Project Report

CS6364: Artificial Intelligence

Shreeprasad Sonar
NetID: SXS210482

Introduction

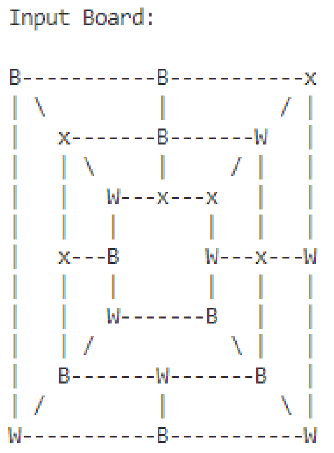
This project intends to build a computer program that plays variant of Nine Mens Morris game. Python programming language is utilized for implementation. The first step is to create two programs that can compute the optimum move for white in both the opening and midgame/endgame phases of the game. The second half involves the creation of two programs that use the Alpha-Beta pruning algorithm instead of Minimax, but produce the same estimate values as in Part I. The third step necessitates the use of two programs that compute Black's move rather than White's move. Ultimately, the fourth phase demands the development of an improved static estimate function to replace the original static estimation function.

Part I: MINIMAX

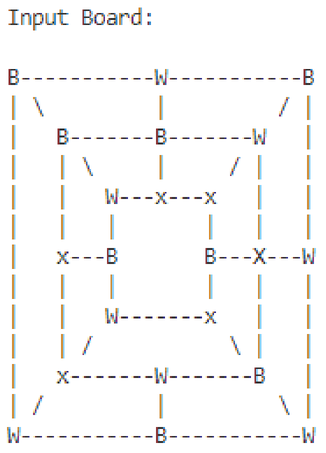
The objective of Part I of the project was to implement the MINIMAX algorithm to determine the best move for the game of Morris-Variant, in both the opening and midgame/endgame phases. The algorithm had to be implemented in two programs, namely MiniMaxOpening and MiniMaxGame, and the programs had to take as input two file names for input and output board positions, and the depth of the tree that needs to be searched.

Program 1: MiniMaxOpening

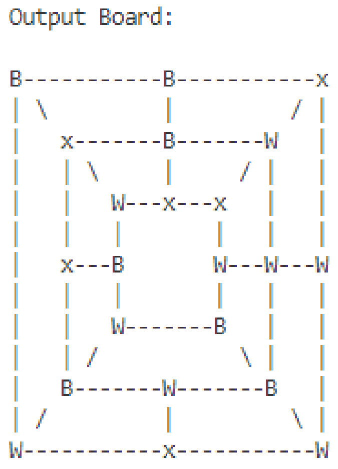
Test Case 1	**Test Case 2**
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WxWBWBWBxBWWWWxxxBWBBx Positions evaluated by static estimation: 139 MINIMAX estimate: 2	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WxWWWBWxxBBXWWxxBBWBWB Positions evaluated by static estimation: 76 MINIMAX estimate: 2



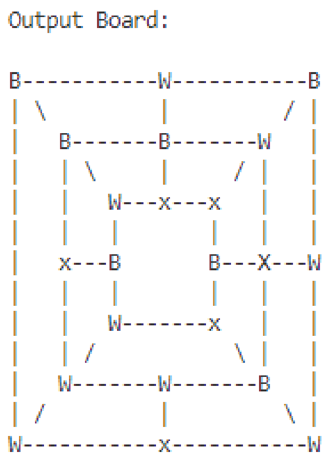
```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```



```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```



```
Output Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---W---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------x-----------W
```

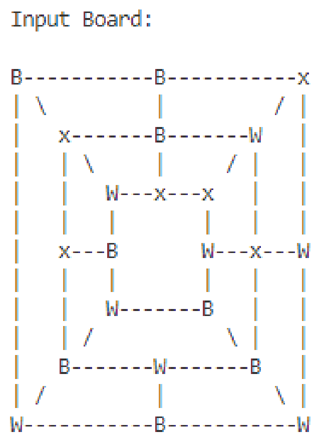


```
Output Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   W-------W-------B   |
| /         |         \ |
W-----------x-----------W
```

