# Heuristic Analysis

The primary three original custom heuristic evaluation functions Heuristics 1 to 3 that were created in `game_agent.py` are described below. Additional Heuristics 4 to 6 were also created to have combinations of each original.

Tournaments were run using the `python tournament.py -v` with all the original and additional Heuristics, which were represented as the agent called "Student". Another computer agent called "ID_Improved" that was designed by others was run before each of them on the same laptop to provide a benchmark to compare the overall performance of all match results with. The "Student" and "ID_Improved" agents had matches against a number of CPU testing agents, including:

**Student and Benchmarking Agents**

- Student - Agent using Alpha-Beta Pruning Algorithm, Iterative Deepening, and Custom Heuristic
- ID_Improved - Agent using Alpha-Beta Pruning, Iterative Deepening, and Improved Score Heuristic

**CPU Testing Agents:**

- Random - Agent using Random Player
- MM_Null - Agent using Minimax Algorithm to Depth of 3 with Null Score Heuristic
- MM_Open - Agent using Minimax to Depth of 3 with Open Move Score Heuristic
- MM_Improved - Agent using Minimax to Depth of 3 with Improved Score Heuristic
- AB_Null - Agent using Alpha-Beta Pruning to Depth 5 with Null Score Heuristic
- AB_Open - Agent using Alpha-Beta Pruning to Depth 5 with Open Move Score Heuristic
- AB_Improved - Agent using Alpha-Beta Pruning to Depth 5 with Improved Score Heuristic

In the following sections we include tables that summarise the results of the tournaments using Heuristics 1 to 3, and an analysis of both the "Student" performance and each of the test agent opponents in each match, as well as comparison with "ID_Improved" for the same.

## • Heuristic 1 - Center Available Factor

Returns a score with a higher weighting of 2.0 for any move when there is a center location in the grid that has not been occupied yet, otherwise a score with normal weighting of 1.0 is returned.

**"Student" performance summary:** The "Student" agent performed poorly as compared to "ID_Improved".

**"ID_Improved" performance summary:** The "ID_Improved" agent performed well, even against Test Agents using the Improved Score heuristic, since they both use the same heuristic.

**"Test agent" performance summary:** Matches where the Test Agent was using the Improved Score heuristic performs much better for scoring moves than only scoring with a higher weighting when the center position is available. The Improved Score heuristic scores based on the difference in remaining moves between the two players.

| Match | Agent | Test Agent | Result | ID_Improved Performance | Other Notes (if any) |
|---|---|---|---|---|---|
| 1 | ID_Improved | Random | 18 to 2 | | |
| 2 | ID_Improved | MM_Null | 14 to 6 | | |

| | | | | | |
|---|---|---|---|---|---|
| 3 | ID_Improved | MM_Open | 11 to 9 | 70.71% | |
| 4 | ID_Improved | MM_Improved | 12 to 8 | | |
| 5 | ID_Improved | AB_Null | 14 to 6 | | |
| 6 | ID_Improved | AB_Open | 15 to 5 | | |
| 7 | ID_Improved | AB_Improved | 15 to 5 | | |

**Table 1.1: Performance of ID_Improved using Heuristic 1**

| Match | Agent | Test Agent | Result | ID_Improved Performance | Other Notes (if any) |
|---|---|---|---|---|---|
| 1 | Student | Random | 13 to 7 | 60.71% | |
| 2 | Student | MM_Null | 15 to 5 | | |
| 3 | Student | MM_Open | 12 to 8 | | |
| 4 | Student | MM_Improved | 10 to 10 | | |
| 5 | Student | AB_Null | 14 to 6 | | |
| 6 | Student | AB_Open | 12 to 8 | | |
| 7 | Student | AB_Improved | 9 to 11 | | |

**Table 1.2: Performance of Student using Heuristic 1**

## • Heuristic 2 - Reflection Available Factor

Returns a score with a normal weighting of 1.0 by default, and when the board is empty as no existing opponent position exists for the current player to reflect in their move.

Otherwise generate a representation of the grid with the opponents' coordinates known, and then create a mirrored reflection of it to determine the location to the current player should move to to follow the Reflection Phenomenon, which when used on all subsequent moves is known to win. Then we iterate through the possible legal moves available to the current player and if one of them matches the opponents' mirrored position we return a score with higher weighting of 2.0.

**"Student" performance summary:** This was the best performance by "Student" against "ID_Improved" with 67.14% vs 60.00% respectively.

**"ID_Improved" performance summary:** The "ID_Improved" agent performed well, except against Test Agents using Alpha-Beta with using the Improved Score heuristic, even though they both use the same heuristic.

