# COMP 472 AI Mini-Project 2

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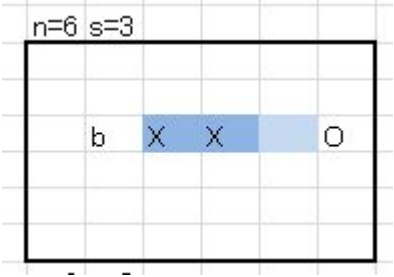
# *Description of Heuristics*

Two heuristics, e1 and e2, were implemented to estimate how favorable each state of the game tree is for the white box player compared to the black box player.

***Heuristic e1***

- e1 is the simple and fast heuristic.
- It is calculated by summing up the total possible wins (horizontal, vertical, diagonal, and anti-diagonal) of both players and then subtracting the total possible wins of white box player by that of the black box player for each state.

# *Heuristic e2: Evaluating the Attack*

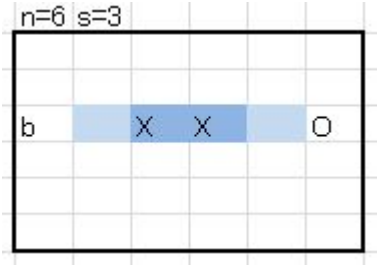



-Find the blue (light and dark) counts of each section.

-Consider only those with minimum length.

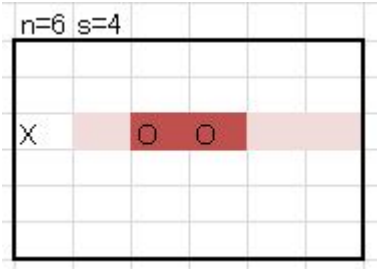
-Count the dark blue cells of the section.

-Points given depend on the progress to win.

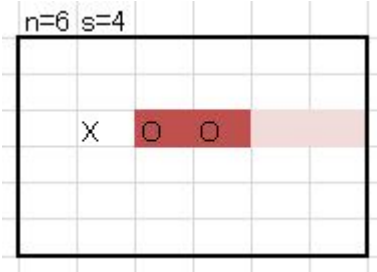



-Sections that are longer than the minimum have a better chance to win.
-Points from longer sections will be weighted higher.
-This makes it so the heuristic is incentivised to block the opponent by shortening their sections with the highest progress.

# *Incentivizing Defence*

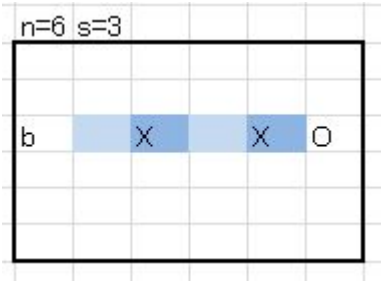


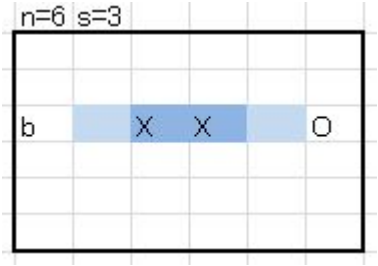

-The X shortens the highlighted section for O, but there's a better way to block.
(Here, O can force a win-in-two)




-The X shortens the highlighted section better.
(Here, O cannot force a win-in-two)
X will prefer this one, since O's section length gets reduced more.

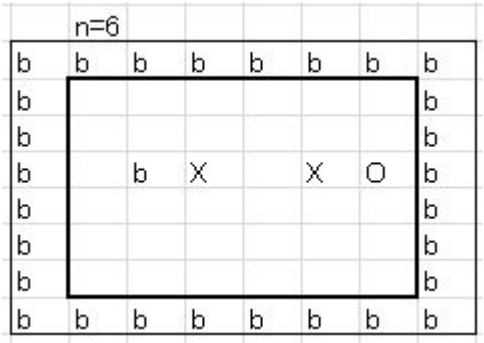
# *Weakness*




-Since the evaluated progress of a section does not make a distinction on the specific position of the pieces inside the section,
… It can lead to an inferior position being ranked the same as a higher one
.
(X could've guaranteed a win instead.)

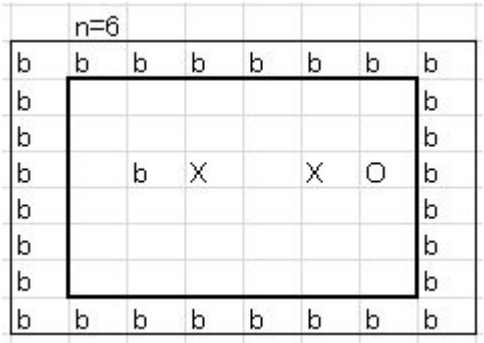
# *Internally*




-Flatten the board into 1D, to fit np.split's format.
-Split on cells that are the opposing player's or a bloc. (np.split will keep the separator in the split as the first element, so just ignore the first element.)