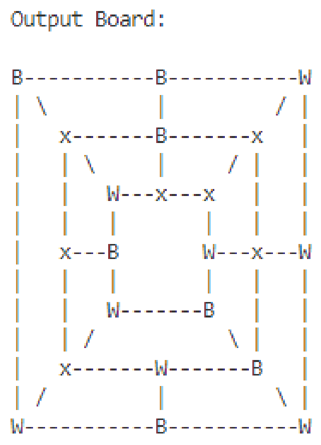
Program 2: MiniMaxGame

Test Case 1	**Test Case 2**
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WBWxWBWBxBWxWWxxxBxBBW Positions evaluated by static estimation: 181 MINIMAX estimate: 992	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WBWWxxWxxBBXWWxxBBWBWB Positions evaluated by static estimation: 121 MINIMAX estimate: 992

Test Case 1

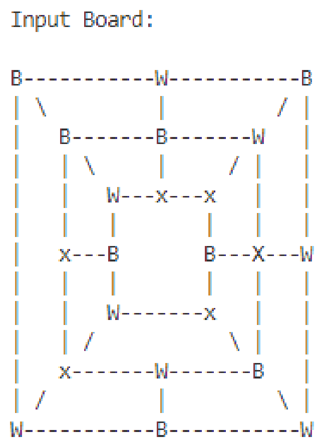


```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

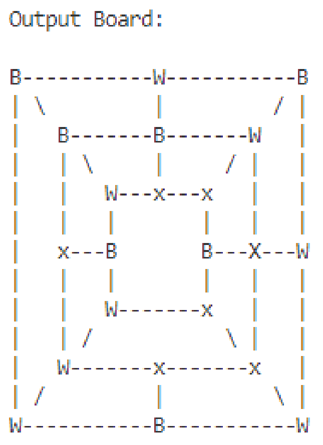


```
Output Board:

B-----------B-----------W
| \         |         / |
|   x-------B-------x   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Test Case 2



```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

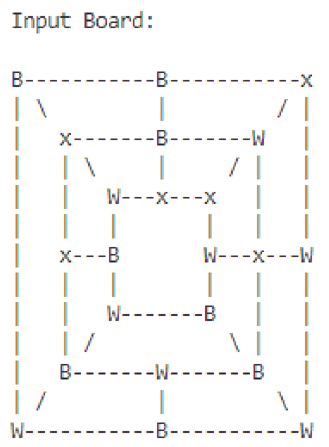
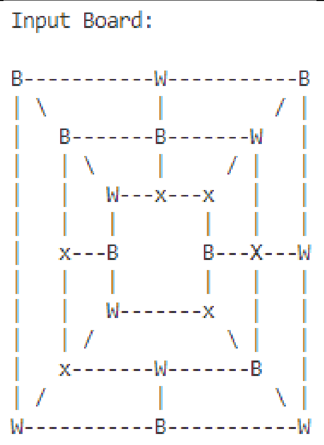
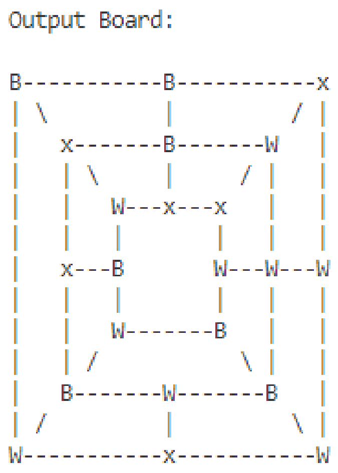
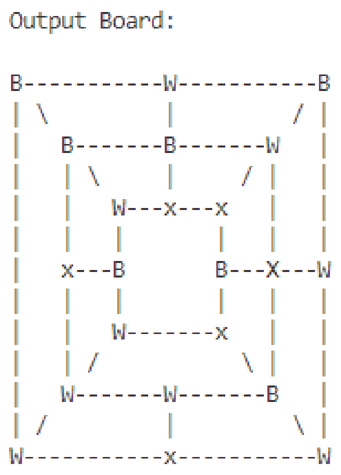


