AI Heuristic Performance Analysis in Chain Reaction

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1 Introduction and Experimental Setup

This report evaluates the performance of various heuristics used in a Minimax-based AI agent for the Chain Reaction game. The experiments were run in two main configurations:

- **Minimax vs Minimax**: Two AIs using different heuristics played against each other for 200 games per heuristic.
- **Minimax vs Random**: Each AI played 20 games against a purely random move generator.

Each agent was constrained by 2 and 3 depth and a 3-second time limit. If the AI failed to respond within this limit, a random move was chosen to ensure the game progressed without stalling.

2 Heuristic Descriptions

- **Orb Count Difference:** Computes the difference between the number of orbs owned by the AI and those owned by the opponent. Simple yet effective in balanced board states.
- **Potential Chain Reactions:** Rewards game states where the AI has cells close to exploding, which can trigger beneficial chain reactions. Penalizes similar conditions for the opponent.
- **Strategic Position:** Gives higher value to corners and edge positions since they are safer from chain reactions and easier to defend.
- **Conversion Potential:** Evaluates how likely the AI can capture and convert opponent orbs in upcoming turns.
- **Mobility:** Counts the number of cells the AI can safely place orbs in. Useful in defensive or congested board states.

3 Results

3.1 Minimax vs Minimax Analysis

Heuristic	Wins	Games	WinRate (%)	Avg Time (s)	Avg Moves
strategic_position	140	200	70.0	2.33	55.9
potential_chain_reactions	140	200	70.0	2.82	59.9
count_difference	135	200	67.5	2.37	60.1
mobility	60	200	30.0	0.23	12.2
conversion_potential	25	200	12.5	0.65	28.7

Table 1: Minimax vs Minimax Performance

3.2 Minimax vs Random Analysis

Heuristic	Wins	Games	WinRate (%)	Avg Time (s)	Avg Moves
count_difference	20	20	100.0	0.73	48.4
strategic_position	20	20	100.0	1.21	54.5
potential_chain_reactions	20	20	100.0	1.33	49.1
mobility	20	20	100.0	0.33	31.8
conversion_potential	16	20	80.0	0.91	44.2

Table 2: Minimax vs Random Performance

3.3 Overall Ranking

Rank	Heuristic
1	strategic_position (Score: 82.0)
2	potential_chain_reactions (Score: 82.0)
3	count_difference (Score: 80.5)
4	mobility (Score: 58.0)
5	conversion_potential (Score: 39.5)

Table 3: Overall Heuristic Performance Ranking

4 Comparative Analysis

From the data above, we can draw the following conclusions about the relative performance of each heuristic:

1. **Strategic Position vs All:** This heuristic performed the best overall due to its focus on corner and edge safety. Its stability and defensiveness likely explain its consistent 70% win rate in competitive matches and 100% win rate against random play.

2. **Potential Chain Reactions:** Equal in score to `strategic_position`, this heuristic focuses on creating offensive opportunities. Its higher average move count and evaluation time indicate deeper tactical planning, which proved effective but computationally heavier.

3. **Count Difference:** A simple yet surprisingly strong baseline. Although not as dominant in head-to-head matches, it still achieved 100% win rate vs random and a solid 67.5% against minimax agents.

4. **Mobility:** Despite achieving 100% against random agents, its performance drops significantly in real matches (only 30% win rate). This shows that safety and flexibility alone aren't enough without positional advantage or offensive potential.

5. **Conversion Potential:** While conceptually promising, it was the weakest in competitive matches. Likely due to overvaluing risky aggressive plays or inaccurate capture estimation.

5 Bar Graph: Win Rates of Heuristics

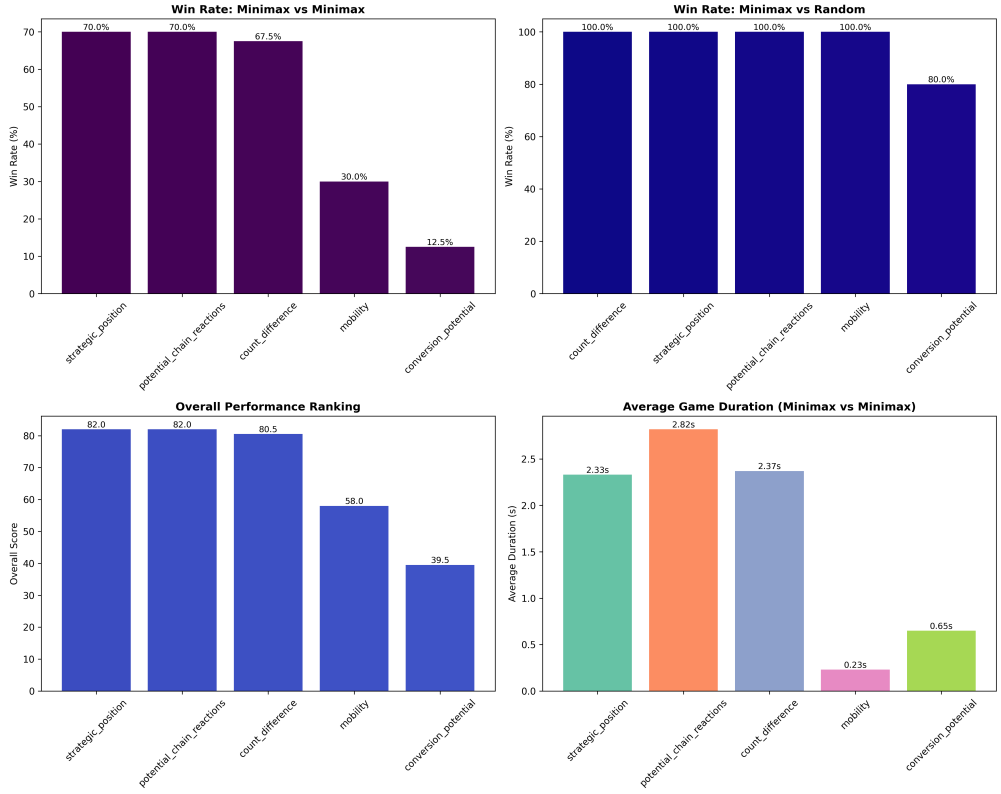

Figure 1: Win Rate Comparison of Heuristics

6 Conclusion

The results indicate that the heuristics `strategic_position` and `potential_chain_reactions` perform best overall, achieving:

- **70% win rate** against other Minimax agents.
- **100% win rate** against the random move agent.

These heuristics balance both offensive and defensive strategies well. Meanwhile, simpler heuristics like `count_difference` offer competitive performance with faster evaluation time. However, heuristics like `conversion_potential` and `mobility` need further tuning to compete effectively in adversarial settings.