**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\*[# of two-side-open-3-in-a-row for me]–10\*[# of two-side-open-3-in-a-row for opponent] + 3\*[# of one-side-open-3-in-a-row for me]–6\*[# of one-side-open-3-in-a-row for opponent] + [#of open-2-in-a-row for me] - [# 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 run and debug. Below is the result of the games play (as well as the bonus) by running *main-alpha-beta-minimax.py.*

**Result:**

**x is player 1**

**o is player 2**

x places the first move at center of the board

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AI turn [o]

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| | | o | | | |

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| | | x | | | |

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Total expanded nodes: 9148

Execution time: 2441.26 ms

AI turn [x]

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| | | x | | | |

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Total expanded nodes: 104

Execution time: 32.74 ms

AI turn [o]

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| | | o | | | |

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| | | x | o | | |

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| | | x | | | |

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Total expanded nodes: 4108

Execution time: 1261.74 ms

AI turn [x]

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| | | x | o | | |

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| | | x | | x | |

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Total expanded nodes: 393

Execution time: 119.86 ms

AI turn [o]

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| | | o | | | |

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| | | x | o | | |

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Total expanded nodes: 9045

Execution time: 2993.01 ms

AI turn [x]

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| | | o | x | | |

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| | | x | o | | |

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Total expanded nodes: 235

Execution time: 80.21 ms

AI turn [o]

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| | | o | x | | |

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| | | x | o | | |

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| | | x | o | x | |

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| | | o | | | |

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Total expanded nodes: 6890

Execution time: 2479.51 ms

AI turn [x]

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| | | o | x | | |

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| | | x | o | x | |

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| | | x | o | x | |

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| | | o | | | |

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Total expanded nodes: 195

Execution time: 72.68 ms

AI turn [o]

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| | | o | x | | |

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| | | x | o | x | |

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| | | x | o | x | |

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| | | o | o | | |

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Total expanded nodes: 7344

Execution time: 3066.71 ms

AI turn [x]

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| | | o | x | | |

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| | | x | o | x | |

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| | | x | o | x | |

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| | | o | o | x | |

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Total expanded nodes: 299

Execution time: 129.66 ms

AI turn [o]

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| | | o | x | | |

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| | | x | o | x | |

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| | | x | o | x | |

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| | | o | o | x | |

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| | | | o | | |

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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

**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

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

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

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

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