram More Levels



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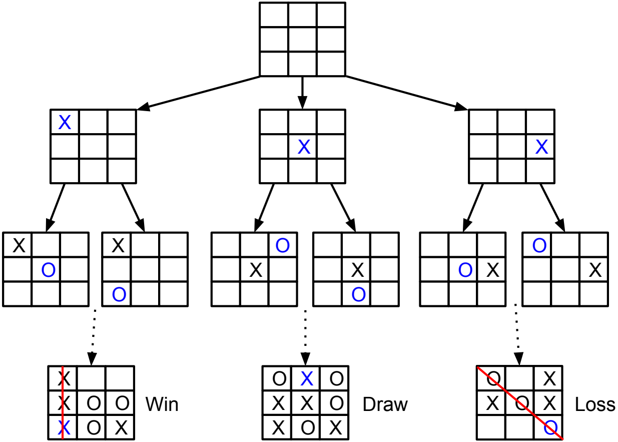

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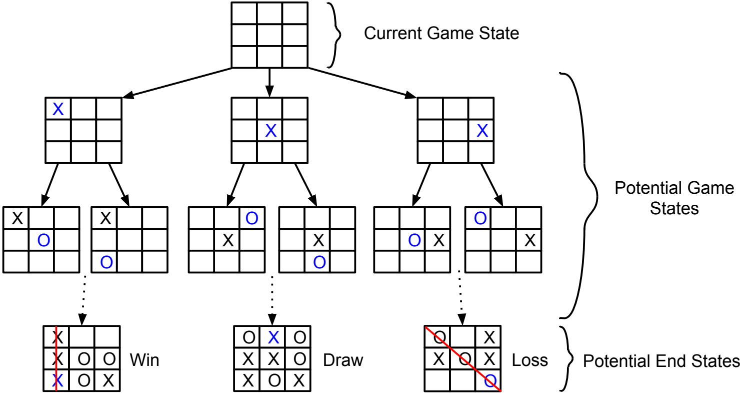
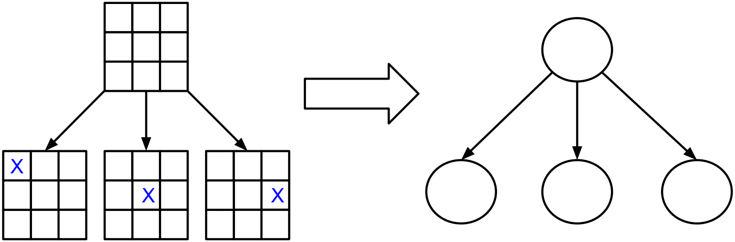
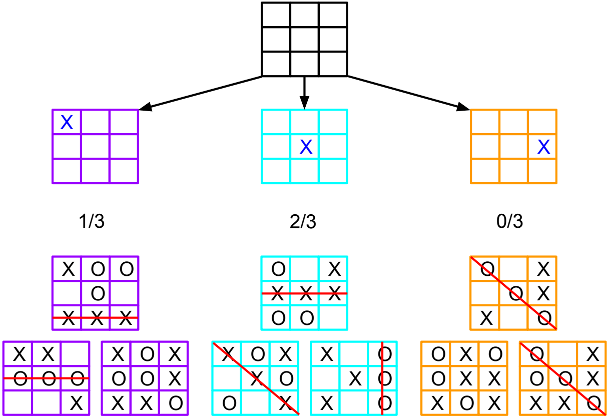


