Udacity - Artificial Intelligence Nanodegree

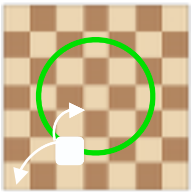
Adversarial Game Playing Project

by George Pampalis, January 2018

Heuristic Analysis

This analysis compares numerous custom heuristic functions, which combine several aspects of the game-playing strategies an agent might want to follow, when evaluating its positions during a tree search.

Specifically, the custom scores include the number of the agent's moves, number of the opponents' moves, and the difference of the two with variable weights (1:1, 2:1, 3:1, 4:1, 1:2, 1:3, 1:4). Another custom score that was utilized measured the distance of a new position not from the center or the edges, but from a radius in the middle of the two (green circle in the picture on the right). The concept this score function tests is whether or not positions halfway across the board offer greater freedom for the agent to move; flee towards the center, as well as towards the edges, if needed (white arrows; as seen in the picture on the right).



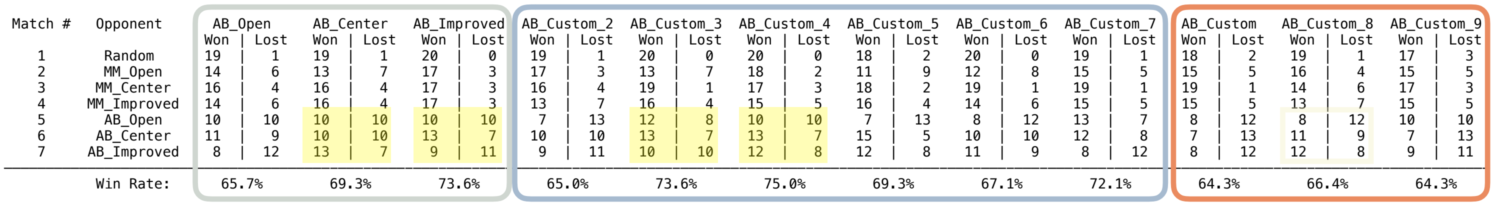
These custom scoring functions were also combined between themselves, in an effort to capture the position that best satisfies all of the heuristic rules.

In order to compare the heuristic functions between themselves as objectively as possible, a few tournaments were run, using the 3 provided sample scoring functions (AB_Open, AB_Center, AB_Improved) against 9 different custom functions every time. Each of the 12 scoring functions were set against the 7 testing functions (Random, MM_Open, MM_Center, MM_Improved, AB_Open, AB_Center, AB_Improved) for a total of 20 matches per pair!

It has to be noted that before computing any result in any custom function, an if-clause was added after the terminal checks to count the number of the opponent's moves. If the current move leads the opponent to have no available move, then it is given a score of positive infinity since the opponent will be blocked (aggressive play).

For the first tournament, the custom functions that were used and their results are shown in the table below, where red is used for distance-based scoring functions, and blue for move-number-based scoring functions.

Function Name	**Objective**
custom_score	Distance of the agent's position from middle radius
custom_score_2	Difference between two times the agent's moves minus the opponent's moves
custom_score_3	Difference between three times the agent's moves minus the opponent's moves
custom_score_4	Difference between four times the agent's moves minus the opponent's moves
custom_score_5	Difference between the agent's moves minus two times the opponent's moves
custom_score_6	Difference between the agent's moves minus three times the opponent's moves
custom_score_7	Difference between the agent's moves minus four times the opponent's moves
custom_score_8	Distance of the agent's position from middle radius (negative; to increase when closer to the middle)
custom_score_9	1 / (Distance of the agent's position from middle radius + 0.1)