-However, when the board gets flattened, there's no longer a distinction between different rows/column/diagonals.
-So surround the board with blocs. That way, when it splits on those blocs, it also splits on rows/column/diagonals.
-This bloc surround is done on a copy of the board. The actual board is unaffected.

# Internally




For each split:

-Compare the length of the split to the minimum length.

-The weight of the split has exponential growth.

-Evaluate the player's progress to win (num of pieces) of the split. This value has exponential growth.

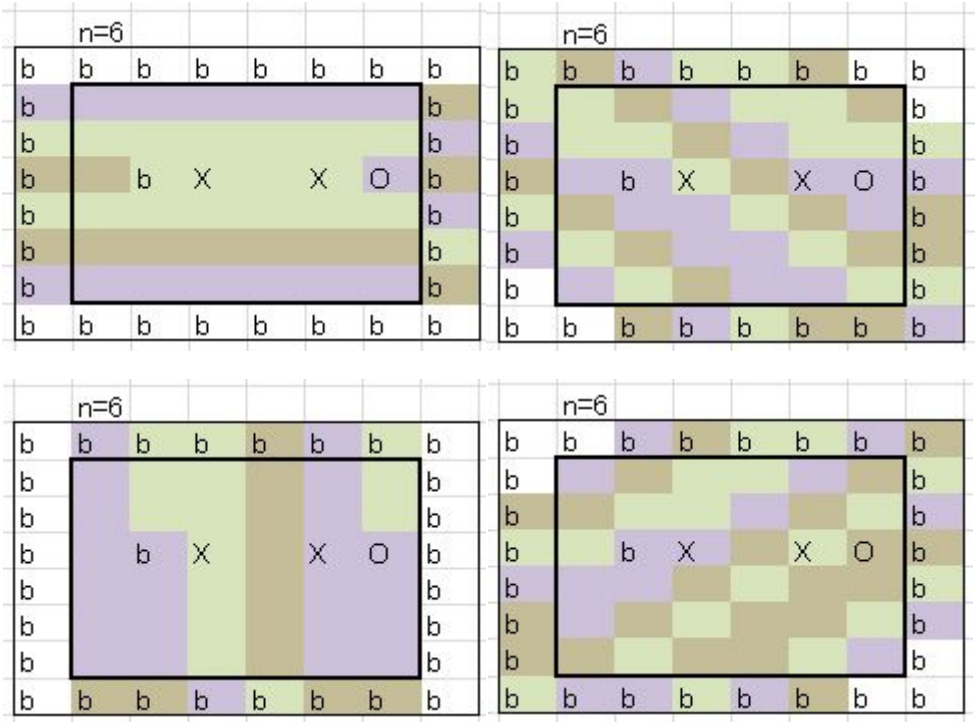
-Compute the product of these two.

(Only the best lines matter, and many equally good lines give more points than a single one.)

-Gather the sum of all splits' product.

-The heuristic is the difference of this sum between the two players.

# Internally




-Highlighted alternating horizontal, vertical, diagonals splits for X (3-colors)
(colors are visual only, the heuristic only cares about the split, not the 3-parity.)

# Result - Scoreboard for GameTrace-4335

4. Game wins:
Player e1 wins, ratio: 3, 30.00%
Player e2 wins, ratio: 7, 70.00%

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:
i Average evaluation time: 4.055583727927435
ii Total states visited: 4903.428571428572
iii Average AD: 5.470677244818484
iv Total evaluations by depth: {depth 0: 0.0, depth 1: 1.5714285714285714, depth 2: 4.428571428571429, depth 3: 35.57142857142857, depth 4: 130.85714285714286, depth 5: 443.42857142857144, depth 6: 4287.571428571428}
v Average ARD: 4.553138486214592
vi Total number of moves: 3.7142857142857144

Summary of the game heuristics e1:
i Average evaluation time: 4.307752829506284
ii Total states visited: 8925.57142857143
iii Average AD: 5.665938858900193
iv Total evaluations by depth: {depth 0: 0.0, depth 1: 0.8571428571428571, depth 2: 8.285714285714286, depth 3: 30.571428571428573, depth 4: 191.57142857142858, depth 5: 622.5714285714286, depth 6: 8071.714285714285}
v Average ARD: 4.624884574200051
vi Total number of moves: 3.2857142857142856