**"Test agent" performance summary:** Matches where the Test Agent was using the Improved Score heuristic perform much better for scoring moves than only scoring with a higher weighting when the oppositions

reflected position is available. The Improved Score heuristic scores based on the difference in remaining moves between the two players.

| Match | Agent | Test Agent | Result | ID_Improved Performance | Other Notes (if any) |
|---|---|---|---|---|---|
| 1 | ID_Improved | Random | 19 to 1 | 67.14% | |
| 2 | ID_Improved | MM_Null | 12 to 8 | | |
| 3 | ID_Improved | MM_Open | 13 to 7 | | |
| 4 | ID_Improved | MM_Improved | 14 to 6 | | |
| 5 | ID_Improved | AB_Null | 14 to 6 | | |
| 6 | ID_Improved | AB_Open | 13 to 7 | | |
| 7 | ID_Improved | AB_Improved | 9 to 11 | | |

**Table 2.1: Performance of ID_Improved using Heuristic 2**

| Match | Agent | Test Agent | Result | ID_Improved Performance | Other Notes (if any) |
|---|---|---|---|---|---|
| 1 | Student | Random | 16 to 4 | 60.00% | |
| 2 | Student | MM_Null | 14 to 6 | | |
| 3 | Student | MM_Open | 11 to 9 | | |
| 4 | Student | MM_Improved | 9 to 11 | | |
| 5 | Student | AB_Null | 13 to 7 | | |
| 6 | Student | AB_Open | 11 to 9 | | |
| 7 | Student | AB_Improved | 10 to 10 | | |

**Table 2.2: Performance of Student using Heuristic 2**

- ## Heuristic 3 - Partition Possible Factor

Returns a score with a normal weighting of 1.0 by default, and when the board is empty as no positions have been occupied yet.

Otherwise either returns a score with a higher weighting of 4.0 when any of the current players legal moves are either vertically or horizontally adjacent to a sequence of two grid locations that have previously been occupied and are blocked, or returns a score with a higher weighting of 2.0 when any of the current players legal moves are either vertically or horizontally adjacent to a single grid locations that have previously been occupied and are blocked.

**"Student" performance summary:** The "Student" agent performed poorly as compared to "ID_Improved".

**"ID_Improved" performance summary:** The "ID_Improved" agent performed well against all Test Agents.

**"Test agent" performance summary:** Matches where the Test Agent was using the Open Score or the Improved Score heuristics performed much better for scoring moves than only scoring with a higher weighting for available moves that were adjacent to one or two already occupied positions in horizontal or vertical sequence. The Open Score heuristic scores based on quantity of players available legal moves. The Improved Score heuristic scores based on the difference in remaining moves between the two players. Hence the poor performance against Test Agents using Open Score heuristics may be because the players strategy may have generated partitions faster but not necessarily caused the player to end up on the side of a partition with the most remaining moves to achieve a win.

| Match | Agent | Test Agent | Result | ID_Improved Performance | Other Notes (if any) |
|---|---|---|---|---|---|
| 1 | ID_Improved | Random | 19 to 1 | 75.00% | |
| 2 | ID_Improved | MM_Null | 17 to 3 | | |
| 3 | ID_Improved | MM_Open | 14 to 6 | | |
| 4 | ID_Improved | MM_Improved | 15 to 5 | | |
| 5 | ID_Improved | AB_Null | 14 to 6 | | |
| 6 | ID_Improved | AB_Open | 13 to 7 | | |
| 7 | ID_Improved | AB_Improved | 13 to 7 | | |

**Table 3.1: Performance of ID_Improved using Heuristic 3**

| Match | Agent | Test Agent | Result | ID_Improved Performance | Other Notes (if any) |
|---|---|---|---|---|---|
| 1 | Student | Random | 14 to 6 | 60.00% | |
| 2 | Student | MM_Null | 15 to 5 | | |
| 3 | Student | MM_Open | 9 to 11 | | |
| 4 | Student | MM_Improved | 9 to 11 | | |

| | | | | | |
|---|---|---|---|---|---|
| 5 | Student | AB_Null | 13 to 7 | | |
| 6 | Student | AB_Open | 11 to 9 | | |
| 7 | Student | AB_Improved | 13 to 7 | | |

**Table 3.2: Performance of Student using Heuristic 3**

## Heuristic Recommendation

The best performing evaluation function against "ID_Improved" was "Student" Heuristic 2 with 67.14% vs 60.00% respectively, and is therefore recommended to be used, and has been submitted in `custom_score()`. The three reasons justifying this recommendation are as follows:

- Least difference in the percentage between the "ID_Improved" benchmark and the "Student" for Heuristic 2. This is supported by data evidence in the column ID_Improved Performance and Student Performance in all tables.
- The "Student" performed poorly in Heuristic 3 against "ID_Improved" where Test Agents using the Open Score or the Improved Score heuristics performed much better for scoring moves than only scoring with a higher weighting for available moves that were adjacent to one or two already occupied positions in horizontal or vertical sequence. This is supported by data evidence in Table 3.2's "Result" column for matches 3 and 4.
- The "Student" performed poorly in Heuristic 1 against "ID_Improved" where Test Agents using the Improved Score heuristic performed much better for scoring moves than only scoring with a higher weighting when the center position is available. This is supported by data evidence in Table 1.2's "Result" column for matches 4 and 7.