

# Isolation Game Heuristic Analysis

For this project, we experimented with five different heuristics. Here's a summary of their results:

	ID_Improved	Student
heuristic1()	75.00%	64.29%
heuristic2()	73.57%	69.29%
heuristic3()	74.29%	72.14%
heuristic4()	70.71%	69.29%
heuristic5()	62.14%	70.00%

We **recommend using `heuristic5()`** because of the four following factors:

- it translates the notion of **positional advantage** to the specific L-shape knight-like moves allowed in the game
- by counting L-shape jumps, it matches the use of a **proven distance measure** (Manhattan vs Euclidean)
- it can leverage **sophisticated game mechanics** (max number of moves over min number of squares) to increase survival rate toward the end of the game (see `heuristic5()` details below)
- it can leverage **function inlining** and **loop unrolling** to explore more branches before timeouts

Below, we provide a justification for each heuristic as well as present how each performs against the `ID\_Improved` heuristic provided by the Udacity staff.

## Heuristic 1

With this heuristic, the **more available moves `player` has available from the evaluated position, the better**. The `heuristic1()` function simply returns the **difference in number of legal moves left** between the players. If `player` and its opponent have the same number of moves, then the returned value is zero. If the returned value is positive (negative), then `player` is doing better (worse) than its opponent. If the returned value is "inf" ("-inf"), then `player` has won (lost) the game.

### Results

Here's how our game-playing agent performs with this heuristic:

```
*****
Evaluating: ID_Improved
*****

Playing Matches:
-----
Match 1: ID_Improved vs Random      Result: 16 to 4
Match 2: ID_Improved vs MM_Null     Result: 15 to 5
Match 3: ID_Improved vs MM_Open     Result: 14 to 6
Match 4: ID_Improved vs MM_Improved Result: 13 to 7
Match 5: ID_Improved vs AB_Null     Result: 19 to 1
Match 6: ID_Improved vs AB_Open     Result: 15 to 5
Match 7: ID_Improved vs AB_Improved Result: 13 to 7

Results:
-----
ID_Improved      75.00%

*****
Evaluating: Student
*****

Playing Matches:
-----
Match 1: Student vs Random      Result: 14 to 6
Match 2: Student vs MM_Null     Result: 13 to 7
Match 3: Student vs MM_Open     Result: 15 to 5
Match 4: Student vs MM_Improved Result: 9 to 11
Match 5: Student vs AB_Null     Result: 13 to 7
Match 6: Student vs AB_Open     Result: 12 to 8
Match 7: Student vs AB_Improved Result: 14 to 6

Results:
-----
Student          64.29%
```

### Analysis

Not a great heuristic, to say the least. Its benefits are that it's **easily interpretable and fast** to compute. On the downside, it is not really "game aware". It is oblivious to the notion of positional advantage and isn't influenced at all by the specific mechanics of the game (only knight moves are allowed).

### Implementation

Here's our implementation for this heuristic:

```
def heuristic1(game, player):
    # Have we won the game?
    if game.is_winner(player):
        return float("inf")

    # Do we even have moves to play?
    if game.is_loser(player):
        return float("-inf")

    # We have moves to play. How many more than our opponent?
    player_moves_left = len(game.get_legal_moves(player))
    opponent_moves_left = len(game.get_legal_moves(game.get_opponent(player)))
    return float(player_moves_left - opponent_moves_left)
```

## Heuristic 2

With this heuristic, as in `heuristic1()` the more moves the player has available from the evaluated position, the better, but **not all starting positions are equal**. If a player's position is closer to the center of the board, it is more probable that this player can do better than a player whose remaining moves are near the edge of the board (where they will have less options to move down the line).

To speed up the runtime execution of this heuristic, we use the **Manhattan distance instead of the Euclidean distance**.

