# Chain Reaction AI: Heuristic Experimentation and Evaluation

## Heuristic Descriptions

We implemented and evaluated six heuristics for AI move selection in the Chain Reaction game. Below are brief descriptions of each:

- **Simple (Cell Count):** Counts the number of cells controlled by the player and subtracts the opponent's count. This is a very basic presence-based heuristic.
- **Orb Count Difference:** Sums all orbs the player controls and subtracts the total orbs the opponent owns. This rewards accumulated strength, not just spread.
- **Edge/Corner Control:** Rewards occupying corner and edge positions, which are harder to capture due to fewer neighbors. These positions are considered strategically safer.
- **Vulnerability Penalty:** Penalizes orbs that are about to explode and are surrounded by enemies. Rewards safe positions where orbs have no adjacent threats.
- **Chain Reaction Opportunity:** Rewards positioning near friendly cells that are close to explosion. Encourages explosive chain setups that can take over enemy cells.
- **Combined (Orb + Chain):** A weighted combination of Orb Count Difference and Chain Reaction Opportunity. Balances stable control with tactical offense.

## Experimental Setup

We conducted AI vs AI matches across all pairwise combinations of the six heuristics using both Red and Blue configurations. Each agent used the Minimax algorithm with Alpha-Beta pruning at search depths 1 and 2. Statistics were collected on winner, move count, and game duration.

## Heuristic Comparison Results

### Depth 1

Table 1: Performance at Depth 1

| Heuristic | Wins | Win Rate |
|---|---|---|
| Orb Count Difference | 9 | 30.0% |
| Edge/Corner Control | 7 | 23.3% |
| Simple | 2 | 6.7% |
| Chain Reaction | 6 | 20.0% |
| Orb + Chain Combined | 6 | 20.0% |

**Total games:** 30
**Average moves:** 104.4
**Average time per game:** 5.98s

### Depth 2

Table 2: Performance at Depth 2

| Heuristic | Wins | Win Rate |
|---|---|---|
| Simple | 8 | 26.7% |
| Orb Count Difference | 7 | 23.3% |
| Orb + Chain Combined | 6 | 20.0% |
| Chain Reaction | 4 | 13.3% |
| Edge/Corner Control | 4 | 13.3% |
| Vulnerability | 1 | 3.3% |

**Total games:** 30
**Average moves:** 97.6
**Average time per game:** 49.58s

## Observations and Analysis

- **Best performing:** At depth 1, the Orb Count Difference heuristic performed best, likely due to its stable reward structure and shallow evaluation. At depth 2, surprisingly, the Simple heuristic outperformed others.
- **Chain Reaction:** While promising in concept, its delayed payoff meant Minimax could not reliably evaluate its benefits at shallow depth. It underperformed without deeper lookahead.
- **Vulnerability:** This heuristic, while theoretically sound, resulted in poor play. After fixing a logic issue where it rewarded risky positions, performance improved slightly but remained low.
- **Combined Heuristic:** The Orb + Chain Reaction heuristic was expected to dominate, but it only performed moderately. Likely, its added complexity didn't outweigh the shallow depth limitations.
- **Trade-offs:** Greedy heuristics dominate at low depths. Complex heuristics like Chain Reaction need either deeper search or more advanced prediction (e.g. simulation rollout or neural guidance).

## AI vs AI Framework

Our UI and backend were adapted to support AI vs AI matchups in Pygame, including automatic logging of results and move timings. The AI agents were alternated between Red and Blue in matches to reduce color bias.

**Examples:**

- Red(Simple) vs Blue(Orb Count): Blue wins, 4.97s
- Red(Chain Reaction) vs Blue(Orb Count): Blue wins, 12.73s
- Red(Orb + Chain) vs Blue(Chain Reaction): Red wins, 13.48s

**Color Performance:**

- Depth 1: Red wins 56.7% of games
- Depth 2: Red wins 36.7% of games

## Conclusion

In low-depth Minimax with Alpha-Beta pruning, greedy and stable heuristics like Orb Count Difference consistently outperform more strategic or reactive ones. The most advanced heuristics show promise but require deeper lookahead to perform reliably. Hybrid heuristics may gain from better weight tuning or adaptive depth.