# Monte Carlo Search Tree and Its Applications

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April 25, 2015

# 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

# Monte Carlo Tree Search (MCTS)

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

# Applying MCTS to Go

Go

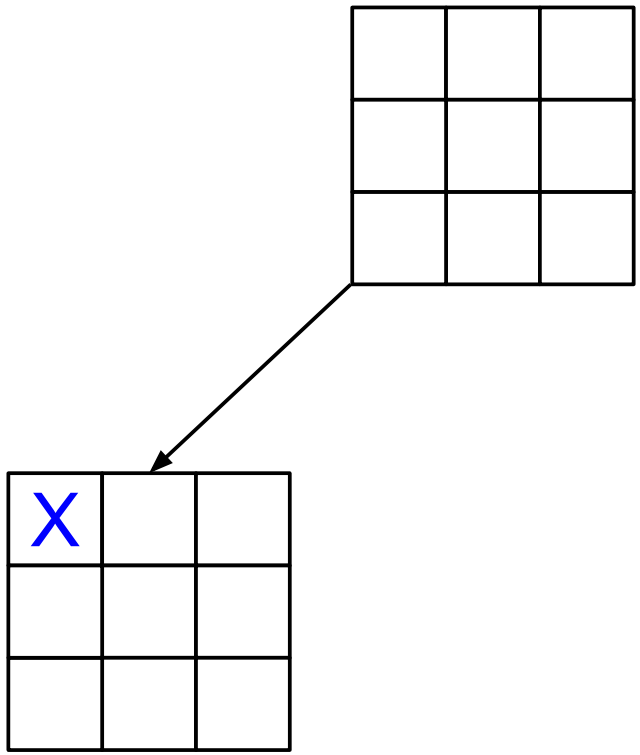
- Board game about positional advantage
- Game board for Chess:
  - 8x8
- Average possible configurations for a game of Chess:
  - $10^{120}$
- Game board for Go:
  - 19x19
- Average possible configurations for a game of Go:
  - $10^{761}$

# Applying MCTS to Narrative Generation

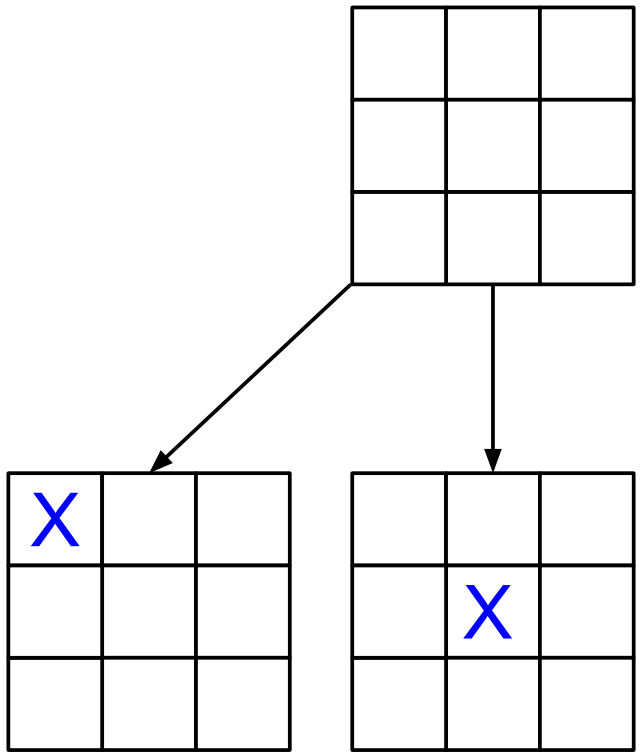
- Useful Applications
  - Video game replay value
  - Educational applications
- The search space scales with the number of characters, items, locations, and actions

# Outline

# TicTacToe Diagram



# TicTacToe Diagram



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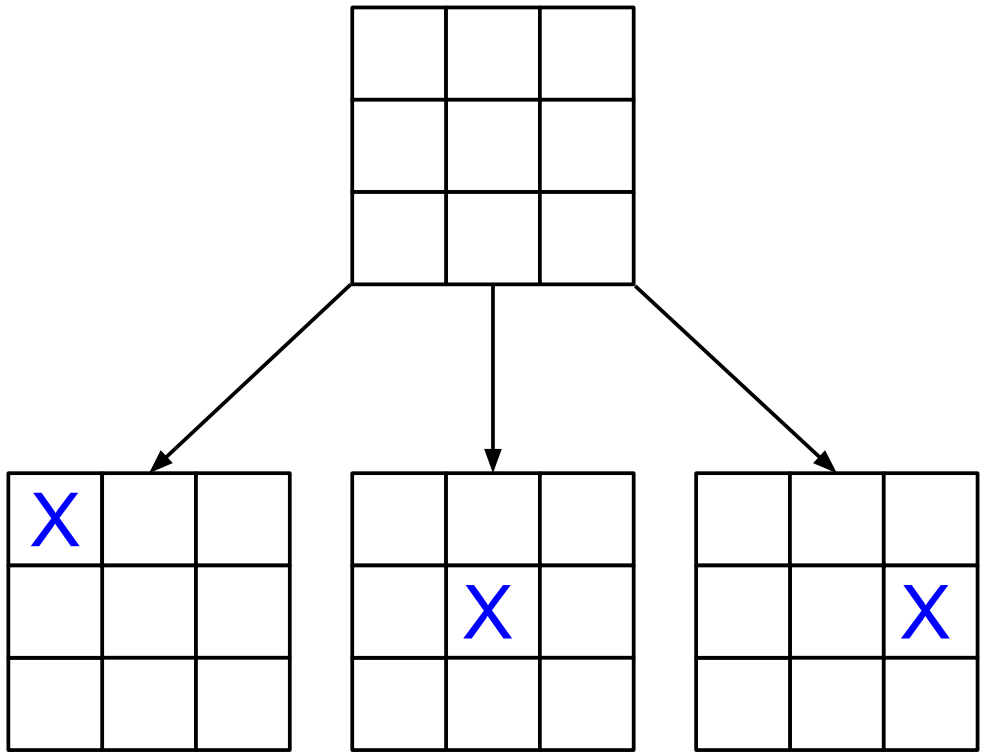
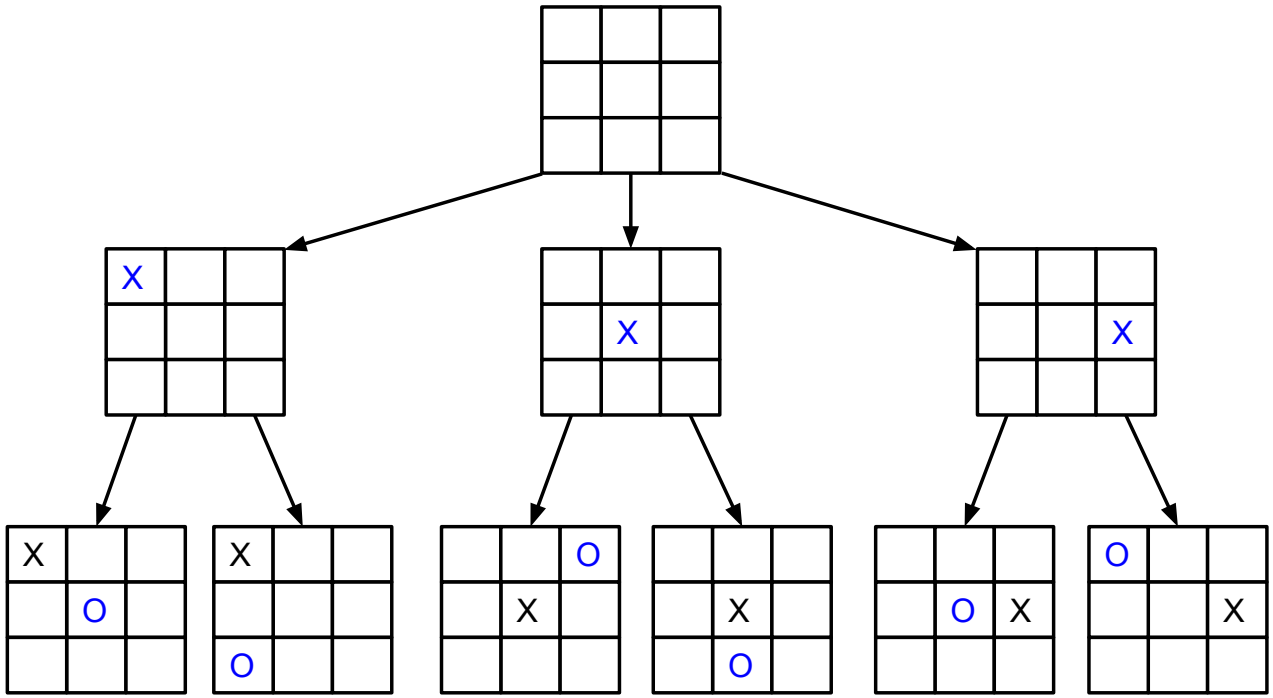


# TicTacToe Diagram More Levels



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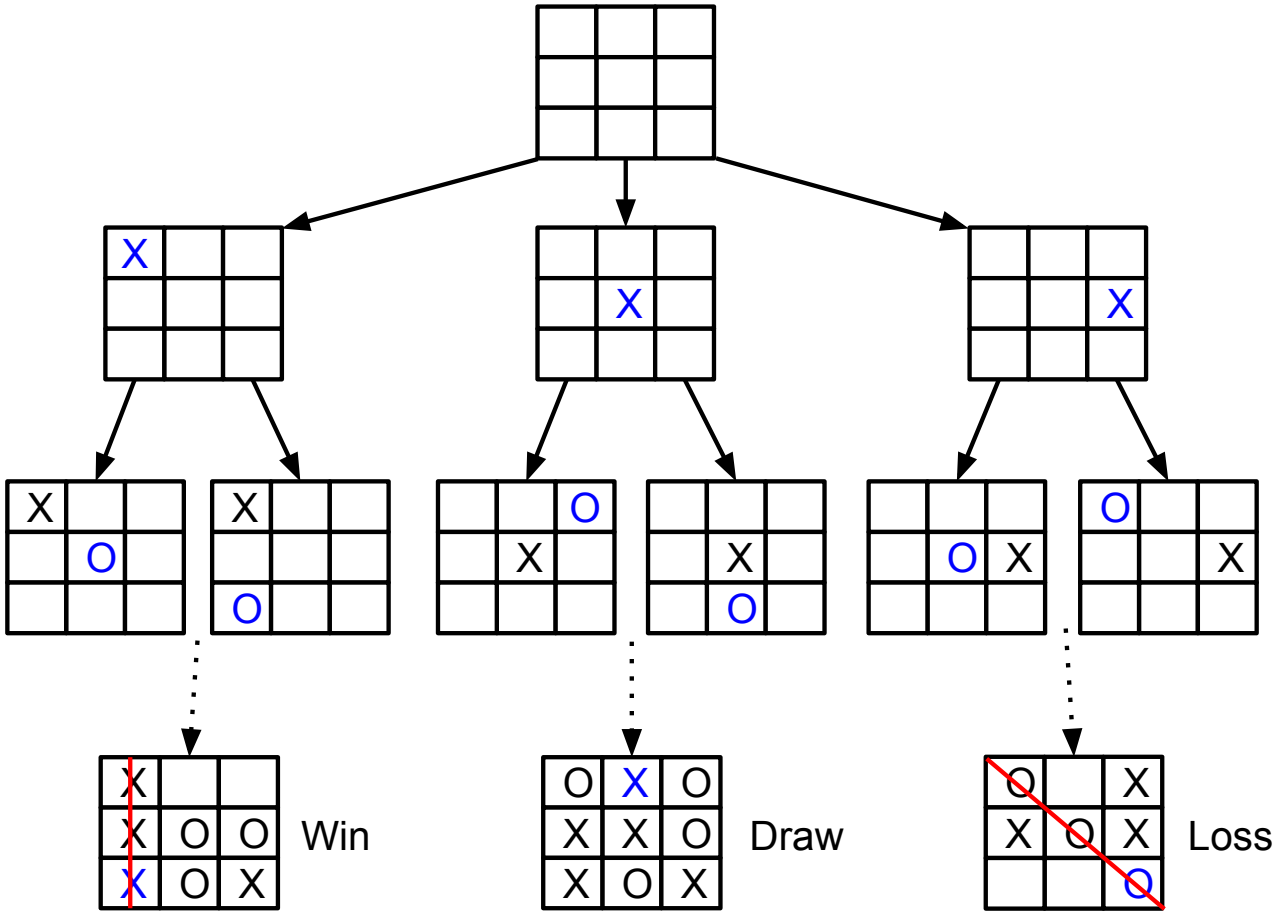

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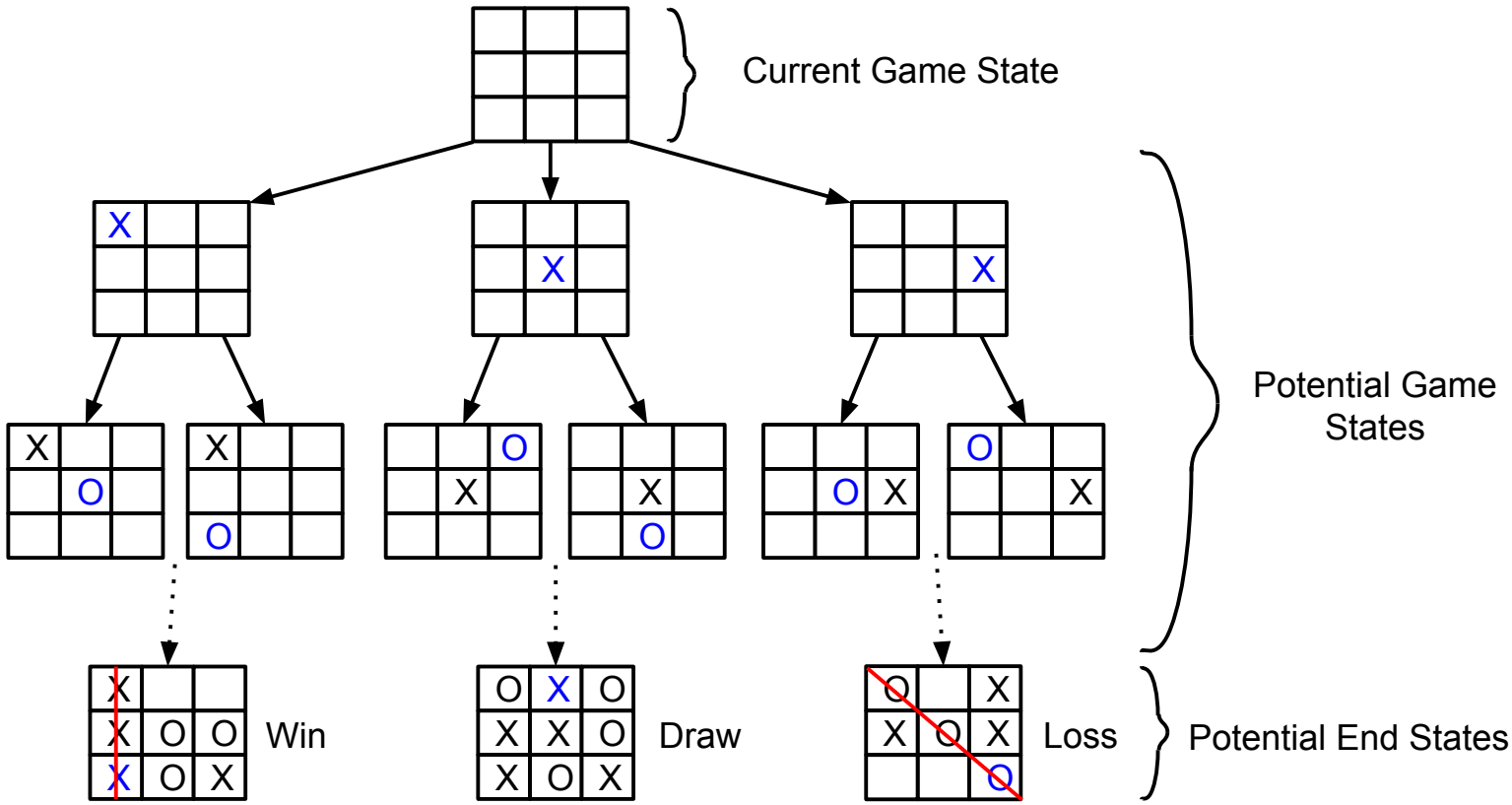
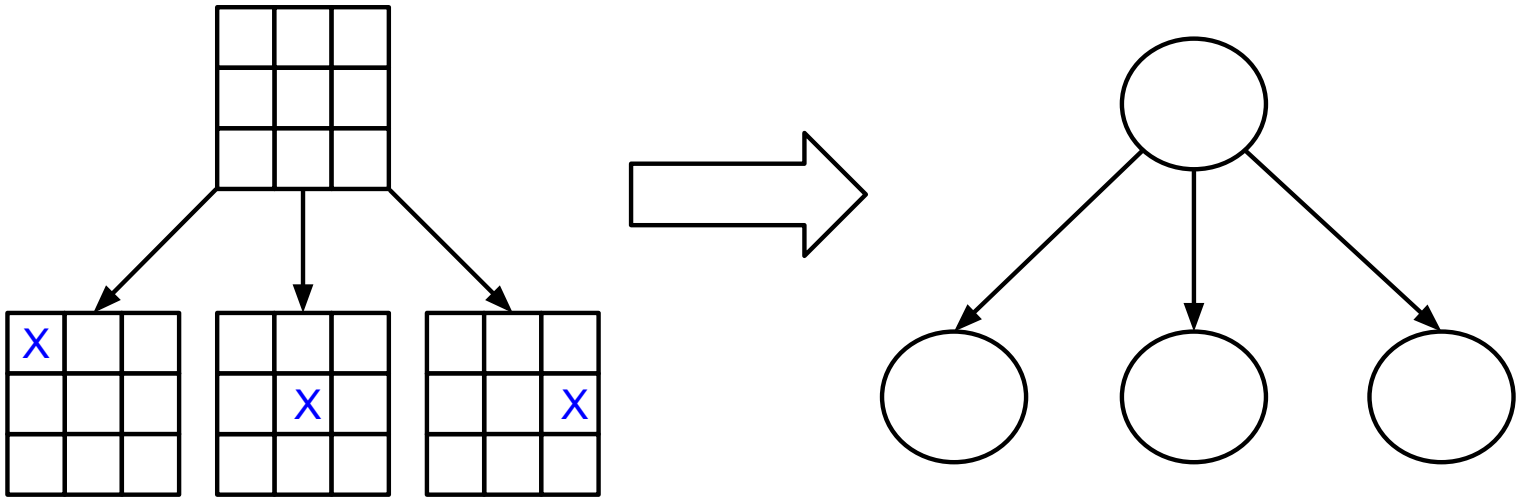
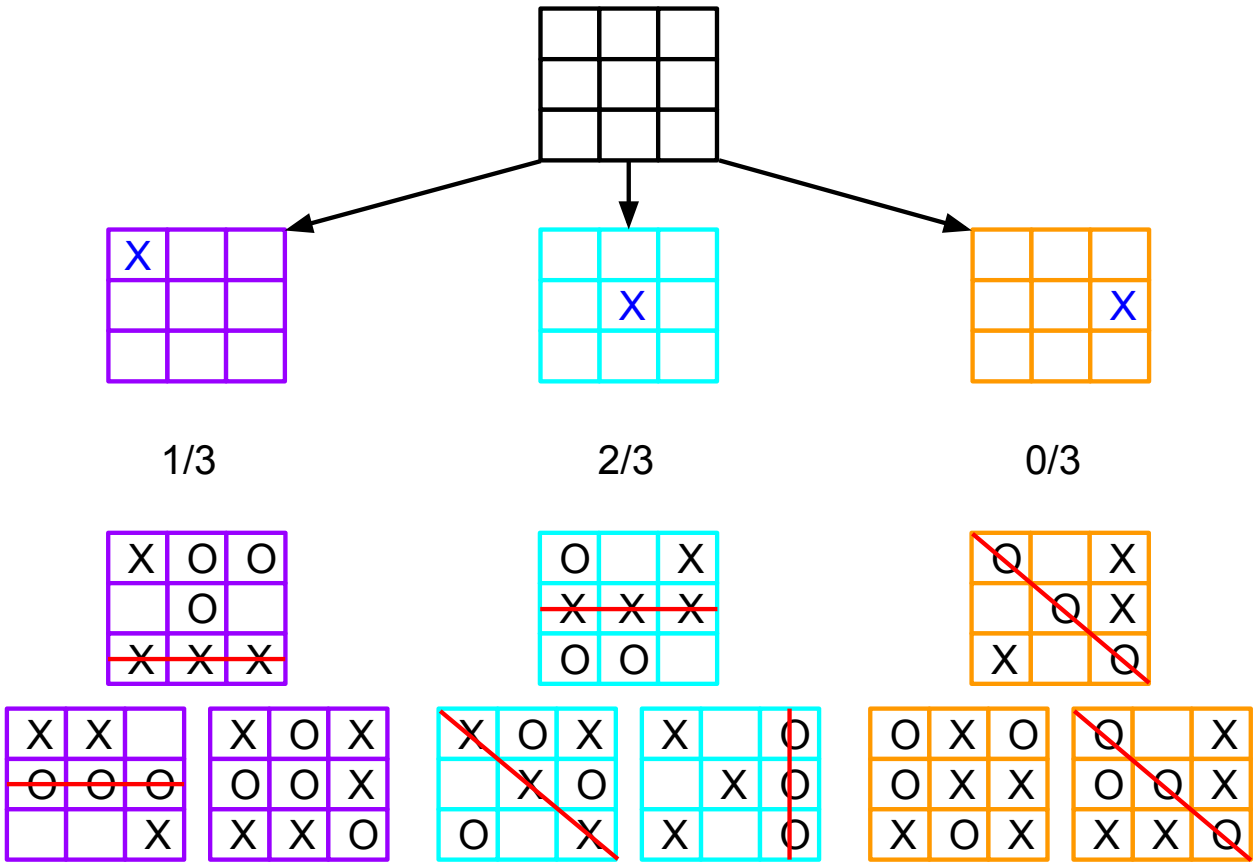