```
Output Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   W-------x-------x   |
| /         |         \ |
W-----------B-----------W
```

Part II: Alpha-Beta

In this part, we are required to implement the ALPHA-BETA pruning algorithm instead of the MINIMAX algorithm used in Part I. The goal is to write two programs that behave exactly the same as the programs of Part I but return the exact same estimate values while evaluating fewer nodes.

Program 1: ABOpening

Test Case 1	**Test Case 2**
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WxWBWBWBxBWWWWxxxBWBBx Positions evaluated by static estimation: 49 MINIMAX estimate: 2	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WxWWWBWxxBBXWWxxBBWBWB Positions evaluated by static estimation: 29 MINIMAX estimate: 2
	
	

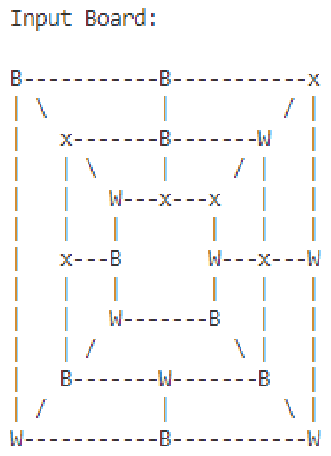
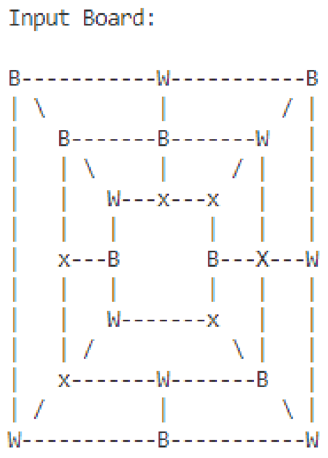
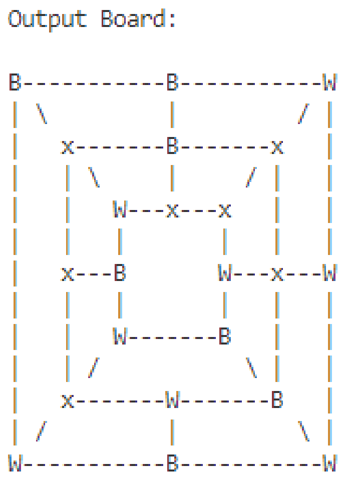
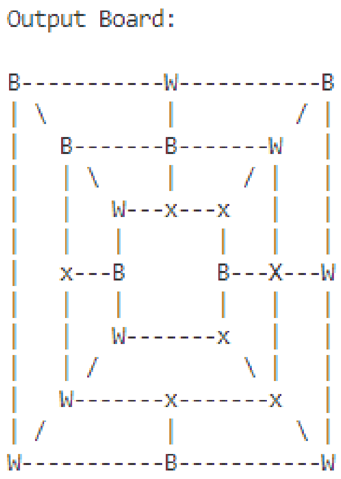
```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---W---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------x-----------W
```

```
Output Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   W-------W-------B   |
| /         |         \ |
W-----------x-----------W
```

Program 2: ABGame

Test Case 1	Test Case 2
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WBWxWBWBxBWxWWxxxBxBBW Positions evaluated by static estimation: 108 MINIMAX estimate: 992	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WBWWxxWxxBBXWWxxBBWBWB Positions evaluated by static estimation: 64 MINIMAX estimate: 992
	
	

Test Case 1:

```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------B-----------W
| \         |         / |
|   x-------B-------x   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Test Case 2:

```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

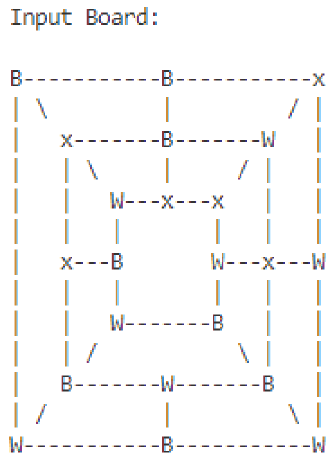
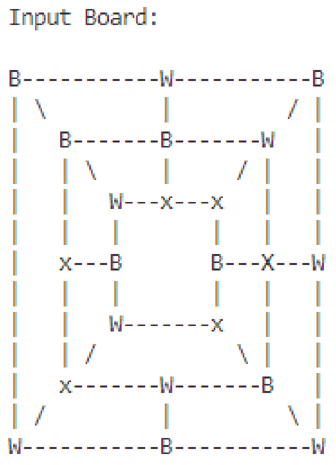
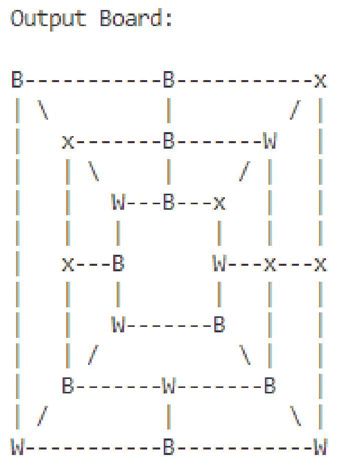
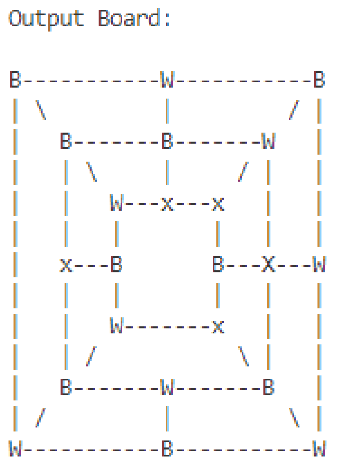
```
Output Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   W-------x-------x   |
| /         |         \ |
W-----------B-----------W
```

In both the cases, alpha-beta is result for board position and estimate is same while evaluating less positions than MiniMax.

Part III: Play A Game For Black

In this part of the project, we were tasked with writing two programs, MiniMaxOpeningBlack and MiniMaxGameBlack, that are similar to the ones written in Part I, but with the difference that the computed move should be Black's move instead of White's move.

Program 1: MiniMaxOpeningBlack

Test Case 1	**Test Case 2**
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WBWBWBWBxBWxxWBxxBWBBx Positions evaluated by static estimation: 290 MINIMAX estimate: 2	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WBWBWBWxxBBXWWxxBBWBWB Positions evaluated by static estimation: 61 MINIMAX estimate: 1
	
	

Test Case 1:

```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Test Case 2:

```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

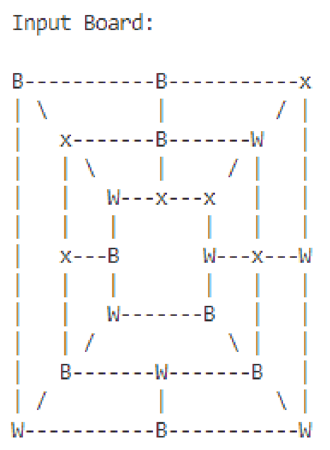
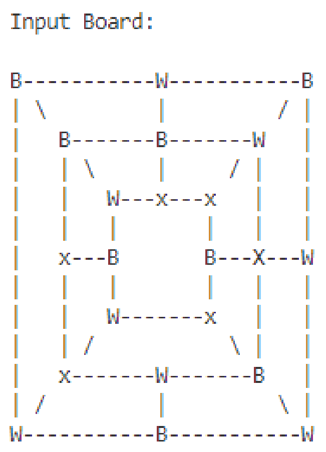
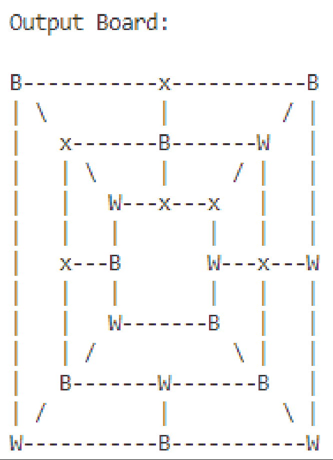
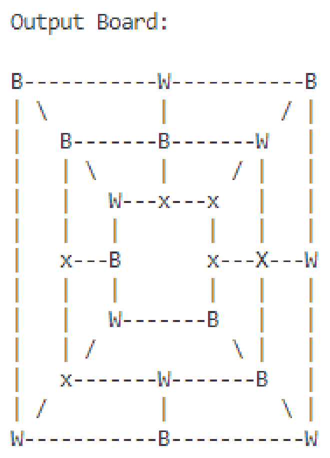
Test Case 1:

```
Output Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---B---x   |   |
|   |   |       |   |   |
|   x---B       W---x---x
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Test Case 2:

```
Output Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Program 2: MiniMaxGameBlack

Test Case 1	Test Case 2
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WBWBWBWBxBWxWWxxxBWBxB Positions evaluated by static estimation: 163 MINIMAX estimate: -1013	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WBWxWBWBxBxXWWxxBBWBWB Positions evaluated by static estimation: 87 MINIMAX estimate: -1019
	
	

Test Case 1

```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------x-----------B
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Test Case 2

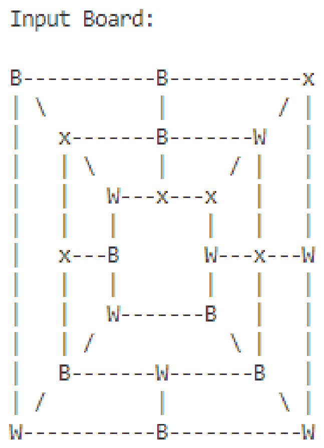
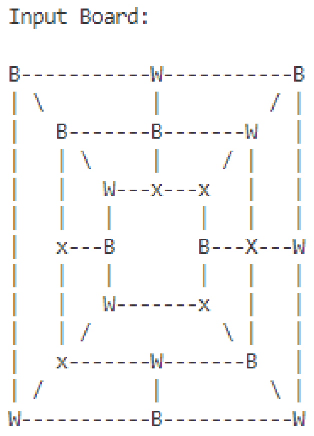
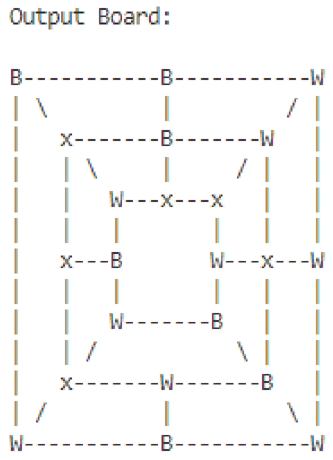
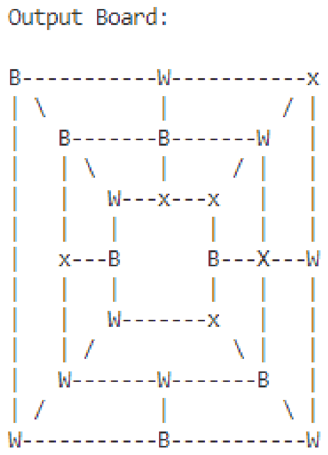
```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       x---X---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Part IV: Static Estimation

In this part of the project, we were asked to implement an improved static estimation function for the Morris-Variant game. The goal of this task is to create a more accurate estimation of the game state than the one provided in the handout. This new function will be used in the programs of Part I, replacing the old estimation function.

Program 1: MiniMaxOpeningImproved

Test Case 1	**Test Case 2**
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WBWxWBWBxBWxWWxxxBWBBW Positions evaluated by static estimation: 139 MINIMAX estimate: 123	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WBWWWBWxxBBXWWxxBBWBWx Positions evaluated by static estimation: 76 MINIMAX estimate: 113
	
	

Test Case 1:

```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

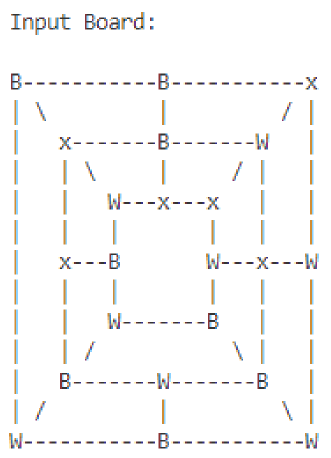
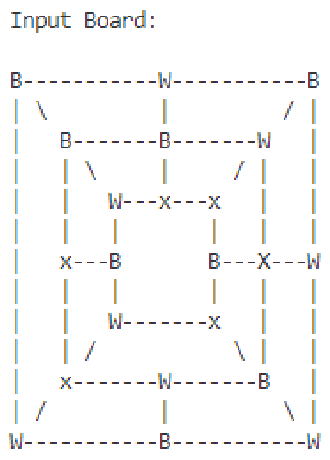
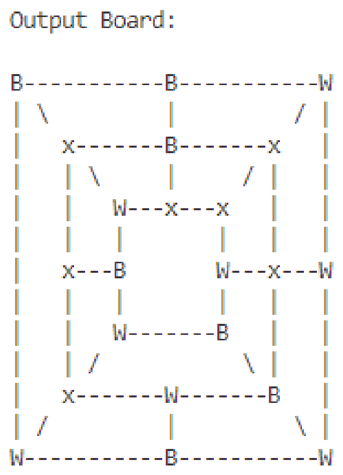
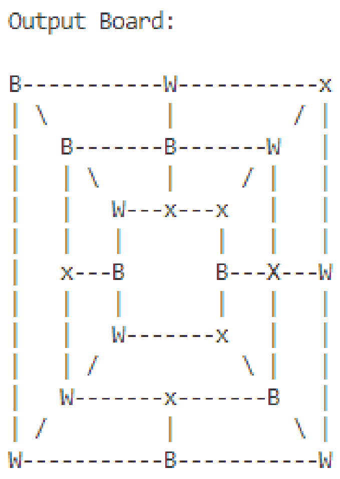
```
Output Board:

B-----------B-----------W
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Test Case 2:

```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------W-----------x
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   W-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

Program 2: MiniMaxGameImproved

Test Case 1	**Test Case 2**
Given Board : WBWBWBWBxBWxWWxxxBWBBx Given Depth : 2 Board Position: WBWxWBWBxBWxWWxxxBxBBW Positions evaluated by static estimation: 181 MINIMAX estimate: 58	Given Board : WBWxWBWxxBBXWWxxBBWBWB Given Depth : 2 Board Position: WBWWxBWxxBBXWWxxBBWBWx Positions evaluated by static estimation: 121 MINIMAX estimate: 68
	
	

```
Input Board:

B-----------B-----------x
| \         |         / |
|   x-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   B-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Input Board:

B-----------W-----------B
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------B-----------W
| \         |         / |
|   x-------B-------x   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       W---x---W
|   |   |       |   |   |
|   |   W-------B   |   |
|   | /           \ |   |
|   x-------W-------B   |
| /         |         \ |
W-----------B-----------W
```

```
Output Board:

B-----------W-----------x
| \         |         / |
|   B-------B-------W   |
|   | \     |     / |   |
|   |   W---x---x   |   |
|   |   |       |   |   |
|   x---B       B---X---W
|   |   |       |   |   |
|   |   W-------x   |   |
|   | /           \ |   |
|   W-------x-------B   |
| /         |         \ |
W-----------B-----------W
```

Here change in static estimation function is reflected on outputs. Outputs produced are different from Part I, while both the functions end up making a mill, black piece removed in improved version is more carefully analyzed so that there is possibility of white forming a mill in the next turn.

Here estimation function is more sophisticated than the one provided in the handout. By taking into account the different potential mills that can be formed on the board, the current mill count difference, and the number of white pieces minus black pieces, function is able to capture more nuances of the game state and provide a more accurate estimate of the relative strength of the two players.

By considering the potential mills on the board, the function is able to take into account the fact that some positions may be more advantageous than others, depending on how they interact with the rest of the board. By considering the current mill count difference, the function can take into account the fact that some positions may be closer to victory than others, and therefore more valuable. Finally, by considering the number of white pieces minus black pieces, function can consider the fact that some positions may be more imbalanced than others, and therefore more vulnerable to attack.