# Adversarial Search in Chain Reaction

Niloy Kumar Mondal
2105044

June 12, 2025

## Contents

# 1 Introduction

This report outlines the implementation of an adversarial search-based AI agent for the game *Chain Reaction*. *Chain Reaction* is a deterministic, perfect-information game characterized by cascading interactions, making it particularly suitable for analyzing minimax search algorithms enhanced with alpha-beta pruning.

# 2 Game Representation

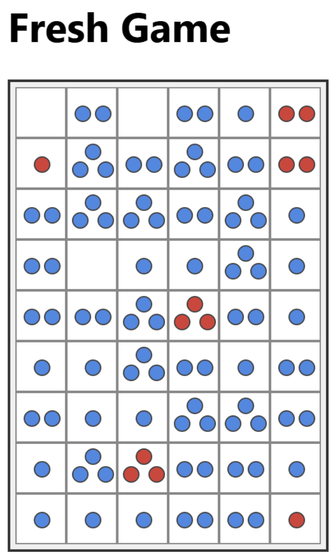


Figure 1: Visualization of the implemented User Interface for Chain Reaction

**User Interface:** Implemented using ReactJS, the UI consists of:

- `Board.js`, `Cell.js`, and their associated CSS files to visualize the game state.
- `server.js` to manage WebSocket communication and synchronize updates by reading from `gamestate.txt`.

# 3 Minimax with Alpha-Beta Pruning

The Minimax algorithm enhanced by alpha-beta pruning efficiently explores game states up to a fixed depth limit, returning the optimal move and its value. Core implemented functions include:

- `simulate_explosion()` for simulating moves and resulting board states.
- `minimax_search()` to perform the minimax search with heuristic evaluations.

# 4 Heuristic Evaluations

Multiple heuristics have been implemented:

1. **Orb Difference:** Advantage based on orb counts.
2. **Near Critical Cells:** Preference for cells close to explosion.
3. **Corner & Edge Control:** Importance given to strategic positions.
4. **Vulnerability Penalty:** Penalty for cells vulnerable to opponent capture.
5. **Cell Count Difference:** Advantage based on controlled cell counts.
6. **Sliding Slope:** Emphasizes central control.
7. **K-circle:** Focuses on proximity to the board center.
8. **K-circle with Rotation:** Similar to K-circle, but optimized for corners.
9. **Maximize Distance:** Maximizing distance from opponent's cells.
10. **Mixed Heuristic:** Weighted combination of multiple heuristics.

# 5 Experimental Setup

Experiments were conducted using the following parameters:

- Depth limit: 4-5-6
- Exploration limit: 10,000

# 6 Results

Performance was evaluated using various heuristics.

Table 1 presents the overall ranking of all heuristics, sorted by their win rate across all AI vs. AI matches. Each heuristic's total wins and win percentage were calculated by aggregating results from all tournament games played as both RED and BLUE.

# 7 Analysis and Trade-offs

The heuristic tournament results reveal several key insights into the effectiveness and trade-offs of different AI evaluation strategies for Chain Reaction:

**Performance Trends:**

- The **Maximize Distance** heuristic achieved the highest overall win rate (75%), indicating that strategies focused on maximizing spatial separation from opponents are particularly effective at both offense and defense.