# Tree Structure



# Sampling



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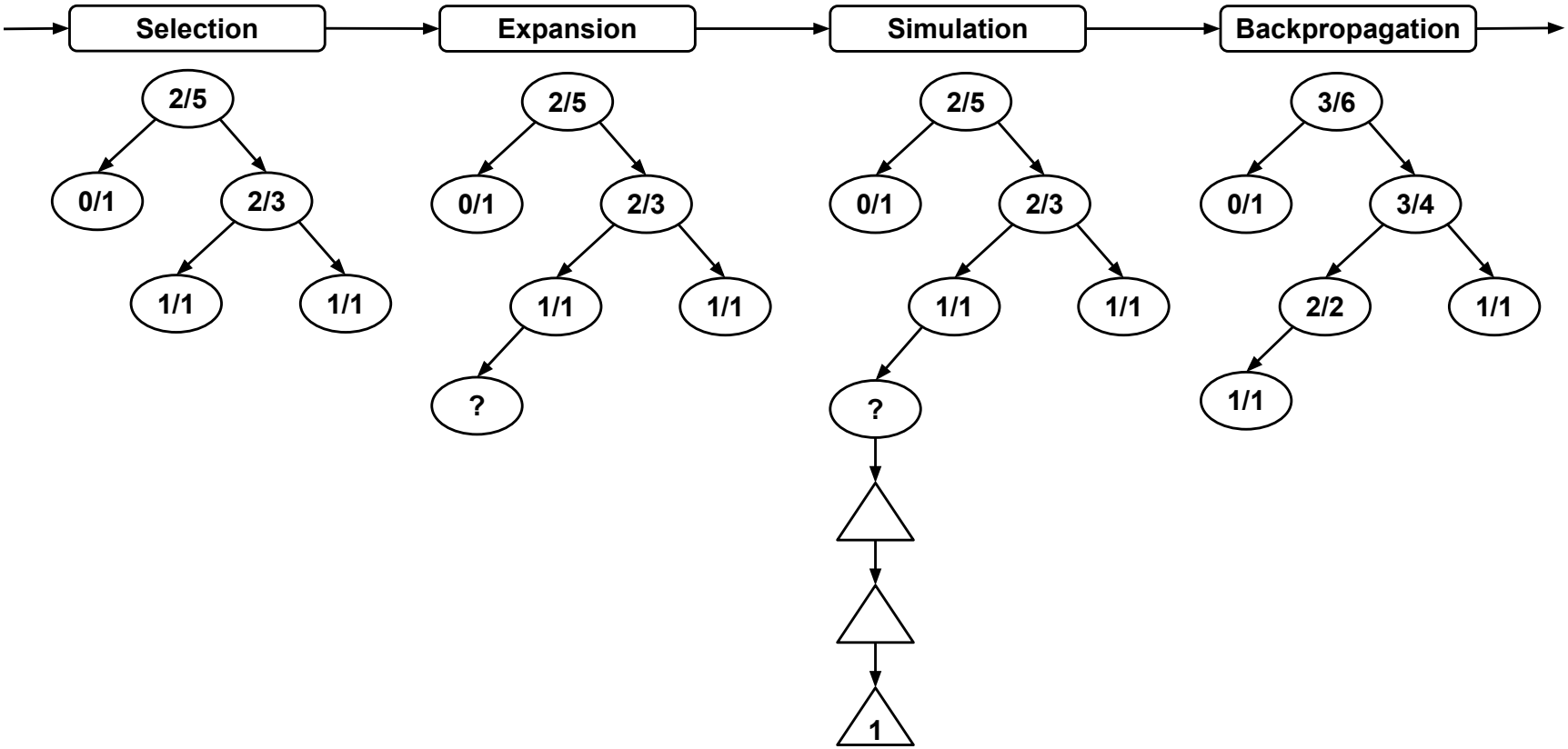

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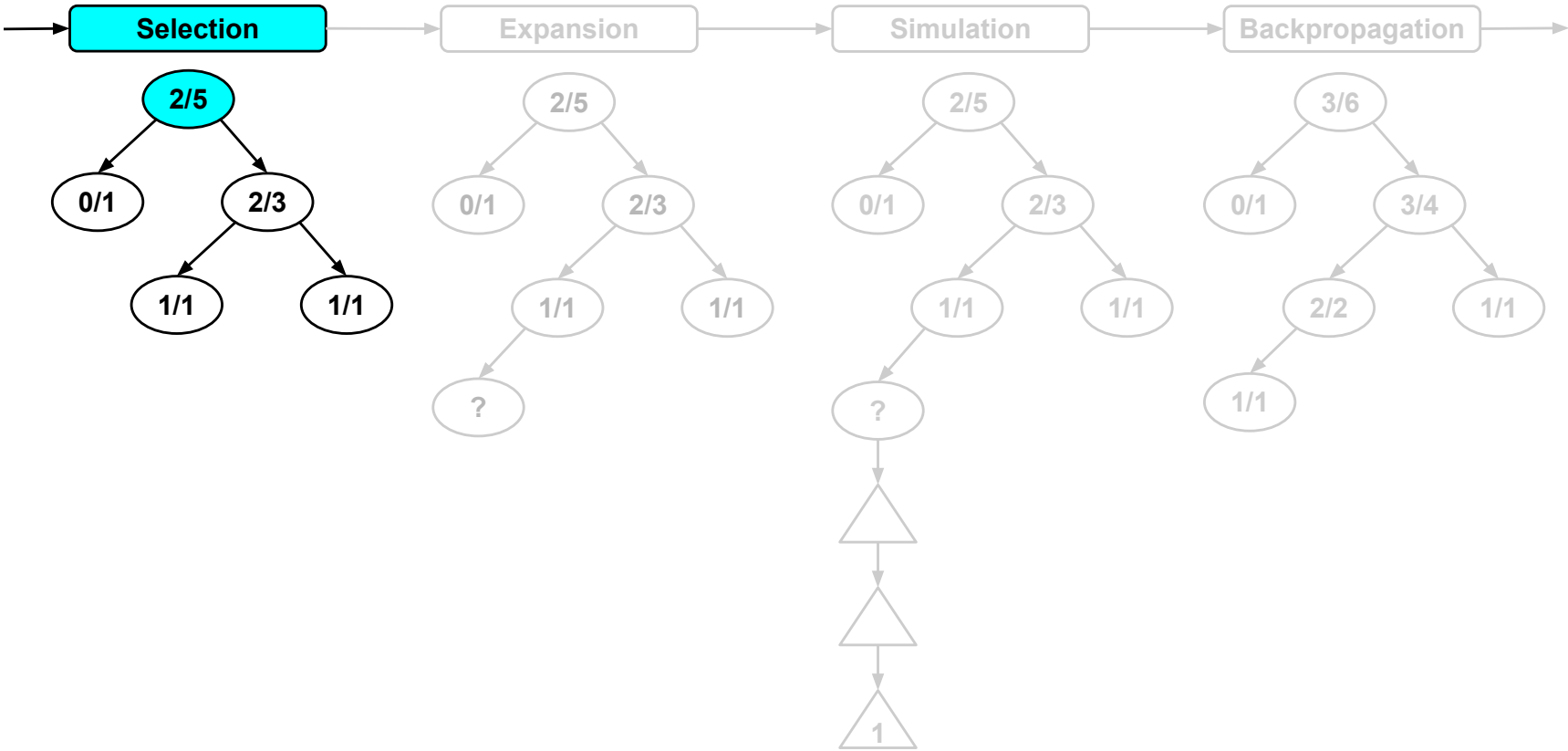

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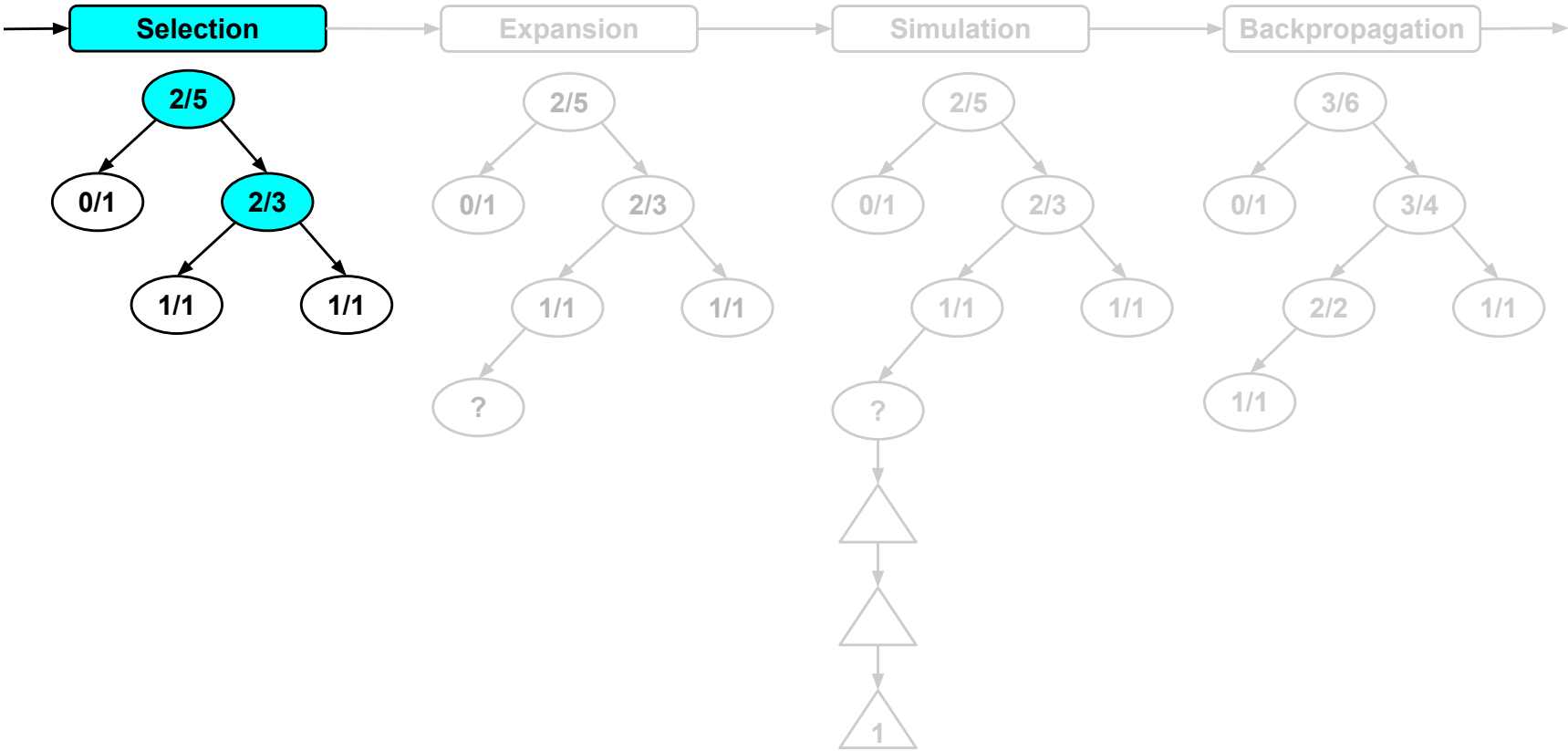

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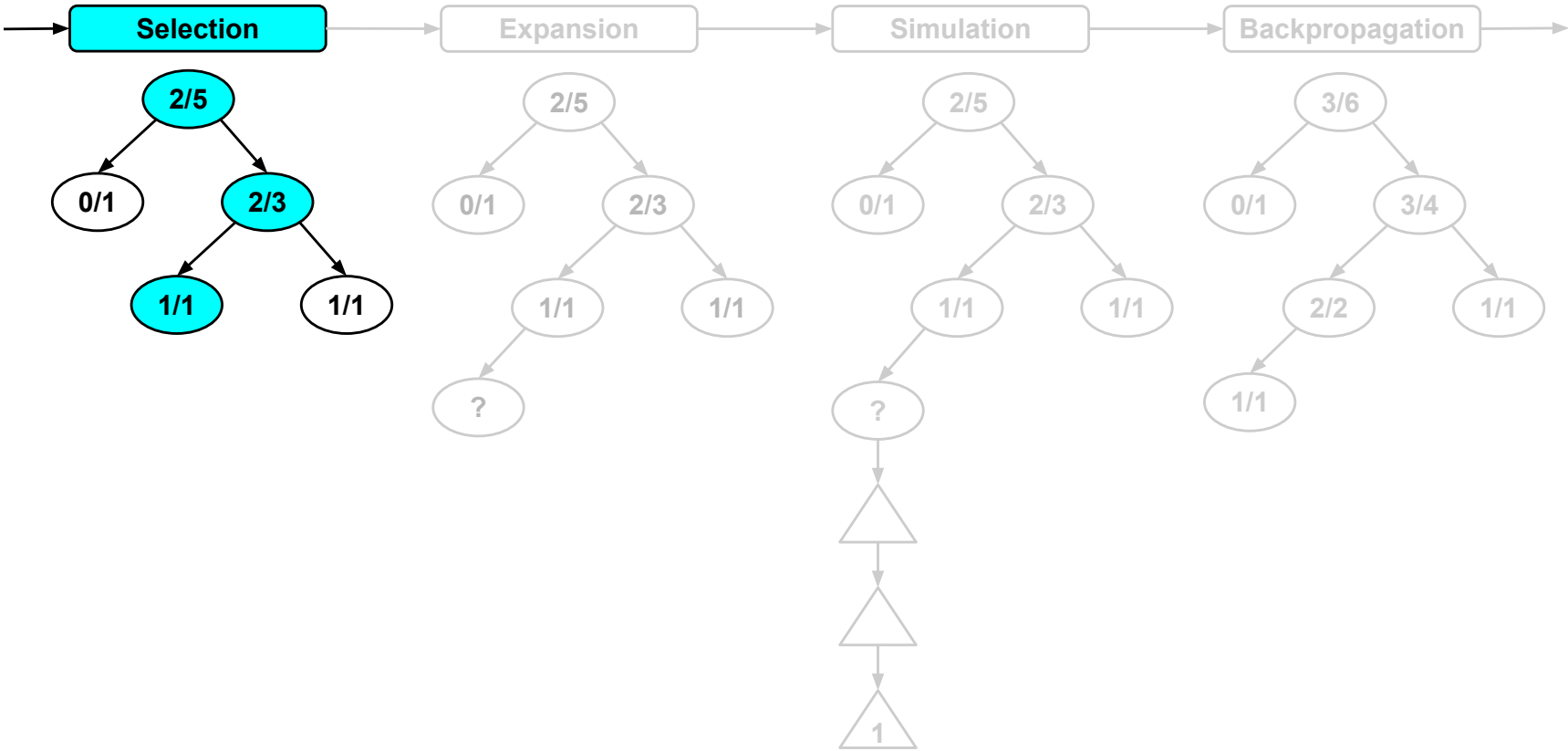