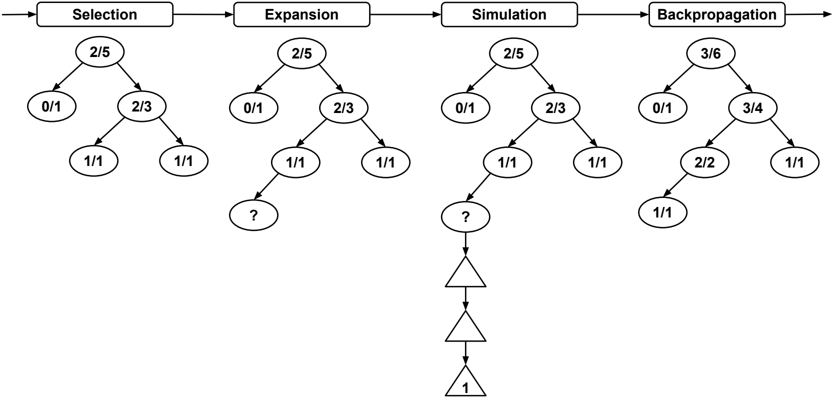
Tree Structure



Sampling



Four Steps Diagram



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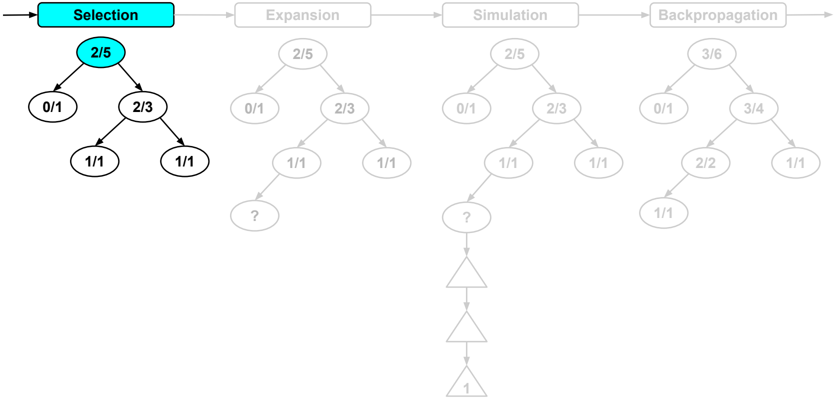

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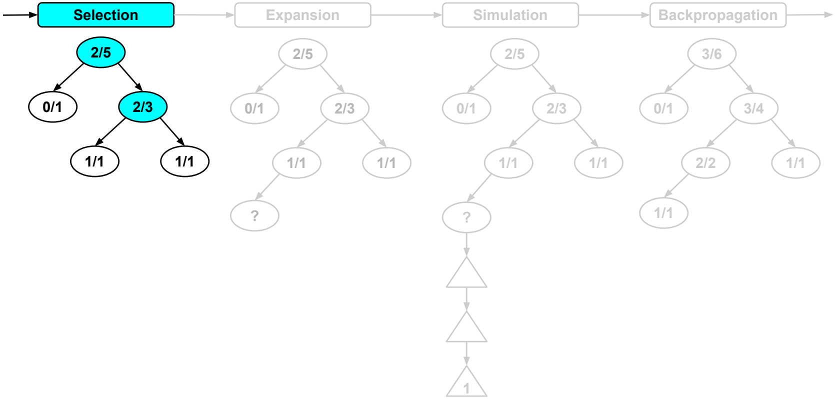

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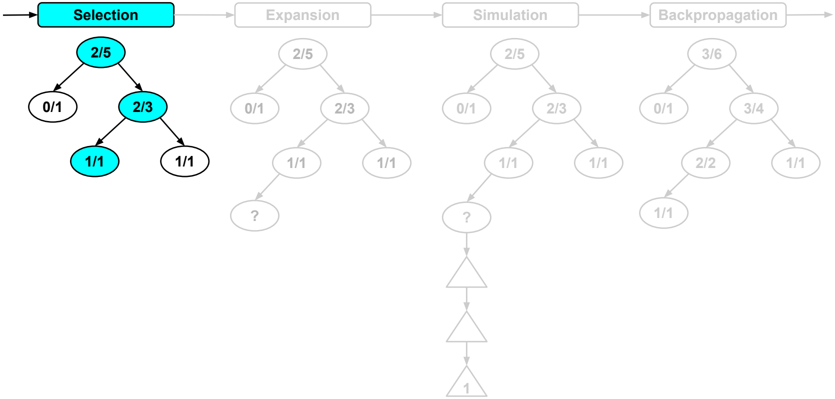

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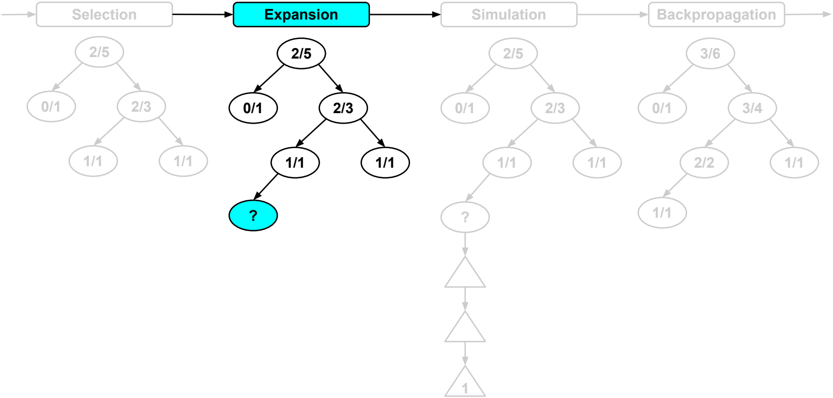

