

CS4750-HW4 Report

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References: https://en.wikipedia.org/wiki/Alpha%E2%80%93beta_pruning, alpha-beta pruning
minimax function is implemented follow the pseudocode from Wikipedia.

Description: Implement the minimax algorithm in Python (*main.py*, *player.py*, *board.py*) to play a two-player, four-in-a-row game, which is a variation of tic-tac-toe: two players, X and O, take turns marking the spaces in a 6×6 grid. Player 1 The player who succeeds in placing 4 of their marks consecutively in a horizontal, vertical, or diagonal row wins the game. The heuristic function that we used for our minimax algorithm is $h(n) = 5 * [\# \text{ of two-side-open-3-in-a-row for me}] - 10 * [\# \text{ of two-side-open-3-in-a-row for opponent}] + 3 * [\# \text{ of one-side-open-3-in-a-row for me}] - 6 * [\# \text{ of one-side-open-3-in-a-row for opponent}] + [\# \text{ of open-2-in-a-row for me}] - [\# \text{ of open-2-in-a-row for opponent}]$ where:

- “one-side-open-3-in-a-row”: there is a blank space at one end of a 3-in-a-row.
- “two-side-open-3-in-a-row”: there are blank spaces at both ends of a 3-in-a-row.
- “open-2-in-a-row”: there are blank spaces at one or both ends of a 2-in-a-row.

Player 1, with symbol X, running the minimax algorithm searching in the depth of 4 moves ahead. Player 2, with symbol O, running the minimax algorithm searching in the depth of 2 moves ahead. Player 1 moves first by placing X in the middle of the board. Each player then take turn placing their symbol on the board in the location that give them the highest heuristic value after running the minimax algorithm. Since our minimax algorithm took too long to run, we also implement the second version of minimax, the alpha-beta minimax (*main-alpha-beta-*

minimax.py). The alpha-beta minimax is very similar to the normal minimax above, but used alpha-beta pruning to prevent expanding entirely the min nodes that going to had lower heuristic value than current best heuristic value for max. Using the alpha-beta minimax, we were able to reduce the number of nodes we need to search significantly, and our program ran much faster. The normal minimax program was developed on a windows laptop (8GB of 1600MHz LPDDR3 RAM and 2.2GHz dual-core Intel Core i5) using VS Code, python extension, to run and debug. The alpha-beta pruning minimax program was developed on a MacBook Air laptop (8GB of 1600MHz LPDDR3 RAM and 1.8GHz dual-core Intel Core i5) using Jupyter notebook to code and debug. However, we used Secure4 cluster to run the program for getting the results. We setup the node by using 32GB RAM with 8 cores CPU. Below is the result of the games play (as well as the bonus) by running *main-alpha-beta-minimax.py*.

Links:

- Secure4, <https://doit.missouri.edu/services/research/secure4-research-computing-environment/>

Result:

x is player 1

o is player 2

x places the first move at center of the board

```
-----
|   |   |   |   |   |   |
-----
|   |   |   |   |   |   |
-----
|   |   | x |   |   |   |
-----
|   |   |   |   |   |   |
-----
|   |   |   |   |   |   |
-----
|   |   |   |   |   |   |
-----
```

AI turn [o]

```
-----
|   |   |   |   |   |   |
-----
|   |   | o |   |   |   |
-----
|   |   | x |   |   |   |
-----
|   |   |   |   |   |   |
-----
|   |   |   |   |   |   |
-----
|   |   |   |   |   |   |
-----
```

Total expanded nodes: 9148

Execution time: 2441.26 ms

AI turn [x]

```
-----
|   |   |   |   |   |   |
-----
|   |   | o |   |   |   |
-----
|   |   | x |   |   |   |
-----
|   |   | x |   |   |   |
-----
|   |   |   |   |   |   |
-----
|   |   |   |   |   |   |
-----
```

Total expanded nodes: 104

Execution time: 32.74 ms

AI turn [o]

			o			
			x	o		
			x			

Total expanded nodes: 4108

Execution time: 1261.74 ms

AI turn [x]

			o			
			x	o		
			x		x	

Total expanded nodes: 393

Execution time: 119.86 ms

AI turn [o]

			o			
			x	o		
			x	o	x	

Total expanded nodes: 9045

Execution time: 2993.01 ms

AI turn [x]

			o	x		
			x	o		
			x	o	x	

Total expanded nodes: 235

Execution time: 80.21 ms

AI turn [o]

			o	x		
			x	o		
			x	o	x	
			o			

Total expanded nodes: 6890

Execution time: 2479.51 ms

AI turn [x]

			o	x		
			x	o	x	
			x	o	x	
			o			

Total expanded nodes: 195

Execution time: 72.68 ms

AI turn [o]

			o	x		
			x	o	x	
			x	o	x	
			o	o		

Total expanded nodes: 7344

Execution time: 3066.71 ms

AI turn [x]

			o	x		
			x	o	x	
			x	o	x	
			o	o	x	

Total expanded nodes: 299

Execution time: 129.66 ms

AI turn [o]

			o	x		
			x	o	x	
			x	o	x	
			o	o	x	
				o		

Total expanded nodes: 3890

Execution time: 1668.86 ms

O is the winner

Total Execution time: 14346.24 ms

Bonus:

x is player 1
o is player 2

Player 1 starts the games.

