For our implementation we had three classes: a Game class, a gameState class, and a board class. The Game class dealt with handling the global functions of the program such as the turn player, the minimax algorithm, the depth of the current player's minimax tree, the winner of the game, and logging the game. The gameState class represents a state that keeps track of its heuristic value and the move used to generate it. Finally, the board class handles all the functionality associated with the tic tac toe board itself such as mapping the cells onto the board, filling them with X's and O's, and checking the sequences on the board for various conditions such as open ends and length.

The program works by passing in the initial gameState into minimax within a loop that then recursively gets the best move for the current player by running minimax on the generated children states up to the globally set depth until a winner is determined at which point the loop is exited and the game is printed to a log file.

The average CPU run time for this program was about 2 minutes.

The Game:

```
Starting the game of Tic-Tac-Toe
Initial state:

|   |   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   | O |   | X |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |   |


X's turn
CPU execution time: 0.0274 seconds
138 nodes generated
|   |   |   |   |   |   |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |   |
|   |   |   |   | O |   | X |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |   |




O's turn
CPU execution time: 12.7829 seconds
59276 nodes generated
```

```
| O |   |   |   |   |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
|   |   |   |   | O |   | X |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |



X's turn
CPU execution time: 0.0328 seconds
198 nodes generated
| O |   |   |   |   |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
|   |   |   |   | O |   | X |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |



O's turn
CPU execution time: 13.734 seconds
77300 nodes generated
| O |   |   |   |   |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   |   |   |



X's turn
CPU execution time: 0.0475 seconds
246 nodes generated
| O |   |   |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
```

```
|   |   |   |   |   |   |   |   |   |   |   |

O's turn
CPU execution time: 12.449 seconds
57851 nodes generated
| O |   |   |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
|   |   | O |   |   |   |   |   |   |   |   |

X's turn
CPU execution time: 0.0371 seconds
214 nodes generated
| O |   |   |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
|   |   | O |   |   |   |   |   |   |   |   |

O's turn
CPU execution time: 16.7762 seconds
66148 nodes generated
| O |   |   |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   |   |   |   |
```

```
X's turn
CPU execution time: 0.056 seconds
300 nodes generated
| O |   |   |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 24.5096 seconds
69537 nodes generated
| O |   | O |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   |   |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



X's turn
CPU execution time: 0.0611 seconds
262 nodes generated
| O |   | O |   | X |   |   |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 13.6464 seconds
41811 nodes generated
```

```
| O |   | O |   | X |   | O |   |   |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



X's turn
CPU execution time: 0.0552 seconds
228 nodes generated
| O |   | O |   | X |   | O |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   |   |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 12.9548 seconds
35403 nodes generated
| O |   | O |   | X |   | O |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



X's turn
CPU execution time: 0.0503 seconds
196 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
|   |   | X |   |   |   |   |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   |   |   |   |   |   |   | O |
```

```
|   |   | O |   |   |   |   | X |   |   |



O's turn
CPU execution time: 7.6053 seconds
18605 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
|   |   | X |   |   |   |   |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   |   |   |   |   | O |
|   |   | O |   |   |   |   |   | X |   |   |



X's turn
CPU execution time: 0.0963 seconds
144 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
|   |   | X |   |   |   |   |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   |   |   |   |   | O |
| X |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 4.8312 seconds
8455 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
|   |   | X |   |   |   | O |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   |   |   |   |   | O |
| X |   | O |   |   |   |   |   | X |   |   |
```

```
X's turn
CPU execution time: 0.0678 seconds
100 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
|   |   | X |   |   |   | O |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   | X |   |   |   | O |
| X |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 2.5402 seconds
3273 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
|   |   | X |   |   |   | O |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   | X |   | O |   | O |
| X |   | O |   |   |   |   |   | X |   |   |



X's turn
CPU execution time: 0.0451 seconds
64 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
| X |   | X |   |   |   | O |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   | X |   | O |   | O |
| X |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 1.133 seconds
979 nodes generated
```

```
| O |   | O |   | X |   | O |   | X |   | X |
| X |   | X |   | O |   | O |   |   |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   | X |   | O |   | O |
| X |   | O |   |   |   |   |   | X |   |   |



X's turn
CPU execution time: 0.148 seconds
36 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
| X |   | X |   | O |   | O |   | X |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   | X |   | O |   | O |
| X |   | O |   |   |   |   |   | X |   |   |



O's turn
CPU execution time: 0.1188 seconds
129 nodes generated
| O |   | O |   | X |   | O |   | X |   | X |
| X |   | X |   | O |   | O |   | X |   | O |
| O |   | X |   | O |   | X |   | X |   |   |
|   |   | X |   | O |   | X |   | O |   | O |
| X |   | O |   | O |   |   |   | X |   |   |



O is the winner
Total game time: 123.8084 seconds
```