```
Yan Zhen, Yifan Yao
                                           X
                                                0
                                                      Х
                                           X
                                                 0
                                                      0
CSE 3521
                                           is terminal() returns
Homework #4
                                           utility() returns 1
                                           (w.r.t. human player
  a. is terminal() and utility(board,
                                           selection)
     player)
                                        b. Done
     Testing board:
                                        c. tictactoe_minimax(board,cpu_player,
                                           cur_player)
     X
                                           Turn 1:
     is terminal() returns
     false
                                           Waiting on CPU player...
     utility() returns 0
                                           Complete. (Evaluated
     (w.r.t. human player
                                           55505 states, Expanded
     selection)
                                           29633 states)
     Testing board:
                                           CPU selects position 0
                                           (Expected utility score
                                           0)
          X
                                           Turn 2:
     is terminal() returns
     false
                                           0
     utility() returns 0
                                           Waiting on human
     (w.r.t. human player
                                           player...
     selection)
                                           Player selects position
     Testing board:
     X
          X
                0
                                           Turn 3:
     X
          0
                X
                                           0
                                                 Х
     is terminal() returns
                                           X
     false
                                           Waiting on CPU player...
     utility() returns 0
                                           Complete. (Evaluated
     (w.r.t. human player
                                           1055 states, Expanded
     selection)
                                           582 states)
     Testing board:
```

X

X

0

CPU selects position 7 (Expected utility score 0)	Complete. (Evaluated 5 states, Expanded 3 states)
Turn 4:	CPU selects position 2 (Expected utility score
O X X	0)
O Waiting on human	Turn 8:
player	O X O O X X
Player selects position 5	<pre>X</pre>
Turn 5:	Player selects position
O X X X	8
O Waiting on CPU player	Turn 9:
Complete. (Evaluated 47	O
states, Expanded 26	X O X
states)	Game complete.
CPU selects position 3 (Expected utility score 0)	Draw.
Turn 6:	Turn 0:
O X O X X	Waiting on human player
O Waiting on human player	Player selects position 2
Player selects position	Turn 1:
6	X Waiting on CPU player
Turn 7:	Complete. (Evaluated
0 X	59705 states, Expanded
O X X X X X O	31973 states)
Waiting on CPU player	

CPU selects position 4 (Expected utility score 0)	Complete. (Evaluated 47 states, Expanded 26 states)
Turn 2:	CPU selects position 8 (Expected utility score 0)
O Waiting on human player	Turn 6:
Player selects position 6	O X X O Waiting on human
Turn 3:	player
X O X	Player selects position 0
Waiting on CPU player	Turn 7:
Complete. (Evaluated 1053 states, Expanded 533 states)	X O X O X X O Waiting on CPU player
CPU selects position 1 (Expected utility score 0)	Complete. (Evaluated 5 states, Expanded 3 states)
Turn 4:	CPU selects position 3
O X O X	(Expected utility score 0)
Waiting on human player	Turn 8:
Player selects position 7 Turn 5:	X O X O O X X O Waiting on human player
O X O	Player selects position 5
X X Waiting on CPU player	Turn 9:
	x o x

O O X	
X X O	CPU selects position 6
Game complete.	(Expected utility score
	0)
Draw.	
	Turn 4:
Turn 0:	0
	X
Waiting on human	O X
player	Waiting on human
Distance delegate modition	player
Player selects position 7	Player selects position
1	4
Turn 1:	-
14111 1	Turn 5:
X	
Waiting on CPU player	0
	X X
Complete. (Evaluated	O X
63905 states, Expanded	Waiting on CPU player
34313 states)	Complete (Erralyated 51
CDU gologka mogition 1	Complete. (Evaluated 51 states, Expanded 30
CPU selects position 1 (Expected utility score	states)
0)	500005)
• /	CPU selects position 5
Turn 2:	(Expected utility score
	0)
0	
X	Turn 6:
Waiting on human	
player	O X X O
Player selects position	X X O
3	Waiting on human
3	player
Turn 3:	
	Player selects position
0	2
X	
X	Turn 7:
Waiting on CPU player	0 4
Complete (Proplets)	O X X X O
Complete. (Evaluated	X X O
1421 states, Expanded 805 states)	Waiting on CPU player
ous states;	"arcring on cro prayer

Complete. (Evaluated 5
states, Expanded 3
states)

CPU selects position 0 (Expected utility score 0)

Turn 8:

O O X

Waiting on human player...

Player selects position

Turn 9:

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.

