AI Agents for Ultimate Tic-Tac-Toe

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Overview

- Ultimate Tic-Tac-Toe is a highly structured game involving 9 regular Tic-Tac-Toe boards
- Evaluated three different game-playing algorithms:
    - Minimax
    - Monte Carlo Tree Search
    - Deep Q-learning Network
- Best agent was Minimax with a simple evaluation function
- Agents performed well in games that matched their assumptions

Problem

- 2-player game with nine regular 3 by 3 Tic Tac Toe boards arranged in larger 3 by 3 grid
- At each move, players are restricted to moves in the smaller board corresponding to the same square that the opponent moved in (Figure 1)
- Player wins the game by winning three individual smaller boards that connect in a line (Figure 2)

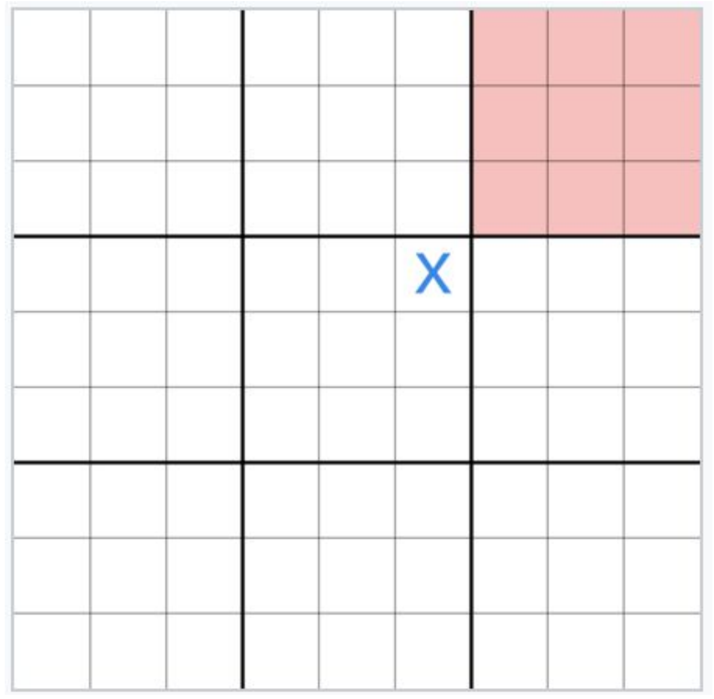


Figure 1: Squares shaded red indicate valid moves after 'X' is placed.

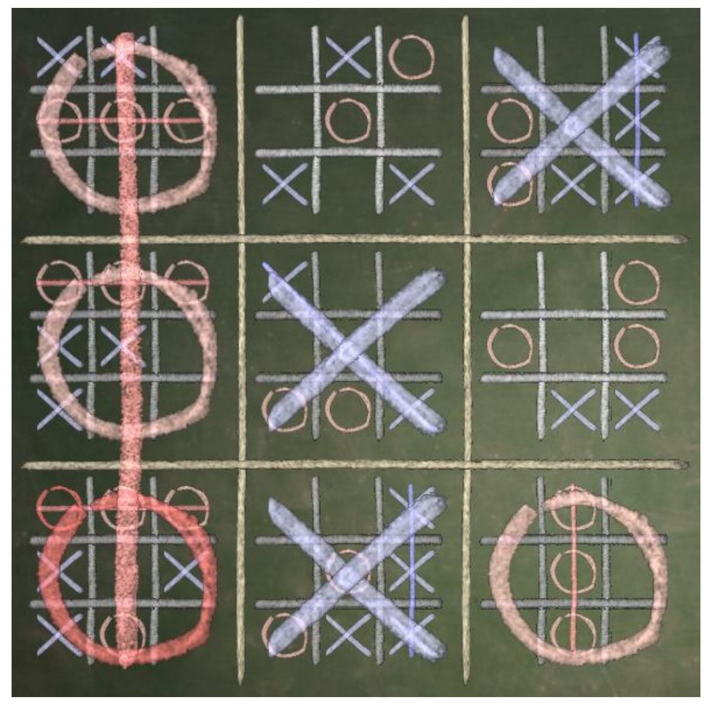


Figure 2: Winning state: 'O' wins the game

Models

Minimax

- Implemented a minimax strategy with alpha-beta pruning
- Simple evaluation function: total number of current miniBoards won