Game 1
X is the winner
Total Execution time: 12100.55 ms

Game 2
This game is tie
Total Execution time: 33310.07 ms

Game 3
This game is tie
Total Execution time: 28012.57 ms

Game 4
X is the winner
Total Execution time: 25889.37 ms

Game 5
O is the winner
Total Execution time: 14611.15 ms

Game 6
O is the winner
Total Execution time: 13130.41 ms

Game 7
X is the winner
Total Execution time: 23568.13 ms

Game 8
This game is tie
Total Execution time: 25827.66 ms

Game 9
This game is tie
Total Execution time: 35193.82 ms

Game 10
O is the winner
Total Execution time: 15465.04 ms

Game 11
X is the winner
Total Execution time: 15193.85 ms

Game 12
O is the winner
Total Execution time: 17258.12 ms

Game 13

O is the winner
Total Execution time: 15615.53 ms

Game 14
O is the winner
Total Execution time: 21112.06 ms

Game 15
X is the winner
Total Execution time: 14905.81 ms

Game 16
This game is tie
Total Execution time: 34016.45 ms

Game 17
X is the winner
Total Execution time: 15173.55 ms

Game 18
X is the winner
Total Execution time: 20603.16 ms

Game 19
This game is tie
Total Execution time: 24919.5 ms

Game 20
O is the winner
Total Execution time: 15731.7 ms

Game 21
O is the winner
Total Execution time: 14062.3 ms

Game 22
This game is tie
Total Execution time: 32334.36 ms

Game 23
X is the winner
Total Execution time: 16014.65 ms

Game 24
This game is tie
Total Execution time: 33987.63 ms

Game 25
X is the winner
Total Execution time: 13445.92 ms

Game 26
O is the winner
Total Execution time: 13780.77 ms

Game 27
X is the winner

Total Execution time: 34416.1 ms

Game 28

X is the winner

Total Execution time: 22889.61 ms

Game 29

X is the winner

Total Execution time: 15171.04 ms

Game 30

O is the winner

Total Execution time: 16303.2 ms

Game 31

This game is tie

Total Execution time: 32168.22 ms

Game 32

This game is tie

Total Execution time: 34259.41 ms

Game 33

X is the winner

Total Execution time: 26719.23 ms

Game 34

This game is tie

Total Execution time: 25206.02 ms

Game 35

X is the winner

Total Execution time: 12881.03 ms

Game 36

This game is tie

Total Execution time: 23138.44 ms

Game 37

X is the winner

Total Execution time: 27566.54 ms

Game 38

This game is tie

Total Execution time: 37238.53 ms

Game 39

O is the winner

Total Execution time: 13382.83 ms

Game 40

X is the winner

Total Execution time: 25793.08 ms

Game 41

This game is tie

Total Execution time: 24021.37 ms

Game 42
This game is tie
Total Execution time: 24855.45 ms

Game 43
O is the winner
Total Execution time: 17068.02 ms

Game 44
This game is tie
Total Execution time: 29795.26 ms

Game 45
O is the winner
Total Execution time: 21336.54 ms

Game 46
O is the winner
Total Execution time: 13450.09 ms

Game 47
O is the winner
Total Execution time: 19038.5 ms

Game 48
O is the winner
Total Execution time: 16159.02 ms

Game 49
O is the winner
Total Execution time: 27743.76 ms

Game 50
This game is tie
Total Execution time: 23864.35 ms

Game 51
O is the winner
Total Execution time: 27594.38 ms

Game 52