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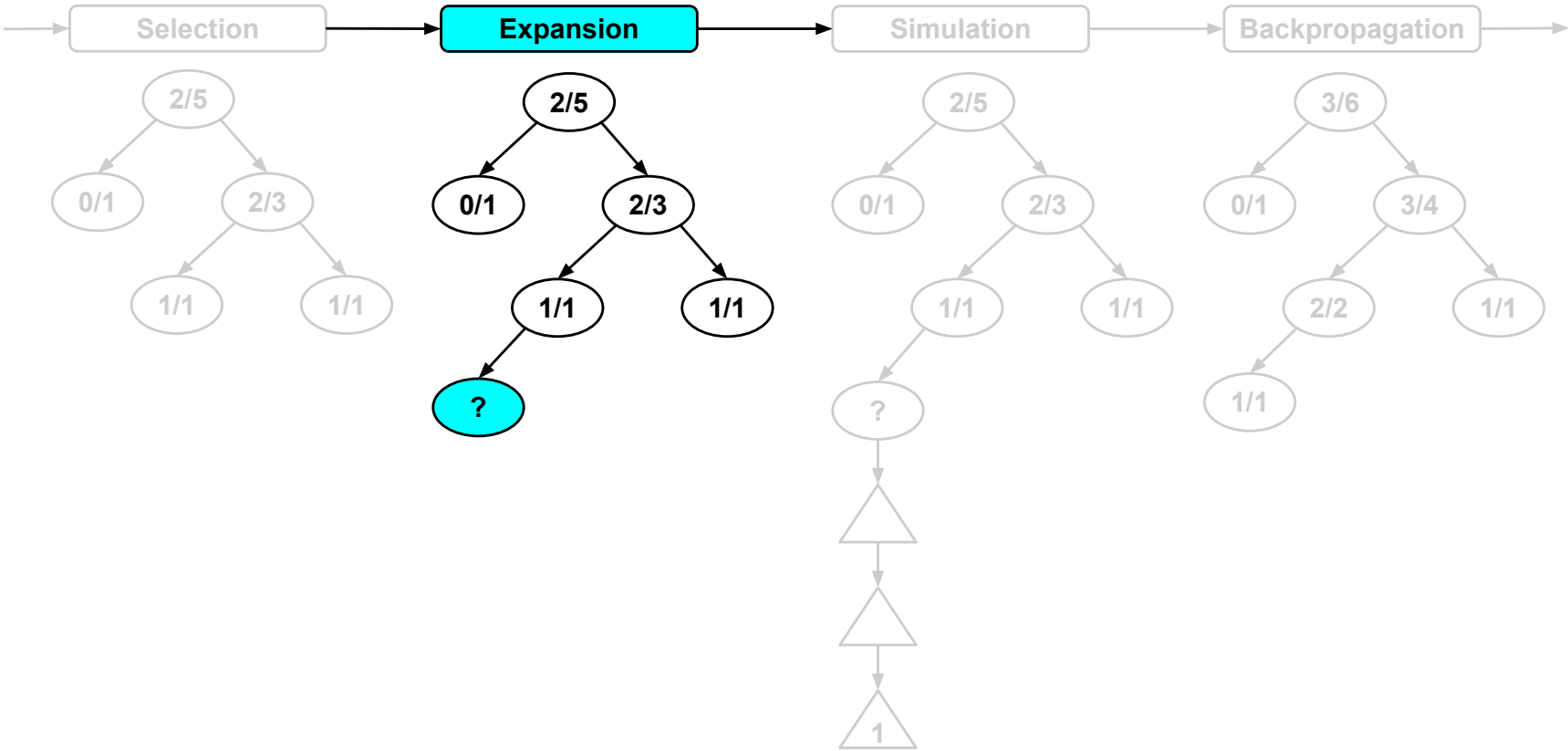

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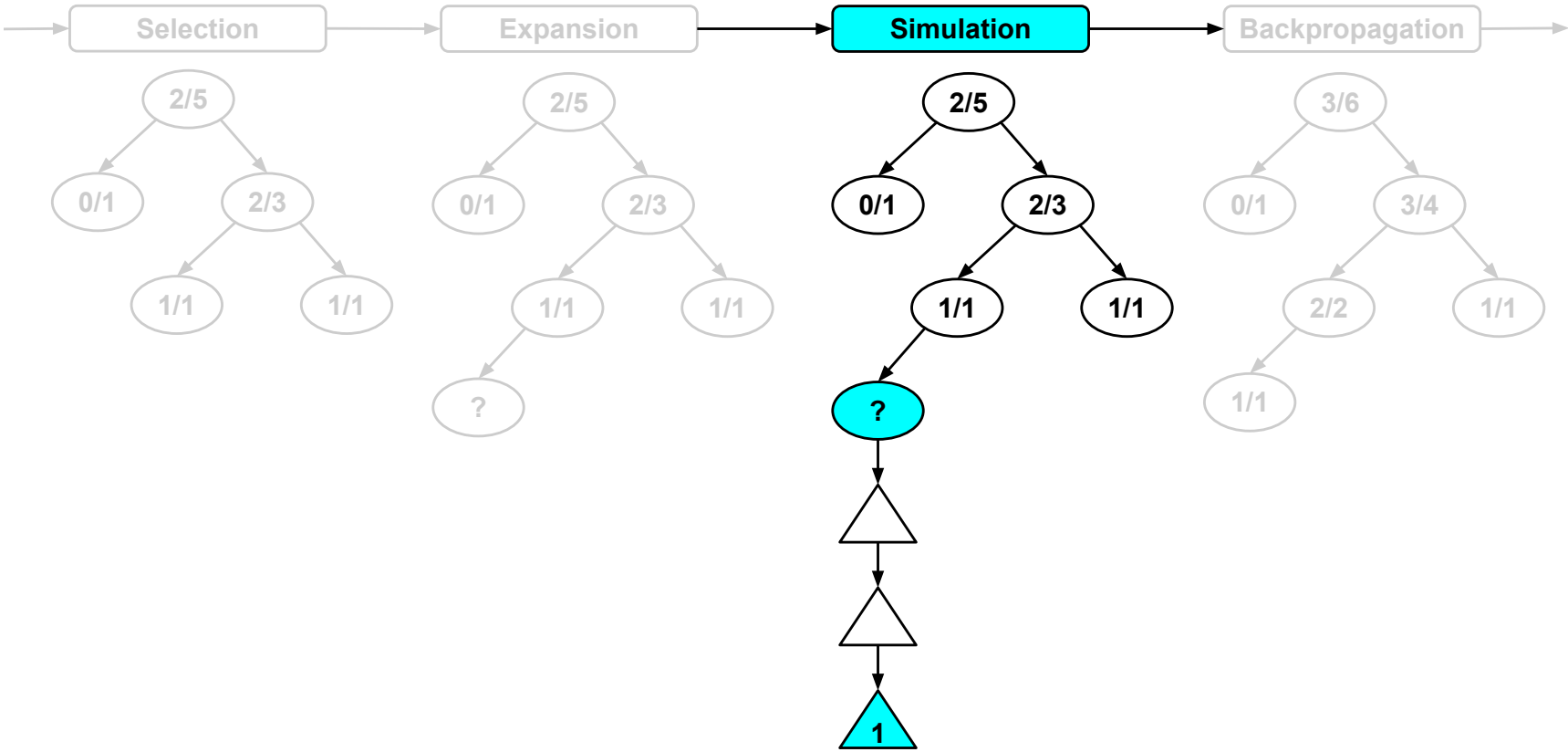

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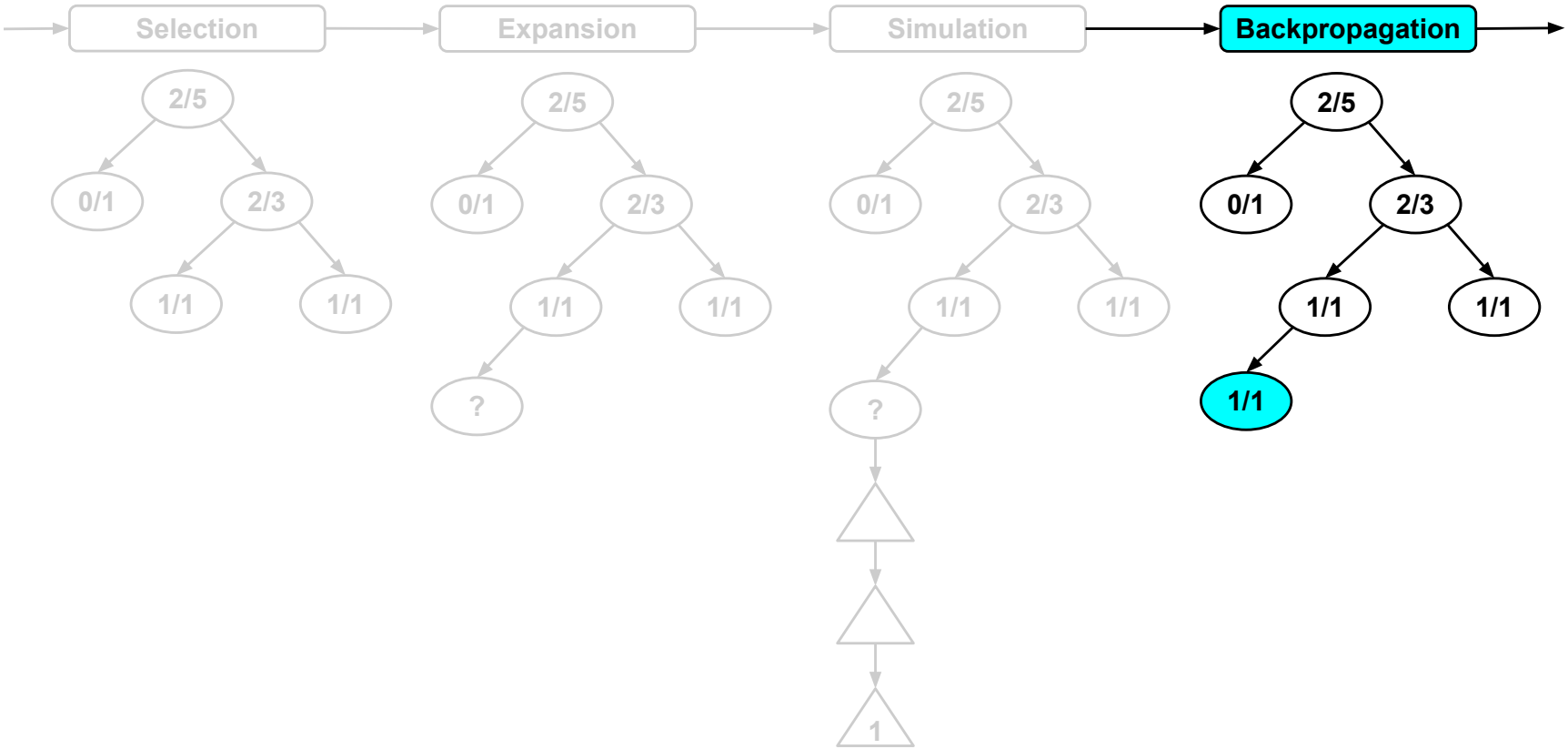

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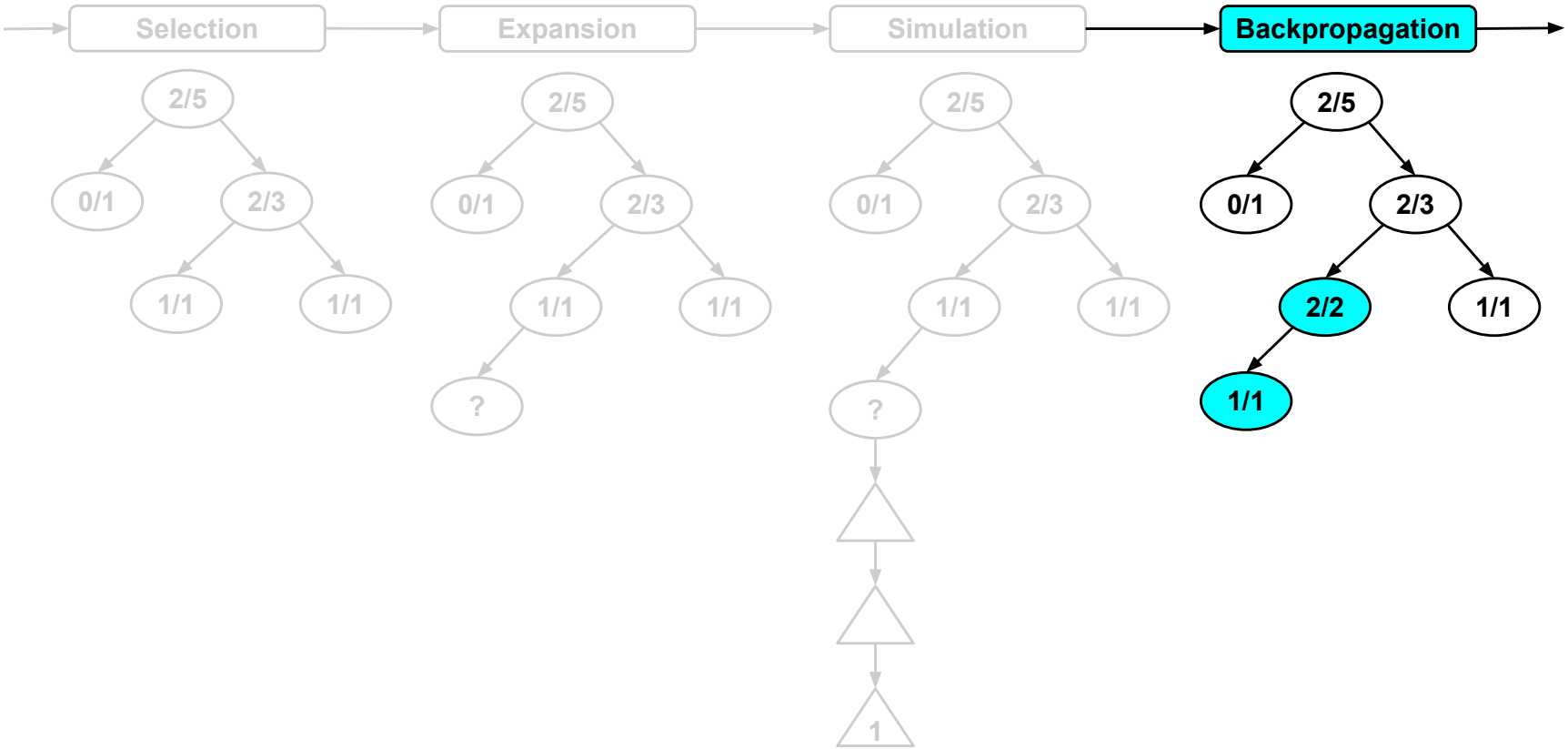