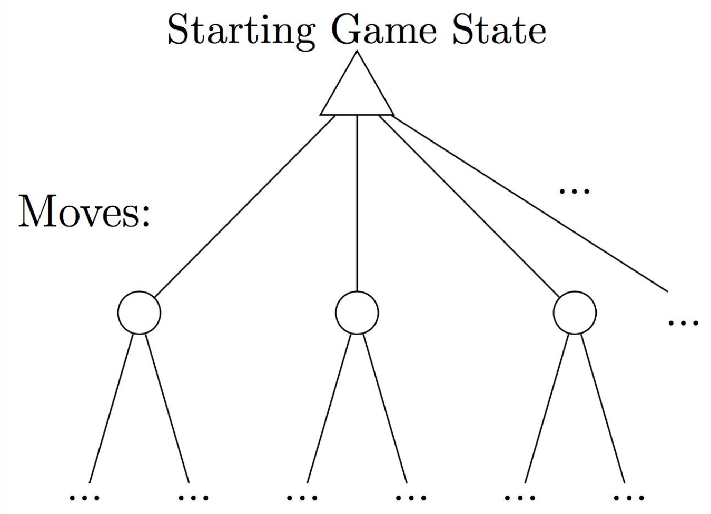


Figure 3: The game is modeled as a search tree, which our Minimax agent traversed to find optimal moves

Monte Carlo Tree Search

- Used Upper Confidence Bound MCTS Algorithm (Figure 4)

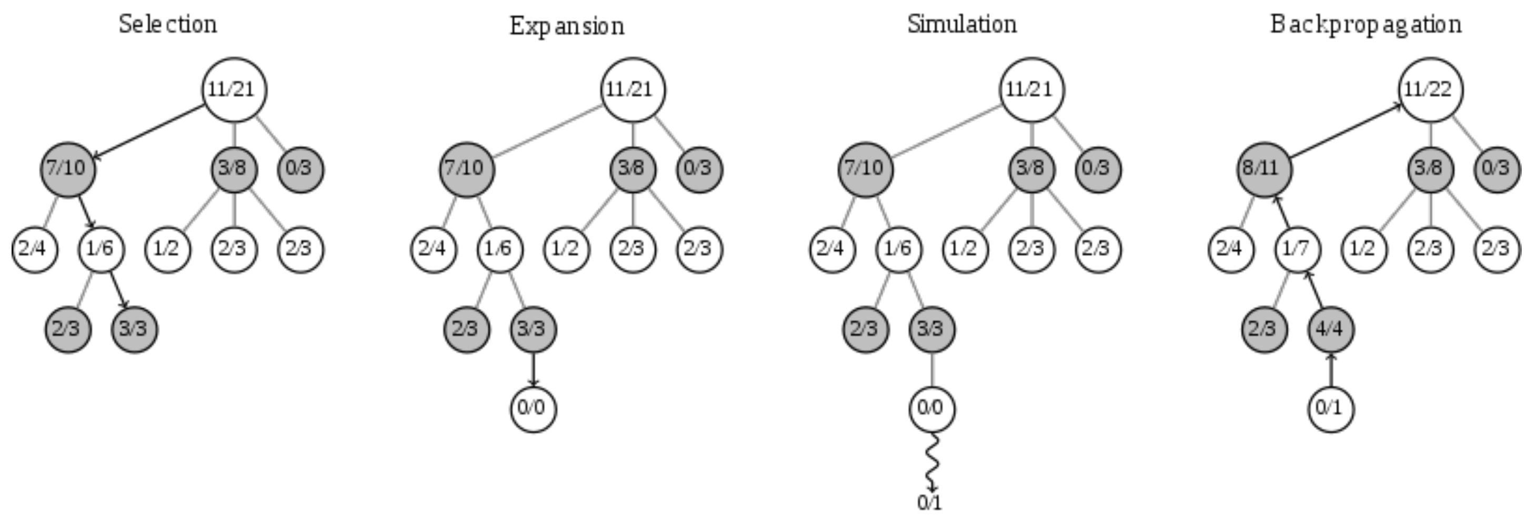


Figure 4: The generic Monte Carlo Tree Search algorithm involves a cycle of four steps. At the end of the search, the agent selects the node with the most visits.

Deep Q-Learning Network

- Architecture: Board > Conv2D (3,3) > Dense > Output
- Output is probability of winning from a given board