### Results

```
*****
Evaluating: ID_Improved
*****
```

Playing Matches:

```
-----
Match 1: ID_Improved vs Random      Result: 16 to 4
Match 2: ID_Improved vs MM_Null     Result: 16 to 4
Match 3: ID_Improved vs MM_Open     Result: 18 to 2
Match 4: ID_Improved vs MM_Improved Result: 12 to 8
Match 5: ID_Improved vs AB_Null     Result: 16 to 4
Match 6: ID_Improved vs AB_Open     Result: 12 to 8
Match 7: ID_Improved vs AB_Improved Result: 13 to 7
```

Results:

```
-----
ID_Improved      73.57%
```

```
*****
Evaluating: Student
*****
```

Playing Matches:

```
-----
Match 1: Student vs Random      Result: 17 to 3
Match 2: Student vs MM_Null     Result: 16 to 4
Match 3: Student vs MM_Open     Result: 14 to 6
Match 4: Student vs MM_Improved Result: 11 to 9
Match 5: Student vs AB_Null     Result: 15 to 5
Match 6: Student vs AB_Open     Result: 11 to 9
Match 7: Student vs AB_Improved Result: 13 to 7
```

Results:

```
-----
Student          69.29%
```

### Analysis

This heuristic performs a bit better, but not by much. Yes, it does benefit from positional advantage, but still isn't really "game aware". What good is a position near the center of the board if you can't really move?

### Implementation

Here's our implementation for this heuristic:

```
def heuristic2(game, player):
    # Have we won the game?
    if game.is_winner(player):
        return float("inf")

    # Do we even have moves to play?
    if game.is_loser(player):
        return float("-inf")

    # We have moves to play. How many more than our opponent?
    player_moves_left = len(game.get_legal_moves(player))
    opponent_moves_left = len(game.get_legal_moves(game.get_opponent(player)))

    if player_moves_left != opponent_moves_left:
        return float(player_moves_left - opponent_moves_left)

    else:
        # If we have the same number of moves available, look for a positional advantage.
        # Use the Manhattan distance to the center of the board to assess positional advantage.
        center_y_pos, center_x_pos = int(game.height / 2), int(game.width / 2)
        player_y_pos, player_x_pos = game.get_player_location(player)
        opponent_y_pos, opponent_x_pos = game.get_player_location(game.get_opponent(player))
        player_distance = abs(player_y_pos - center_y_pos) + abs(player_x_pos - center_x_pos)
        opponent_distance = abs(opponent_y_pos - center_y_pos) + abs(opponent_x_pos - center_x_pos)
        # All we need now is to take the difference between the two distances to evaluate positional advantage.
        # Scale this number between 0 and +-1 (a positional advantage can't be as good as being ahead by one move)
        # Best case, our opponent's distance is 6 from the center (for a 7x7 grid) and we're at pos 0,0 -> return 0.6
        # Worst case, our opponent's distance is 0 from the center (for a 7x7 grid) and we're in a corner -> return -
0.6

        # If both players are at the same distance from the center -> return 0.
        return float(opponent_distance - player_distance) / 10.
```

### Heuristic 3

This heuristic builds on the previous one and infuses a bit of knowledge about the mechanics of the game. As with `heuristic2()`, the more moves `player` has available from the evaluated position, the better, but not all starting positions are equal. If a player's position is closer to the center of the board, it is more probable that this player can do better than a player whose remaining moves are near the edge of the board (where they will have less options to move down the line). If there is no clear positional advantage (i.e. both players are at the same distance from the center, then we measure the longest run of moves we can safely perform inside a 3x3 square defined by the starting position and any of the legal moves we have left. The longest run one can hope to reach is 7.

The following illustration shows a sample 3x3 square where the player can make seven moves, starting East-South, between `p` and one its available legal moves (denoted `7`, here):

# Start the run going East-South

```
# +---+---+---+
# | 5 | 2 | 7 |
# +---+---+---+
# | p | x | 4 |
# +---+---+---+
# | 3 | 6 | 1 |
# +---+---+---+
```

Note that we don't try going beyond finding more than **one** run of seven moves with any one available move.

#### Results

```
*****
Evaluating: ID_Improved
*****

Playing Matches:
-----
Match 1: ID_Improved vs Random      Result: 17 to 3
Match 2: ID_Improved vs MM_Null     Result: 16 to 4
Match 3: ID_Improved vs MM_Open     Result: 14 to 6
Match 4: ID_Improved vs MM_Improved Result: 12 to 8
Match 5: ID_Improved vs AB_Null     Result: 17 to 3
Match 6: ID_Improved vs AB_Open     Result: 12 to 8
Match 7: ID_Improved vs AB_Improved Result: 16 to 4

Results:
-----
ID_Improved      74.29%

*****
Evaluating: Student
*****

Playing Matches:
-----
Match 1: Student vs Random      Result: 16 to 4
Match 2: Student vs MM_Null     Result: 13 to 7
Match 3: Student vs MM_Open     Result: 14 to 6
Match 4: Student vs MM_Improved Result: 12 to 8
Match 5: Student vs AB_Null     Result: 15 to 5
Match 6: Student vs AB_Open     Result: 16 to 4
Match 7: Student vs AB_Improved Result: 15 to 5

Results:
-----
Student          72.14%
...