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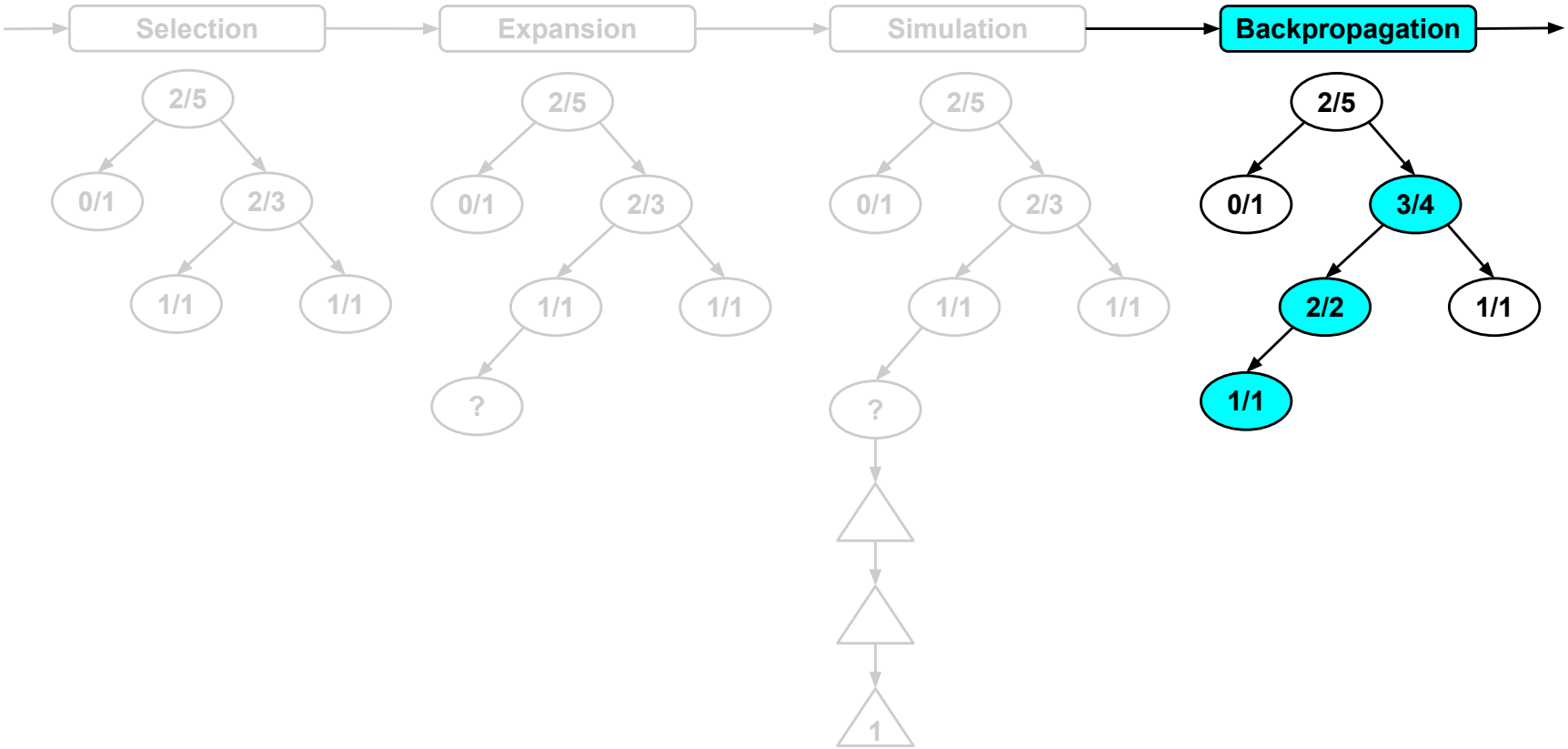

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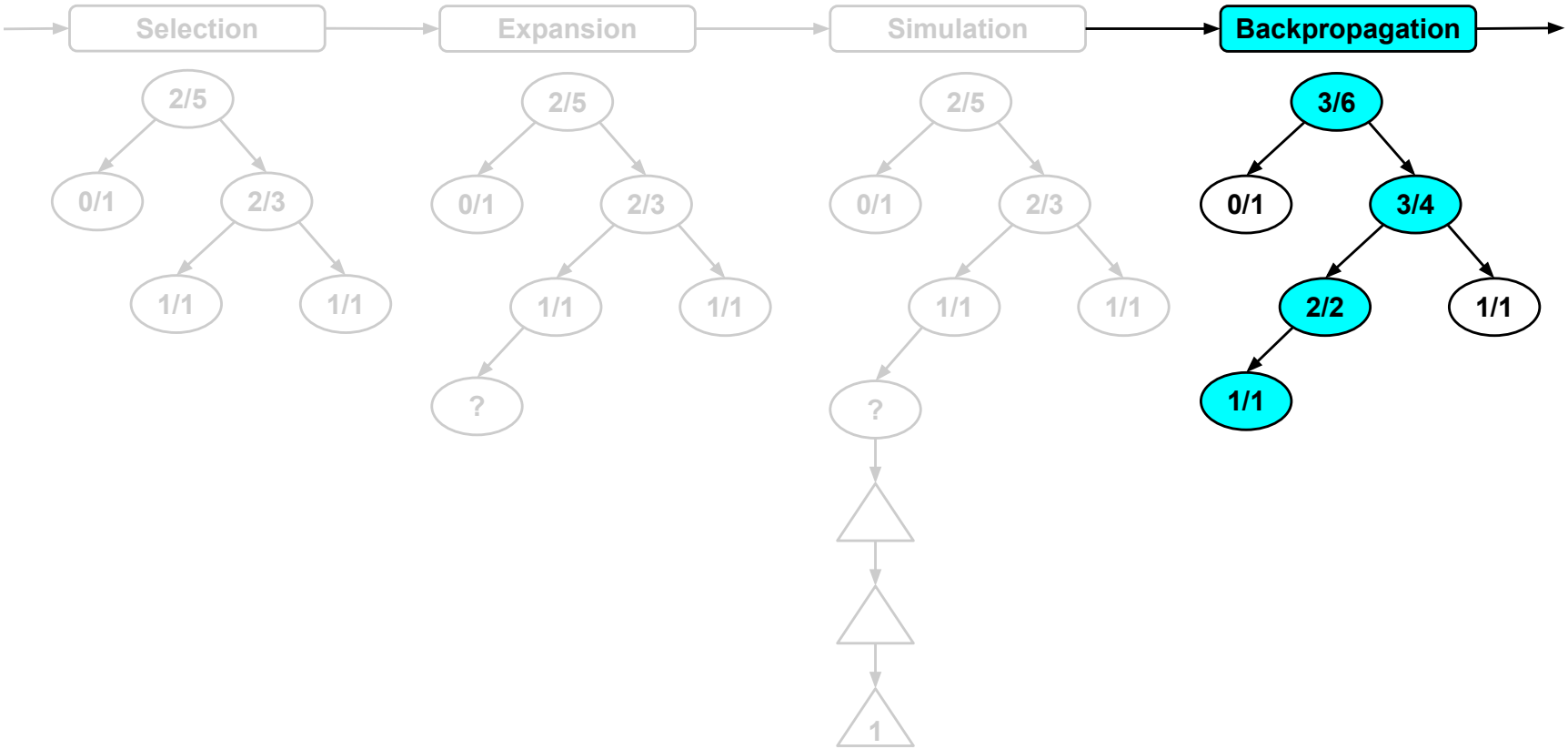

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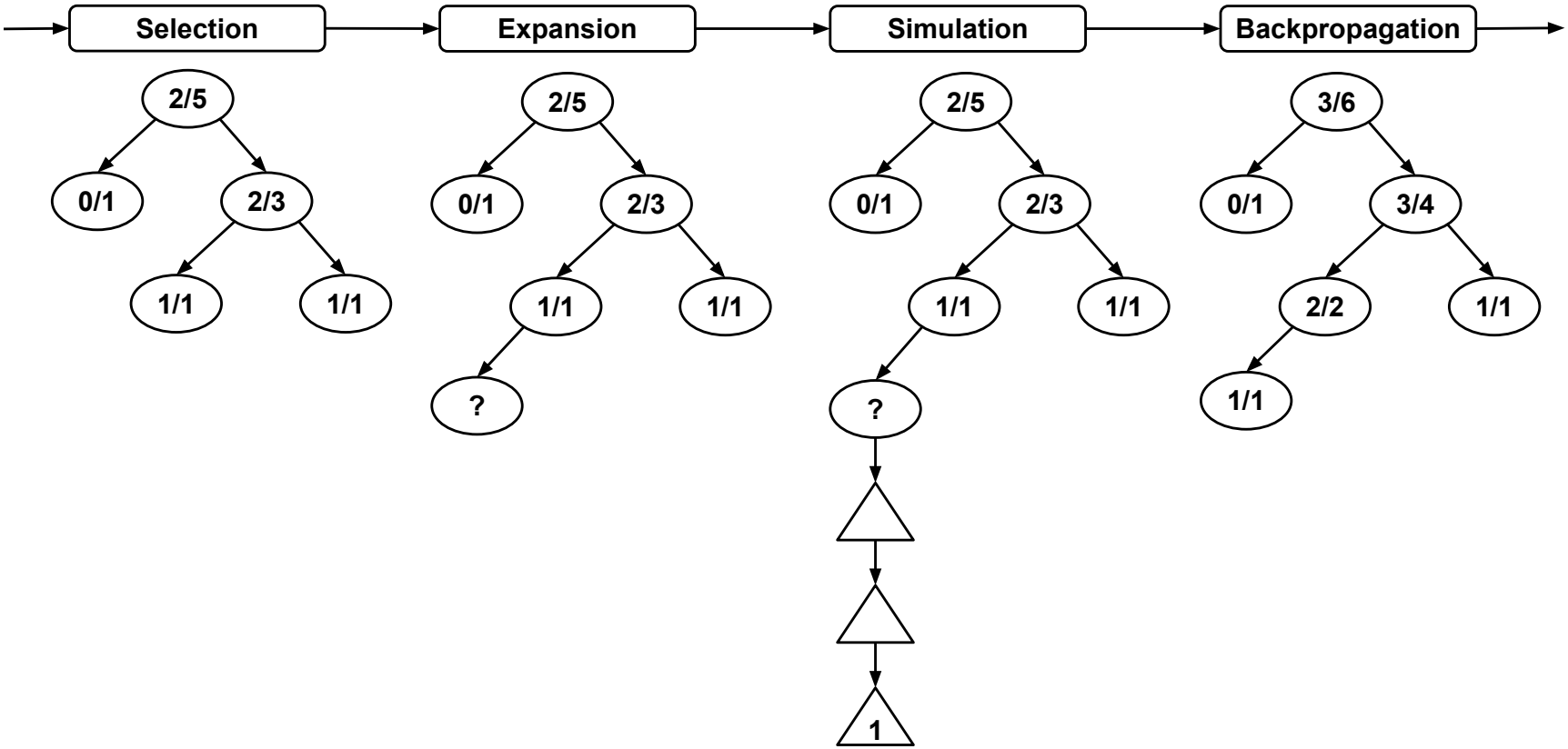

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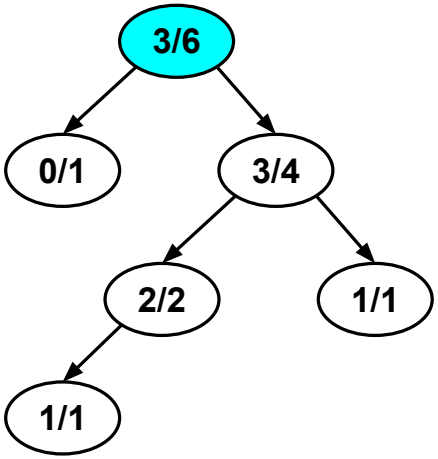


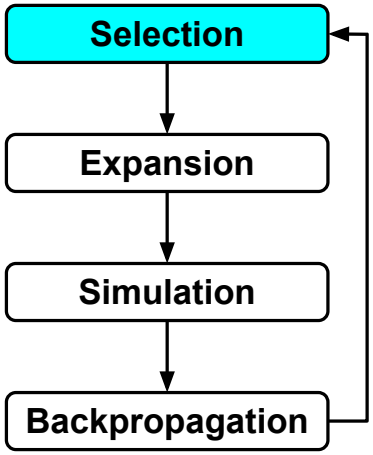

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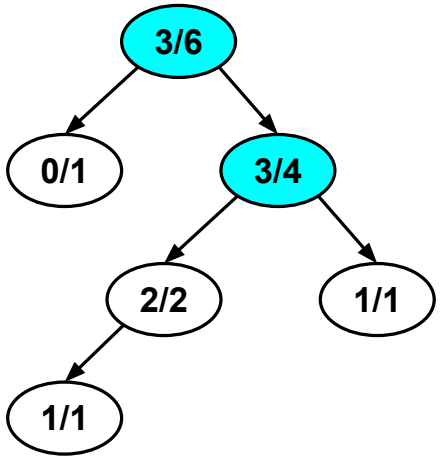


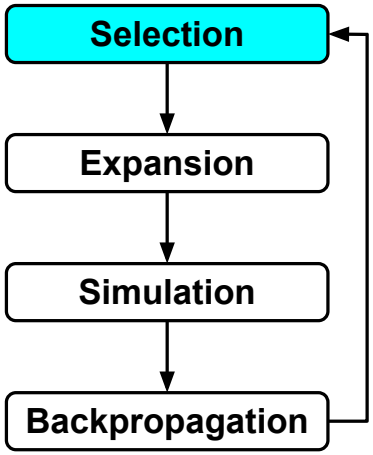

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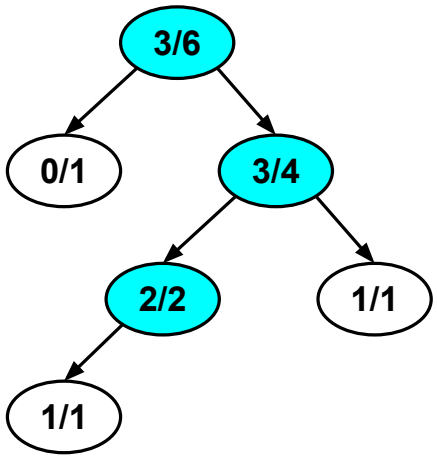


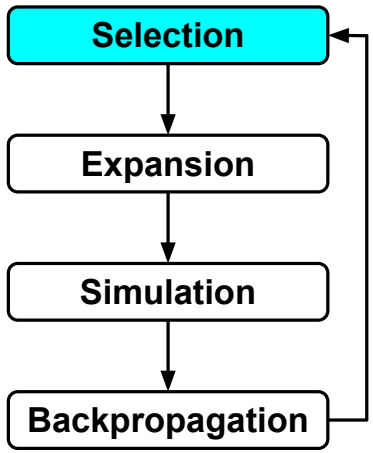

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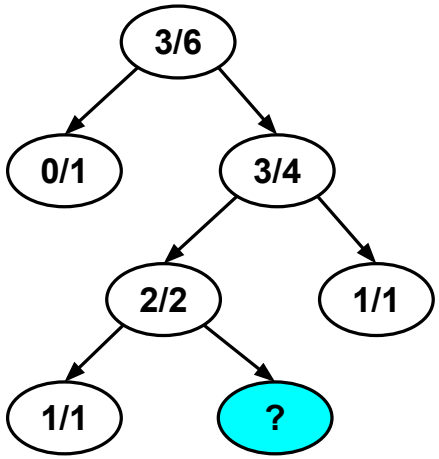


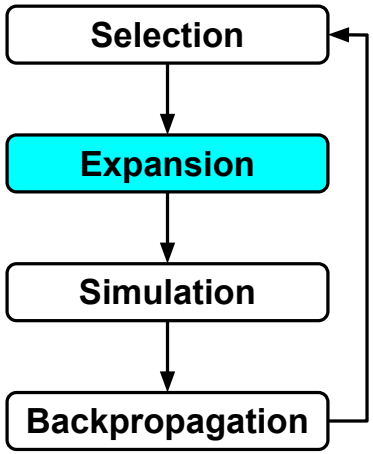

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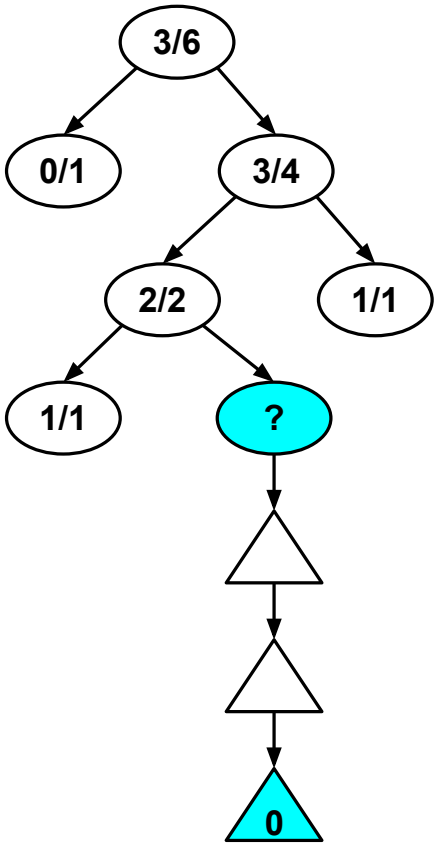


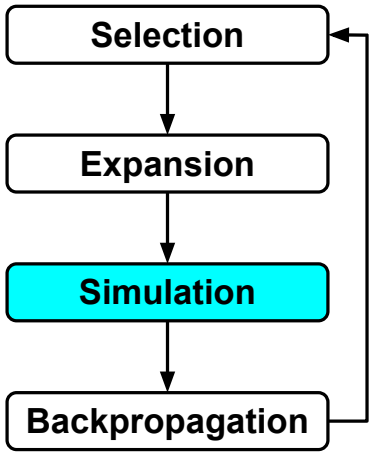

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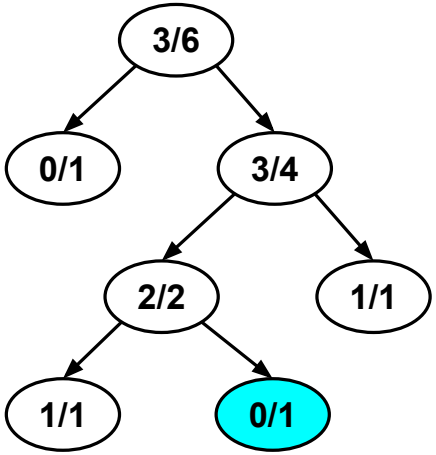