# Result - Scoreboard for GameTrace-4331

4. Game wins:
Player e1 wins, ratio: 4, 40.00%
Player e2 wins, ratio: 6, 60.00%

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:
i Average evaluation time: 11.583941706376915
ii Total states visited: 614.8329744754118
iii Average AD: 15.101025660889894
iv Total evaluations by depth: {depth 0: 55.03297447541181, depth 1: 56.43297447541181, depth 2: 57.632974475411814, depth 3: 68.93297447541181, depth 4: 91.73297447541181, depth 5: 121.13297447541181, depth 6: 494.03297447541183}
v Average ARD: 14.542896911884451
vi Total number of moves: 3.1

Summary of the game heuristics e1:
i Average evaluation time: 12.204780103475885
ii Total states visited: 914.8572125599337
iii Average AD: 15.984081656586152
iv Total evaluations by depth: {depth 0: 58.85721255993364, depth 1: 59.557212559933646, depth 2: 61.057212559933646, depth 3: 69.45721255993365, depth 4: 83.65721255993364, depth 5: 150.25721255993363, depth 6: 785.9572125599336}
v Average ARD: 16.033999726886577
vi Total number of moves: 2.8

# Result - Scoreboard for GameTrace-5441

4. Game wins:
Player e1 wins, ratio: 3, 30.00%
Player e2 wins, ratio: 7, 70.00%

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:
i Average evaluation time: 0.7018343461884392
ii Total states visited: 811.2222222222222
iii Average AD: 4.118552916853067
iv Total evaluations by depth: {depth 0: 0.0, depth 1: 1.1111111111111112, depth 2: 206.11111111111111, depth 3: 4.777777777777778, depth 4: 2.0, depth 5: 25.77777777777778, depth 6: 571.4444444444445}
v Average ARD: 3.8929402600836687
vi Total number of moves: 4.555555555555555

Summary of the game heuristics e1:
i Average evaluation time: 4.949893800575449
ii Total states visited: 718.2004903015015
iii Average AD: 7.853361933880544
iv Total evaluations by depth: {depth 0: 23.700490301501468, depth 1: 23.80049030150147, depth 2: 137.20049030150147, depth 3: 23.700490301501468, depth 4: 27.700490301501468, depth 5: 24.10049030150147, depth 6: 601.3004903015014}
v Average ARD: 7.407152162132805
vi Total number of moves: 3.8

# Result - Scoreboard for GameTrace-5445

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e1:

i Average evaluation time: 66.31650795758372

ii Total states visited: 9699.89921309948

iii Average AD: 68.19852720764304

iv Total evaluations by depth: {depth 0: 315.5992130994797, depth 1: 316.5992130994797, depth 2: 317.0992130994797, depth 3: 328.89921309947965, depth 4: 336.9992130994797, depth 5: 464.69921309947966, depth 6: 9513.59921309948}

v Average ARD: 67.89214604885568

vi Total number of moves: 5.3

4. Game wins:
Player e1 wins, ratio: 4, 40.00%
Player e2 wins, ratio: 4, 40.00%

Summary of the game heuristics e2:
i Average evaluation time: 71.34416187473772
ii Total states visited: 6486.196425512862
iii Average AD: 72.72056789005983
iv Total evaluations by depth: {depth 0: 341.09642551286214, depth 1: 341.79642551286213, depth 2: 344.89642551286215, depth 3: 349.89642551286215, depth 4: 387.89642551286215, depth 5: 448.79642551286213, depth 6: 6318.396425512862}
v Average ARD: 72.21215090327672
vi Total number of moves: 5.4

# Result - Scoreboard for GameTrace-8655

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:

i Average evaluation time: 205.7757949360148

ii Total states visited: 2349.3836793243563

iii Average AD: 206.15112130128645

iv Total evaluations by depth: {depth 0: 1019.5086793243565, depth 1: 1019.5086793243565, depth 2: 1019.5086793243565, depth 3: 1019.5086793243565, depth 4: 1019.6336793243565, depth 5: 1020.5086793243565, depth 6: 2348.1336793243563}

v Average ARD: 206.18874265148747

vi Total number of moves: 1.875

4. Game wins:
Player e1 wins, ratio: 10, 100.00%
Player e2 wins, ratio: 0, 0.00%

Summary of the game heuristics e1:
i Average evaluation time: 251.48230245355444
ii Total states visited: 3414.9768738911825
iii Average AD: 251.83813318930254
iv Total evaluations by depth: {depth 0: 1249.087985002294, depth 1: 1249.087985002294, depth 2: 1249.087985002294, depth 3: 1249.1990961134052, depth 4: 1249.976873891183, depth 5: 1253.5324294467384, depth 6: 3409.532429446738}
v Average ARD: 251.8467922034689
vi Total number of moves: 1.7777777777777777

