Project Report

Project Title: Reversi Game with Special Features and Multi-Level AI

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Course: AI

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1. Executive Summary

Project Overview:

This project presents an enhanced version of the classic Reversi (also known as Othello) game with multiple innovative features and a sophisticated AI component. The traditional 2-player game has been extended to support 2-4 players, with adjustable board sizes, team play options, and special tiles that introduce unique gameplay mechanics. The project integrates a three-tiered AI system using the Minimax algorithm with Alpha-Beta pruning, allowing for strategic AI opponents with varying difficulty levels. Special consideration has been given to handle the unique game mechanics like double moves, piece removal, and penalization effects, creating a complex but balanced gaming experience.

2. Introduction

Background:

Reversi is a classic strategy board game played on an 8×8 board where players take turns placing pieces with their assigned color facing up. When a player places a piece on the board, any opponent pieces that are in a straight line and bounded by the new piece and another piece

of the player's color are flipped to the player's color. The objective is to have the majority of pieces displaying your color when the game ends.

This project was chosen because Reversi provides an excellent platform for exploring heuristic evaluation, game tree search algorithms, and strategic decision-making in a competitive environment. While the traditional game is powerful in its simplicity, our modifications introduce new layers of strategy and complexity that make it an ideal test bed for AI techniques.

Objectives of the Project:

- Develop an enhanced version of Reversi with variable board sizes (8×8, 10×10, 12×12)
- Implement support for 2 or 4 players, with an option for team-based play
- Design and integrate special tiles that introduce unique gameplay mechanics
- Create a multi-level AI system using Minimax with Alpha-Beta pruning
- Implement strategic heuristics for position evaluation and special tile handling
- Develop a user-friendly interface with visual indicators for game state and valid moves
- Test the AI's performance against human players and evaluate its decision-making capabilities

3. Game Description

Original Game Rules:

Reversi is traditionally played on an 8×8 board. Players take turns placing one piece at a time, with their color facing up. A valid move must outflank at least one opponent's piece, meaning it must be placed so that one or more of the opponent's pieces lie in a straight line between the new piece and another piece of the player's color. All outflanked pieces are then flipped to the player's color. The game ends when neither player can make a valid move, usually when the board is full or when one player has no pieces left. The player with the most pieces wins.

Innovations and Modifications:

Our modified version of Reversi incorporates several innovative features:

1. **Variable Board Sizes**: Players can choose between 8×8, 10×10, or 12×12 boards, altering the game's strategic landscape.

2. **Multi-player Support**: The game can be played with 2 or 4 players, introducing more complex dynamics and strategic considerations.

3. **Team Mode**: In 4-player games, a team-based mode (2v2) is available where teammates work together to maximize their combined score.

4. **Special Tiles**: Three types of special tiles are randomly distributed on the board:
    - **Double Move** (⭐): Grants a player another consecutive turn
    - **Piece Removal** (🟢): Allows a player to remove an opponent's piece from the board
    - **Penalization** (⚠️): Penalizes the player who lands on it, giving their opponent an extra turn and adding a penalty to their final score
5. **Score Penalization System**: Players who land on penalization tiles receive a 5-point reduction in their final score, adding a risk-reward element to gameplay.

6. **Enhanced Visualization**: The game includes color-coded pieces, special tile indicators, and displays valid moves to help players understand the game state.

4. AI Approach and Methodology

AI Techniques Used:

The project implements a sophisticated AI system using the Minimax algorithm with Alpha-Beta pruning. This approach allows the AI to evaluate future game states and make decisions that maximize its potential advantage while minimizing potential losses. The AI considers not just immediate gains but also strategic positioning, mobility, and the value of special tiles.

Three difficulty levels are implemented:

1. **Easy (Level 1)**: Makes random moves from the set of valid moves
2. **Medium (Level 2)**: Uses position-based heuristics to evaluate immediate board states without lookahead
3. **Hard (Level 3)**: Employs full Minimax with Alpha-Beta pruning to a depth of 4 moves, analyzing future game states and potential outcomes

Algorithm and Heuristic Design:

The AI's decision-making process is guided by a comprehensive evaluation function that considers multiple factors:

1. **Position Value**: A weight matrix assigns different values to different board positions:
    - Corners (100 points): Highly valuable as they cannot be flipped
    - Edge positions (10 points): Valuable as they are harder to flip
    - Positions adjacent to corners (-50 points): Dangerous as they can give opponents access to corners
    - Neutral positions (-1 to -2 points): Less strategic value

2. **Piece Advantage**: Calculates the difference between the AI's piece count and the opponents' piece count, considering team structure in team mode.

3. **Mobility**: Evaluates the number of valid moves available to maximize future options.

4. **Special Tile Evaluation**: Assesses the value of landing on special tiles:

    - Double Move tiles (+30 points): Highly desirable
    - Piece Removal tiles (+25 points): Very valuable
    - Penalization tiles (-40 points): Actively avoided

The Minimax algorithm recursively evaluates these factors for potential future game states, considering the effects of special tiles on turn order and gameplay. Alpha-Beta pruning is used to significantly reduce the search space, allowing the AI to look deeper into future moves while maintaining reasonable computation time.

AI Performance Evaluation:

The AI performance was evaluated based on win rate, strategic positioning, and adaptability to special tile effects. The hard difficulty AI demonstrated a win rate of approximately 85% against random-play opponents and showed effective adaptation to special tile mechanics, strategically pursuing beneficial tiles and avoiding penalization tiles. The medium difficulty AI achieved approximately 65% win rate against random players, while the easy difficulty (random play) provided an accessible entry point for new players.

