Advance Game Playing

Analysis of Evaluation Functions

As part of the Advance Game Playing project, 3 different Heuristic functions are presented in this document.

An introduction to each of the 3 different approaches will be provided first, followed by a comparison and analysis.

Introduction

The 3 heuristic functions that will be used as part of our Game Agent are:

1. **Improved Negative Distance to Center (INDC)**: Based on the distance to the center of the board and weighted based on the difference between opponent and player legal moves
2. **Distance to Opponent Heuristic (DOH)**: Based on the distance to the opponent, getting a higher score when moving further away from the opponent
3. **Improved Distance to Opponent Heuristic (IDOH)**: Adding the maximization of the difference between the current player's moves and the opponent's to the Distance to Opponent Heuristic

We have classified the available Heuristic Functions in 2 main groups or categories, that will be introduced first to help understand the ideas behind the selection of the 3 final Evaluation Functions.

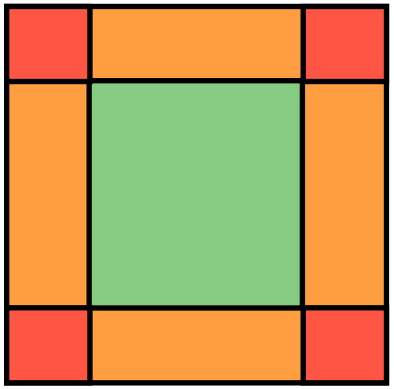
A brief description of the 3 functions together with the analysis will be presented last.

Evaluation Based on Position

Position Based Evaluation Function are based on the distance towards different elements of the board (edge, center or opponent).

The closest a player is to the **edge** of the board the less number of legal moves that will be available (taking as reference an empty board).

- **Corner Positions** allow max of 2-4 moves
- **Edge Positions** allow max of 4-6 moves
- **Center Positions** allow max of 6-8 moves



Similarly, the distance to the **center** of the board can be used to determine how close a position is from the edge, returning a higher score for positions closer to the center.

Another way of evaluation a move based on the position is by considering the distance to the **opponent** player.

2 different approaches can be considered in this cases by considering better moves those that get closer to the reference point center, opponent or edge (we will call these cases **negative distance** as we are reducing the distance to the reference); or those that get further away from the reference point (**positive,** as we are increasing the distance to the reference).

Evaluation Based on Number of Legal Moves Left

This category of Evaluation Functions return a score based on the number of legal moves left for the players (current player, opponent or both).

The higher the number of available legal moves at the position being evaluated for the **current player**, the higher the chances the player won't be stuck at a position and lose.

In a similar way, having current player occupy a position that was a legal move for the opponent, reduces the possibilities for the **opponent**. Said in a different way, the goal is to minimize the available legal moves for the opponent.

Combining both evaluations above, we obtain the **improved** version of these kind of evaluation functions by maximizing the difference between current player's legal moves and the opponent's.

Choosing an Evaluation Function

Heuristic Functions based on the number of left legal moves seem to provide a good result, being the combination of current and opponent player's moves the most effective heuristic. In order to improve these heuristic functions, we need to add another variable not based on the number of left moves.

Distance based heuristics seem to behave efficiently but they don't consider the number of legal moves left when choosing among the available options, what could lead to the evaluation of a position as optimal when no next move is possible.

Our proposal is to combine the 2 approaches above to come up with a Heuristic Function that is capable of beating the AB_Improved Heuristic.

Improved Negative Distance to Center Heuristic (INDCH)

The Improved Negative Distance to Center Heuristic (INDCH) is based on the distance to the center of the board (a position closer to the center returns a higher score) and the number of legal moves left for the opponent and the current player.

As discussed previously, considering the distance alone will lead to considering dead ends as possible next moves.

To overcome this limitation we add the consideration of number of legal moves left for current and opponent players, and maximize the difference between the number of moves.

This evaluation function will evaluate a move based on the following formula:

$$s = k * (m_p - m_o) + d_c$$
$$d_c = (h - y)^2 + (w - x)^2$$

where:

- ***s*** represents the score
- d_c is the distance to the center of the board
- ***k*** is a factor based on the width and height of the board
- m_p corresponds to the number of Player's Legal Moves
- m_o corresponds to the number of Opponent's Legal Moves
- ***(x, y)*** represent the position of Player
- ***(w, h)*** represent the current width and height of the board

Negative Distance in this context means that a lower distance between the center and the position under evaluation is scored higher, to increase the probability of choosing positions closer to the Board center.

