CSCE 523

Assignment 2 Lines of Action

2d Lt Marvin Newlin

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Dr. Peterson

1. **Solution**
   1. **Implementation**

To implement this solution to Lines of Action required 4 total methods inside of the WorkBoard.java class. They are listed in the table below.

|  |
| --- |
| h\_value(Workboard b, int player) : int |
| min\_max\_AB(int depth, int alpha, int beta) : Move |
| MaxValue(WorkBoard b, int depth, int alpha, int beta, int maxPlayer) : int |
| MinValue(WorkBoard b, int depth, int alpha, int beta, int maxPlayer) : int |

The h\_value and min\_max\_AB methods are the required provided methods. MaxValue and MinValue are the recursively called methods that the min\_max\_AB function calls. The min\_max\_AB function begins by calling the MaxValue function which calls the MinValue function and then this pattern repeats until the depth limit is reached or a terminal node is reached.

The overall structure of the 3 methods follows the Alpha Beta Minimax function pseudocode from the textbook on page 170. Since the MaxValue and MinValue functions are only helpers, they only return ints and not Move objects. The min\_max\_AB function maintains the current move with the maximum value and returns the move with that value. Additionally, the min\_max\_AB function calls the Board.to\_move field in its initial call to determine who the maximizing player is, and that player gets passed through each call to MaxValue and MinValue. In this way, the function can be player agnostic, i.e. it can maximize for white or black depending on what is selected.

One final note is that in order to make the program search to a deeper ply, I had to edit the searchtime field inside of WorkBoard.java. I changed its value from 0L to 5000L as that was an appropriate value for allowing the function to search for a decent amount of time.

Additionally, to get the image files for the GUI to display in IntelliJ, I had to append “src/” to the front of each file name to get them to be visible.

* 1. **Heuristic Implementation**

In order to implement our Static Board Evaluator (heuristic), I utilized a weighted average of pieces approach found on page 22 of Mark Winand’s thesis, *Informed Search in Complex Games*. In it he described a 2-D array of integer values called pieceSquareTable that contained a weighted value for each cell of the board. This array was then used to calculate a weighted average of the pieces as follows:

**For each piece in the piece list do**

**pieceCount += 1**

**WeightedSum += pieceSquareTable[piece.y][piece.x]**

**Avg = WeightedSum/pieceCount**

**hVal = (int) opponentAvg – selfAvg**

As is noticeable from the algorithm, the h\_value function calculated the weighted piece average for both black & white players and depending upon the player passed in, returns the value of opponentAvg – selfAvg. Since all the values in the table are negative, this subtraction will yield a positive value when the opponent has a higher negative average (more pieces or pieces in locations like corners).

1. **Compilation & Execution**

To compile the program inside of IntelliJ IDEA, right click the LOAGUI file and select “Run LOAGUI.main()”

From there, the GUI will take over. Ensure that you select to play as Black.

1. **Results**

The results of a 3-ply and a 9-ply game are shown below. As far as effectiveness, the 3-ply strategy was harder to beat than the 9-ply game. As expected, the 3-ply search was very quick and the 9-ply search became rather large in the middle stages of the game, in some cases taking around 120 seconds to complete the search while searching close 500 million nodes. The results of the 9-ply game below was me winning, however, the computer was only 1-2 moves away from winning. The result of the 3-ply game was the computer winning

This implementation would benefit from a move ordering strategy and/or a heuristic like killer moves. The lack of ordering moves resulted in a very long search time in the larger ply games.

**3-Ply Game Results**

DoneRefresh

Depth: 1 Time: 0.012 Nodes Searched: 1239 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.077 Nodes Searched: 133060 Leaf Nodes: 0

Nodes per Second = 1744142.8571428573

Search Time: 0.078s Best move: h7-f5

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1585 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.081 Nodes Searched: 219517 Leaf Nodes: 0

Nodes per Second = 2729654.3209876544

Search Time: 0.081s Best move: h6-d6

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1498 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.075 Nodes Searched: 218166 Leaf Nodes: 0

Nodes per Second = 2928853.3333333335

Search Time: 0.075s Best move: h5-f3

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1301 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.057 Nodes Searched: 171967 Leaf Nodes: 0

Nodes per Second = 3039789.4736842103

Search Time: 0.057s Best move: h4-f4

DoneRefresh

Depth: 1 Time: 0.008 Nodes Searched: 1414 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.25 Nodes Searched: 219541 Leaf Nodes: 0

Nodes per Second = 883820.0

Search Time: 0.25s Best move: a7-d4

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1357 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.078 Nodes Searched: 239437 Leaf Nodes: 0

Nodes per Second = 3087102.564102564

Search Time: 0.078s Best move: h3-e6

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1592 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.094 Nodes Searched: 295793 Leaf Nodes: 0

Nodes per Second = 3163670.212765957

Search Time: 0.094s Best move: a2-c4

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1567 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.08 Nodes Searched: 244249 Leaf Nodes: 0

Nodes per Second = 3072700.0

Search Time: 0.08s Best move: a6-d3

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1562 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.076 Nodes Searched: 243985 Leaf Nodes: 0

Nodes per Second = 3230881.5789473685

Search Time: 0.076s Best move: a4-c6

DoneRefresh

Depth: 1 Time: 0.005 Nodes Searched: 1302 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.175 Nodes Searched: 116212 Leaf Nodes: 0

Nodes per Second = 671508.5714285715

Search Time: 0.175s Best move: e6-e3

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 1131 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.033 Nodes Searched: 100139 Leaf Nodes: 0

Nodes per Second = 3068787.8787878784

Search Time: 0.034s Best move: e3-b6

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 1124 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.031 Nodes Searched: 103651 Leaf Nodes: 0