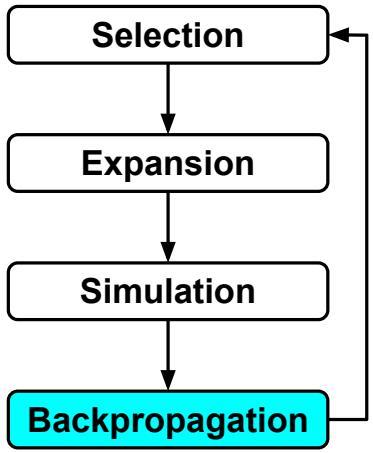

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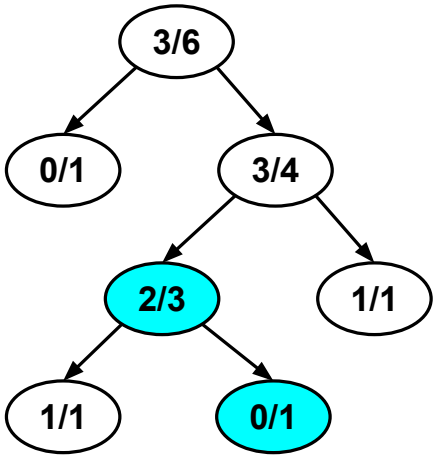


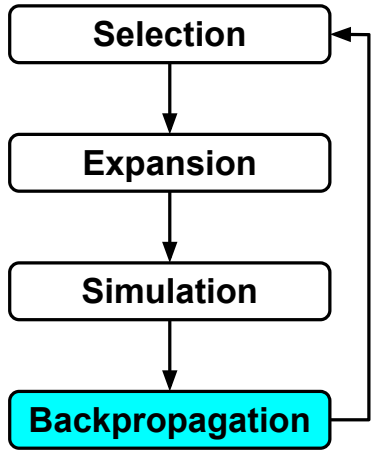

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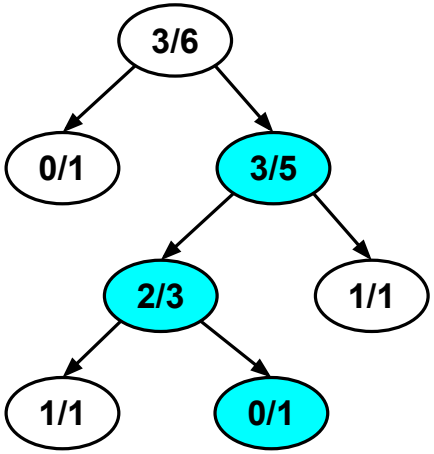


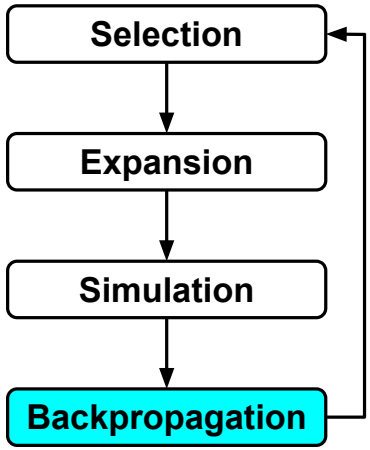

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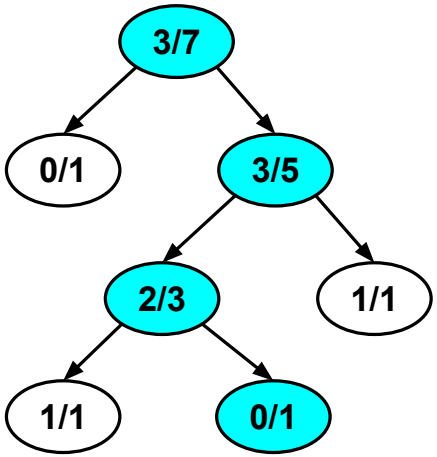


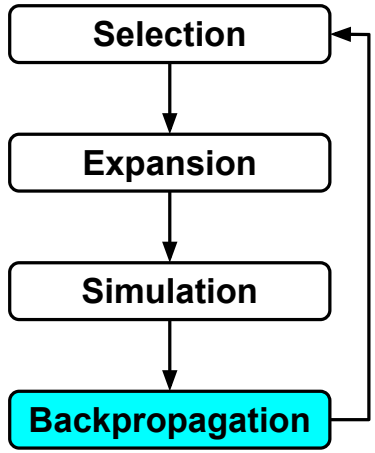

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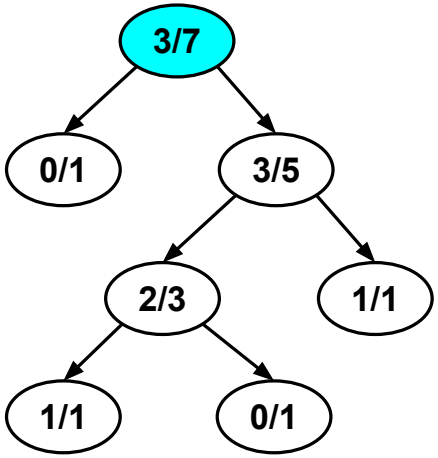


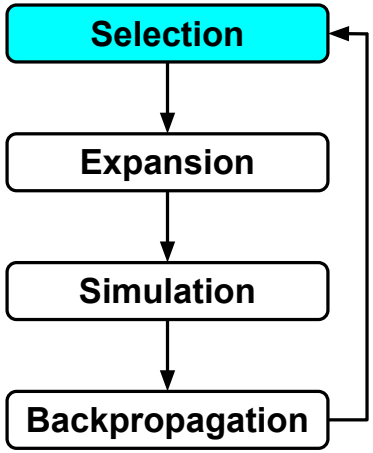

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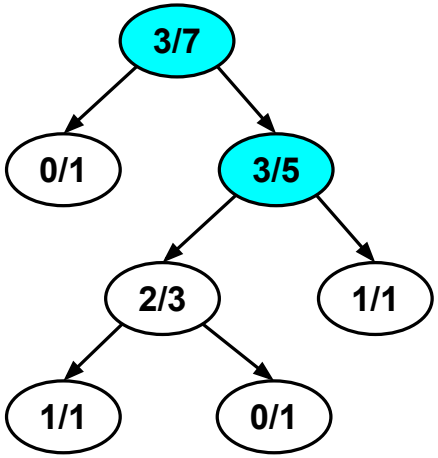


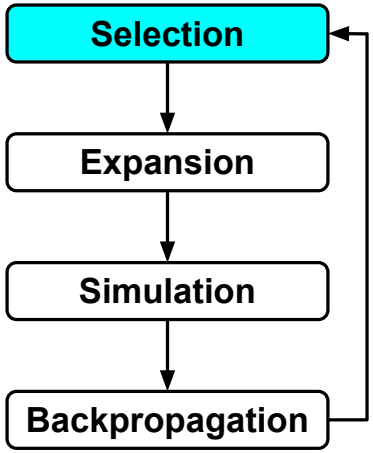

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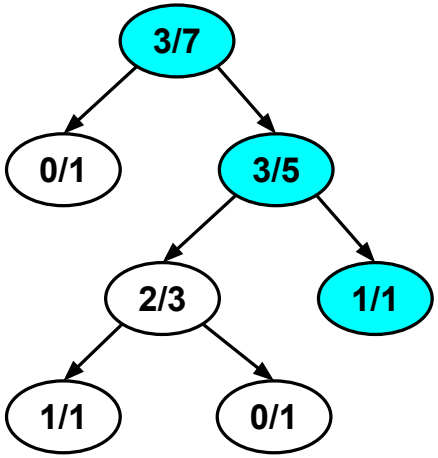


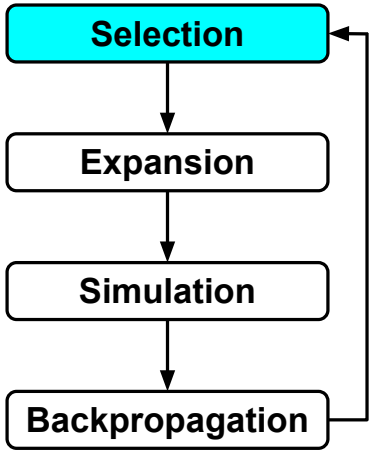

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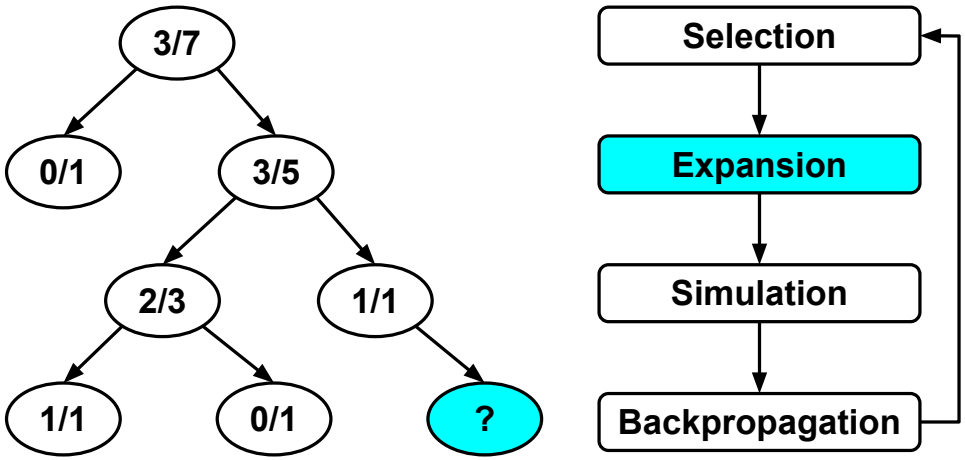

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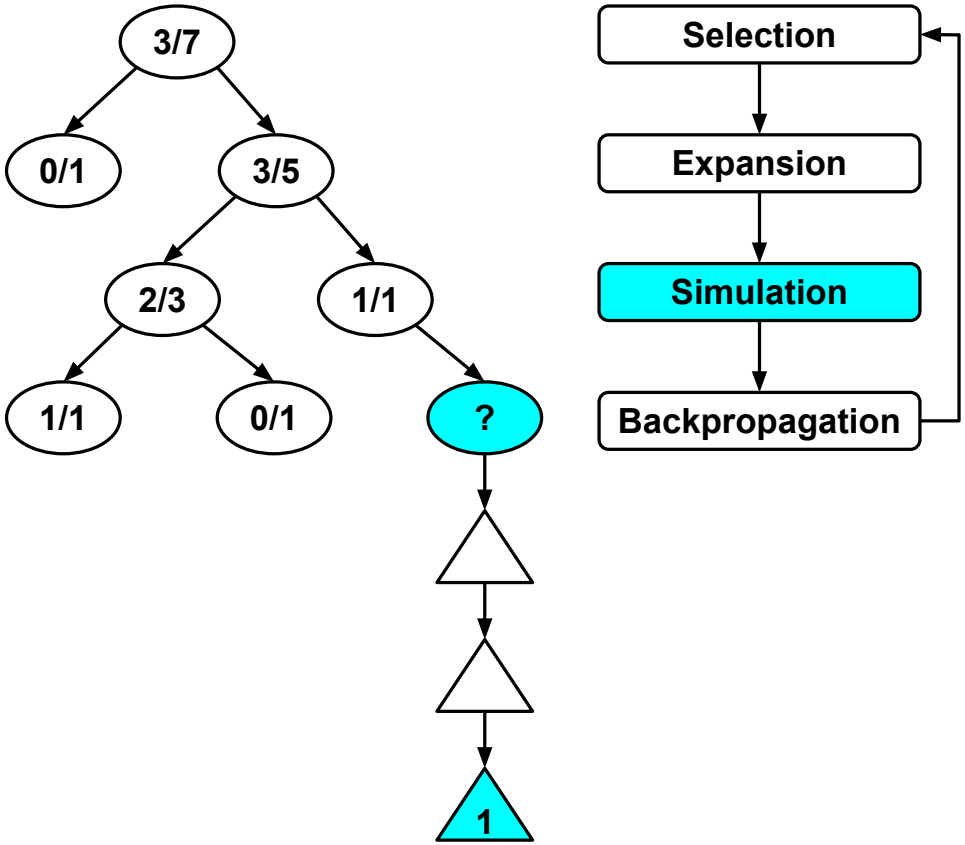

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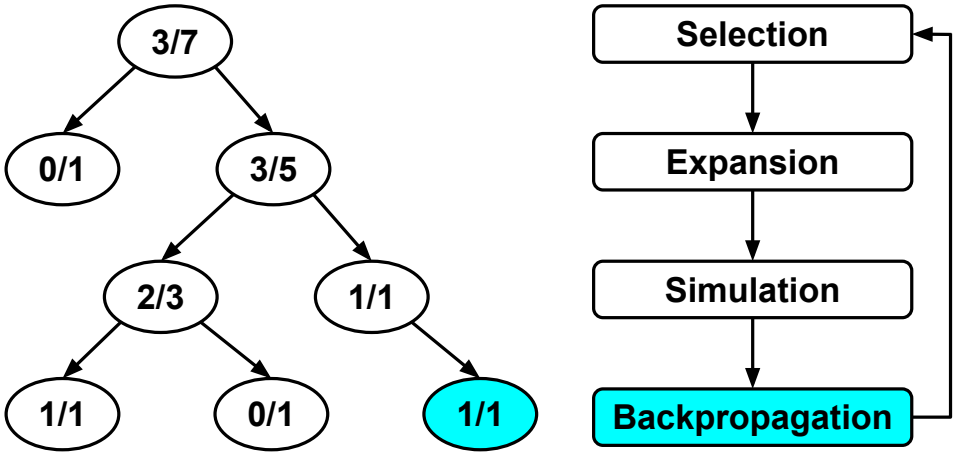

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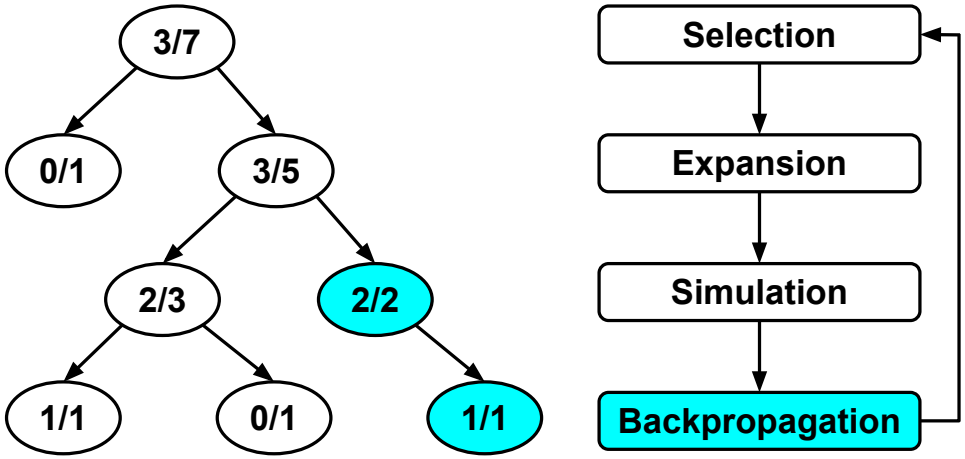

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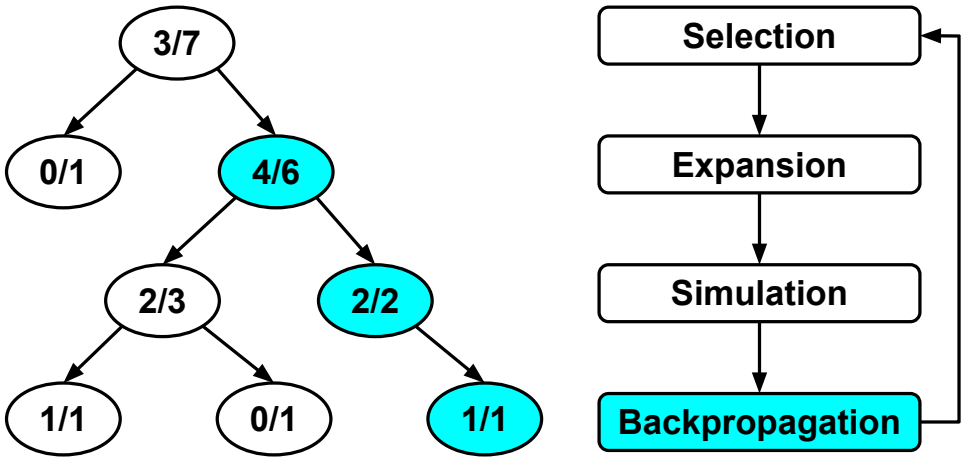
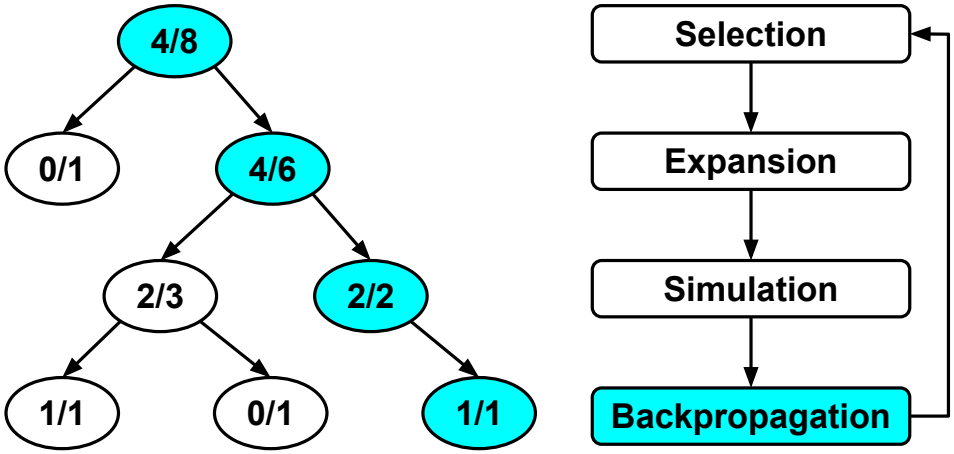


# Four Steps Diagram



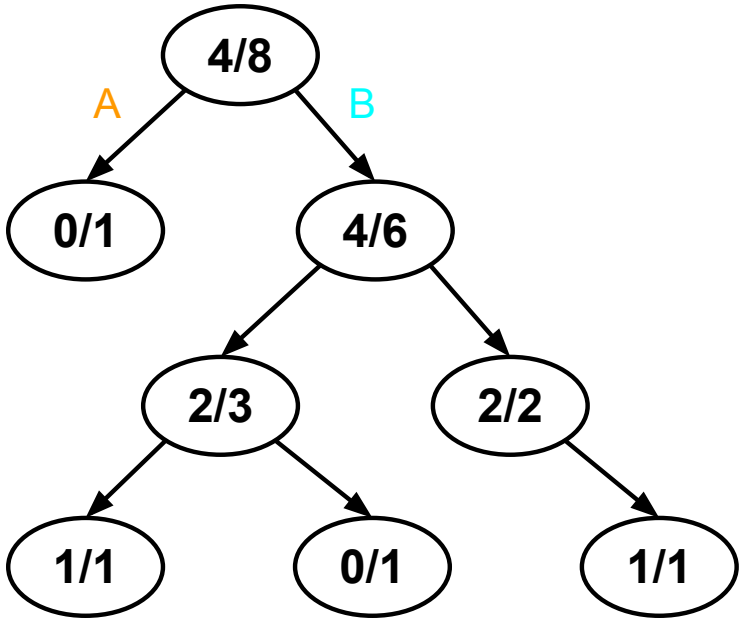
# What Happens When We Choose a Move?