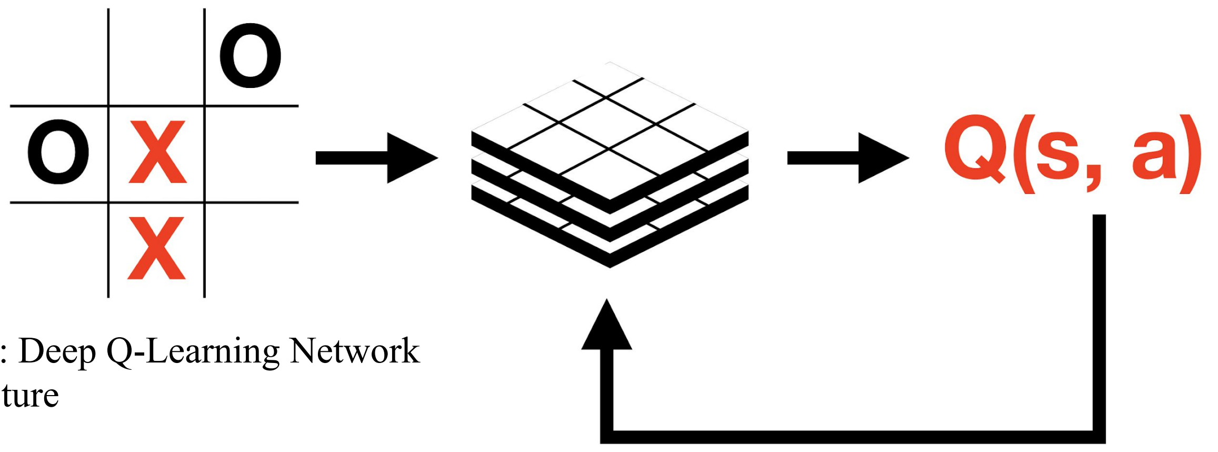
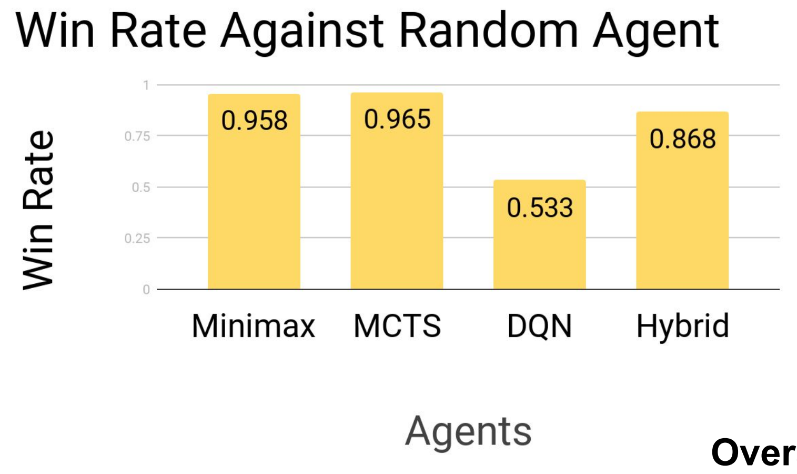
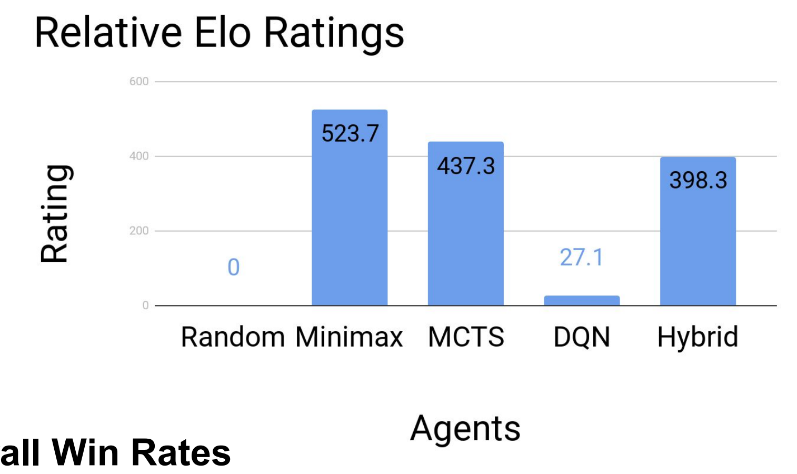


Figure 5: Deep Q-Learning Network Architecture

Results





Overall Win Rates

Player 2

Player 1		Random	Minimax	MCTS	DQN	Hybrid
	Random		0.055	0.03	0.515	0.12
	Minimax	0.97		0.72	0.98	0.63
	MCTS	0.96	0.345		0.965	0.575
	DQN	0.58	0.05	0.055		0.16
	Hybrid	0.855	0.44	0.495	0.83	

- MCTS is more effective than minimax against random agent, probably because MCTS incorporates randomness into game tree
- Minimax wins against MCTS probably because minimax expects "worst case" while MCTS expects random play
- MCTS seems better at beginning while minimax seems better at end, but hybrid does not perform better
- Architecture of DQN was probably not suited for how structured yet small the board space was

Summary and Future Work

- MCTS is most effective against random agent, but minimax is most effective against "intelligent" agents
- Future: use Asynchronous Advantage Actor-Critic (A3C) combined with MCTS - modeled after AlphaZero network