THE GEORGE WASHINGTON UNIVERSITY
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Design and development of a board game - Strategical TicTacToe

202302_Guided Research

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Project Objective

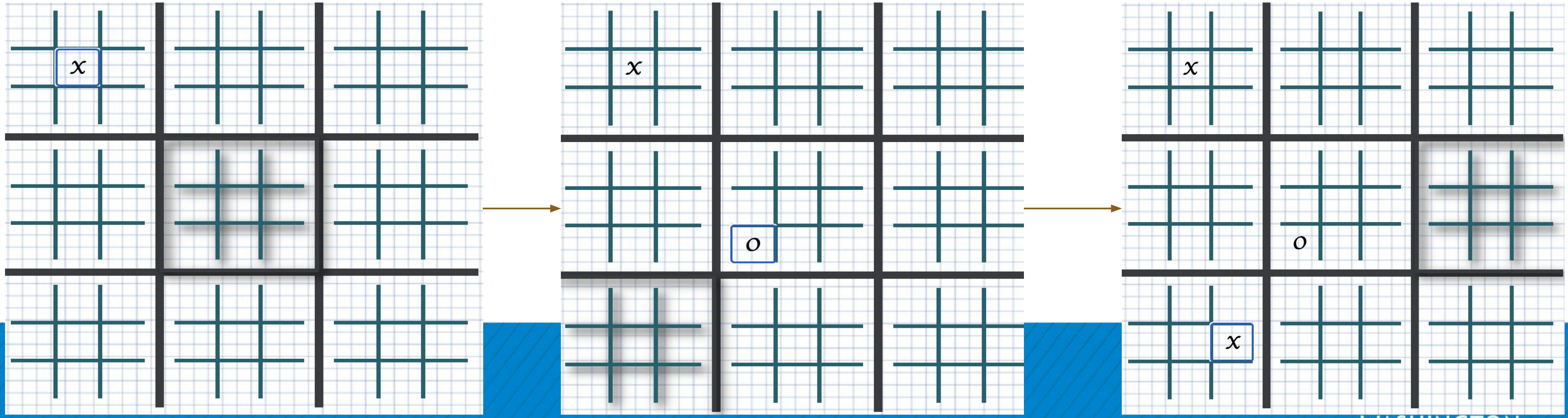
Brief answers to Heilmeir questions

- Investigate and implement various AI algorithms for the game.
- Designed and developed a board game with tactical decision-making and strategic planning elements.
- Analyzed different AI approaches, including heuristics, minimax, alpha-beta pruning, adversarial search algorithms, and memorization, to enhance AI performance.
- Unique heuristics- strategies to evaluate the board and combining tactical and strategic elements.
- Develop different agents and measure the performance of the different algorithms.