Now we have:

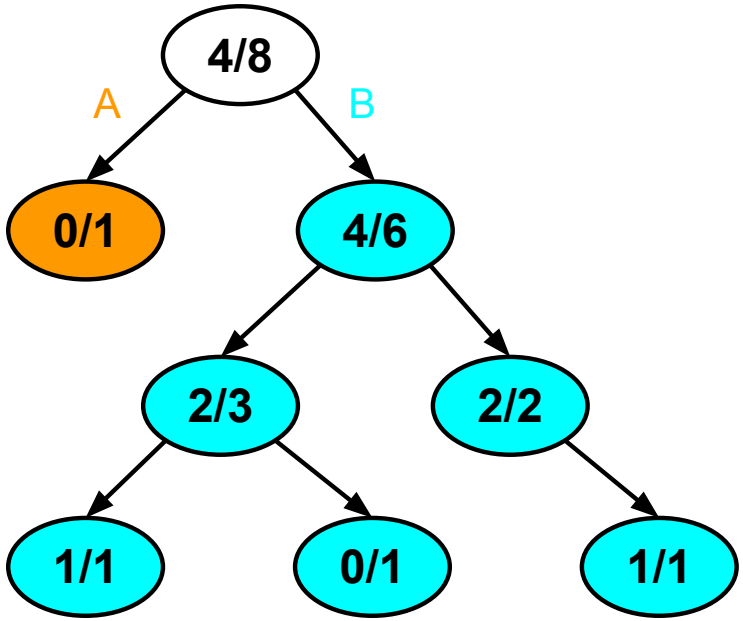
- A tree structure
- A method of generating the tree

What happens when we need to choose a move?

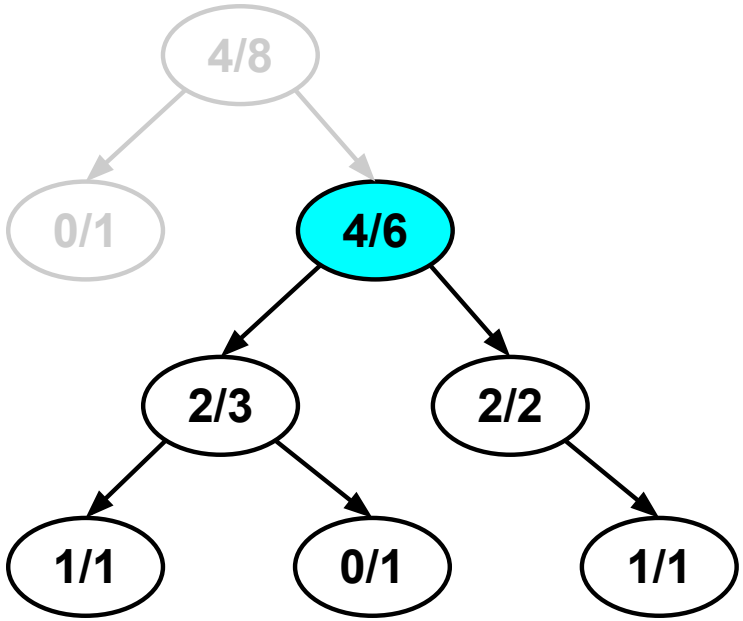
# Choosing a Move



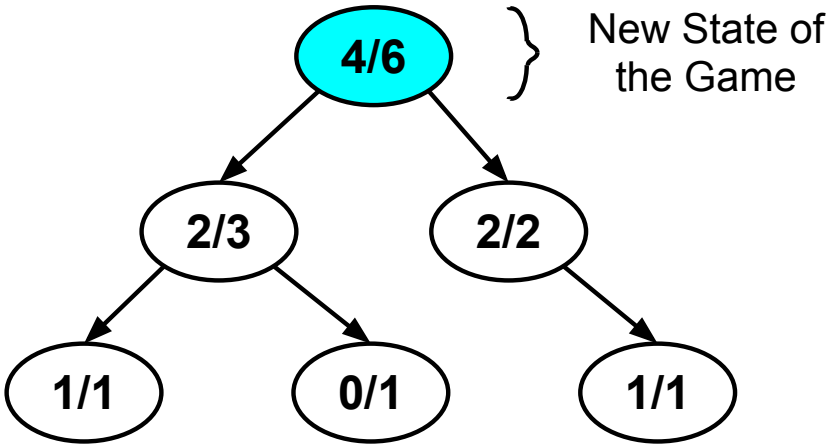
# Choosing a Move



# 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)

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

- 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

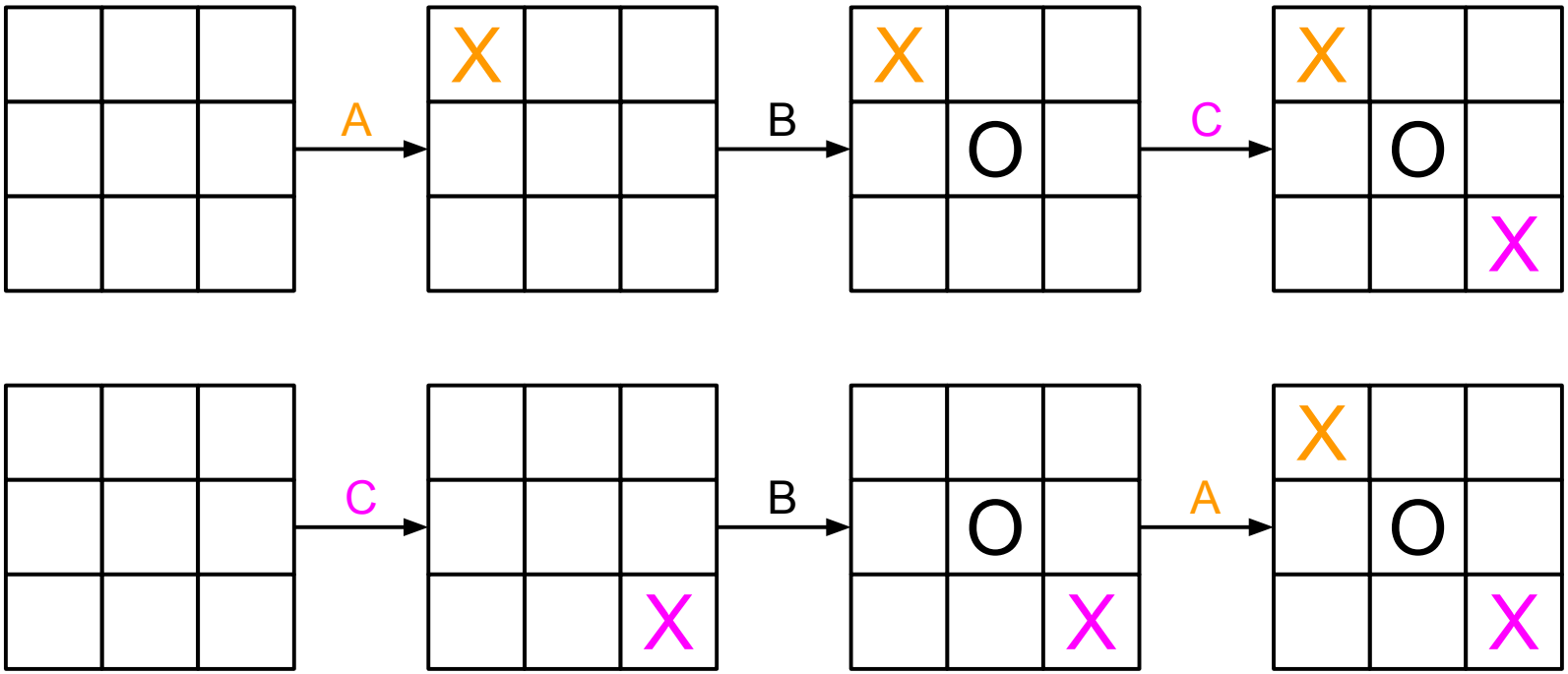
# Outline

# 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?

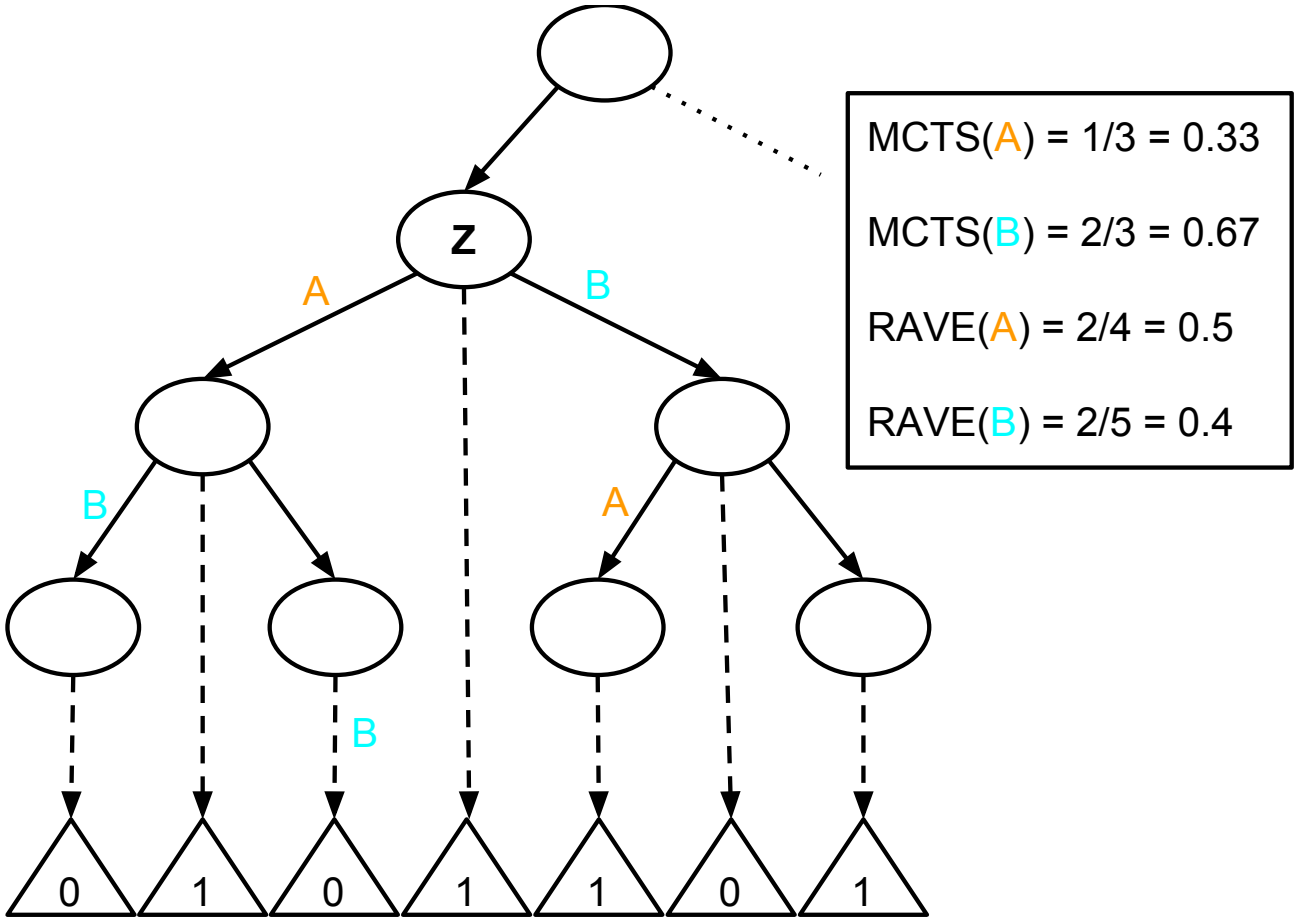
# Tree Redundancy



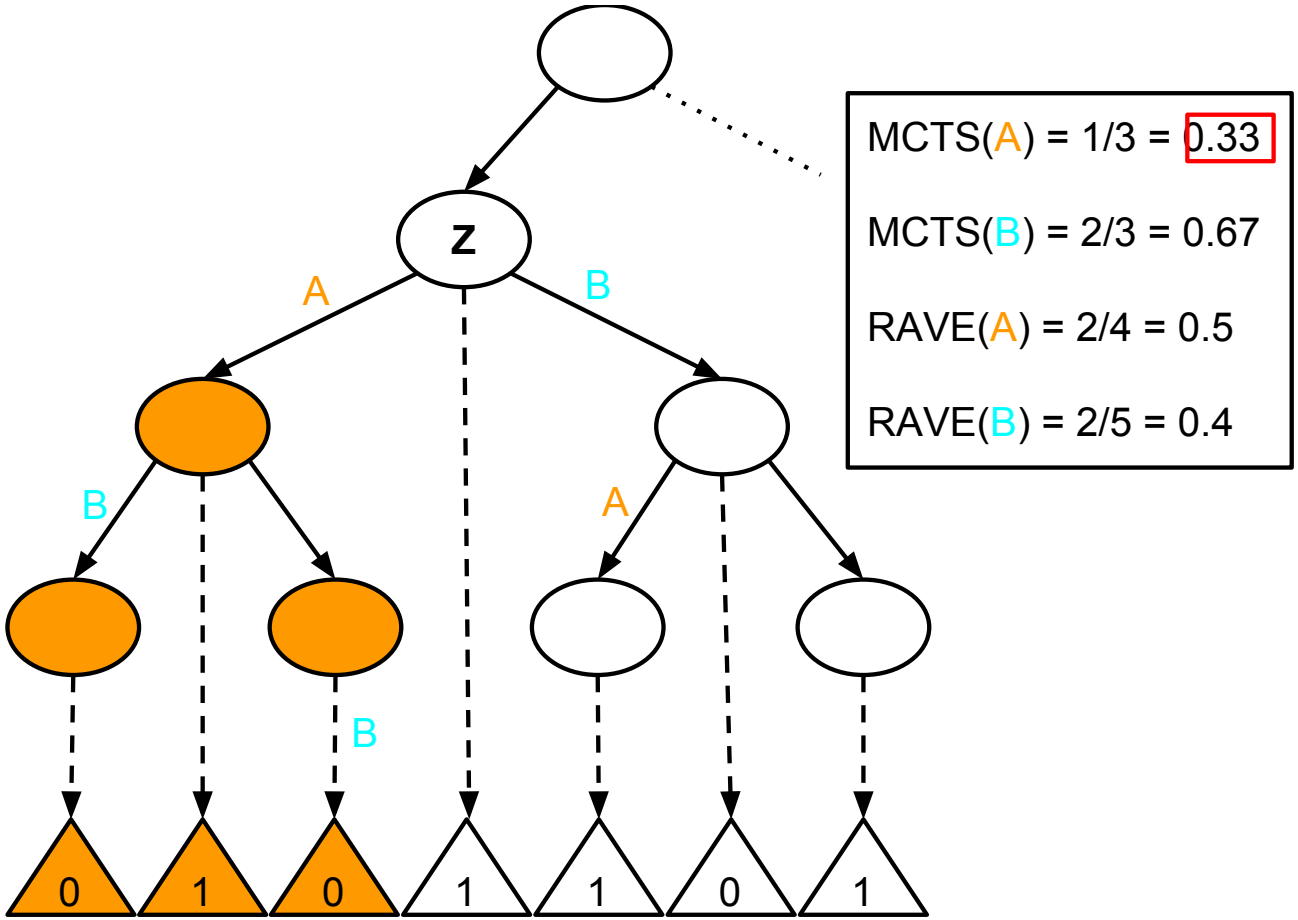
# Rapid Action Value Estimate (RAVE)