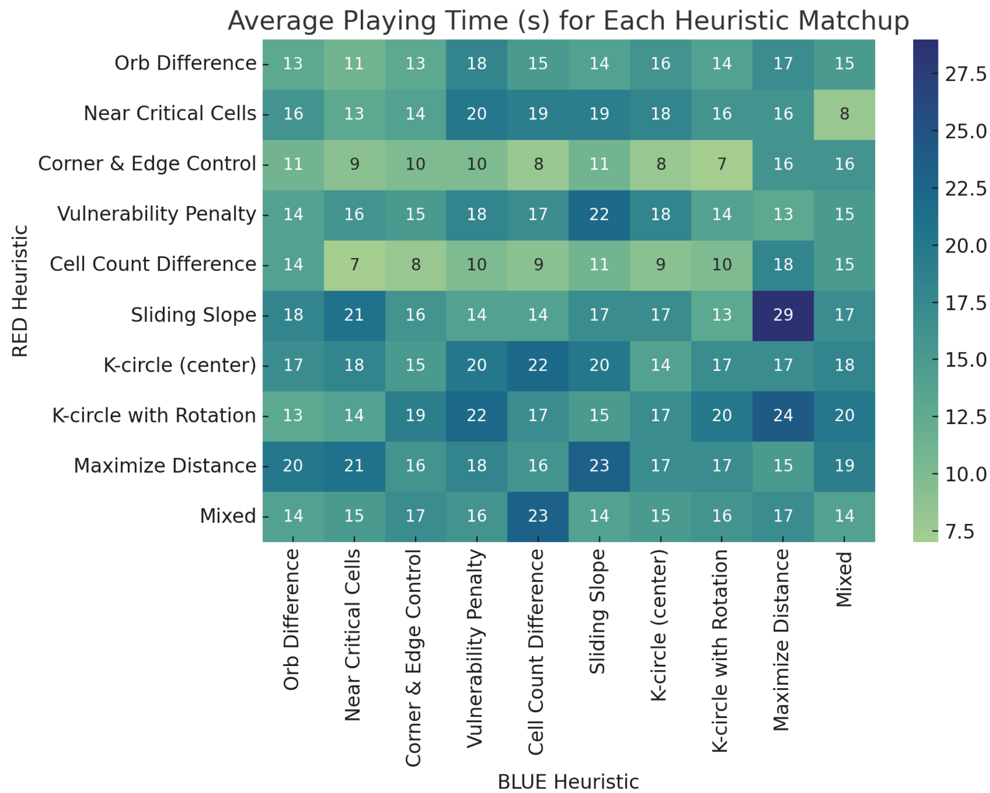


Figure 2: Visualization of playing duration for depth 4

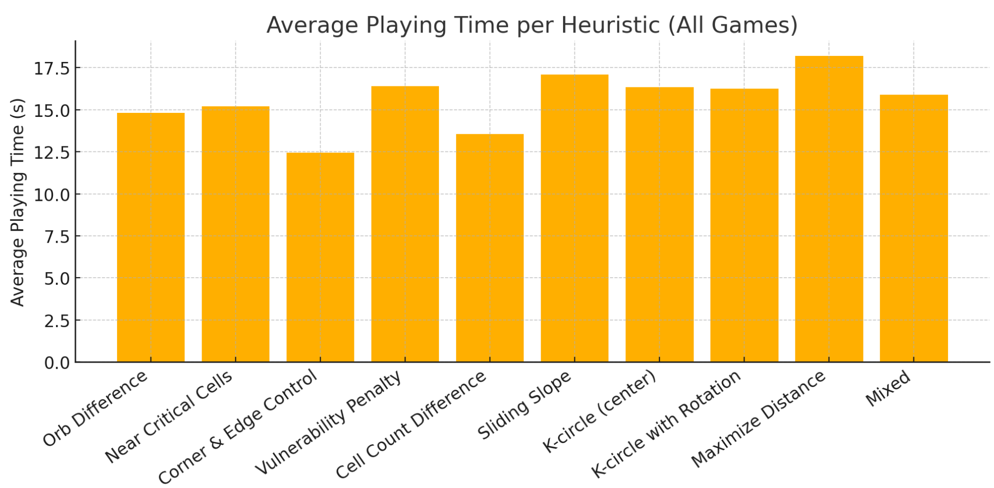


Figure 3: Visualization of avarage playing duration for depth 4

| Rank | Heuristic | Total Wins/20 | Win Rate (%) |
|---|---|---|---|
| 1 | Maximize Distance | 15 | 75.0 |
| 2 | Near Critical Cells | 14 | 70.0 |
| 3 | K-circle with Rotation | 13 | 65.0 |
| 4 | Mixed | 12 | 60.0 |
| 4 | K-circle (center) | 12 | 60.0 |
| 6 | Corner & Edge Control | 10 | 50.0 |
| 6 | Sliding Slope | 10 | 50.0 |
| 8 | Orb Difference | 9 | 45.0 |
| 8 | Cell Count Difference | 9 | 45.0 |
| 10 | Vulnerability Penalty | 6 | 30.0 |

Table 1: Sorted heuristic rankings by win rate.

- **Near Critical Cells**, **K-circle with Rotation**, and the **Mixed** heuristic also performed strongly, each achieving a win rate of 60% or higher, suggesting that both local cell threats and a balanced blend of heuristics contribute to strategic depth.
- Simpler heuristics such as **Vulnerability Penalty** and **Cell Count Difference** were less competitive, highlighting that naive approaches may overlook crucial tactical and positional factors in the game.

**Playing Time:**

- Heuristics that involve more sophisticated positional analysis, such as **Maximize Distance** and the **Mixed** approach, generally resulted in longer average game durations, as shown in the playing time heatmap and bar plots. These approaches require deeper computation per move and tend to produce more prolonged, strategic contests.
- Simpler heuristics led to faster games, but sometimes at the expense of sound tactical play.

**Trade-offs:**

- There is a clear trade-off between **search complexity** and **practical strength**: advanced heuristics improve win rates but increase computational cost and game length.
- While the **Mixed** heuristic does not always top the win rate rankings, its ability to blend multiple features often ensures consistently good results across varied opponents.
- Some heuristics excel in particular match-ups but not universally, indicating that *meta-strategic diversity* may be valuable when deploying agents in real-world or tournament settings.

Overall, the results demonstrate that integrating deeper board analysis and combining multiple evaluation principles leads to stronger AI performance in Chain Reaction, though these benefits must be weighed against increased playing time and computational demand.