UDACITY – Artificial Intelligence Nanodegree
Project 2 – Heuristic Analysis
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Heuristics implementation:

The following heuristics were implemented:

AB_Custom_3:

This heuristic is based on the intersections of the legal moves between the *player* (max) and its *opponent* (min), based on the idea that a low number of intersections leads to more legal moves options for the *player*, having higher scores. Thus, considering that the maximum number of immediate legal moves for a given player is 8, the score is calculated as following:

score = 8 – number of legal moves intersections.

The heuristic was implemented in the function *get_intersection_score()* and called on *custom_score_3()*.

AB_Custom_2:

This heuristic is based on the distance of the *player* (max) to its *opponent* (min), based on the idea that higher distances gives more legal moves options for the *player*. The distance is calculate as the sum of the number of squares in the horizontal and vertical directions, as following:

player position = (x1, y1)
opponent position = (x2, y2)
score = distance = | x1 – x2 | + | y1 – y2 |

The heuristic was implemented in the function *get_distance_score()* and called on *custom_score_2()*.

AB_Custom:

This heuristic is a combination of the functions *get_intersection_score() and get_distance_score().* Each turn the heuristic calls the two functions and multiply the scores as following:

score = intersection score x distance score

The heuristic was implemented in the function *custom_score()*.

Heuristics evaluation:

To evaluate the performance of the implemented heuristics with more accurate results, the *tournament.py* script was ran 10 times, obtaining the following results:

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TOURNAMENT #1:

Match #     Opponent    AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
   1         Random      8  |  2       7  |  3       8  |  2       7  |  3
   2         MM_Open     7  |  3       6  |  4       8  |  2       5  |  5
   3        MM_Center    7  |  3       8  |  2       7  |  3       7  |  3
   4       MM_Improved   4  |  6       6  |  4       6  |  4       7  |  3
   5         AB_Open     4  |  6       5  |  5       6  |  4       4  |  6
   6        AB_Center    6  |  4       6  |  4       4  |  6       3  |  7
   7       AB_Improved   3  |  7       4  |  6       3  |  7       5  |  5
--------------------------------------------------------------------------
           Win Rate:     55.7%         60.0%         60.0%         54.3%

Your agents forfeited 250.0 games while there were still legal moves available to play.

TOURNAMENT #2:

Match #     Opponent    AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
   1         Random      7  |  3       8  |  2       5  |  5       7  |  3
   2         MM_Open     8  |  2       5  |  5       6  |  4       4  |  6
   3        MM_Center    6  |  4       6  |  4       6  |  4       7  |  3
   4       MM_Improved   5  |  5       6  |  4       8  |  2       6  |  4
   5         AB_Open     4  |  6       5  |  5       3  |  7       4  |  6
   6        AB_Center    5  |  5       6  |  4       8  |  2       4  |  6
   7       AB_Improved   6  |  4       6  |  4       4  |  6       2  |  8
--------------------------------------------------------------------------
           Win Rate:     58.6%         60.0%         57.1%         48.6%

Your agents forfeited 253.0 games while there were still legal moves available to play.

TOURNAMENT #3:

Match #     Opponent    AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
   1         Random      9  |  1       6  |  4       9  |  1       7  |  3
   2         MM_Open     8  |  2       7  |  3       5  |  5       4  |  6
   3        MM_Center    7  |  3       8  |  2       9  |  1       5  |  5
   4       MM_Improved   4  |  6       7  |  3       5  |  5       4  |  6
   5         AB_Open     5  |  5       5  |  5       4  |  6       5  |  5
   6        AB_Center    8  |  2       4  |  6       6  |  4       5  |  5
   7       AB_Improved   4  |  6       6  |  4       6  |  4       4  |  6
--------------------------------------------------------------------------
           Win Rate:     64.3%         61.4%         62.9%         48.6%

Your agents forfeited 249.0 games while there were still legal moves available to play.

TOURNAMENT #4:

Match #     Opponent    AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
   1         Random      8  |  2       7  |  3       5  |  5       6  |  4
   2         MM_Open     7  |  3       7  |  3       4  |  6       7  |  3
   3        MM_Center    8  |  2       8  |  2       5  |  5       5  |  5
   4       MM_Improved   7  |  3       5  |  5       7  |  3       8  |  2
   5         AB_Open     3  |  7       6  |  4       5  |  5       4  |  6
   6        AB_Center    6  |  4       4  |  6       5  |  5       4  |  6
   7       AB_Improved   7  |  3       4  |  6       4  |  6       4  |  6
--------------------------------------------------------------------------
           Win Rate:     65.7%         58.6%         50.0%         54.3%

Your agents forfeited 254.0 games while there were still legal moves available to play.

TOURNAMENT #5:

Match #     Opponent    AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
   1         Random      9  |  1       9  |  1       8  |  2       6  |  4
   2         MM_Open     5  |  5       6  |  4       5  |  5       5  |  5
   3        MM_Center    8  |  2       7  |  3       6  |  4       5  |  5
   4       MM_Improved   4  |  6       7  |  3       6  |  4       5  |  5
   5         AB_Open     6  |  4       7  |  3       4  |  6       4  |  6
   6        AB_Center    7  |  3       3  |  7       5  |  5       7  |  3
   7       AB_Improved   6  |  4       3  |  7       5  |  5       2  |  8
--------------------------------------------------------------------------
           Win Rate:     64.3%         60.0%         55.7%         48.6%

Your agents forfeited 248.0 games while there were still legal moves available to play.