```

#### Analysis

With this heuristic, we're catching up to the baseline player. We use positional advantage and are "game aware". Still, being able to find **one** square where one can make seven move, doesn't say much, especially at the beginning of the game where that constraint is easy to satisfy for both players.

#### Implementation

Here's our implementation for this heuristic:

```
def heuristic3(game, player):
    # Have we won the game?
    if game.is_winner(player):
        return float("inf")

    # Do we even have moves to play?
    if game.is_loser(player):
        return float("-inf")

    # We have moves to play. How many more than our opponent?
    player_moves = game.get_legal_moves(player)
    opponent_moves = game.get_legal_moves(game.get_opponent(player))
```

```

player_moves_left = len(player_moves)
opponent_moves_left = len(opponent_moves)

if player_moves_left != opponent_moves_left:
    return float(player_moves_left - opponent_moves_left)

else:
    # If we have the same number of moves available, look for a positional advantage.
    # Use the Manhattan distance to the center of the board to assess positional advantage.
    center_y_pos, center_x_pos = int(game.height / 2), int(game.width / 2)
    player_y_pos, player_x_pos = game.get_player_location(player)
    opponent_y_pos, opponent_x_pos = game.get_player_location(game.get_opponent(player))
    player_distance = abs(player_y_pos - center_y_pos) + abs(player_x_pos - center_x_pos)
    opponent_distance = abs(opponent_y_pos - center_y_pos) + abs(opponent_x_pos - center_x_pos)
    if player_distance != opponent_distance:
        # All we need now is to take the difference between the two distances to evaluate positional advantage.
        # Scale this number between >-1 and <+1 (a positional advantage can't be as good (bad) as being ahead
        (behind) by one move)
        # Best case, our opponent's distance is 6 from the center (for a 7x7 grid) and we're at pos 0,0 -> return
0.6
        # Worst case, our opponent's distance is 0 from the center (for a 7x7 grid) and we're in a corner -> return
-0.6
        return float(opponent_distance - player_distance) / 10.

    else:
        # If both players are at the same distance from the center, assess best survival odds.
        # What's the longest run we can achieve between our current position and any of our legal moves left?
        longest_player_run = get_longest_jumping_run(game, player_y_pos, player_x_pos, player_moves)
        longest_opponent_run = get_longest_jumping_run(game, opponent_y_pos, opponent_x_pos, opponent_moves)

        # All we need now is to take the difference between the two numbers to evaluate which player can last the
longest in a tight spot.
        # Scale this number between >-0.1 and <+0.1 (for now, we'll assume this ability to survive in a tight space
        # is not as valuable as a positional advantage) [Note: we could be wrong about this, but it's worth a try!]
        # Best case, our opponent's longest run is 1 and ours is 7 -> return +0.06
        # Worst case, our opponent's longest run is 7 and ours is 1 -> return -0.06
        # If the two numbers are the same, return 0.
        return float(longest_player_run - longest_opponent_run) / 100.

```

For the implementation of `get\_longest\_jumping\_run()`, please see game\_agent.py.

## Heuristic 4

With this heuristic, we actually ignore positional advantage and the difference in number of available moves between players to specifically assess the contribution of the game-aware statistic used in the previous heuristic.

### Results

```

*****
Evaluating: ID_Improved
*****

```

Playing Matches:

```

-----
Match 1: ID_Improved vs Random      Result: 16 to 4
Match 2: ID_Improved vs MM_Null     Result: 17 to 3
Match 3: ID_Improved vs MM_Open     Result: 13 to 7
Match 4: ID_Improved vs MM_Improved Result: 13 to 7
Match 5: ID_Improved vs AB_Null     Result: 12 to 8
Match 6: ID_Improved vs AB_Open     Result: 14 to 6
Match 7: ID_Improved vs AB_Improved Result: 14 to 6