- d. Done
- e. 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:

0

O X X

```
Waiting on human
player...
                                    0
                                          X
                                               0
                                    0
                                          Х
                                               Х
Player selects position
                                    X
                                          0
                                    Waiting on human
                                    player...
Turn 5:
                                    Player selects position
0
0
     Х
          Х
                                    Turn 9:
Waiting on CPU player...
                                    0
                                          X
                                               0
Complete. (Evaluated 29
                                    0
                                          X
                                               Χ
states, Expanded 18
                                    X
                                          0
states)
                                    Game complete.
CPU selects position 2
                                    Draw.
(Expected utility score
0)
                                    Turn 0:
Turn 6:
                                    Waiting on human
O
          0
                                    player...
0
     Х
          X
                                    Player selects position
Waiting on human
player...
                                    Turn 1:
Player selects position
                                    Waiting on CPU player...
Turn 7:
                                    Complete. (Evaluated
0
     X
          0
                                     2459 states, Expanded
0
     X
          X
                                    1412 states)
Х
Waiting on CPU player...
                                    CPU selects position 0
                                     (Expected utility score
Complete. (Evaluated 5
                                    0)
states, Expanded 3
states)
                                    Turn 2:
CPU selects position 7
                                    0
(Expected utility score
                                    X
0)
                                    Waiting on human
                                    player...
Turn 8:
```

```
Player selects position
                                    Waiting on human
                                    player...
Turn 3:
                                    Player selects position
0
     Х
                                    Turn 7:
Waiting on CPU player...
                                    0
                                          Х
                                               0
Complete. (Evaluated 327
                                    Х
                                          X
states, Expanded 195
                                    Waiting on CPU player...
states)
CPU selects position 7
                                    Complete. (Evaluated 5
(Expected utility score
                                    states, Expanded 3
0)
                                    states)
Turn 4:
                                    CPU selects position 5
                                     (Expected utility score
0
     Χ
                                    0)
X
                                    Turn 8:
Waiting on human
player...
                                    O
                                          X
                                               0
                                    Х
                                          X
Player selects position
                                          X
                                    Waiting on human
                                    player...
Turn 5:
                                    Player selects position
0
     Χ
Х
     X
                                    Turn 9:
Waiting on CPU player...
                                    0
                                          X
                                               0
Complete. (Evaluated 43
                                    X
                                          X
                                               0
states, Expanded 27
                                    X
                                          0
                                               Χ
states)
                                    Game complete.
CPU selects position 2
                                    Draw.
(Expected utility score
0)
                                    Turn 0:
Turn 6:
                                    Waiting on human
0
     X
         0
                                    player...
Χ
```

0

Х

```
Player selects position
                                    Player selects position
Turn 1:
                                    Turn 5:
X
Waiting on CPU player...
                                    X
                                    Х
                                          0
                                               0
Complete. (Evaluated
3648 states, Expanded
                                    Waiting on CPU player...
2143 states)
                                    Complete. (Evaluated 47
CPU selects position 4
                                    states, Expanded 29
(Expected utility score
                                    states)
0)
                                    CPU selects position 0
Turn 2:
                                     (Expected utility score
                                     0)
X
                                    Turn 6:
Waiting on human
player...
                                    0
                                               Χ
                                          0
                                    X
                                               0
Player selects position
                                    Waiting on human
                                    player...
Turn 3:
                                    Player selects position
Х
0
Х
                                    Turn 7:
Waiting on CPU player...
                                    O
                                               Х
Complete. (Evaluated 295
                                    X
                                          0
                                               0
states, Expanded 171
                                    Χ
                                          Х
states)
                                    Waiting on CPU player...
CPU selects position 5
                                    Complete. (Evaluated 5
(Expected utility score
                                    states, Expanded 3
0)
                                    states)
Turn 4:
                                    CPU selects position 6
                                     (Expected utility score
Χ
                                    0)
0
     0
                                    Turn 8:
Waiting on human
player...
                                    0
                                               Х
```

	X 0 0 O X X Waiting on human	Player selects position 4
	player	Turn 2:
	Player selects position 1	X O Waiting on CPU player
	Turn 9:	Complete. (Evaluated
	O X X X X X O O O O X X	7332 states, Expanded 3864 states)
	Game complete. Draw.	CPU selects position 1 (Expected utility score 0)
		·
	The value of Evaluated and Expanded are reducing dramatically	Turn 3:
	when we are having more moves. It meets our expectation since when we	X X O
	are making another movement, the	Waiting on human
	possible outcome is reduced. And the program is no-longer making	player
	unprofitable movements.	Player selects position 2
f.	D	Turn 4:
	MiniMax:	X X O
	Turn 0:	0
	Waiting on CPU player	Waiting on CPU player
	Complete. (Evaluated 549946 states, Expanded 294778 states)	Complete. (Evaluated 198 states, Expanded 104 states)
	CPU selects position 0 (Expected utility score 0)	CPU selects position 6 (Expected utility score 0)
	Turn 1:	Turn 5:
	X Waiting on human player	X X O O X Waiting on human player