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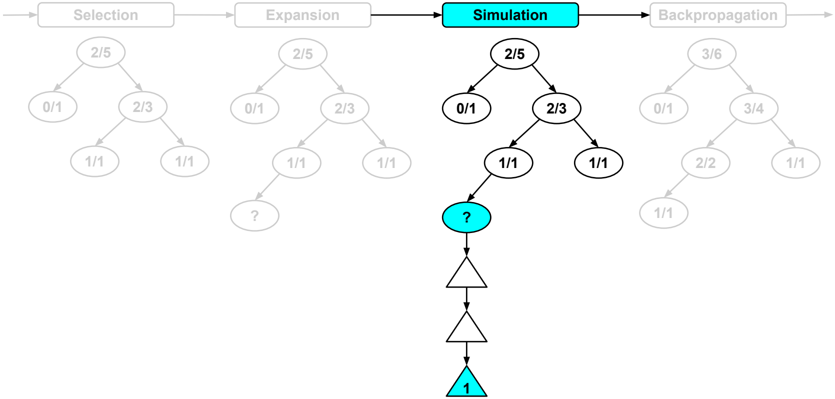

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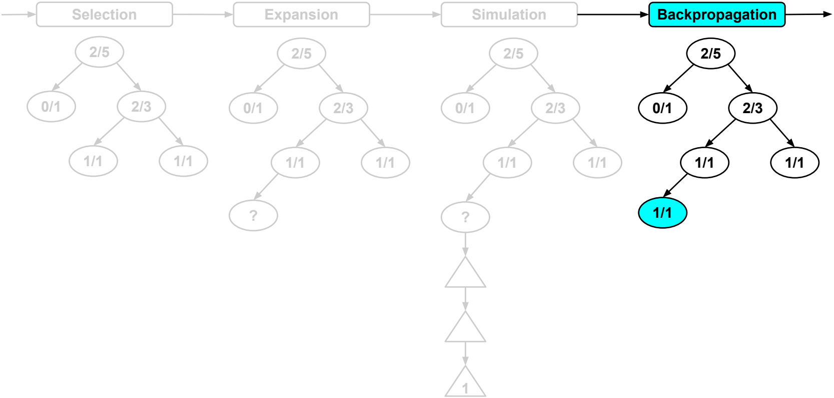

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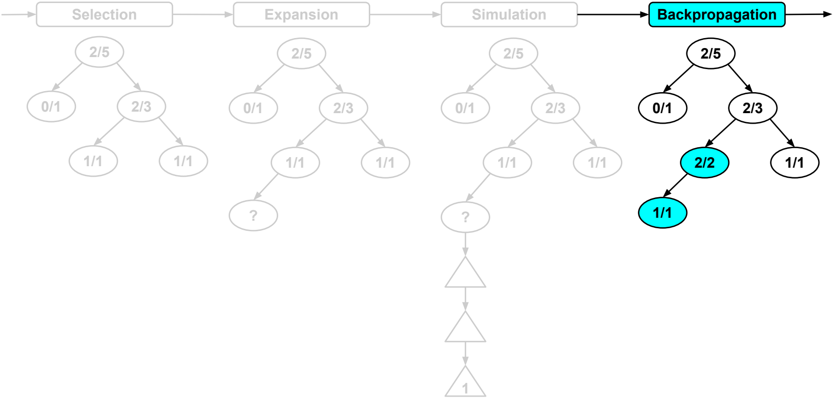