Nodes per Second = 3379838.709677419

Search Time: 0.031s Best move: f3-b3

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 782 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.027 Nodes Searched: 89713 Leaf Nodes: 0

Nodes per Second = 3351666.6666666665

Search Time: 0.027s Best move: b3-e6

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 720 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.027 Nodes Searched: 94967 Leaf Nodes: 0

Nodes per Second = 3543962.962962963

Search Time: 0.027s Best move: a3-c3

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 566 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.031 Nodes Searched: 117619 Leaf Nodes: 0

Nodes per Second = 3812419.35483871

Search Time: 0.031s Best move: f4-d2

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 720 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.032 Nodes Searched: 125088 Leaf Nodes: 0

Nodes per Second = 3931500.0

Search Time: 0.032s Best move: h2-e5

**9-Ply Game Results**

DoneRefresh

Depth: 1 Time: 0.009 Nodes Searched: 1347 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.099 Nodes Searched: 182899 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 5.284 Nodes Searched: 13509026 Leaf Nodes: 0

Nodes per Second = 2591459.500378501

Search Time: 5.285s Best move: a7-c7

DoneRefresh

Depth: 1 Time: 0.009 Nodes Searched: 1347 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.182 Nodes Searched: 184307 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 5.346 Nodes Searched: 14980481 Leaf Nodes: 0

Nodes per Second = 2836912.6449682005

Search Time: 5.346s Best move: h3-e6

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1263 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.062 Nodes Searched: 182142 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 6.19 Nodes Searched: 16323797 Leaf Nodes: 0

Nodes per Second = 2666753.1502423263

Search Time: 6.19s Best move: h6-d6

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 1347 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.066 Nodes Searched: 207851 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 7.064 Nodes Searched: 21005018 Leaf Nodes: 0

Nodes per Second = 3003144.960362401

Search Time: 7.064s Best move: a6-c4

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1350 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.07 Nodes Searched: 208222 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 7.362 Nodes Searched: 21695687 Leaf Nodes: 0

Nodes per Second = 2975449.470252649

Search Time: 7.362s Best move: h7-e4

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1437 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.087 Nodes Searched: 276592 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 11.742 Nodes Searched: 34546355 Leaf Nodes: 0

Nodes per Second = 2965796.6274910574

Search Time: 11.742s Best move: h5-f5

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1265 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.056 Nodes Searched: 175646 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 7.995 Nodes Searched: 23185187 Leaf Nodes: 0

Nodes per Second = 2922088.555347092

Search Time: 7.995s Best move: h2-f2

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1136 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.047 Nodes Searched: 141450 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 5.041 Nodes Searched: 13636332 Leaf Nodes: 0

Nodes per Second = 2733369.966276532

Search Time: 5.041s Best move: e6-e3

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1007 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.055 Nodes Searched: 177026 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 6.187 Nodes Searched: 18393382 Leaf Nodes: 0

Nodes per Second = 3001683.368352998

Search Time: 6.187s Best move: h4-f6

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 1134 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.062 Nodes Searched: 207286 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 7.586 Nodes Searched: 22082310 Leaf Nodes: 0

Nodes per Second = 2938403.638281044

Search Time: 7.586s Best move: a5-c5

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 928 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.042 Nodes Searched: 134744 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 3.809 Nodes Searched: 10781484 Leaf Nodes: 0

Nodes per Second = 2866147.545287477

Search Time: 3.809s Best move: a4-b5

DoneRefresh

Depth: 1 Time: 0.001 Nodes Searched: 580 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.018 Nodes Searched: 51069 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 1.217 Nodes Searched: 3704502 Leaf Nodes: 0

DoneRefresh

Depth: 7 Time: 92.62 Nodes Searched: 259951629 Leaf Nodes: 0

Nodes per Second = 2847201.252429281

Search Time: 92.62s Best move: e4-d5

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 703 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.022 Nodes Searched: 71689 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 1.965 Nodes Searched: 6039657 Leaf Nodes: 0

DoneRefresh

Depth: 7 Time: 168.722 Nodes Searched: 481837792 Leaf Nodes: 0

Nodes per Second = 2892034.4768317114

Search Time: 168.723s Best move: f6-g5 (not an ideal search time)

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 753 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.021 Nodes Searched: 61756 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 1.37 Nodes Searched: 4083441 Leaf Nodes: 0

DoneRefresh

Depth: 7 Time: 114.046 Nodes Searched: 319232507 Leaf Nodes: 0

Nodes per Second = 2835508.978833102

Search Time: 114.046s Best move: g5-e3

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 632 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.017 Nodes Searched: 50753 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 1.011 Nodes Searched: 3212477 Leaf Nodes: 0

DoneRefresh

Depth: 7 Time: 88.769 Nodes Searched: 253541362 Leaf Nodes: 0

Nodes per Second = 2892960.6506776013

Search Time: 88.769s Best move: c7-e7

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 531 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.016 Nodes Searched: 51085 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 1.597 Nodes Searched: 5319590 Leaf Nodes: 0

DoneRefresh

Depth: 7 Time: 159.854 Nodes Searched: 493115282 Leaf Nodes: 0

Nodes per Second = 3118386.077295532

Search Time: 159.854s Best move: a2-e6

DoneRefresh

Depth: 1 Time: 0.0 Nodes Searched: 643 Leaf Nodes: 0

DoneRefresh

Depth: 3 Time: 0.028 Nodes Searched: 95822 Leaf Nodes: 0

DoneRefresh

Depth: 5 Time: 3.756 Nodes Searched: 12910346 Leaf Nodes: 0

Nodes per Second = 3462942.225772098

Search Time: 3.756s Best move: c4-b4