Distance to Opponent Heuristic (DOH)

By computing the distance of the move under evaluation and the current position of out opponent, we can build an evaluation function that returns a score based on this distance.

By following the approach of distance calculation that is used in the Heuristic "AB_Center" provided, we compute the distance to the opponent based on the following formula:

$$d_o = (y_p - y_o)^2 + (x_p - x_o)^2$$

where:

- d_o is the distance to the opponent's position
- (x_p, y_p) represent the position under evaluation for Player
- (x_o, p_o) represent the position of Opponent

By returning this score, the higher the distance between the position under evaluation and that of the opponent, the higher the score.

Improved Distance to Opponent Heuristic (IDOH)

We add the maximization of the difference between current player's moves and opponent's moves to weight the evaluation based on distance to the opponent, the same way we did with the distance to the center of the board in INDCH.

In this case we consider high distance for high scoring, thus we need to add the distance to our evaluation instead of subtracting it as we did in INDCH:

$$s = k * (m_p - m_o) + d_o$$

Other Heuristic Functions

Other heuristic functions that were considered and discarded after running various tournaments against the rest of the evaluation functions are listed and briefly described below:

1. **Position Based Heuristic (PBH)**: Based on the position of the legal moves of player, getting a lower score if destination position is close to the edge of the board
2. **Moves Weighted Negative Distance to Center Heuristic (MNDCH)**: Based on the distance to the center and weighted with the number of legal moves on the destination position
3. **Moves Weighted Position Based Heuristics (MPH)**: Based on the number of legal moves left and PBH
4. **Position Weighted Improved Heuristic (PIH)**: Using PBH as a factor to weight the maximization of the difference between current and opponent player's left legal moves
5. **Negative Distance to Opponent Heuristic (NDOH)**: Opposite to DOH
6. **Negative Distance to Center Heuristic (NDCH)**: Opposite to DCH

Analysis

For the Analysis phase, the following steps were followed to reduce the number of evaluation functions to be considered:

1. First individual battles were run, by confronting 2 distance evaluation functions at a time to understand how the distance was contributing to the results, by considering higher distances between reference points as high score (positive, P) or low score (negative, N):
    - PPH vs PNH
    - DCPH vs DCNH
    - DOPH vs DONH
    - MPDOH vs PDOH
    - INDCH vs NDCH
    - IPDOH vs PDOH

    As it can be seen, those evaluation functions involving distance take advantage of the results from step 1, where the battle between P and N was performed. Only the evaluation function that won in step 1 are considered in this second step. Note that some additional combinations are added (not related to distance).

3. Based on results from steps 1 and 2, 3 of the evaluation functions are chosen for the final tournament agains the Random and MM and AB Agents using the provided heuristic

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**************************
    Playing Matches
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Match #   Opponent    AB_Improved   AB_Custom   AB_Custom_2  AB_Custom_3
                       Won | Lost   Won | Lost   Won | Lost   Won | Lost
   1       Random      187 |  13    185 |  15    184 |  16    193 |   7
   2       MM_Open     150 |  50    143 |  57    159 |  41    140 |  60
   3      MM_Center    172 |  28    173 |  27    174 |  26    176 |  24
   4     MM_Improved   139 |  61    154 |  46    148 |  52    137 |  63
   5       AB_Open     102 |  98    106 |  94    93  |  107   105 |  95
   6      AB_Center    113 |  87    109 |  91    106 |  94    109 |  91
   7     AB_Improved   98  |  102   110 |  90    101 |  99    95  |  105
----------------------------------------------------------------------------
          Win Rate:      68.6%        70.0%        68.9%        68.2%
```

Figure 1. *Tournament Results for the selected 3 evaluation functions*

2. With the goal of improving the results of the evaluation function considered until the moment, we go from 1-D heuristics where only 1 parameter is considered (number of moves left, distance to center, distance to edge, …) to 2-D heuristics where more than 1 parameter are combined together in different ways:

    - MPPH vs PPH
    - PIH vs IH
    - MNDCH vs NDCH

    functions Open (based on number of legal moves left for player), Center (based on Positive Distance from position under evaluation to center of the board) and Improved (based on the maximization between player's and opponent's legal moves left).

    The results can be seen in ***Figure 1.***, where:

    - AB_Custom uses INDCH
    - AB_Custom_2 uses IDOH
    - AB_Custom_3 uses DOH

    With **AB_Custom (INDCH)** being the winner.

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Heuristics Analysis for the Game Playing AI Agent for Isolation Game (knight version)

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