# Result - Scoreboard for GameTrace-8651

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:

i Average evaluation time: 0.997014229297638

ii Total states visited: 710.0

iii Average AD: 5.997127187297378

iv Total evaluations by depth: {depth 0: 0.0, depth 1: 0.0, depth 2: 0.0, depth 3: 0.0, depth 4: 0.4, depth 5: 1.2, depth 6: 708.4}

v Average ARD: 5.970900461561143

vi Total number of moves: 3.0

4. Game wins:
Player e1 wins, ratio: 10, 100.00%
Player e2 wins, ratio: 0, 0.00%

Summary of the game heuristics e1:
i Average evaluation time: 6.595381283760072
ii Total states visited: 965.3332481781641
iii Average AD: 10.760747397597664
iv Total evaluations by depth: {depth 0: 28.833248178164165, depth 1: 29.166581511497498, depth 2: 28.99991484483083, depth 3: 28.99991484483083, depth 4: 29.666581511497498, depth 5: 31.333248178164165, depth 6: 961.3332481781641}
v Average ARD: 10.247124985798424
vi Total number of moves: 2.6666666666666665

# Result - Scoreboard for GameTrace-8555

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:

i Average evaluation time: 153.99668866390667

ii Total states visited: 3314.9327434398074

iii Average AD: 154.21985339096958

iv Total evaluations by depth: {depth 0: 795.0994101064742, depth 1: 795.0994101064742, depth 2: 1482.2660767731406, depth 3: 795.2660767731409, depth 4: 795.0994101064742, depth 5: 795.0994101064742, depth 6: 2662.766076773141}

v Average ARD: 154.28863202129483

vi Total number of moves: 3.5

4. Game wins:
Player e1 wins, ratio: 5, 50.00%
Player e2 wins, ratio: 5, 50.00%

Summary of the game heuristics e1:
i Average evaluation time: 37.557495046322714
ii Total states visited: 3088.0836205217497
iii Average AD: 38.24993172819035
iv Total evaluations by depth: {depth 0: 219.5836205217499, depth 1: 219.75028718841656, depth 2: 526.5836205217499, depth 3: 219.91695385508322, depth 4: 219.5836205217499, depth 5: 219.75028718841656, depth 6: 2816.7502871884167}
v Average ARD: 38.11872103215336
vi Total number of moves: 3.3333333333333335

# Result - Scoreboard for GameTrace-8551

5. Average gametrace (Note: Incl. 'Total's reported below have been averaged.):

Summary of the game heuristics e2:

i Average evaluation time: 15.766791955343686

ii Total states visited: 477.5572734375672

iii Average AD: 18.76833002191685

iv Total evaluations by depth: {depth 0: 91.55727343756713, depth 1: 91.70013058042427, depth 2: 162.55727343756712, depth 3: 91.55727343756713, depth 4: 91.55727343756713, depth 5: 91.55727343756713, depth 6: 422.5572734375672}

v Average ARD: 18.764268540327276

vi Total number of moves: 2.0

4. Game wins:
Player e1 wins, ratio: 8, 80.00%
Player e2 wins, ratio: 2, 20.00%

Summary of the game heuristics e1:
i Average evaluation time: 10.587884688883694
ii Total states visited: 463.9288902989227
iii Average AD: 12.099092488284478
iv Total evaluations by depth: {depth 0: 80.0717474417798, depth 1: 80.0717474417798, depth 2: 353.21460458463696, depth 3: 80.0717474417798, depth 4: 80.21460458463694, depth 5: 80.78603315606551, depth 6: 219.50031887035124}
v Average ARD: 12.088565285786043
vi Total number of moves: 2.0

# *Analysis of GameTrace*

On average, heuristic e2 takes less time to run than heuristic e1 on smaller board sizes. It also visits less nodes than e1 because it was implemented to be accurate and it is shown in the above results. On the other hand, with higher board sizes, e1 tends to take less time to run. A similar trend was observed for the number of states visited.

With increasing depth, overall, either one of the player are disqualified for taking too long to compute the next move making the other player win by default. This can be seen in the result where the total number of moves is less than the amount needed to win.(e.g total number of moves = 2.7).

The use of alpha-beta allows to search less heuristic states compared to minimax that evaluates all states. Hence, alpha-beta takes less time to evaluate the states on average. This can be seen in the scoreboard when comparing the result between the gametrace-4331 and 4335. For example, in gametrace-4331 the number of states evaluated for both heuristic using alphabeta were found to be lower than what was observed in the gametrace-4335 which uses minimax.

Finally, the winning ratio between e1 and e2 was favored towards e2 when the board sizes were smaller. As the board size increase , the ratio tend to favor the e1 heuristic. The win ratio in the larger board sizes is dependant on which player gets disqualified first. This can be observed by the number of moves of both being lower than the line-up size.

# *Team Contributions*

Divide tasks with github issues in the second half of MP2.

Some contributions on github were done while pair(/team) programming.

Once we had the results, we analyzed the data together.

We built the presentation slides together.