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 Match #    Opponent      AB_Open     AB_Center   AB_Improved  AB_Custom_2  AB_Custom_3  AB_Custom_4  AB_Custom_5  AB_Custom_6  AB_Custom_7   AB_Custom    AB_Custom_8  AB_Custom_9
                         Won | Lost  Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost  Won | Lost   Won | Lost   Won | Lost
    1        Random      19  |   1   19  |   1    20  |   0    19  |   1    20  |   0    20  |   0    18  |   2    20  |   0    19  |   1  18  |   2    19  |   1    17  |   3
    2        MM_Open     14  |   6   13  |   7    17  |   3    17  |   3    13  |   7    18  |   2    11  |   9    12  |   8    15  |   5  15  |   5    16  |   4    15  |   5
    3       MM_Center    16  |   4   16  |   4    17  |   3    16  |   4    19  |   1    17  |   3    18  |   2    19  |   1    19  |   1  19  |   1    14  |   6    17  |   3
    4      MM_Improved   14  |   6   16  |   4    17  |   3    13  |   7    16  |   4    15  |   5    16  |   4    14  |   6    15  |   5  15  |   5    13  |   7    15  |   5
    5        AB_Open     10  |  10   10  |  10    10  |  10     7  |  13    12  |   8    10  |  10     7  |  13     8  |  12    13  |   7   8  |  12     8  |  12    10  |  10
    6       AB_Center    11  |   9   10  |  10    13  |   7    10  |  10    13  |   7    13  |   7    15  |   5    10  |  10    12  |   8   7  |  13    11  |   9     7  |  13
    7      AB_Improved    8  |  12   13  |   7     9  |  11     9  |  11    10  |  10    12  |   8    12  |   8    11  |   9     8  |  12   8  |  12    12  |   8     9  |  11
------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
           Win Rate:      65.7%       69.3%        73.6%        65.0%        73.6%        75.0%        69.3%        67.1%        72.1%       64.3%        66.4%        64.3%
```

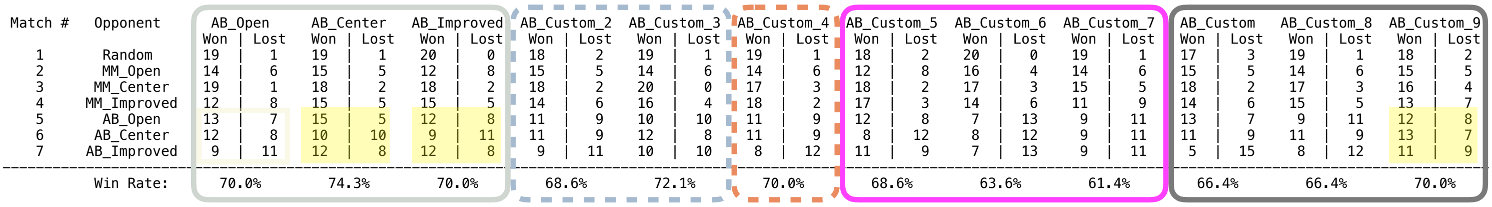
The results of the first tournament vary between 64% and 75%. Specifically, the best scoring functions which will be used in the next round are:

"Distance-from" functions	**"Number-of-moves" functions**
AB_Center	**AB_Custom_4**
AB_Custom_8	**AB_Custom_3** *tied with* AB_Improved

As a next step, another tournament was run that included the 3 custom scoring functions of the above table (in bold), which were used as a benchmark. The available 6 custom scoring slots were assigned to a "multiplicative crossbreed" of the previous best scoring functions. Each multiplication was between a distance-based term and a move-number-based term, in an effort to try and combine the best of both worlds. As such, the resulting functions are shown below:

Function Name	**Old Name**	**Objective**
custom_score		AB_Center * AB_Improved
custom_score_2	custom_score_3	Difference between three times the agent's moves minus the opponent's moves
custom_score_3	custom_score_4	Difference between four times the agent's moves minus the opponent's moves
custom_score_4	custom_score_8	Distance of the agent's position from middle radius (negative; to increase when closer to the middle)
custom_score_5		custom_score_4 * custom_score_2
custom_score_6		custom_score_4 * custom_score_3
custom_score_7		custom_score_4 * AB_Improved
custom_score_8		AB_Center * custom_score_2
custom_score_9		AB_Center * custom_score_3

The results of the second tournament can be seen below. The gray box encases the results for the sample scoring functions, the dotted blue and red boxes are the results of the previously tested functions, while the magenta and black boxes are combinations (multiplication) of a distance-based function with a move-based function.



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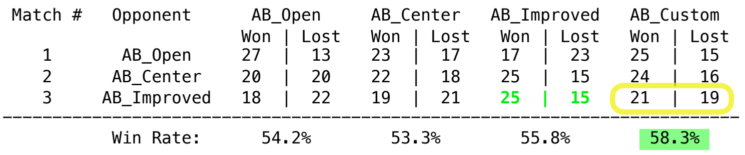
 Match #    Opponent     AB_Open     AB_Center   AB_Improved  AB_Custom_2  AB_Custom_3  AB_Custom_4  AB_Custom_5  AB_Custom_6  AB_Custom_7  AB_Custom    AB_Custom_8  AB_Custom_9
                        Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost   Won | Lost  Won | Lost    Won | Lost   Won | Lost
    1        Random     19  |   1    19  |   1    20  |   0    18  |   2    19  |   1    19  |   1    18  |   2    20  |   0    19  |   1   17  |   3     19  |   1    18  |   2
    2        MM_Open    14  |   6    15  |   5    12  |   8    15  |   5    14  |   6    14  |   6    12  |   8    16  |   4    14  |   6   15  |   5     14  |   6    15  |   5
    3       MM_Center   19  |   1    18  |   2    18  |   2    18  |   2    20  |   0    17  |   3    18  |   2    17  |   3    15  |   5   18  |   2     17  |   3    16  |   4
    4      MM_Improved  12  |   8    15  |   5    15  |   5    14  |   6    16  |   4    18  |   2    17  |   3    14  |   6    11  |   9   14  |   6     15  |   5    13  |   7
    5        AB_Open    13  |   7    15  |   5    12  |   8    11  |   9    10  |  10    11  |   9    12  |   8     7  |  13     9  |  11   13  |   7      9  |  11    12  |   8
    6       AB_Center   12  |   8    10  |  10     9  |  11    11  |   9    12  |   8    11  |   9     8  |  12     8  |  12     9  |  11   11  |   9     11  |   9    13  |   7
    7      AB_Improved   9  |  11    12  |   8    12  |   8     9  |  11    10  |  10     8  |  12    11  |   9     7  |  13     9  |  11    5  |  15      8  |  12    11  |   9
--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
           Win Rate:     70.0%        74.3%        70.0%        68.6%        72.1%        70.0%        68.6%        63.6%        61.4%       66.4%        66.4%        70.0%
```