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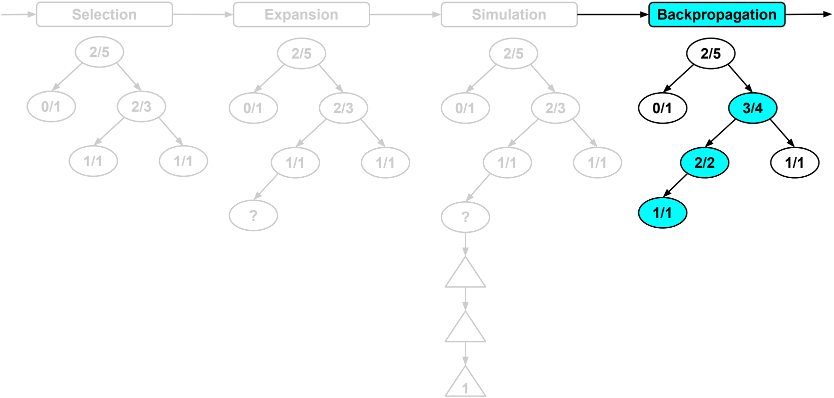

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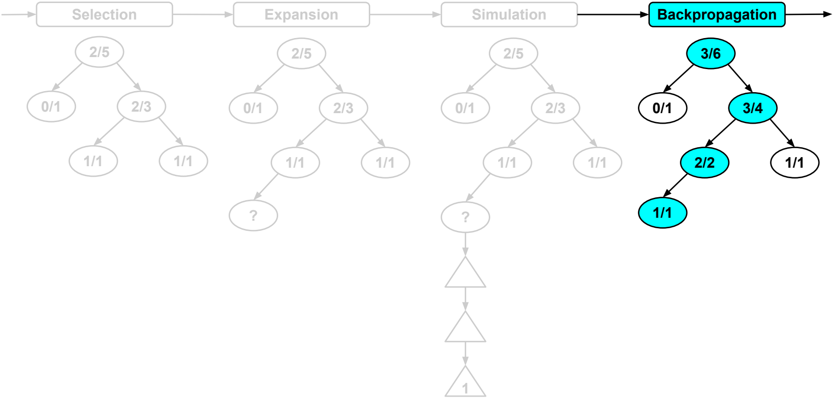

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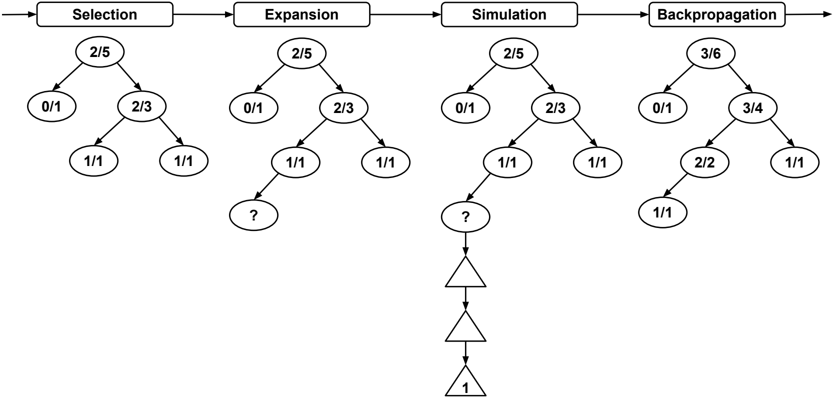

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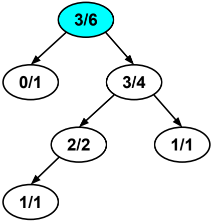

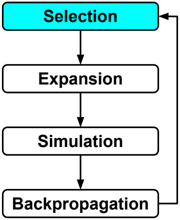

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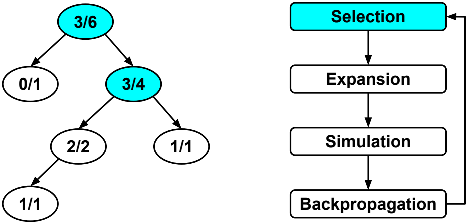

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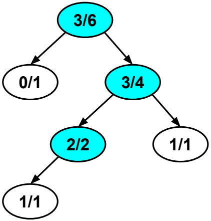

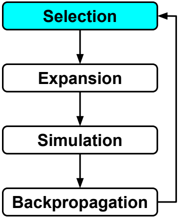

Selection

Expansion

Simulation

Backpropagation

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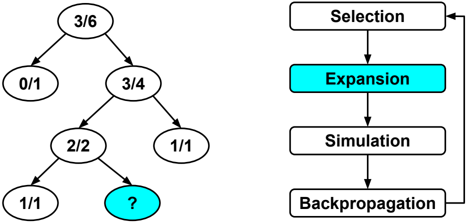