TOURNAMENT #6:

Match #     Opponent    AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
   1         Random     10  |  0       7  |  3       7  |  3       8  |  2
   2         MM_Open     7  |  3       6  |  4       7  |  3       6  |  4
   3        MM_Center    8  |  2       6  |  4       7  |  3       7  |  3
   4       MM_Improved   5  |  5       5  |  5       6  |  4       4  |  6
   5         AB_Open     5  |  5       4  |  6       6  |  4       5  |  5
   6        AB_Center    5  |  5       5  |  5       5  |  5       2  |  8
   7       AB_Improved   3  |  7       5  |  5       3  |  7       5  |  5
--------------------------------------------------------------------------
           Win Rate:     61.4%         54.3%         58.6%         52.9%

Your agents forfeited 248.0 games while there were still legal moves available to play.
```

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TOURNAMENT #7:

 Match #    Opponent     AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
    1       Random       8  |  2       8  |  2       9  |  1       7  |  3
    2       MM_Open      4  |  6       6  |  4       8  |  2       5  |  5
    3      MM_Center     7  |  3       8  |  2       9  |  1       5  |  5
    4     MM_Improved    7  |  3       6  |  4       4  |  6       4  |  6
    5       AB_Open      4  |  6       5  |  5       6  |  4       4  |  6
    6      AB_Center     6  |  4       5  |  5       6  |  4       4  |  6
    7     AB_Improved    6  |  4       4  |  6       3  |  7       3  |  7
     -------------------------------------------------------------------
           Win Rate:     60.0%         60.0%         64.3%         45.7%

Your agents forfeited 248.0 games while there were still legal moves available to play.

TOURNAMENT #8:

 Match #    Opponent     AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
    1       Random       6  |  4       7  |  3       6  |  4       9  |  1
    2       MM_Open      6  |  4       7  |  3       7  |  3       4  |  6
    3      MM_Center     9  |  1       7  |  3      10  |  0       6  |  4
    4     MM_Improved    5  |  5       7  |  3       5  |  5       7  |  3
    5       AB_Open      7  |  3       6  |  4       4  |  6       7  |  3
    6      AB_Center     5  |  5       7  |  3       6  |  4       5  |  5
    7     AB_Improved    5  |  5       4  |  6       5  |  5       5  |  5
     -------------------------------------------------------------------
           Win Rate:     61.4%         64.3%         61.4%         61.4%

Your agents forfeited 252.0 games while there were still legal moves available to play.

TOURNAMENT #9:

 Match #    Opponent     AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
    1       Random       9  |  1       9  |  1       7  |  3       9  |  1
    2       MM_Open      7  |  3       8  |  2       5  |  5       6  |  4
    3      MM_Center     7  |  3       7  |  3       6  |  4       6  |  4
    4     MM_Improved    5  |  5       5  |  5       6  |  4       4  |  6
    5       AB_Open      5  |  5       4  |  6       3  |  7       4  |  6
    6      AB_Center     5  |  5       5  |  5       5  |  5       3  |  7
    7     AB_Improved    6  |  4       3  |  7       4  |  6       5  |  5
     -------------------------------------------------------------------
           Win Rate:     62.9%         58.6%         51.4%         52.9%

Your agents forfeited 246.0 games while there were still legal moves available to play.

TOURNAMENT #10:

 Match #    Opponent     AB_Improved    AB_Custom    AB_Custom_2   AB_Custom_3
                        Won | Lost    Won | Lost    Won | Lost    Won | Lost
    1       Random       9  |  1       8  |  2       8  |  2       8  |  2
    2       MM_Open      8  |  2       6  |  4       5  |  5       6  |  4
    3      MM_Center     6  |  4       9  |  1       9  |  1       6  |  4
    4     MM_Improved    6  |  4       7  |  3       8  |  2       6  |  4
    5       AB_Open      4  |  6       6  |  4       5  |  5       2  |  8
    6      AB_Center     5  |  5       7  |  3       6  |  4       3  |  7
    7     AB_Improved    6  |  4       6  |  4       5  |  5       3  |  7
     -------------------------------------------------------------------
           Win Rate:     62.9%         70.0%         65.7%         48.6%

Your agents forfeited 247.0 games while there were still legal moves available to play.
```

As there is too much variation on the *tournament.py* script results for each run, the mean value for each heuristic result was calculated, obtaining the following values:

Win rate in percents for each tournament:

	AB_Improved	AB_Custom	AB_Custom_2	AB_Custom_3
Tournment 1	55.7	60.0	60.0	54.3
Tournment 2	58.6	60.0	57.1	48.6
Tournment 3	64.3	61.4	62.9	48.6
Tournment 4	65.7	58.6	50.0	54.3
Tournment 5	64.3	60.0	55.7	48.6
Tournment 6	61.4	54.3	58.6	52.9
Tournment 7	60.0	60.0	64.3	45.7
Tournment 8	61.4	64.3	61.4	61.4
Tournment 9	62.9	58.6	51.4	52.9
Tournment 10	62.9	70.0	65.7	48.6
Mean	**61.7**	**60.7**	**58.7**	**51.6**

Based on the data, the recommended heuristic to use is *AB_Custom* due to the following reasons:

1. The mean win ratio is significant better than *AB_Custom_2* and *AB_Custom_3*, and very close to *AB_Improved*.
2. Although it uses a combination of two evaluation functions, which could cause an increase in the complexity, as both are linear functions and the simple multiplication of the two functions is also linear, we have better overall results with no added complexity.
3. From the three implemented functions, it has the lowest mean value for the number of moves to reach a final outcome, calculated by modifying the *sample_players.py* script to run with each function. After 10 runs for each function, the following mean values were obtained: 32.4 moves for *AB_Custom_3*, 30.1 moves for *AB_Custom_2* and 26.5 moves for *AB_Custom*.