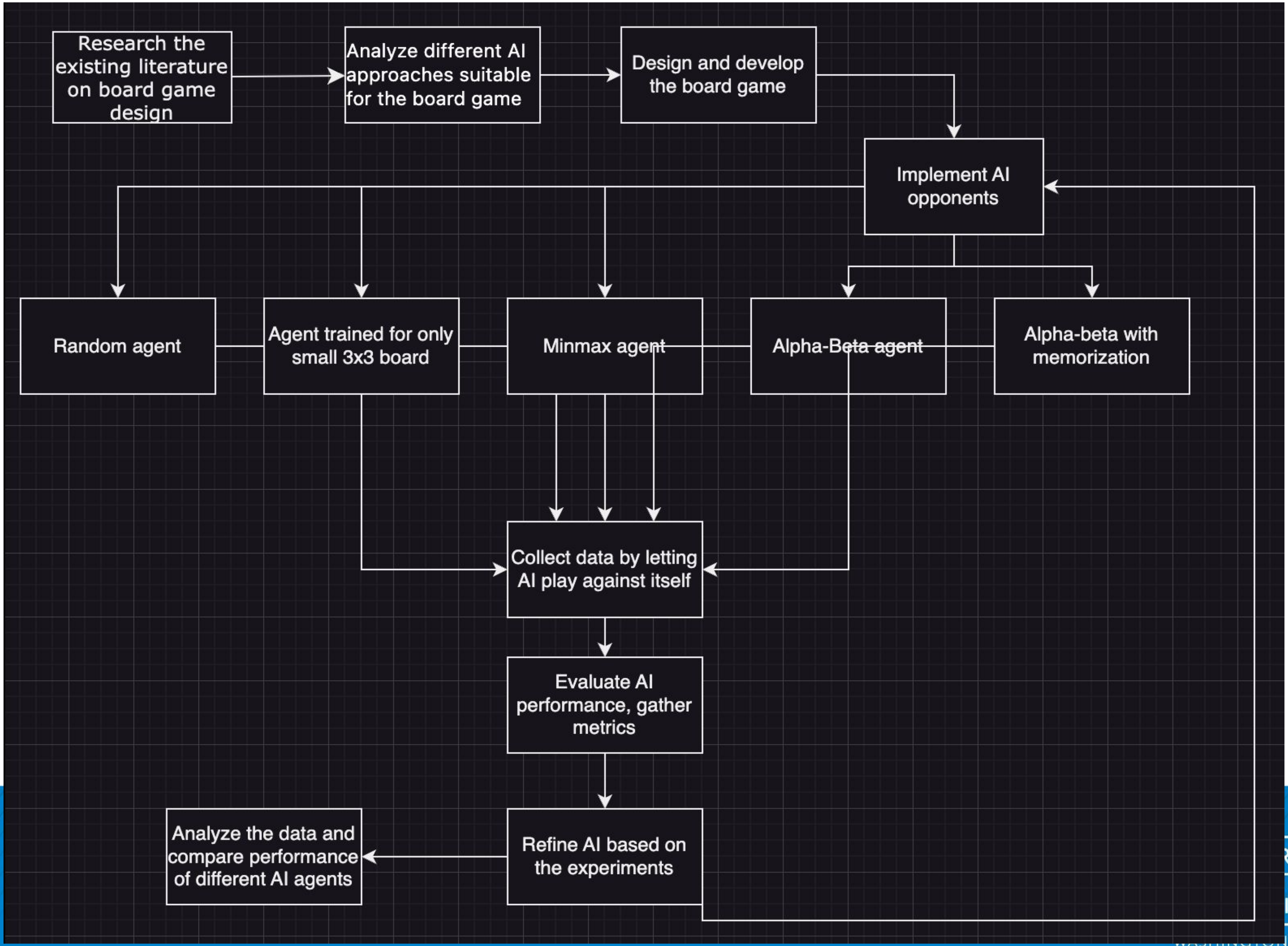
Game rules

The board is made up of 9 small 3-by-3 boards that, when put together, make one big 3-by-3 board. Each player takes a turn, and just like in standard Tic-Tac-Toe, a player gets a small board by putting one of the symbols(X/O) in a row. When a player wins a small board, they move their sign to the spot on the big board where the small board was. The game stops when one person gets three of the same symbol in a row on the big board, or when all the squares are used up and there is a tie.

To make the game more interesting, each player must place their symbol on the small board where the previous player's symbol was placed:



Technical Approach



AI agents

1. Random Agent - agent that does stochastic actions.
2. Simple TTT agent
   - AI agent which is highly competitive in a normal 3 by 3 games and considers only the playable current board.

3. Minimax Agent
   - Agent using Minimax algorithm to travel through the whole tree

4. Alpha-Beta Agent
   - The Minimax method, augmented with alpha-beta pruning, used to reduce the quantity of pathways examined by the algorithm.

5. Alpha-Beta with memorization
   - Storing scores of the previously traversed boards in the act of avoiding the recalculation of previously assessed positions in order to save time.

Heuristics

Heuristic - 1

The scoring of a board is determined by analysing the presence of a certain pattern, denoted as 'X' for player 1 or 'O' for player 2, in rows, columns, and diagonals. The use of memoization is employed in order to keep previously calculated board evaluations inside a memory dictionary, hence enhancing the efficiency of subsequent computations.

- Strengths
  - Customizable Target - The target parameter allows the algorithm to evaluate the board for different players (e.g., 'X' or 'O'), making it flexible and adaptable for both players in a two-player game.
- Weaknesses
  - simplistic: The algorithm's heuristic evaluation is based solely on the occurrence of the target pattern in rows, columns, and diagonals. It does not take into account other aspects, such as board control, potential threats, or blocking moves, which may limit its strategic depth.
  - Lack of Context: The algorithm analyses the board position without considering the game circumstances, opponent's actions, or future ramifications. In complicated game settings, it may overlook chances or make bad judgements.
  - Lack of Weighting: The method treats all target pattern occurrences in rows, columns, and diagonals identically. It does not distinguish between crucial and less important positions, possibly resulting in unsatisfactory judgements for the big board.

Heuristic - 2

The scoring also based on occurrences of player and opponent symbols in rows, columns, and diagonals. But, the heuristic assigns scores of +10 for player winning patterns and -10 for opponent winning patterns. The score is used to assess the board's desirability for the player.

- Strengths
  - Quick Evaluation: The algorithm swiftly checks rows, columns, and diagonals for winning patterns to make heuristic judgements during gaming.
  - Simplicity: The heuristic is basic, understandable, and implementable, making it suited for simple applications and rapid prototyping.