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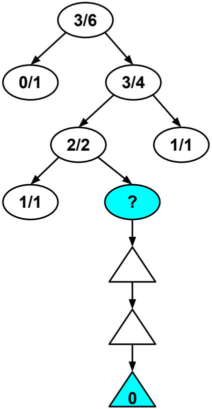

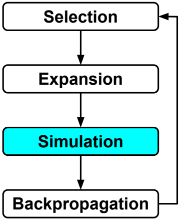
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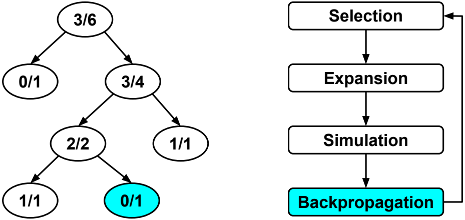

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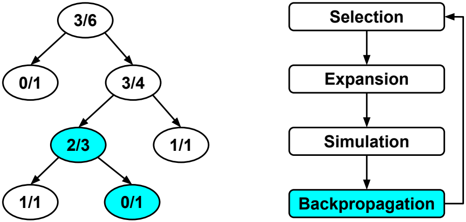

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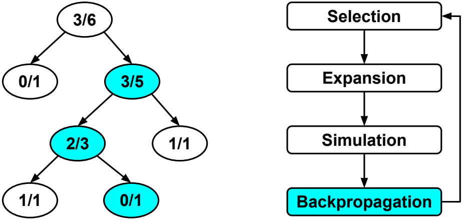

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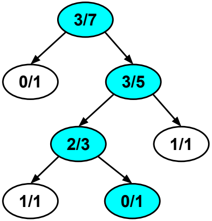

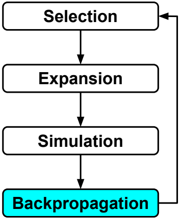

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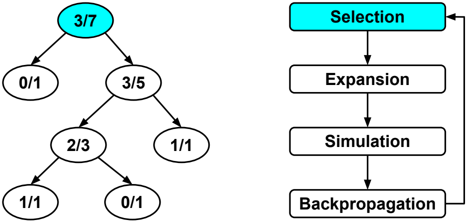

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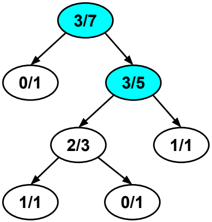

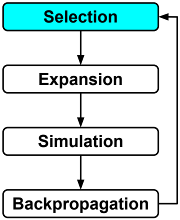

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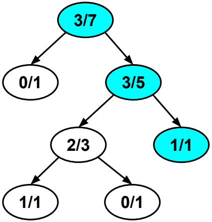

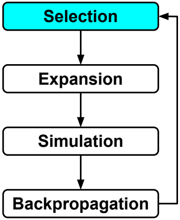

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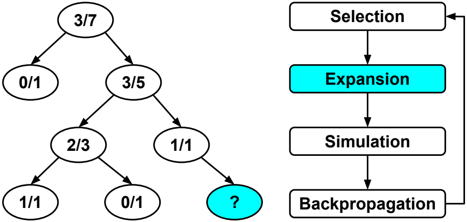

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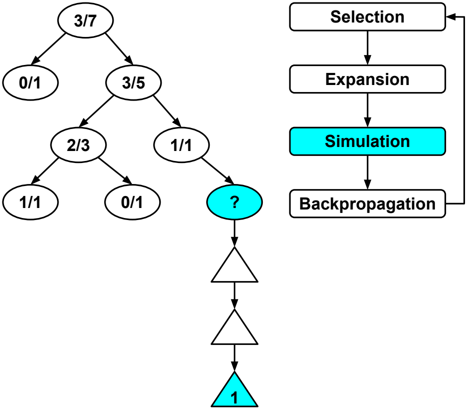

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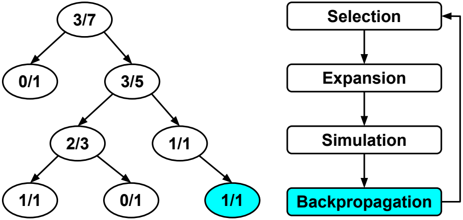

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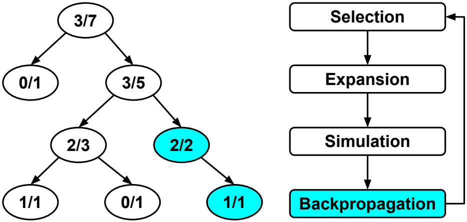

