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CSE 3521

Homework #4

1. is\_terminal() and utility(board, player)

Testing board:

X

is\_terminal() returns false

utility() returns 0 (w.r.t. human player selection)

Testing board:

O X

is\_terminal() returns false

utility() returns 0 (w.r.t. human player selection)

Testing board:

X X O

X O X

O

is\_terminal() returns false

utility() returns 0 (w.r.t. human player selection)

Testing board:

X X O

X O X

X O O

is\_terminal() returns true

utility() returns 1 (w.r.t. human player selection)

1. Done
2. tictactoe\_minimax(board,cpu\_player,cur\_player)

Turn 1:

X

Waiting on CPU player...

Complete. (Evaluated 55505 states, Expanded 29633 states)

CPU selects position 0 (Expected utility score 0)

Turn 2:

O

X

Waiting on human player...

Player selects position 1

Turn 3:

O X

X

Waiting on CPU player...

Complete. (Evaluated 1055 states, Expanded 582 states)

CPU selects position 7 (Expected utility score 0)

Turn 4:

O X

X

O

Waiting on human player...

Player selects position 5

Turn 5:

O X

X X

O

Waiting on CPU player...

Complete. (Evaluated 47 states, Expanded 26 states)

CPU selects position 3 (Expected utility score 0)

Turn 6:

O X

O X X

O

Waiting on human player...

Player selects position 6

Turn 7:

O X

O X X

X O

Waiting on CPU player...

Complete. (Evaluated 5 states, Expanded 3 states)

CPU selects position 2 (Expected utility score 0)

Turn 8:

O X O

O X X

X O

Waiting on human player...

Player selects position 8

Turn 9:

O X O

O X X

X O X

Game complete.

Draw.

Turn 0:

Waiting on human player...

Player selects position 2

Turn 1:

X

Waiting on CPU player...

Complete. (Evaluated 59705 states, Expanded 31973 states)

CPU selects position 4 (Expected utility score 0)

Turn 2:

X

O

Waiting on human player...

Player selects position 6

Turn 3:

X

O

X

Waiting on CPU player...

Complete. (Evaluated 1053 states, Expanded 533 states)

CPU selects position 1 (Expected utility score 0)

Turn 4:

O X

O

X

Waiting on human player...

Player selects position 7

Turn 5:

O X

O

X X

Waiting on CPU player...

Complete. (Evaluated 47 states, Expanded 26 states)

CPU selects position 8 (Expected utility score 0)

Turn 6:

O X

O

X X O

Waiting on human player...

Player selects position 0

Turn 7:

X O X

O

X X O

Waiting on CPU player...

Complete. (Evaluated 5 states, Expanded 3 states)

CPU selects position 3 (Expected utility score 0)

Turn 8:

X O X

O O

X X O

Waiting on human player...

Player selects position 5

Turn 9:

X O X

O O X

X X O

Game complete.

Draw.

Turn 0:

Waiting on human player...

Player selects position 7

Turn 1:

X

Waiting on CPU player...

Complete. (Evaluated 63905 states, Expanded 34313 states)

CPU selects position 1 (Expected utility score 0)

Turn 2:

O

X

Waiting on human player...

Player selects position 3

Turn 3:

O

X

X

Waiting on CPU player...

Complete. (Evaluated 1421 states, Expanded 805 states)

CPU selects position 6 (Expected utility score 0)

Turn 4:

O

X

O X

Waiting on human player...

Player selects position 4

Turn 5:

O

X X

O X

Waiting on CPU player...

Complete. (Evaluated 51 states, Expanded 30 states)

CPU selects position 5 (Expected utility score 0)

Turn 6:

O

X X O

O X

Waiting on human player...

Player selects position 2

Turn 7:

O X

X X O

O X

Waiting on CPU player...

Complete. (Evaluated 5 states, Expanded 3 states)

CPU selects position 0 (Expected utility score 0)

Turn 8:

O O X

X X O

O X

Waiting on human player...

Player selects position 8

Turn 9:

O O X

X X O

O X X

Game complete.

Draw.

Out code plays the way as we expected, and we cannot beat it.

The value of Evaluated and Expanded are reducing dramatically when we are having more moves. It meets our expectation since when we are making another movement, the possible outcome is reduced. However, the program still makes some bad decisions, instead of trying to win the game, it selected an unprofitable path.

1. Done
2. tictactoe\_minimax\_alphabeta(board,cpu\_player,cur\_player,alpha,beta)

Turn 0:

Waiting on human player...

Player selects position 4

Turn 1:

X

Waiting on CPU player...

Complete. (Evaluated 2459 states, Expanded 1412 states)

CPU selects position 0 (Expected utility score 0)

Turn 2:

O

X

Waiting on human player...

Player selects position 5

Turn 3:

O

X X

Waiting on CPU player...