- Weaknesses
  - Lack of Depth: The heuristic only analyses immediate winning rows, columns, and diagonals. It does not include preventing opponent threats or generating winning possibilities.
  - No Board Control: The algorithm does not consider board control or strategic placement, which might provide an advantage in the game.
  - Overemphasis on Immediate victories: The heuristic gives immediate player victories a high score of 10, which may lead to concentrating primarily on short wins rather than longer-term methods that might generate greater outcomes.
  - Lack of Weighting: All winning patterns—rows, columns, and diagonals—are equally weighted, which may lead to poor judgements in complicated game circumstances.

Heuristic - 3

The heuristic evaluates winning patterns differently for smaller and bigger boards, considers player control over the next small board move, and employs memoization to speed up future computations. **Especially strong** in the free zone stage of the game.

- Strengths
  - Comprehensive Evaluation: The algorithm considers player and opponent winning patterns, player control over the next tiny board move, and smaller and bigger boards. This gives a fuller board evaluation.
  - Memoization: The method memorises board evaluations to minimise unnecessary computations and improve performance.

- Weaknesses
  - Player Control Consideration: The algorithm considers the player's next little board move, which may reveal strategic posture and possible benefits.
  - Board Position Analysis: The algorithm ignores the location of the smaller boards inside the Ultimate Tic-Tac-Toe board, which might affect strategic choices.
  - Lack of Depth: Although the heuristic examines numerous aspects, it does not include more advanced methods like strategic blocking or trapping the opponent.

Heuristic - 4&5

Combination of 2 heuristics: one evaluates the winning position of the large board and the other evaluates the whole board in the domain of the small board.

- Strengths
  - Comprehensive Evaluation: The heuristics evaluate winning sequences, centre movements, and corner moves for both players on the bigger board (heur4) and each smaller board (heur5).
  - Balanced Scoring: Winning sequences and smart movements relatively get lower incremental points for more nuanced assessment.
  - Player-Controlled Sequences: Heuristics reward player-controlled winning sequences, promoting strategic play.
- Weaknesses
  - Overemphasis on Winning Sequence: The heuristics emphasise winning sequences on both big and small boards, which may lead to disregarding other strategic elements of the game.
  - Fixed Incremental Scoring: The heuristic scores may not appropriately represent the strategic value of various plays or winning sequences.
  - Lack of Evaluation Depth: The heuristics do not include advanced strategic factors like opponent blocking or long-term planning, which might lead to poor decision-making.

Depth

Up until this point, I have used a fixed depth for all of the tree-traversing agents. However, the significance of depth varies over various phases of the game. During the first phases of the game, the search space remains very expansive. During the endgame phase, the available search area becomes much reduced, hence amplifying the significance of movements that might lead to a favourable outcome.

The significance of speed is noteworthy; nonetheless, it is crucial to acknowledge that as the depth increases, the number of nodes in the tree increases exponentially, thus leading to a corresponding exponential growth in the time required to traverse the tree.

Results

The research entails a comprehensive investigation of several artificial intelligence methodologies, including heuristics, tree-traversal algorithms such as minimax and alpha-beta pruning, adversarial search algorithms, and numerous other methods. This comprehensive investigation facilitates a comprehensive comprehension of the advantages and constraints of various artificial intelligence approaches.

The AI agents developed as part of the project are designed to exhibit strategic decision-making. By implementing various AI algorithms, the game achieves a higher level of challenge and engagement, providing players with an experience that requires tactical thinking and planning.

The project incorporates ***data collection*** and ***analysis*** to evaluate the performance of AI opponents. By collecting gameplay data, such as win rates and game duration, the project can objectively measure and compare the effectiveness of different AI strategies.

Results

Efficient Memorization: In some of the heuristic algorithms used, the project leverages memoization to store previously computed board evaluations. This approach speeds up subsequent evaluations, optimizing the game's performance during real-time gameplay.

The project evaluates various AI algorithms' performance and provides valuable insights into which AI strategies are most suitable for particular game scenarios, leading to informed decisions for future development and improvements.

Results

There are various records for the different games played by different agents in both directions(they take turns when it comes to who will start first). There are every combination of these 5 agents playing with each other:

- Random
- Simple TTT
- Minimax
- Alpha-Beta
- Alpha-Beta with memorization

And amongst 3,4,5 there are only computational differences.

When it comes to heuristics, strength level also follow the upward direction as in their names:
5+4>3>2>1

Future Work

The project identifies areas for future research, including investigating adversarial search algorithms and memory-based techniques. This not only expands the research horizons but also indicates a willingness to continuously improve the game and its AI components.

The subsequent group of agents use a learning mechanism in an attempt to enhance performance. Further research must be done in the field of reinforcement learning, with a specific emphasis on Q-learning.