This game is tie
Total Execution time: 25390.38 ms

Game 53
This game is tie
Total Execution time: 20829.55 ms

Game 54
This game is tie
Total Execution time: 27922.86 ms

Game 55
O is the winner
Total Execution time: 13805.32 ms

Game 56
X is the winner
Total Execution time: 24315.29 ms

Game 57
O is the winner
Total Execution time: 22005.21 ms

Game 58
O is the winner
Total Execution time: 15845.01 ms

Game 59
This game is tie
Total Execution time: 29672.7 ms

Game 60
X is the winner
Total Execution time: 12713.45 ms

Game 61
X is the winner
Total Execution time: 15392.06 ms

Game 62
O is the winner
Total Execution time: 13834.92 ms

Game 63
This game is tie
Total Execution time: 34349.29 ms

Game 64
This game is tie
Total Execution time: 28559.31 ms

Game 65
O is the winner
Total Execution time: 14195.71 ms

Game 66
This game is tie
Total Execution time: 22669.97 ms

Game 67
O is the winner
Total Execution time: 16120.85 ms

Game 68
This game is tie
Total Execution time: 25301.43 ms

Game 69
This game is tie
Total Execution time: 24383.48 ms

Game 70

X is the winner
Total Execution time: 34710.79 ms

Game 71
This game is tie
Total Execution time: 25157.03 ms

Game 72
This game is tie
Total Execution time: 24060.17 ms

Game 73
This game is tie
Total Execution time: 24848.8 ms

Game 74
O is the winner
Total Execution time: 18170.58 ms

Game 75
O is the winner
Total Execution time: 13716.17 ms

Game 76
This game is tie
Total Execution time: 30184.15 ms

Game 77
X is the winner
Total Execution time: 12589.41 ms

Game 78
This game is tie
Total Execution time: 23946.66 ms

Game 79
O is the winner
Total Execution time: 16068.36 ms

Game 80
X is the winner
Total Execution time: 11659.31 ms

Game 81
O is the winner
Total Execution time: 20704.76 ms

Game 82
This game is tie
Total Execution time: 33571.45 ms

Game 83
X is the winner
Total Execution time: 15590.58 ms

Game 84
This game is tie

Total Execution time: 33104.86 ms

Game 85

This game is tie

Total Execution time: 26320.14 ms

Game 86

X is the winner

Total Execution time: 14599.41 ms

Game 87

This game is tie

Total Execution time: 25059.17 ms

Game 88

This game is tie

Total Execution time: 28215.24 ms

Game 89

O is the winner

Total Execution time: 21844.42 ms

Game 90

This game is tie

Total Execution time: 23611.29 ms

Game 91

This game is tie

Total Execution time: 26351.29 ms

Game 92

X is the winner

Total Execution time: 15687.69 ms

Game 93

X is the winner

Total Execution time: 26009.42 ms

Game 94

O is the winner

Total Execution time: 14801.21 ms

Game 95

This game is tie

Total Execution time: 32602.83 ms

Game 96

O is the winner

Total Execution time: 20981.5 ms

Game 97

This game is tie

Total Execution time: 27531.09 ms

Game 98

This game is tie

Total Execution time: 24275.95 ms

Game 99
This game is tie
Total Execution time: 22508.32 ms

Game 100
O is the winner
Total Execution time: 14719.75 ms

O is the winner: 32%

X is the winner: 26%

This game is tie: 42%

x is player 1
o is player 2

Player 2 starts the games.