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

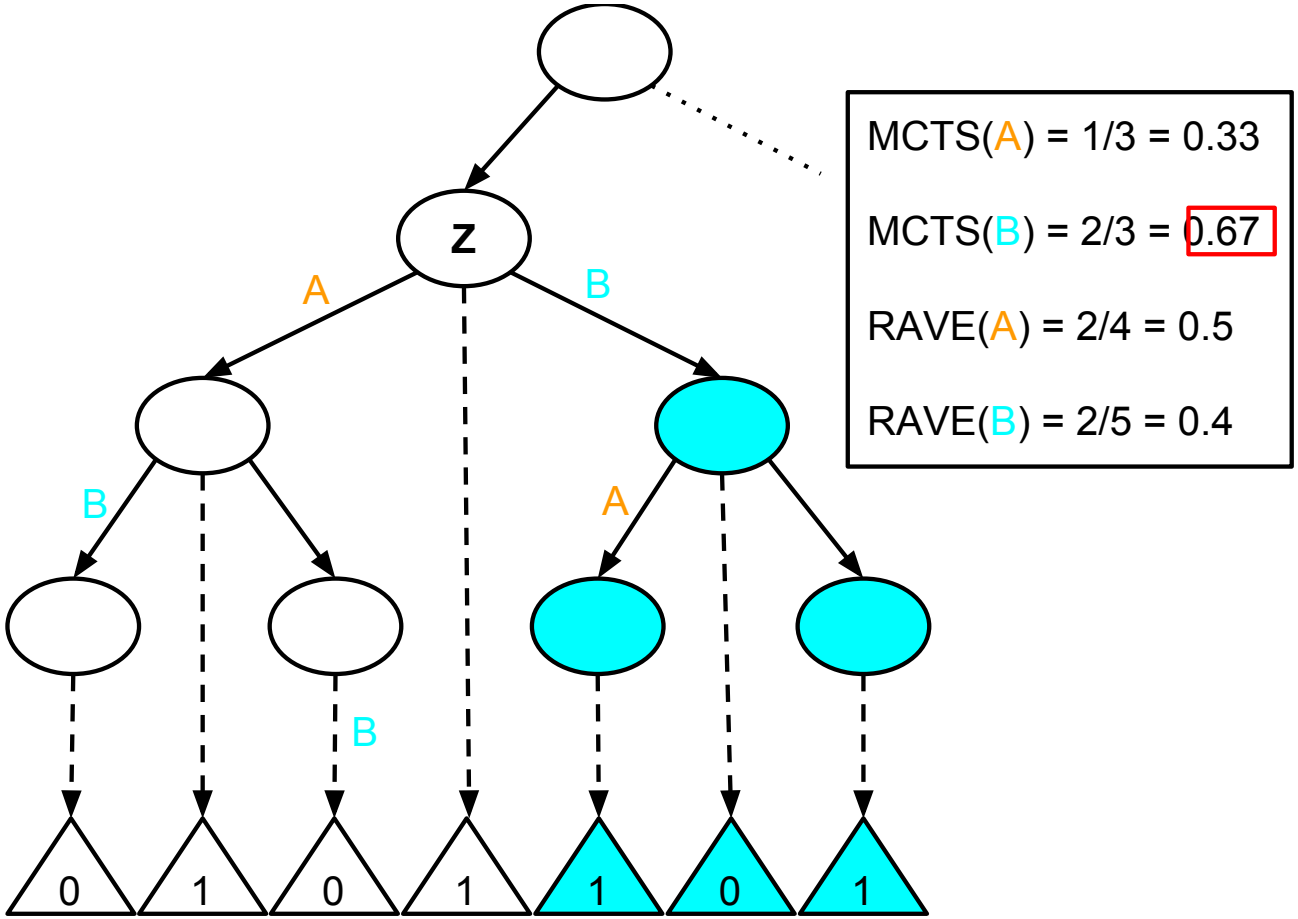
# RAVE Diagram



# MCTS Values


z
A
B
B
A
B
0
1
0
1
1
0
1
MCTS(A) = 1/3 = 0.33
MCTS(B) = 2/3 = 0.67
RAVE(A) = 2/4 = 0.5
RAVE(B) = 2/5 = 0.4

# MCTS Values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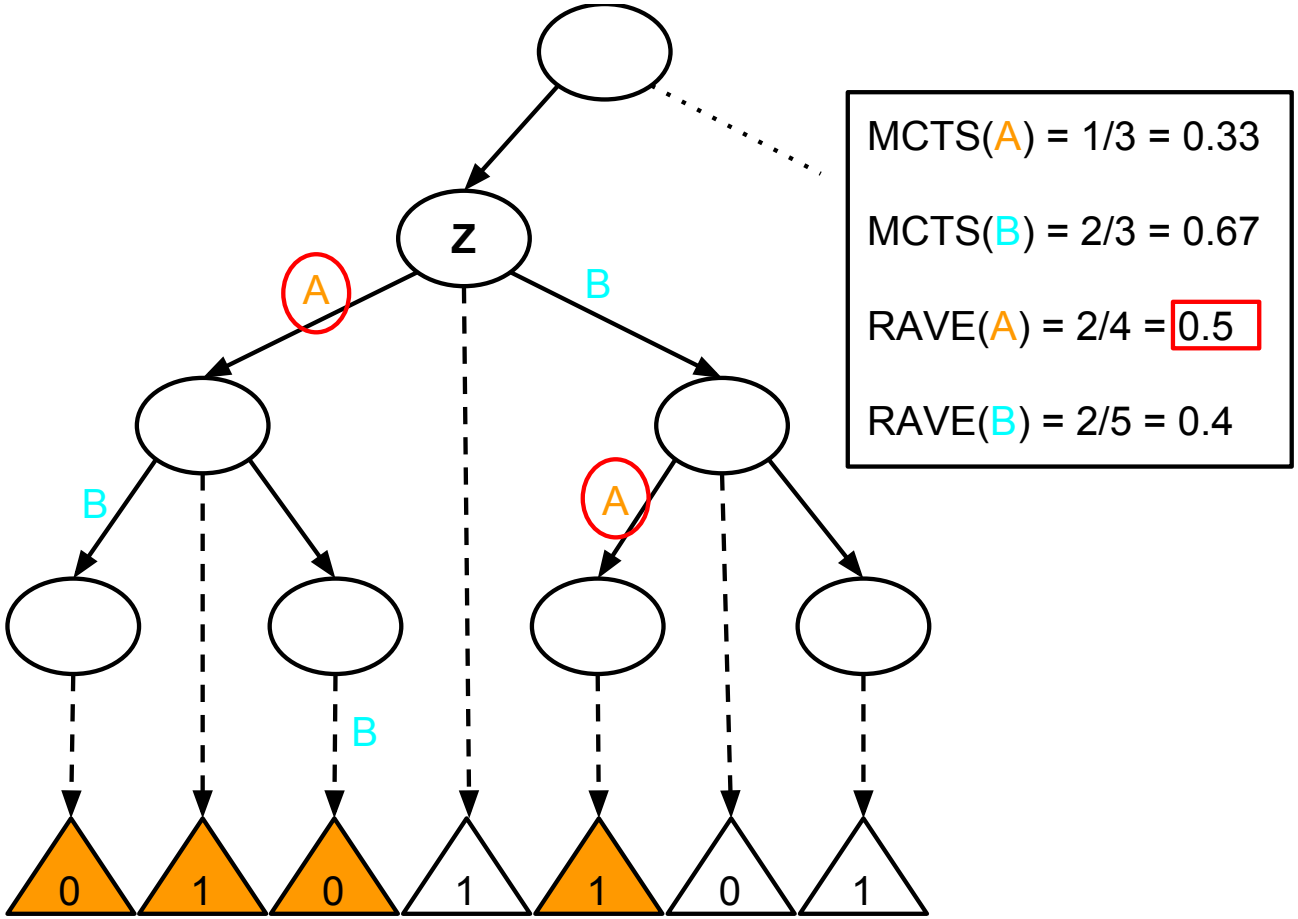
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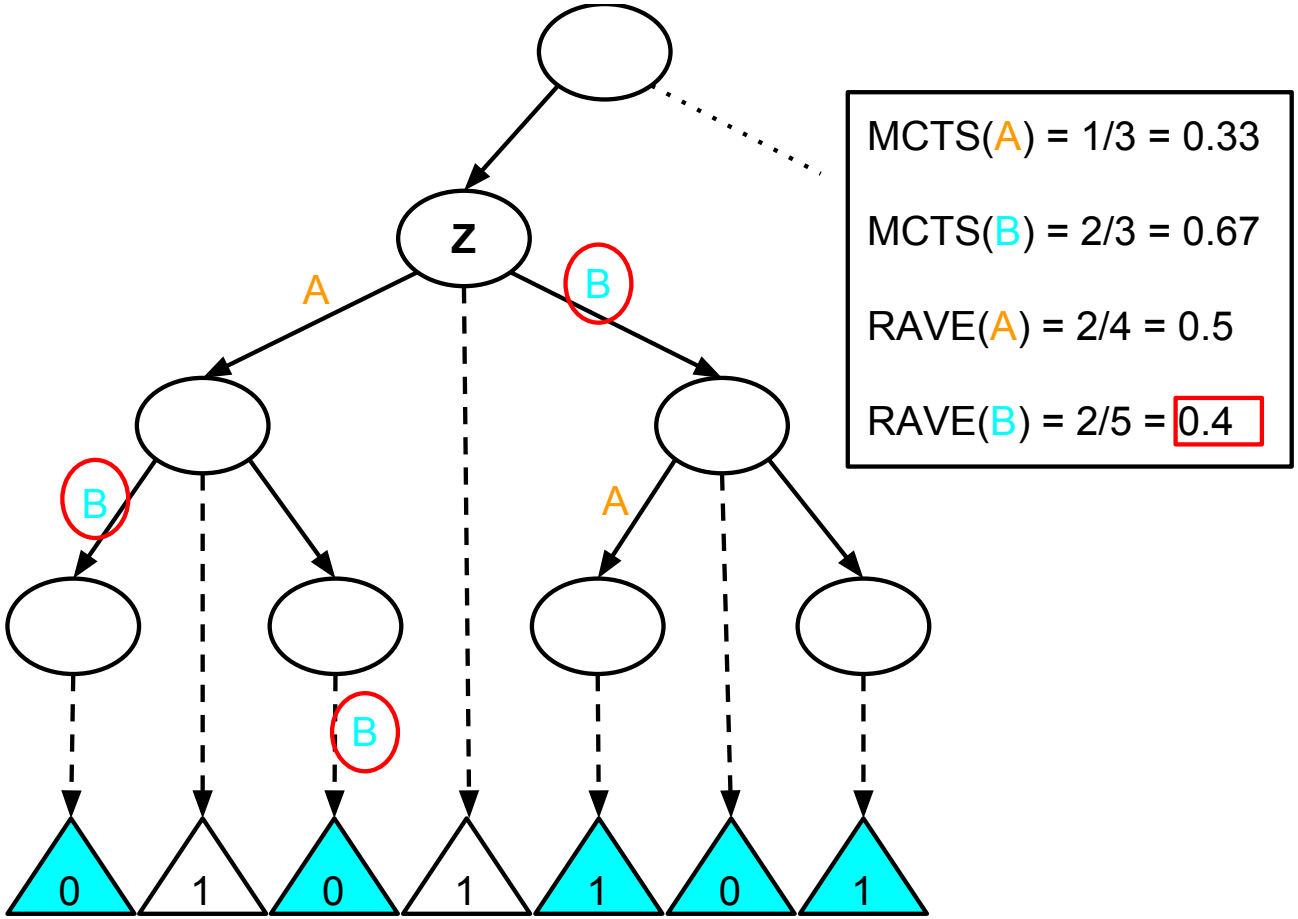
# RAVE Values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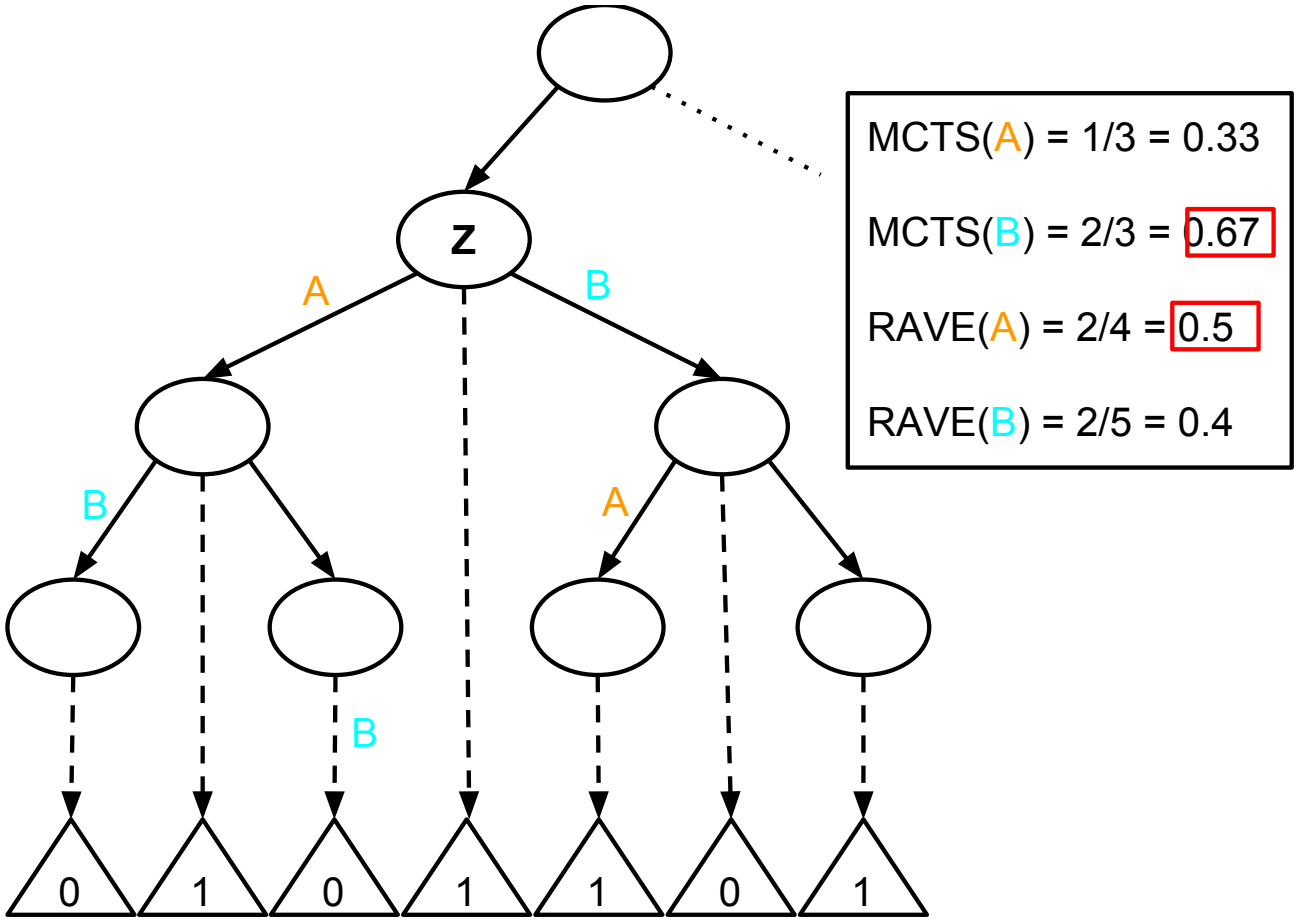
1
MCTS(A) = 1/3 = 0.33
MCTS(B) = 2/3 = 0.67
RAVE(A) = 2/4 = 0.5
RAVE(B) = 2/5 = 0.4

# MCTS RAVE Comparison



# 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

# Outline

# Narrative Generation

Kartal et al. applied MCTS to Narrative Generation

- Crime story
- User defines the set up and goals for the story
  - 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

- Actions drive the story
- Actions are believable based on context
  - Example: Inspector searches for clues
  - Example: Character A kills Character B

# Example 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.

- Actions take the place of moves as nodes
- No clear end state
- The researchers used a set threshold during simulation

# Evaluation function

- Method of giving nodes value
- Incorporates believability and goal completion
- Ensures stories are interesting

Value(story) = Believability(story) * GoalCompletion(story)

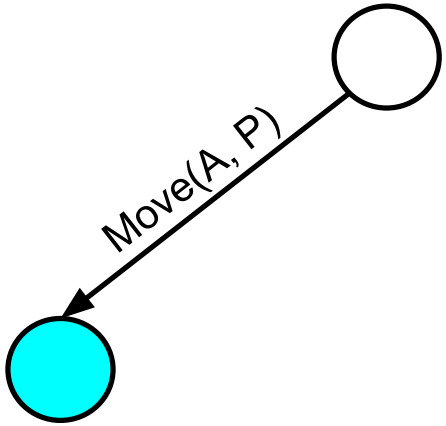
- Believability is the mathematical product of every action in a story
- The value is between 0 and 1

# Narrative Generation Test

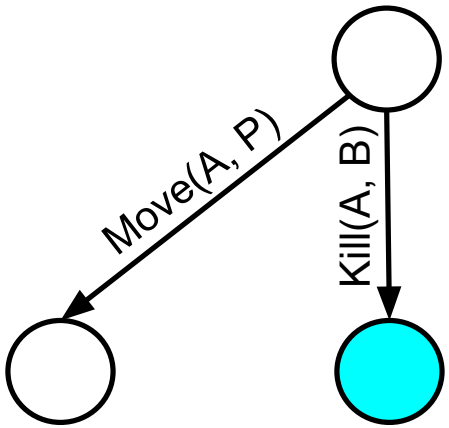
MCTS compared against three deterministic algorithms

