

# Chain Reaction Game: AI Implementation and Heuristic Exploration

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## 1 Overview

The Chain Reaction game is a strategic two-player game played on a grid, where players alternate placing orbs. When a cell reaches its critical mass, it explodes, distributing orbs to adjacent cells and potentially causing a chain reaction. The objective is to eliminate the opponent's orbs entirely. This report examines an AI implementation for this game, utilizing the Minimax algorithm with alpha-beta pruning and a variety of heuristics to guide decision-making.

## 2 Game and AI Framework

The game operates on a 9x6 grid and supports two play modes:

- **Human vs AI:** A human player faces an AI opponent.
- **AI vs AI:** Two AI agents compete, with the option to assign different heuristics to each.

The AI leverages the Minimax algorithm with alpha-beta pruning, exploring the game tree to a depth of 3 for AI vs AI mode (configurable via `depth_R` and `depth_B`) and 4 for Human vs AI mode. Seven distinct heuristics are implemented to evaluate board states, selectable in AI vs AI mode via user input.

## 3 Evaluation Heuristics

The following heuristics are employed to assess board states:

### 3.1 Smart Heuristic

This heuristic aggregates multiple factors: orb count (weighted by 10), positional bonuses for corners (+5) and edges (+3), bonuses for cells one (+6) or two (+3) orbs from critical mass, and a penalty (-8) for adjacent opponent cells near critical mass. It aims to balance immediate and strategic considerations.

Heuristic	Evaluation Criteria
Smart Heuristic	Combines orb count, cell position weights (corners +5, edges +3), proximity to critical mass (+6 or +3), and threats from adjacent opponent cells (-8).
Balanced Heuristic	Normalizes orb count (1.0), proximity to critical mass (+4.0), position (corners +3.0, edges +2.0), threats (+3.0), mobility (+0.5), and cell control (+0.5) to [-100, 100].
Orb Count Heuristic	Difference in total orb counts between players.
Cell Control Heuristic	Difference in number of cells occupied by each player.
Mobility Heuristic	Difference in legal moves available to each player.
Edge Stability Heuristic	Difference in orb counts on edges (excluding corners).
Critical Cells Heuristic	Difference in cells one orb away from critical mass.

Table 1: Heuristics Overview

### 3.2 Balanced Heuristic

A normalized heuristic (range [-100, 100]) that evaluates orb count (1.0), proximity to critical mass (+4.0), positional weights (corners +3.0, edges +2.0), threats from adjacent critical opponent cells (+3.0), mobility (0.5 per legal move), and cell control (0.5 per cell). It provides a broad, comparable score.

### 3.3 Orb Count Heuristic

Computes the difference in total orbs between the player and opponent. It's simple and fast but overlooks positional dynamics.

### 3.4 Cell Control Heuristic

Measures the difference in occupied cells. Like Orb Count, it's efficient but doesn't account for orb distribution or explosion potential.

### 3.5 Mobility Heuristic

Evaluates the difference in legal moves, reflecting flexibility. It may shine in later stages when moves are scarce.

### 3.6 Edge Stability Heuristic

Focuses on orb counts along edges (excluding corners), emphasizing perimeter control as a strategic asset.

### 3.7 Critical Cells Heuristic

Counts cells one orb from critical mass, highlighting potential explosion triggers that could shift the game state.

## 4 Heuristic Evaluation

Each heuristic offers a unique lens on the board: - **Smart Heuristic**: Comprehensive but computationally intensive due to multiple factors. - **Balanced Heuristic**: Balanced and normalized, ideal for consistent state comparison. - **Orb Count and Cell Control**: Quick but shallow, missing chain reaction potential. - **Mobility**: Key in constrained endgames where options dwindle. - **Edge Stability**: Supports long-term board control strategies. - **Critical Cells**: Focuses on imminent explosions, critical in dynamic phases. The AI vs AI mode’s heuristic selection feature allows exploration of these trade-offs, as each AI can use a different evaluation strategy.

## 5 Experimental Results: Human vs AI

To assess the effectiveness of each heuristic, the AI (using a search depth of 4) played 5 games against a human player for each heuristic. The results are summarized below:

Heuristic	AI Wins	Human Wins
Smart Heuristic	5	0
Balanced Heuristic	5	0
Orb Count Heuristic	2	3
Cell Control Heuristic	2	3
Mobility Heuristic	3	2
Edge Stability Heuristic	4	1
Critical Cells Heuristic	4	1

Table 2: Human vs AI Game Outcomes by Heuristic

The Smart and Balanced heuristics proved highly effective, with the AI winning all 5 games against the human player. This indicates their strength in evaluating complex board states, leveraging factors like orb count, positional advantages, and threats. Conversely, the human won 3 out of 5 games against the simpler Orb Count and Cell Control heuristics, suggesting these lack the depth to consistently counter human strategies. Against Mobility, Edge Stability, and Critical Cells, the human won 1 to 2 games, reflecting moderate AI performance due to their focus on specific strategic aspects.

## 6 AI vs AI Gameplay

In AI vs AI mode, two configurations were tested: Random vs Heuristic and Heuristic A vs Heuristic B.

### 6.1 Random vs Heuristic

One AI used a random move selection strategy, while the other employed a user-selected heuristic. The Smart and Balanced heuristics consistently defeated the random AI, winning all 5 games. Simpler heuristics showed mixed results: Orb Count and Cell Control lost 1/2 out of 5 games, while Mobility, Edge Stability, and Critical Cells lost 0/1 out of 5, indicating that more complex heuristics reliably outperform random play, though simpler ones occasionally falter.

### 6.2 Heuristic A vs Heuristic B

When pitting two heuristics against each other, more complex heuristics like Smart and Balanced generally exhibited higher winning probabilities against simpler ones like Orb Count or Cell Control. The Smart Heuristic, for instance, typically dominated due to its comprehensive evaluation. However, in some cases, weaker heuristics like Critical Cells prevailed over stronger ones, likely due to specific board states where focusing on imminent explosions outweighed broader strategic considerations. This variability highlights the game's dynamic nature and the context-dependent effectiveness of heuristics.

## 7 Final Thoughts

This implementation demonstrates the power of heuristic-driven AI in Chain Reaction. The diversity of heuristics—from simple counts to complex weighted evaluations—offers flexibility in tailoring AI behavior. The experimental results confirm that comprehensive heuristics like Smart and Balanced excel, while simpler ones are less consistent. Future enhancements could include adaptive heuristic selection based on game phase or hybrid heuristics combining the strengths of multiple approaches.