Chain Reaction AI vs. AI Experimentation Report (Task 5)

Student ID: 2105023

June 16, 2025

Abstract

This report presents the results of AI vs. AI experiments for the Chain Reaction game, as part of CSE 318 Assignment-03, Task 5. The experiments evaluate the performance of a Random-move agent against a Minimax agent with varying depths and heuristics, as well as Minimax agents with different heuristics competing against each other. Key metrics include win rates, average game times, and nodes explored. The findings highlight the effectiveness of different heuristics and the impact of search depth on performance.

1 Experimental Setup

The experiments were conducted using the Chain Reaction game implementation on a 9x6 board. Two sets of experiments were performed:

- **Random vs. Minimax**: A Random-move agent (Red) competed against a Minimax agent (Blue) with depths of 1, 2, and 3, and six heuristic functions (0 to 5). Each configuration ran for 10 games.
- **Minimax vs. Minimax**: Pairs of Minimax agents with different heuristics (0 to 5) competed at a fixed depth of 2, with each pair playing two games (swapping colors).

The heuristics used were:

1. Heuristic 0: Explosion Cascade
2. Heuristic 1: Strategic Positioning
3. Heuristic 2: Defensive Stability
4. Heuristic 3: Chain Amplification
5. Heuristic 4: Territorial Dominance
6. Heuristic 5: Critical Mass Control

Metrics collected include win rates, average time per game, and average nodes explored by the Minimax agent. A time limit of 3000 ms per move was enforced. The experiments were run using the provided Java implementation, with results logged to `report.txt`.

2 Random vs. Minimax Results

The Random agent was consistently outperformed by the Minimax agent, with win rates varying by depth and heuristic. Table 1 summarizes the results.

Table 1: Random (Red) vs. Minimax (Blue) Results (10 games per configuration)

Depth	Heuristic	Win Rate (%)	Avg. Time (ms)	Avg. Nodes Explored
1	0	20.00	27.50	1441.70
1	1	100.00	33.30	2131.30
1	2	80.00	15.70	1911.30
1	3	30.00	11.70	1581.80
1	4	80.00	26.80	2026.10
1	5	90.00	12.30	2116.10
2	0	100.00	178.50	84621.40
2	1	100.00	144.00	64898.00
2	2	100.00	193.00	65227.90
2	3	100.00	163.60	73995.60
2	4	100.00	273.70	66188.10
2	5	100.00	136.80	66326.60
3	0	100.00	1195.50	558495.40
3	1	100.00	1057.30	633912.70
3	2	100.00	1386.20	533320.80
3	3	100.00	1940.50	757293.60
3	4	100.00	2191.90	528083.80
3	5	100.00	1284.30	589530.80

2.1 Observations

- At depth 1, Heuristic 1 (Strategic Positioning) achieved a 100% win rate, while Heuristic 0 (Explosion Cascade) and Heuristic 3 (Chain Amplification) performed poorly (20% and 30%, respectively).
- At depths 2 and 3, the Minimax agent won 100% of games across all heuristics, indicating that deeper search significantly improves performance against a Random agent.
- Average time per game and nodes explored increased exponentially with depth, with depth 3 games taking up to 2191.90 ms (Heuristic 4) and exploring up to 757293.60 nodes (Heuristic 3).
- Heuristic 1 at depth 1 was notably efficient, achieving a perfect win rate with fewer nodes (2131.30) compared to depth 2 or 3.

3 Minimax vs. Minimax Results

Minimax agents with different heuristics competed at a fixed depth of 2. Each pair played two games, with results summarized in Table 2.

Table 2: Minimax vs. Minimax Win Summary (Wins out of 2 games)

Heuristic	0	1	2	3	4	5
0	-	1	1	1	2	2
1	1	-	1	1	2	0
2	1	1	-	2	2	1
3	1	1	0	-	2	2
4	0	0	0	0	-	0
5	0	2	1	0	2	-

3.1 Observations

- Heuristic 4 (Territorial Dominance) performed poorly, losing all games against other heuristics.
- Heuristic 0 (Explosion Cascade) and Heuristic 3 (Chain Amplification) were strong, each winning at least one game against most opponents except Heuristic 4.
- Heuristic 5 (Critical Mass Control) showed mixed performance, notably defeating Heuristic 1 (2-0) but losing to Heuristic 0 and Heuristic 3.
- Average game times ranged from 263 ms to 916 ms, with Heuristic 4 vs. Heuristic 3 taking the longest (916 ms).
- Nodes explored per game were similar across heuristics, typically between 59,393 and 106,601, indicating that heuristic choice impacted decision quality more than search efficiency.

4 Discussion

- **Best Performing Heuristic**: In Random vs. Minimax experiments, Heuristic 1 (Strategic Positioning) excelled at depth 1 with a 100% win rate and reasonable efficiency. In Minimax vs. Minimax, Heuristic 0 and Heuristic 3 were dominant, suggesting their focus on explosion cascades and chain reactions aligns well with the game's dynamics.
- **Trade-offs**: Deeper search (depth 3) guaranteed wins against Random but was computationally expensive, making depth 2 a practical balance. Heuristic 4's poor performance indicates that territorial dominance alone is insufficient without considering chain reactions or critical mass timing.

- **Limitations**: The small sample size (10 games for Random vs. Minimax, 2 games for Minimax vs. Minimax) limits statistical confidence. Future experiments could increase game counts and explore dynamic depth adjustment.

5 Conclusion

The AI vs. AI experiments demonstrate that Minimax with alpha-beta pruning significantly outperforms a Random agent, with heuristic choice and search depth critically impacting performance. Heuristic 1 is highly effective at shallow depths, while Heuristics 0 and 3 excel in competitive settings. The results underscore the importance of tailoring heuristics to the game's explosive and cascading nature.