Complete. (Evaluated 187 states, Expanded 105 states)

CPU selects position 3 (Expected utility score 0)

Turn 4:

O

O X X

Waiting on human player...

Player selects position 6

Turn 5:

O

O X X

X

Waiting on CPU player...

Complete. (Evaluated 29 states, Expanded 18 states)

CPU selects position 2 (Expected utility score 0)

Turn 6:

O O

O X X

X

Waiting on human player...

Player selects position 1

Turn 7:

O X O

O X X

X

Waiting on CPU player...

Complete. (Evaluated 5 states, Expanded 3 states)

CPU selects position 7 (Expected utility score 0)

Turn 8:

O X O

O X X

X O

Waiting on human player...

Player selects position 8

Turn 9:

O X O

O X X

X O X

Game complete.

Draw.

Turn 0:

Waiting on human player...

Player selects position 4

Turn 1:

X

Waiting on CPU player...

Complete. (Evaluated 2459 states, Expanded 1412 states)

CPU selects position 0 (Expected utility score 0)

Turn 2:

O

X

Waiting on human player...

Player selects position 1

Turn 3:

O X

X

Waiting on CPU player...

Complete. (Evaluated 327 states, Expanded 195 states)

CPU selects position 7 (Expected utility score 0)

Turn 4:

O X

X

O

Waiting on human player...

Player selects position 8

Turn 5:

O X

X

O X

Waiting on CPU player...

Complete. (Evaluated 43 states, Expanded 27 states)

CPU selects position 2 (Expected utility score 0)

Turn 6:

O X O

X

O X

Waiting on human player...

Player selects position 3

Turn 7:

O X O

X X

O X

Waiting on CPU player...

Complete. (Evaluated 5 states, Expanded 3 states)

CPU selects position 5 (Expected utility score 0)

Turn 8:

O X O

X X O

O X

Waiting on human player...

Player selects position 6

Turn 9:

O X O

X X O

X O X

Game complete.

Draw.

Turn 0:

Waiting on human player...

Player selects position 2

Turn 1:

X

Waiting on CPU player...

Complete. (Evaluated 3648 states, Expanded 2143 states)

CPU selects position 4 (Expected utility score 0)

Turn 2:

X

O

Waiting on human player...

Player selects position 8

Turn 3:

X

O

X

Waiting on CPU player...

Complete. (Evaluated 295 states, Expanded 171 states)

CPU selects position 5 (Expected utility score 0)

Turn 4:

X

O O

X

Waiting on human player...

Player selects position 3

Turn 5:

X

X O O

X

Waiting on CPU player...

Complete. (Evaluated 47 states, Expanded 29 states)

CPU selects position 0 (Expected utility score 0)

Turn 6:

O X

X O O

X

Waiting on human player...

Player selects position 7

Turn 7:

O X

X O O

X X

Waiting on CPU player...

Complete. (Evaluated 5 states, Expanded 3 states)

CPU selects position 6 (Expected utility score 0)

Turn 8:

O X

X O O

O X X

Waiting on human player...

Player selects position 1

Turn 9:

O X X

X O O

O X X

Game complete.

Draw.

The value of Evaluated and Expanded are reducing dramatically when we are having more moves. It meets our expectation since when we are making another movement, the possible outcome is reduced. And the program is no-longer making unprofitable movements.

1. D

MiniMax:

Turn 0:

Waiting on CPU player...

Complete. (Evaluated 549946 states, Expanded 294778 states)

CPU selects position 0 (Expected utility score 0)

Turn 1:

X

Waiting on human player...

Player selects position 4

Turn 2:

X

O

Waiting on CPU player...

Complete. (Evaluated 7332 states, Expanded 3864 states)

CPU selects position 1 (Expected utility score 0)

Turn 3:

X X

O

Waiting on human player...

Player selects position 2

Turn 4:

X X O

O

Waiting on CPU player...

Complete. (Evaluated 198 states, Expanded 104 states)

CPU selects position 6 (Expected utility score 0)

Turn 5:

X X O

O

X

Waiting on human player...

Player selects position 3

Turn 6:

X X O

O O

X

Waiting on CPU player...

Complete. (Evaluated 14 states, Expanded 8 states)

CPU selects position 5 (Expected utility score 0)

Turn 7:

X X O

O O X

X

Waiting on human player...

Player selects position 8

Turn 8:

X X O

O O X

X O

Waiting on CPU player...

Complete. (Evaluated 2 states, Expanded 1 states)

CPU selects position 7 (Expected utility score 0)

Turn 9:

X X O

O O X

X X O

Game complete.

Draw.

MiniMax w/ Alpha-Beta Pruning:

Turn 0:

Waiting on CPU player...