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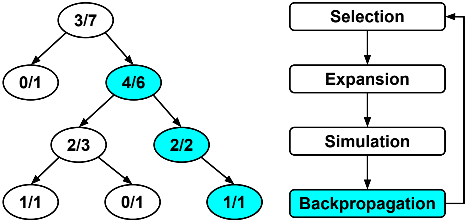

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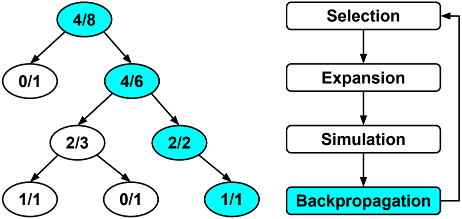


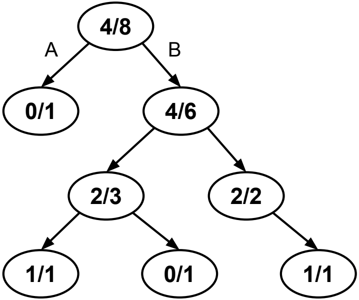
What Happens When We Choose a Move?

Now we have:

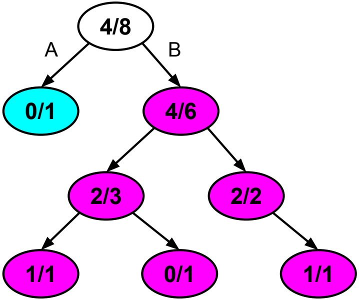
- A tree structure
- A method of generating the tree

What happens when we need to choose a move?

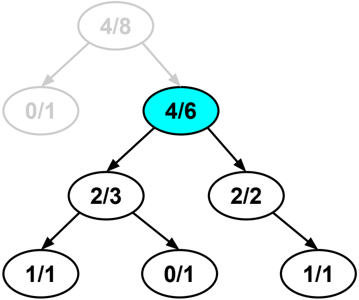
Choosing a Move



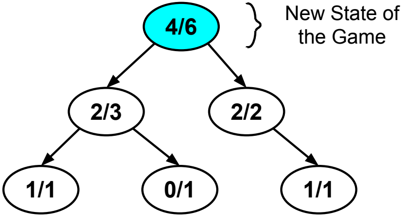
Choosing a Move



Choosing a Move



Choosing a Move



Exploration vs Exploitation

- We might overlook better paths
- Exploration vs Exploitation
  - Exploration looks at more options
  - Exploitation focuses on the most promising path
- Must find a balance between the two

Upper Confidence Bound Applied to Trees (UCT)

$$UCT(node) = \underbrace{\frac{W(node)}{N(node)}}_{\text{Value of the Node}} + \underbrace{\sqrt[c]{\frac{ln(N(parentNode))}{N(node)}}}_{\text{Exploration Bonus}}$$

- W represents the number of simulated wins
- N represents the total number of simulations
- C is an experimental constant
- Used during tree traversal
- Balances exploration vs exploitation

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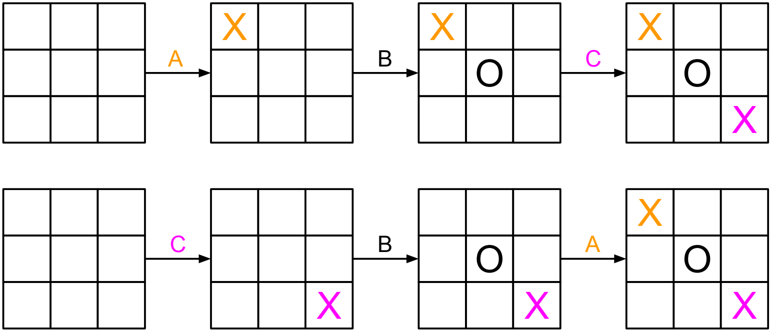
MCTS applied to Go

What variations can we make specific to Go?

In Go each player takes turn placing pieces on a game board

- How much does the order of these moves matter?
- Can we use this to improve MCTS in the context of Go?