Game 1
O is the winner
Total Execution time: 16201.96 ms

Game 2
O is the winner
Total Execution time: 25630.91 ms

Game 3
O is the winner
Total Execution time: 12549.8 ms

Game 4
X is the winner
Total Execution time: 24890.03 ms

Game 5
X is the winner
Total Execution time: 25011.97 ms

Game 6
O is the winner
Total Execution time: 26029.54 ms

Game 7
X is the winner
Total Execution time: 25529.56 ms

Game 8
O is the winner
Total Execution time: 32416.46 ms

Game 9
O is the winner
Total Execution time: 17155.23 ms

Game 10
This game is tie
Total Execution time: 26428.54 ms

Game 11
O is the winner
Total Execution time: 21785.26 ms

Game 12
This game is tie
Total Execution time: 24152.46 ms

Game 13
O is the winner
Total Execution time: 12669.15 ms

Game 14
O is the winner
Total Execution time: 32509.43 ms

Game 15
O is the winner
Total Execution time: 17481.48 ms

Game 16
O is the winner
Total Execution time: 16861.9 ms

Game 17
O is the winner
Total Execution time: 23737.81 ms

Game 18
O is the winner
Total Execution time: 15292.44 ms

Game 19
X is the winner
Total Execution time: 20874.46 ms

Game 20
O is the winner
Total Execution time: 13507.21 ms

Game 21
X is the winner
Total Execution time: 20142.88 ms

Game 22
This game is tie
Total Execution time: 34544.38 ms

Game 23

O is the winner
Total Execution time: 12727.18 ms

Game 24
O is the winner
Total Execution time: 25811.9 ms

Game 25
O is the winner
Total Execution time: 27479.6 ms

Game 26
O is the winner
Total Execution time: 33335.23 ms

Game 27
X is the winner
Total Execution time: 36672.08 ms

Game 28
O is the winner
Total Execution time: 25618.62 ms

Game 29
O is the winner
Total Execution time: 22415.69 ms

Game 30
X is the winner
Total Execution time: 36750.92 ms

Game 31
X is the winner
Total Execution time: 20163.51 ms

Game 32
O is the winner
Total Execution time: 12478.74 ms

Game 33
O is the winner
Total Execution time: 12941.29 ms

Game 34
O is the winner
Total Execution time: 37868.11 ms

Game 35
X is the winner
Total Execution time: 10478.05 ms

Game 36
X is the winner
Total Execution time: 24135.85 ms

Game 37
X is the winner

Total Execution time: 28603.88 ms

Game 38

X is the winner

Total Execution time: 20123.14 ms

Game 39

X is the winner

Total Execution time: 10717.26 ms

Game 40

O is the winner

Total Execution time: 26528.16 ms

Game 41

X is the winner

Total Execution time: 25466.93 ms

Game 42

X is the winner

Total Execution time: 34445.0 ms

Game 43

X is the winner

Total Execution time: 26798.01 ms

Game 44

X is the winner

Total Execution time: 23410.89 ms

Game 45

O is the winner

Total Execution time: 36354.85 ms

Game 46

X is the winner

Total Execution time: 25080.05 ms

Game 47

O is the winner

Total Execution time: 17654.84 ms

Game 48

X is the winner

Total Execution time: 22298.94 ms

Game 49

This game is tie

Total Execution time: 35311.24 ms

Game 50

X is the winner

Total Execution time: 23755.8 ms

Game 51

X is the winner

Total Execution time: 27947.59 ms

Game 52
O is the winner
Total Execution time: 27033.92 ms

Game 53
O is the winner
Total Execution time: 26001.72 ms

Game 54
O is the winner
Total Execution time: 12133.42 ms

Game 55
O is the winner
Total Execution time: 23402.43 ms

Game 56
X is the winner
Total Execution time: 10850.28 ms

Game 57
X is the winner
Total Execution time: 24488.22 ms

Game 58
O is the winner
Total Execution time: 36048.79 ms

Game 59
X is the winner
Total Execution time: 30187.57 ms

Game 60
X is the winner
Total Execution time: 10487.76 ms

Game 61
O is the winner
Total Execution time: 12586.79 ms

Game 62
X is the winner
Total Execution time: 17353.82 ms

Game 63
O is the winner
Total Execution time: 17391.08 ms

Game 64
O is the winner
Total Execution time: 12841.23 ms

Game 65
X is the winner
Total Execution time: 24160.5 ms

Game 66
X is the winner
Total Execution time: 38868.66 ms

Game 67
Total Execution time: 23234.19 ms

Game 68
O is the winner
Total Execution time: 13163.36 ms

Game 69
O is the winner
Total Execution time: 36761.99 ms

Game 70
O is the winner
Total Execution time: 12932.72 ms

Game 71
X is the winner
Total Execution time: 10060.04 ms

Game 72
X is the winner
Total Execution time: 26837.46 ms

Game 73
O is the winner
Total Execution time: 14786.34 ms

Game 74
O is the winner
Total Execution time: 16020.05 ms

Game 75
O is the winner
Total Execution time: 23938.05 ms

Game 76
O is the winner
Total Execution time: 12887.53 ms

Game 77
This game is tie
Total Execution time: 24300.18 ms

Game 78
X is the winner
Total Execution time: 10498.14 ms

Game 79
X is the winner
Total Execution time: 22558.23 ms

Game 80
X is the winner

Total Execution time: 9881.16 ms

Game 81

X is the winner

Total Execution time: 24792.53 ms

Game 82

X is the winner

Total Execution time: 17693.77 ms

Game 83

O is the winner

Total Execution time: 34023.79 ms

Game 84

This game is tie

Total Execution time: 35655.02 ms

Game 85

O is the winner

Total Execution time: 29562.44 ms

Game 86

O is the winner

Total Execution time: 12746.77 ms

Game 87

X is the winner

Total Execution time: 26600.91 ms

Game 88

X is the winner

Total Execution time: 25796.87 ms

Game 89

O is the winner

Total Execution time: 32211.46 ms

Game 90

X is the winner

Total Execution time: 20046.32 ms

Game 91

X is the winner

Total Execution time: 36473.6 ms

Game 92

O is the winner

Total Execution time: 16256.12 ms

Game 93

X is the winner

Total Execution time: 23867.72 ms

Game 94

X is the winner

Total Execution time: 26554.86 ms

Game 95
O is the winner
Total Execution time: 27688.79 ms

Game 96
X is the winner
Total Execution time: 25282.07 ms

Game 97
X is the winner
Total Execution time: 25919.12 ms

Game 98
X is the winner
Total Execution time: 24328.53 ms

Game 99
X is the winner
Total Execution time: 19623.19 ms

Game 100
X is the winner
Total Execution time: 15265.01 ms

O is the winner: 48%

X is the winner: 46%

This game is tie: 6%