```

Results:

```

-----
ID_Improved      70.71%

```

```

*****
Evaluating: Student
*****

```

Playing Matches:

```

-----
Match 1: Student vs Random      Result: 14 to 6
Match 2: Student vs MM_Null     Result: 18 to 2
Match 3: Student vs MM_Open     Result: 14 to 6
Match 4: Student vs MM_Improved Result: 12 to 8
Match 5: Student vs AB_Null     Result: 14 to 6
Match 6: Student vs AB_Open     Result: 11 to 9
Match 7: Student vs AB_Improved Result: 14 to 6

```

Results:

```

-----
Student          69.29%

```

### Analysis

This is quite a remarkable result. Using a simple, single game-specific mechanic is enough for the two game-playing agents to compete neck-to-neck. This may also suggest that positional advantage (being close to the center of the board) may not matter that much in the long run.

### Implementation

Here's our implementation for this heuristic:

```
def heuristic4(game, player):
    # Have we won the game?
    if game.is_winner(player):
        return float("inf")

    # Do we even have moves to play?
    if game.is_loser(player):
        return float("-inf")

    # We have moves to play. How many more than our opponent?
    player_moves = game.get_legal_moves(player)
    opponent_moves = game.get_legal_moves(game.get_opponent(player))

    player_y_pos, player_x_pos = game.get_player_location(player)
    opponent_y_pos, opponent_x_pos = game.get_opponent_location(game.get_opponent(player))
    longest_player_run = get_longest_jumping_run(game, player_y_pos, player_x_pos, player_moves)
    longest_opponent_run = get_longest_jumping_run(game, opponent_y_pos, opponent_x_pos, opponent_moves)

    return float(longest_player_run - longest_opponent_run)
```

For the implementation of `get\_longest\_jumping\_run()`, please see game\_agent.py.

## Heuristic 5

With this heuristic, we keep exploring game tactics. Specifically, we assess our ability to survive the longest. We look at **all** the 3x3 squares in which the player's current position appears and **sum the runs of moves** that can be performed over all these squares (jumping back and forth up to seven times in a 3x3 square). This allows us to evaluate how long we can survive if we're cornered in a tight zone.

### Results

```
*****
Evaluating: ID_Improved
*****
```

Playing Matches:

```
-----
Match 1: ID_Improved vs Random      Result: 16 to 4
Match 2: ID_Improved vs MM_Null     Result: 12 to 8
Match 3: ID_Improved vs MM_Open     Result: 14 to 6
Match 4: ID_Improved vs MM_Improved Result: 9 to 11
Match 5: ID_Improved vs AB_Null     Result: 12 to 8
Match 6: ID_Improved vs AB_Open     Result: 11 to 9
Match 7: ID_Improved vs AB_Improved Result: 13 to 7
```

Results:

```
-----
ID_Improved      62.14%
```

```
*****
Evaluating: Student
*****
```

Playing Matches:

```
-----
Match 1: Student vs Random      Result: 16 to 4
Match 2: Student vs MM_Null     Result: 16 to 4
Match 3: Student vs MM_Open     Result: 8 to 12
Match 4: Student vs MM_Improved Result: 14 to 6
Match 5: Student vs AB_Null     Result: 14 to 6
Match 6: Student vs AB_Open     Result: 14 to 6
Match 7: Student vs AB_Improved Result: 16 to 4
```

Results:

```
-----
Student          70.00%
```

...

### Analysis

With this heuristic, we systematically beat the `ID\_Improved` player. Using more **sophisticated game mechanics**, we make sure that our player can keep moving for as long as possible, even if cornered.

### Implementation

Here's our implementation for this heuristic:

```
def heuristic5(game, player):
    # Have we won the game?
```

```
if game.is_winner(player):
    return float("inf")

# Do we even have moves to play?
if game.is_loser(player):
    return float("-inf")

# We have moves to play. How many more than our opponent?
player_moves = game.get_legal_moves(player)
opponent_moves = game.get_legal_moves(game.get_opponent(player))

player_y_pos, player_x_pos = game.get_player_location(player)
opponent_y_pos, opponent_x_pos = game.get_player_location(game.get_opponent(player))
longest_player_run = get_sum_jumping_runs(game, player_y_pos, player_x_pos, player_moves)
longest_opponent_run = get_sum_jumping_runs(game, opponent_y_pos, opponent_x_pos, opponent_moves)

return float(longest_player_run - longest_opponent_run)
```

For the implementation of `get\_sum\_jumping\_runs()`, please see `game_agent.py`.