- Breadth-first search
- Depth-first search
- Best-first search

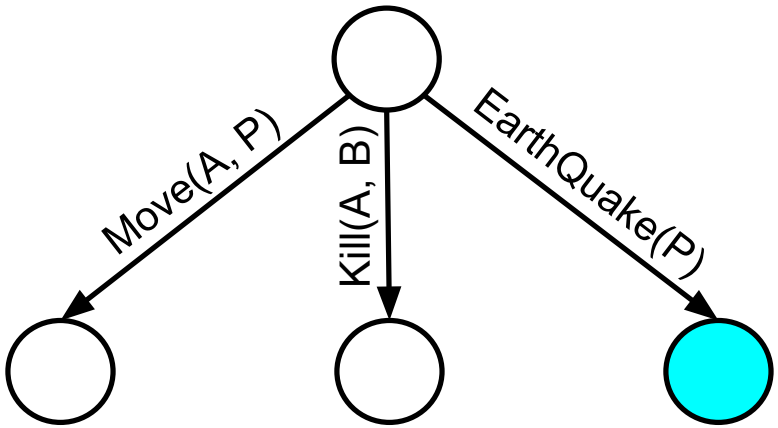
# Breadth-First Search



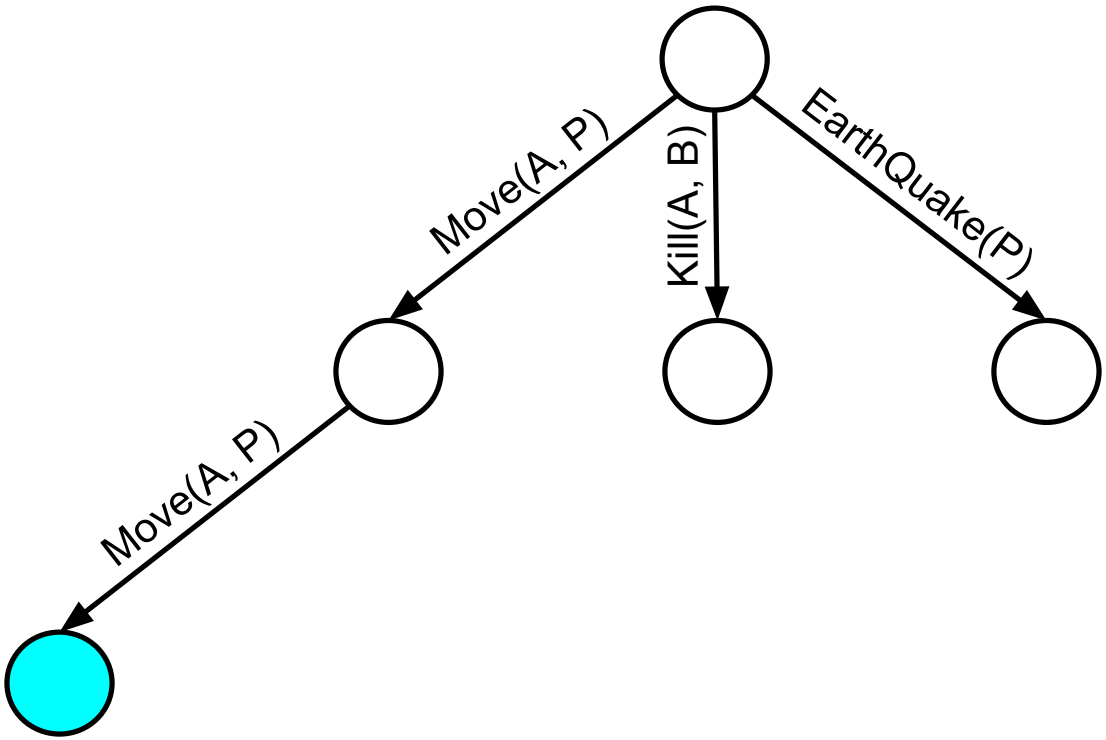
# Breadth-First Search



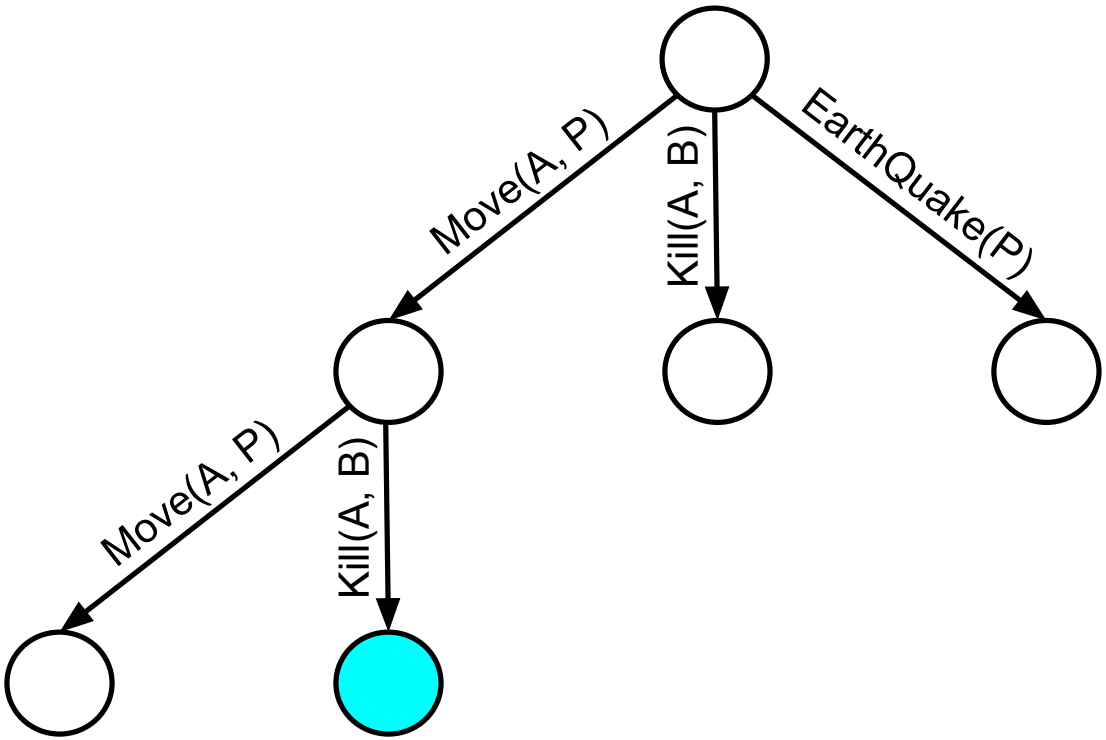
# Breadth-First Search



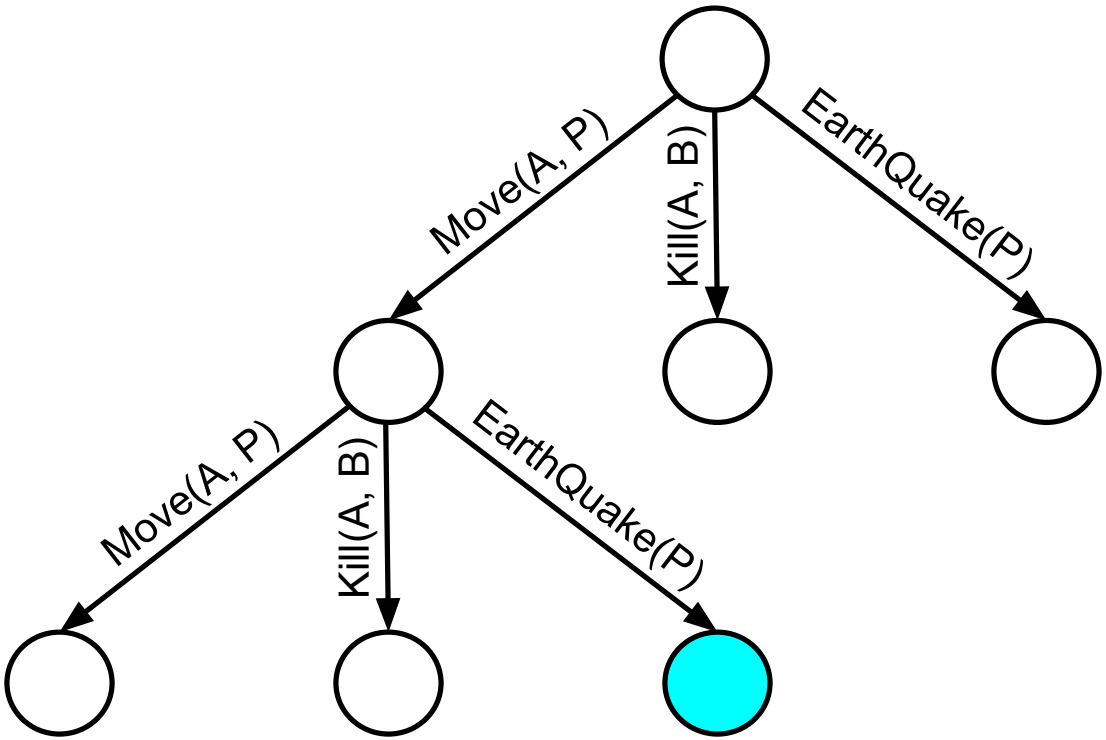
# Breadth-First Search



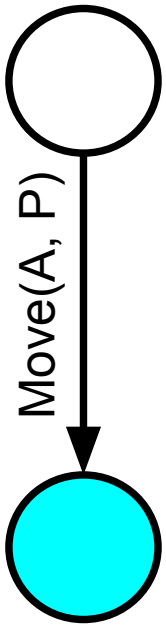
# Breadth-First Search



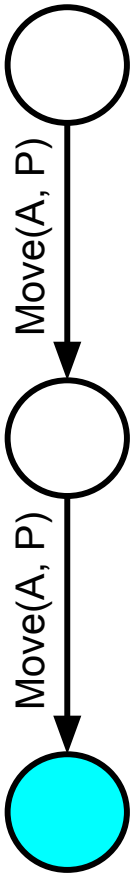
# Breadth-First Search



# Depth-First Search



# Depth-First Search



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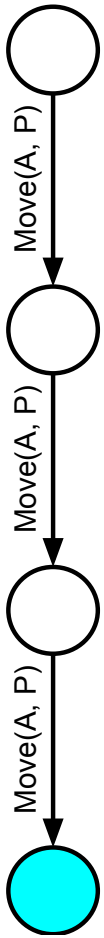

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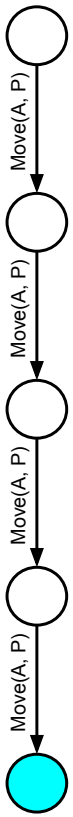
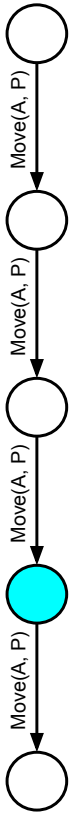


# Depth-First Search



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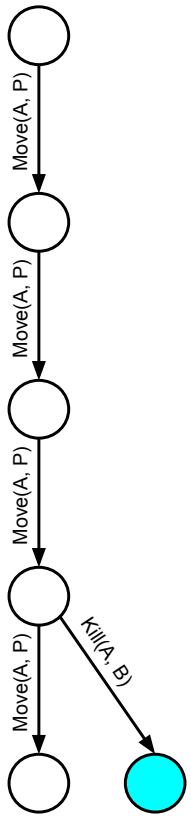
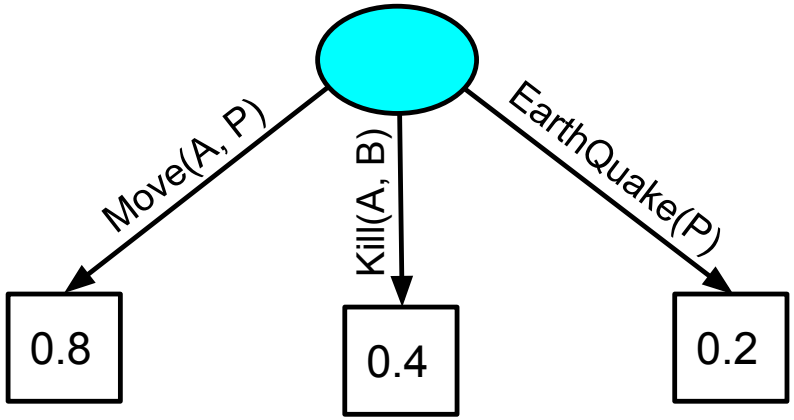


# Best-First Search



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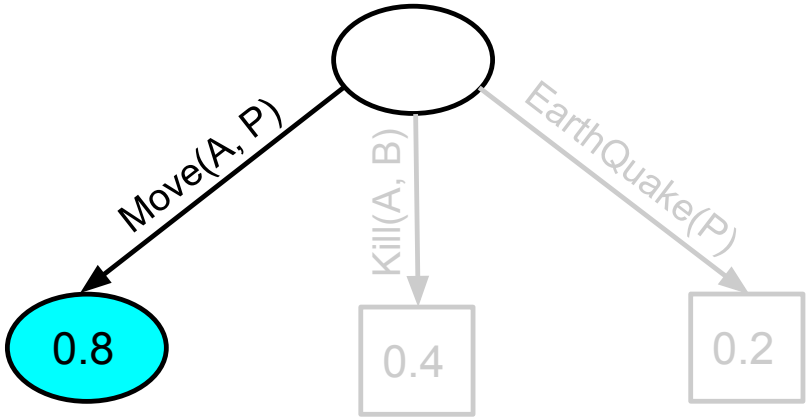

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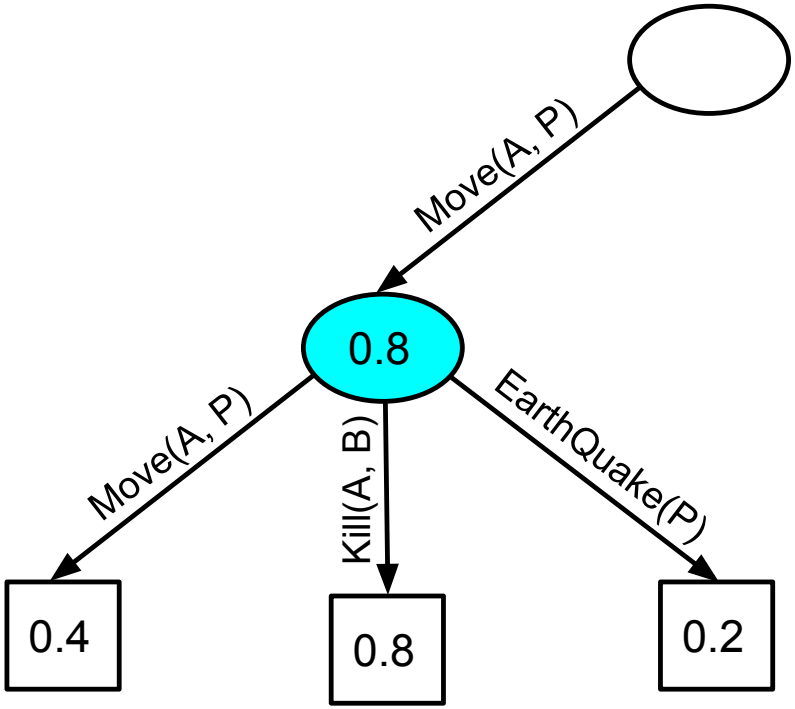

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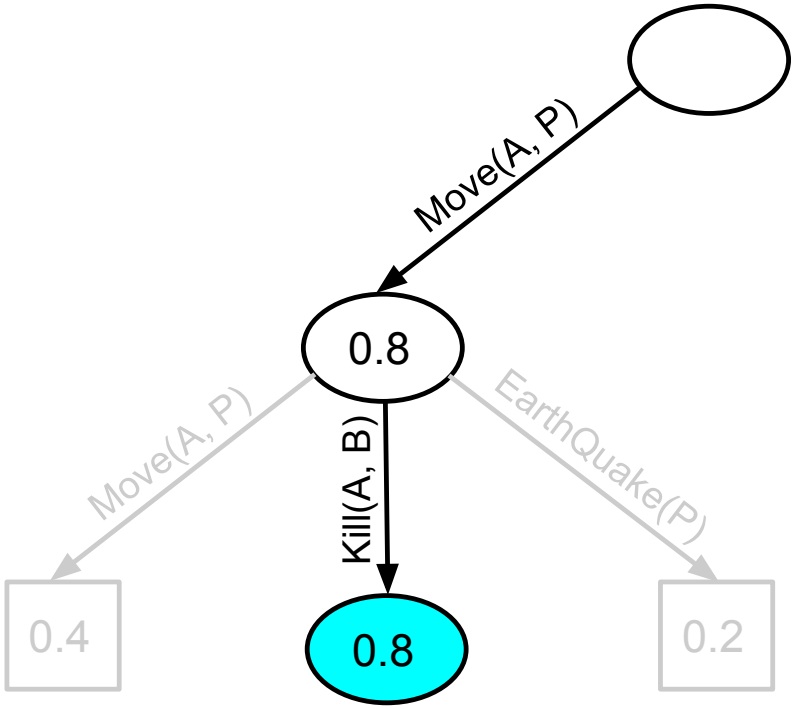
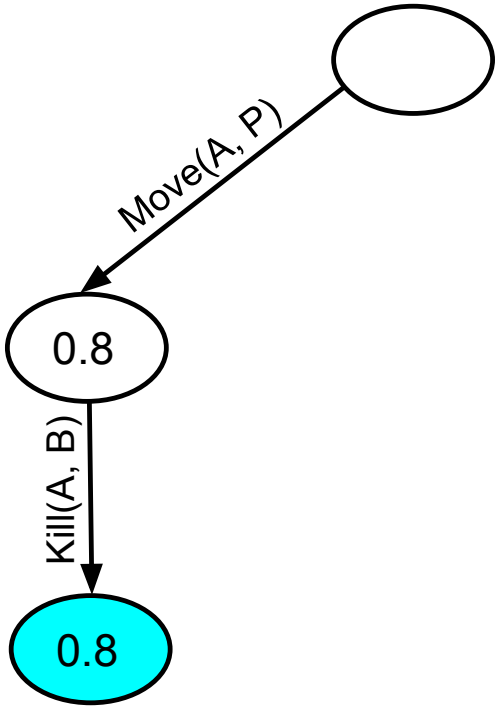


# Best-First Search



# 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

# Stories Produced by MCTS

- Stories from MCTS tended to be believable
- Completed both user defined goals
- Some Problems
- Overall reasonable narratives

# 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.

# Outline

# 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

# Any Questions?