From the above outcomes, other than AB_Center and AB_Improved, the only scoring function that stands out is AB_Custom_9, which calculates the product of the distance from the center times the difference of four times the agent's number of moves minus the opponent's number of moves [distance_from_center * (4*own_moves - opp_moves)].

Consequently, two final tournaments were run, comparing only the three sampled functions (AB_Open, AB_Center, AB_Improved) and the AB_Custom_9 function (which will now be renamed simply as AB_Custom) against only alpha-beta opponents. Simultaneously, the number of matches was doubled.



```
 Match #    Opponent      AB_Open      AB_Center    AB_Improved   AB_Custom
                         Won | Lost   Won | Lost   Won | Lost   Won | Lost
    1        AB_Open     27  |  13    23  |  17    17  |  23    25  |  15
    2       AB_Center    20  |  20    22  |  18    25  |  15    24  |  16
    3      AB_Improved   18  |  22    19  |  21    25  |  15    21  |  19
--------------------------------------------------------------------------
           Win Rate:      54.2%        53.3%        55.8%        58.3%
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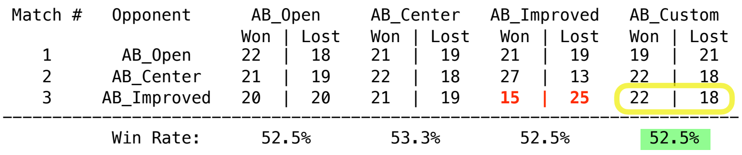

```
 Match #    Opponent      AB_Open      AB_Center    AB_Improved   AB_Custom
                         Won | Lost   Won | Lost   Won | Lost   Won | Lost
    1        AB_Open     22  |  18    21  |  19    21  |  19    19  |  21
    2       AB_Center    21  |  19    22  |  18    27  |  13    22  |  18
    3      AB_Improved   20  |  20    21  |  19    15  |  25    22  |  18
--------------------------------------------------------------------------
           Win Rate:      52.5%        53.3%        52.5%        52.5%
```

The results from the last two tournaments show that only AB_Custom can win consistently against AB_Improved, even if by a small margin. By taking into account three different factors (distance from center, own moves and opponent's moves), AB_Custom can be better at selecting the moves that lead to victory, even against very powerful opponents.

Last but not least, it must be noted that larger radii seem to work better for knight pawns. This may be attributed to the L-shaped movement that knights follow, which enables them to move to greater distances and take advantage of even remote positions on the board.