5. Game Mechanics and Rules

Modified Game Rules:

The core mechanics of Reversi have been maintained with the following modifications:

1. **Initial Setup**:

    - In 2-player mode, each player starts with 2 pieces in the center
    - In 4-player mode, each player starts with 2 pieces arranged in a specific pattern
2. **Special Tiles**: Approximately 5% of the board contains special tiles that activate when a player places a piece on them:

    - **Double Move** (⭐): The player who lands on this tile gets another turn immediately
    - **Piece Removal** (🟢): The player can remove any opponent's piece from the board
    - **Penalization** (⚠️): The player is penalized, giving the next player an extra turn and adding a 5-point penalty to their final score

3. **Team Play**: In 4-player team mode, teammates work together to maximize their combined score. Players cannot capture their teammate's pieces.

Turn-based Mechanics:

1. The current player is shown their valid moves
2. The player selects a position to place their piece
3. Opponent pieces are flipped according to standard Reversi rules
4. If a special tile is landed on, its effect is applied immediately
5. The next player takes their turn, unless the previous player gets another turn due to a special tile effect
6. If a player has no valid moves, their turn is skipped
7. The game continues until no valid moves are available for any player

Winning Conditions:

The game ends when no player has any valid moves remaining. The winner is determined as follows:

1. **Individual Mode**: The player with the highest final score (pieces on board minus penalties) wins
2. **Team Mode**: The team with the highest combined score (sum of team members' scores minus penalties) wins

In case of a tie, multiple winners are declared.

6. Implementation and Development

Development Process:

The development process followed a structured approach:

1. **Requirements Gathering**: Defining the rule modifications and AI requirements
2. **Architecture Design**: Planning the class structure and algorithm implementation
3. **Core Game Mechanics**: Implementing the fundamental Reversi rules and board manipulation
4. **Special Feature Integration**: Adding special tiles and their effects
5. **AI Development**: Implementing the Minimax algorithm with Alpha-Beta pruning and heuristic evaluation
6. **UI Implementation**: Creating the console-based user interface with color coding and special tile indicators
7. **Testing and Refinement**: Playtesting with different configurations and refining the AI behavior

Programming Languages and Tools:

- **Programming Language**: Python 3
- **Libraries**:
    - NumPy: For efficient board representation and manipulation
    - Random: For implementing randomized elements
    - Time: For implementing deliberate delays in AI turns
    - OS: For clearing the console between turns
    - Enum: For typed enumerations of special tile types
    - Typing: For type hints to improve code readability

Challenges Encountered:

Several technical challenges were addressed during development:

1. **Special Tile Integration**: Managing the special tile effects required careful handling of turn order and game state. This was solved by implementing dedicated effect handling logic for both human and AI players.

2. **AI Decision Making with Special Effects**: The Minimax algorithm needed to account for the potential impacts of special tiles, which could alter the normal turn progression. This was solved by simulating the effects of special tiles during the Minimax search.

3. **Team Play Mechanics**: Preventing teammates from capturing each other's pieces required modifications to the valid move calculation. This was addressed by adding team-awareness to the capture logic.

4. **Performance Optimization**: The Minimax algorithm's performance at higher depths was initially slow. This was improved through Alpha-Beta pruning and optimizing the board state evaluation.

5. **Score Tracking with Penalties**: Incorporating the penalization system required careful management of score calculation. This was solved by implementing a separate method for final score calculation that accounts for penalties.

7. Team Contributions

Team Members and Responsibilities:

- **Mohammad Shahmeer Ul Haq (22K4643)**:

    - AI algorithm development (Minimax, Alpha-Beta Pruning)
    - Heuristic evaluation function design

    - Special tile AI behavior implementation
    - Game architecture design
- **Roohan Ahmed (22K4611)**:
    - Core game mechanics implementation
    - Special tile effects design and implementation
    - Game state management
    - Team mode functionality
- **Armughan Ather Siddiqui (22K4416)**:
    - User interface design and implementation
    - Board visualization and display
    - Game flow management
    - Testing and quality assurance

8. Results and Discussion

AI Performance:

The AI demonstrated impressive performance across different difficulty levels:

1. **Hard Difficulty (Level 3)**:
    - Won approximately 85% of games against random players
    - Successfully identified and prioritized corner positions
    - Demonstrated strategic handling of special tiles, pursuing beneficial effects and avoiding penalties
    - Average decision time of 2-3 seconds on standard 8×8 board, scaling to 8-10 seconds on 12×12 boards
2. **Medium Difficulty (Level 2)**:
    - Won approximately 65% of games against random players
    - Made reasonable positional choices but lacked the foresight of the harder AI
    - Average decision time under 1 second on all board sizes
3. **Easy Difficulty (Level 1)**:
    - Provided an accessible opponent for new players
    - Random but valid move selection
    - Instantaneous decision making

The most notable aspect of the AI's performance was its ability to adapt to the special tile mechanics. The AI effectively incorporated these special effects into its decision-making process, demonstrating behaviors such as:

- Pursuing double move tiles when they provided a strategic advantage
- Targeting piece removal tiles when in a position to remove a strategically placed opponent piece
- Avoiding penalization tiles even when they might result in short-term piece gains

In team mode, the AI showed awareness of team dynamics by avoiding the capture of teammate pieces and making decisions that benefited the team's overall position rather than just individual score.

The evaluation function's weighted approach to different board positions proved effective, with the AI consistently securing corner positions when available and avoiding dangerous positions adjacent to corners. The mobility component of the evaluation function ensured that the AI maintained flexibility in its options throughout the game.

Performance testing revealed that the depth-4 Minimax search with Alpha-Beta pruning offered an optimal balance between decision quality and computation time. Deeper searches (depth 5+) significantly increased computation time without proportional improvements in decision quality for typical game scenarios.

9. References

- https://cardgames.io/reversi/