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1. [2 marks] in tic-tac-toe program `tt24.py`, about how many nodes are in each of the following? For each answer, use one of these numbers: 1000, 4000, 8000, 16000, 32000, 60000, 300000, 600000, 900000.

   a) tree of all continuations of the game ____________

   b) tree of all continuations of the game if we prune isomorphic positions ____________

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2. [4 marks] a) In this `tic-tac-toe` code, where can you insert line `if so_far == 1: break`
   so that `negamax()` is still correct? answer: immediately after line ____

```
 5) def negamax(d, psn, ptm): # 1/0/-1 win/draw/loss
 6)     if psn.has_win(opponent(ptm)): return -1
 7)     L = psn.legal_moves()
 8)     if len(L) == 0: return 0
 9)     so_far = -1
10)     for cell in L:
11)         psn.brd[cell] = ptm
12)         nmx = negamax(d+1, psn, opponent(ptm))
13)         so_far = max(so_far, -nmx)
14)         psn.brd[cell] = Cell.e
15)     return so_far
```

   b) From the empty board position, what is the ratio
   (calls made after making change in a))/(calls made before change)? **Circle only one answer.**

   1/2 1/3 1/6 5/6 2/3

3. [2 marks] x-bias tic-tac-toe (xttt) is this game: `x` gets 3-in-a-row: `x` win, `o` loss, game ends; `o` gets 3-in-a-row: game continues; board full and `x` did not win: draw. Modify this function (from `tt24.py`) (insert/delete/change one or more lines) so that `tt24.py` plays xttt.

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0)  def has_win(self, z):                          explain your changes here
1)    for t in Win_lines:
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5)        return True
6)    return False
```

4. [4 marks] For the nim position below,

   i) the number of winning moves is ________

   ii) one winning move is to remove ________ stones from pile ________ .

pile	size	binary	SHOW YOUR WORK FOR ii) HERE
a	15	1 1 1 1	
b	27	1 1 0 1 1	
c	14	1 1 1 0	
d	25	1 1 0 0 1	

5. [2 marks] Here is the end condition for the game of nim:

   if it is your turn and the total number of stones left is 0 then you lose.

   Pim is similar to nim, except it has this end condition:

   if it is your turn and the total number of stones left is 0 or 1 then the game ends and you lose, e.g. pim(0 0 0) and pim(0 0 1) are losing positions.

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position	value	position	value	position	value	position	value
(0 0 0)	L	(0 1 1)	___	(1 1 1)	___	(0 2 2)	___
(0 0 1)	___	(0 0 3)	___	(0 0 4)	___	(1 1 2)	___
(0 0 2)	___	(0 1 2)	___	(0 1 3)	___		

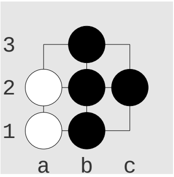
6. [2 marks] Find a 3-pile nim position with exactly 2 winning moves or explain why no such position exists.

7. [2 marks] For each tic-tac-toe position with `x` to play, give `x`'s minimax score `x` ($-1/0/1$ lose/draw/win).

```
      o . .      . . .      . . .      . . .      o . .      . . .
      . . .      . o .      . x o      . x .      . . x      . . x
      . . x      . . x      . . .      . . o      . . .      . . o

score ___        ___        ___        ___        ___        ___
```

8. [6 marks] Here is a go position after 1.B[b1] 2.W[a2] 3.B[b2] 4.W[c3] 5.B[b3] 6.W[a1] 7.B[c2] 8.W[pass]. a) From this position for black to play, draw a strategy tree for black with minimax score $B - W = +9$.



```
. x .
o x x
o x .
```

b) After move 1 above, give a move 2 that is better for white than move 2 above.

your move: `2.W[____]`

your move's $B - W$ minimax score ________

c) After move 5, black knew that it could score +9 by a theoretical property discussed in the lectures. Explain the property.

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```
. . .        . . o        . . .        . . .        . . .        . . o
. . .        . . .        . x .        . x .        . o .        . . .
. x o        . x .        . . o        . o .        x . .        x . .

score ___     ___          ___          ___          ___          ___
```

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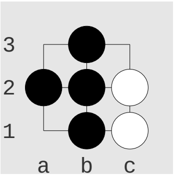

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```
. . .       . . .       . x o       . x .       . . x       . . x
. x .       . x .       . . .       . . .       . o .       . . .
. . o       . o .       . . .       . . o       . . .       o . .

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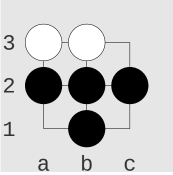

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