Complete. (Evaluated 20866 states, Expanded 12413 states)

CPU selects position 0 (Expected utility score 0)

Turn 1:

X

Waiting on human player...

Player selects position 4

Turn 2:

X

O

Waiting on CPU player...

Complete. (Evaluated 871 states, Expanded 525 states)

CPU selects position 1 (Expected utility score 0)

Turn 3:

X X

O

Waiting on human player...

Player selects position 2

Turn 4:

X X O

O

Waiting on CPU player...

Complete. (Evaluated 64 states, Expanded 38 states)

CPU selects position 6 (Expected utility score 0)

Turn 5:

X X O

O

X

Waiting on human player...

Player selects position 3

Turn 6:

X X O

O O

X

Waiting on CPU player...

Complete. (Evaluated 10 states, Expanded 6 states)

CPU selects position 5 (Expected utility score 0)

Turn 7:

X X O

O O X

X

Waiting on human player...

Player selects position 8

Turn 8:

X X O

O O X

X O

Waiting on CPU player...

Complete. (Evaluated 2 states, Expanded 1 states)

CPU selects position 7 (Expected utility score 0)

Turn 9:

X X O

O O X

X X O

Game complete.

Draw.

Compare to two algorithms, MiniMax w/ Alpha-Beta Pruning have relatively few numbers of Evaluated and Expanded states. Results meet our expectation, but it is unexpected that both algorithms chose the exact same path.

MiniMax:

Turn 0:

Waiting on CPU player...

Complete. (Evaluated 549946 states, Expanded 294778 states)

CPU selects position 4 (Expected utility score 0)

Turn 1:

X

Waiting on human player...

Player selects position 0

Turn 2:

O

X

Waiting on CPU player...

Complete. (Evaluated 6812 states, Expanded 3614 states)

CPU selects position 1 (Expected utility score 0)

Turn 3:

O X

X

Waiting on human player...

Player selects position 7

Turn 4:

O X

X

O

Waiting on CPU player...

Complete. (Evaluated 258 states, Expanded 150 states)

CPU selects position 3 (Expected utility score 0)

Turn 5:

O X

X X

O

Waiting on human player...

Player selects position 5

Turn 6:

O X

X X O

O

Waiting on CPU player...

Complete. (Evaluated 16 states, Expanded 10 states)

CPU selects position 2 (Expected utility score 0)

Turn 7:

O X X

X X O

O

Waiting on human player...

Player selects position 6

Turn 8:

O X X

X X O

O O

Waiting on CPU player...

Complete. (Evaluated 2 states, Expanded 1 states)

CPU selects position 8 (Expected utility score 0)

Turn 9:

O X X

X X O

O O X

Game complete.

Draw.

MiniMax w/ Alpha-Beta Pruning:

Turn 0:

Waiting on CPU player...

Complete. (Evaluated 12826 states, Expanded 7365 states)

CPU selects position 4 (Expected utility score 0)

Turn 1:

X

Waiting on human player...

Player selects position 0

Turn 2:

O

X

Waiting on CPU player...

Complete. (Evaluated 832 states, Expanded 497 states)

CPU selects position 1 (Expected utility score 0)

Turn 3:

O X

X

Waiting on human player...

Player selects position 7

Turn 4:

O X

X

O

Waiting on CPU player...

Complete. (Evaluated 105 states, Expanded 67 states)

CPU selects position 3 (Expected utility score 0)

Turn 5:

O X

X X

O

Waiting on human player...

Player selects position 5

Turn 6:

O X

X X O

O

Waiting on CPU player...

Complete. (Evaluated 12 states, Expanded 8 states)

CPU selects position 2 (Expected utility score 0)

Turn 7:

O X X

X X O

O

Waiting on human player...

Player selects position 6

Turn 8:

O X X

X X O

O O

Waiting on CPU player...

Complete. (Evaluated 2 states, Expanded 1 states)

CPU selects position 8 (Expected utility score 0)

Turn 9:

O X X

X X O

O O X

Game complete.

Draw.

The new move\_expand\_order will slightly reduce the number of Evaluated, Expanded for MiniMax. However, the new move\_expand\_order significantly reduced the number of Evaluated, Expanded for MiniMax with Alpha-Beta Pruning (~8000 Evaluated, ~5000 Expanded).

MiniMax

Evaluated, Expanded

549946,294778

7332,3864

198,104

14,8

2,1

MiniMax w/ new move\_expand\_order

Evaluated, Expanded

549946,294778

6812,3614

258,150

16,10

2,1

MiniMax w/ Alpha-Beta Pruning

Evaluated, Expanded

20866,12413

871,525

64,38

10,6

2,1

MiniMax w/ new move\_expand\_order, Alpha-Beta Pruning

Evaluated, Expanded

12826,7365

832,497

105,67

12,8

2,1