Player selects position 3	O O X X X O Game complete.
Turn 6:	Draw.
X X O O O X	MiniMax w/ Alpha-Beta Pruning:
Waiting on CPU player	Turn 0:
Complete. (Evaluated 14 states, Expanded 8 states)	Waiting on CPU player Complete. (Evaluated
CPU selects position 5 (Expected utility score	20866 states, Expanded 12413 states)
0) Turn 7:	CPU selects position 0 (Expected utility score 0)
X X O O O X X	Turn 1:
Waiting on human player	X Waiting on human player
Player selects position 8	Player selects position 4
Turn 8:	Turn 2:
X X O O O X X O Waiting on CPU player	X O Waiting on CPU player
Complete. (Evaluated 2 states, Expanded 1 states)	Complete. (Evaluated 871 states, Expanded 525 states)
CPU selects position 7 (Expected utility score 0)	CPU selects position 1 (Expected utility score 0)
Turn 9:	Turn 3:
х х о	X X O

Waiting on human player Player selects position 2	X X O O O X X Waiting on human player
Turn 4:	Player selects position 8
X X O O Waiting on CPU player Complete. (Evaluated 64 states, Expanded 38 states)	Turn 8: X X O O O X X O Waiting on CPU player
CPU selects position 6 (Expected utility score 0)	Complete. (Evaluated 2 states, Expanded 1 states)
Turn 5: X X O O X Waiting on human	CPU selects position 7 (Expected utility score 0) Turn 9:
<pre>player Player selects position 3</pre>	X X O O X X X O Game complete.
Turn 6:	Draw.
X X O O O X Waiting on CPU player Complete. (Evaluated 10 states, Expanded 6 states)	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.
CPU selects position 5 (Expected utility score 0) Turn 7:	MiniMax: Turn 0: Waiting on CPU player

Complete. (Evaluated	Complete. (Evaluated 258
549946 states, Expanded 294778 states)	states, Expanded 150 states)
CPU selects position 4 (Expected utility score 0)	CPU selects position 3 (Expected utility score 0)
Turn 1:	Turn 5:
X Waiting on human player Player selects position	O X X X O Waiting on human player
0	F = 3.7 C = 1 1 1
Turn 2:	Player selects position 5
O X	Turn 6:
Waiting on CPU player	O X X X O
Complete. (Evaluated 6812 states, Expanded 3614 states)	O Waiting on CPU player
CPU selects position 1 (Expected utility score 0)	Complete. (Evaluated 16 states, Expanded 10 states)
Turn 3:	CPU selects position 2 (Expected utility score 0)
O X	,
X Waiting on human	Turn 7:
player	$egin{array}{cccc} O & X & X & X \\ X & X & O & & & \end{array}$
Player selects position 7	O Waiting on human
Turn 4:	player
О Х	Player selects position 6
X O	Turn 8:
Waiting on CPU player	o x x

X X O O O Waiting on CPU player	X Waiting on CPU player
Complete. (Evaluated 2 states, Expanded 1 states)	Complete. (Evaluated 832 states, Expanded 497 states)
CPU selects position 8 (Expected utility score 0)	CPU selects position 1 (Expected utility score 0)
Turn 9: O X X X X O	Turn 3: O X X Waiting on human
O O X Game complete.	player
Draw.	Player selects position 7
MiniMax w/ Alpha-Beta Pruning:	Turn 4:
Turn 0:	O X X O
Waiting on CPU player	Waiting on CPU player
Complete. (Evaluated 12826 states, Expanded 7365 states)	Complete. (Evaluated 105 states, Expanded 67 states)
CPU selects position 4 (Expected utility score 0)	CPU selects position 3 (Expected utility score 0)
Turn 1:	Turn 5:
X Waiting on human player	O X X X O Waiting on human
Player selects position 0	player Player selects position
Turn 2:	5
0	Turn 6:

0 X Х Х 0 0 Waiting on CPU player... Complete. (Evaluated 12 states, Expanded 8 states) CPU selects position 2 (Expected utility score 0) Turn 7: 0 Х Х Х Х 0 Waiting on human player... Player selects position 6 Turn 8: 0 Х Х Χ Х 0 Waiting on CPU player... Complete. (Evaluated 2 states, Expanded 1 states) CPU selects position 8 (Expected utility score 0) Turn 9: 0 X Χ X X 0 0 0 Х 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