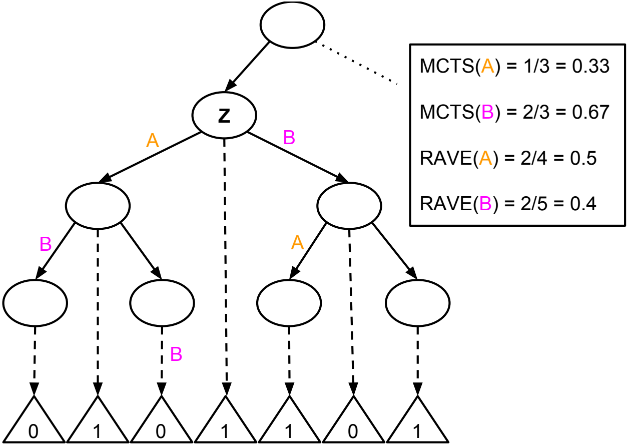
Tree Redundancy



Rapid Action Value Estimate (RAVE)

- Takes advantage of tree redundancy
- Moves have no contextual dependencies
- Stores the value of a move with in a subtree at each node

RAVE Diagram



MCTS(A) = 1/3 = 0.33

MCTS(B) = 2/3 = 0.67

RAVE(A) = 2/4 = 0.5

RAVE(B) = 2/5 = 0.4

RAVE

- Very powerful approach
- Each simulation provides us with more information
- Sometimes we do need contextual dependencies
    - Example: Close tactical battles

MC RAVE

- Combines MCTS values with RAVE values
- Uses a weighted average
- Favors RAVE values when fewer simulations have been performed
  - Contextual dependencies are unknown
- Favors MCTS values when more simulations have been performed
  - Contextual dependencies are more developed

Go Results

- Deterministic approaches could hardly defeat low level amateurs
- Computer Go programs use MC RAVE
  - MoGo
  - Crazy Stone
- Can compete against top pros in 9x9 Go
- Can compete against top pros in handicapped 19x19 Go

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Narrative Generation

Kartal et al applied MCTS to Narrative Generation

- Crime story
- Goals and set up of the story set by the user
  - Example Setup: The detective starts in his office
  - Example Goal: The killer must be arrested

Unlike Go and other games

- Slightly different tree structure
- Evaluation function needed

Actions

Move(A, P): A moves to place P.
Kill(A, B): B’s health to zero(dead).
Earthquake(P): An earthquake strikes at place P. This causes people at P to die (health=0), items to be stuck, and place P to collapse.

- Actions drive the story
- Different actions take the place of moves as nodes
- Set threshold during simulation

Evaluation function

- Method of giving nodes value
- Ensures stories are interesting
- Incorporates believability and goal completion
  - Actions are believable based on context
    - Example: Inspector searches for clues
    - Example: Character A kills Character B
  - Important to complete the goals set by the user
- The value is between 0 and 1
- Product of every action in a story

Narrative Generation Test

MCTS compared against three deterministic algorithms

- Breadth-first search
    - Expands tree level by level
- Depth-first search
    - Expands tree down one path at a time
- Best-first search
    - Expands tree by choosing the node with the highest estimated value

Test Conditions

Goals for the narrative:

- At least two people are killed
- The killer is arrested

Each algorithm was given two budgets

- 100,000 nodes
- 3 million nodes

Each algorithm ran three times
The score of the narratives were averaged

Results

	MCTS	Breadth-first	Depth-first	Best-first
Low Budget	0.07	0.05	<0.001	0.005
High Budget	0.9	0.06	<0.01	<0.01

- MCTS performed the best in both
- Breadth-first came the closest out of the deterministic algorithms

High Scoring Example Story From MCTS

Alice picked up a vase from her house. Bob picked up a rifle from his house. Bob went to Alice's house. While there, greed got the better of him and Bob stole Alice's vase! This made Alice furious. Alice pilfered Bob's vase! This made Bob furious. Bob slayed Alice with a rifle! Bob fled to downtown. Bob executed Inspector Lestrade with a rifle! Charlie took a baseball bat from Bob's house. Sherlock went to Alice's house. Sherlock searched Alice's house and found a clue about the recent crime. Bob fled to Alice's house. Sherlock wrestled the rifle from Bob! This made Bob furious. Sherlock performed a citizen's arrest of Bob with his rifle and took Bob to jail.

Low Scoring Example from Breadth-First

Sherlock moved to Alice's House. An Earthquake occurred at Alice's House! Sherlock and Alice both died due to the earthquake.

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Conclusion

- MCTS successful in extending AI capabilities
- Tackles problems with larger search spaces
- Effective in Go and Narrative Generation
- Applicable to other problems
    - Can outperform humans in many puzzles
    - Real time games
    - Super Mario Brothers