# Perfect Analysis in miniature Othello

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**Abstract**

More than 20 years has passed after J. Feinstein (1993) found that a perfect play on 6×6 board of Othello gives a 16-20 win for the second player, but standard 8×8 board has not yet been. In this paper, we analyzed for 4×4, 4×6, 4×8, 4×10 and 6×6 boards of Othello. From these results, we discuss which it is, win/loss/draw in 8×8 board or more board.

*Keywords*: perfect analysis, perfect play, Alpha-Beta Pruning, rectangular Othello

## 1. Introduction

Othello is categorized into two-player zero-sum finite deterministic games of perfect information [1]. Games in this class are possible to look ahead in theory, thus if both players play the best move, these are classified into a win, loss or draw game [2].

In 1993, Joel Feinstein found that a perfect play on 6×6 board of Othello gives a 16-20 win for the second player [3]; he looked at 40 billion positions, run time was 2weeks. Then computer Othello surpasses a much more human since more than 20 years has been passed. However, standard 8×8 board of Othello has not been solved (we couldn't find the articles solved it). The cause is that number of the positions is too large: in 8×8 board, perfect analysis in a realistic time is impossible even if we use the latest supercomputer.

In this paper, we show the perfect play of 4×4, 4×6, 4×8, 4×10 and 6×6 boards of Othello. From these results, we discuss the feature of the Othello game in

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8×8 board or more. In Section 2, we introduce the rules of Othello. In Section 3, we introduce computer Othello. In Section 4, we explains perfect play. In Section 5, our experimental results are presented. We ran the perfect analysis in 4×4, 4×6, 4×8, 4×10 and 6×6 board of Othello. In Section 6, we discusses conclusion.

## 2. Othello[‡]

First of all, we will introduce the rules of Othello. See Figure 1. The game always begins with this setup. In the case of Reversi, we put randomly by two in central squares, thus there may be a parallel. One player uses the black side of the pieces (circular chips), the other the white sides. Black always moves first.

Both players put the pieces of own color to an empty board in turn. A player's move consists of outflanking his opponent's the pieces. Then, He flip outflanked the pieces to his color. To outflank means to place the piece on the board so that his opponent's rows of the piece are bordered at each end by the piece of his color. If a player cannot make a move that flips at least one of his opponent the pieces, then he has to pass. If he is able to make a valid move however, then passing is not allowed. The game ends when neither player can make a valid move. The winner is the player who has more the pieces than his opponent.

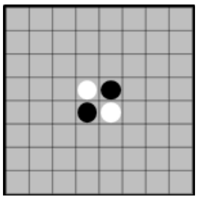

Fig. 1. Board and Starting position.

## 3. Computer Othello

The making of the thinking routines is indispensable in studying perfect analysis of the board game. This is because the end-game routine is the perfect analysis, the evaluation function in the middle-game routine is available for the ordering of the search in perfect analysis.

In addition, end-game is classified into solver for WLD (win/loss/draw) score and solver for exact score. Both the perfect analyses, but there is a difference in the evaluation of the end. In solver for exact score, the end is evaluated with the piece difference. However, it is necessary to consider if one was wiped out in the middle[§] . This routine can find best one move. In solver for WLD score, the end is evaluated in three ways win, loss, and draw. In this way, if the range of the evaluation value is small, pruning (Alpha-Beta Pruning [4]) occurs relatively large. Therefore, the solver for exact score can estimate that it is several times of the execution time by run the first WLD.

### 3.1. *Speed up of the program*

Currently, our program read approximately 1.5-2 million moves per second. There are some ideas for this.

At first, we implemented doubly-linked list storing the empty the pieces. This function reduce search cost so as to go to the end-game. From this, Search speed is approximately two times faster than previous version.

Next, our program had a function to count number of the pieces in specified the color, but we have removed it. Instead, it was adjusted from the time of reversal and restoration by adding a variable that stores number of the pieces into structure. This effect was approximately 1.5 times. In addition, we planned the shift to the Bid Board (way to represent the board in only logical operations and bit shifting) which helped speedup of the processing. Unfortunately, we have not yet implemented it.

## 4. Perfect Play

The perfect play is a sequence when both sides continue to choosing the best move. In computer Othello, the sequence to an end is not saved because we should just find even the best move of next; a return value is sufficient. Because our program is based on the thinking routines for such a game, it has become inefficient program to repeat the perfect analysis again after finding the next move. There is little harmful effect until perfect analysis of the 6×6 board. For example, it will takes 11 months to select the after next

‡ Othello is a registered trademark.

§ For example, in 4×8 board, the evaluation value at **26-0** must be **+32**.

move if we search the board to take one year to perfect analysis.

## 5. Experiments

We derived the perfect play of 4×4, 4×6, 4×8, 4×10 and 6×6 boards. CPU that we used for the experiments is Intel Core i7-4770 processor. First, see Table 1.

Table 1. Execution results of perfect analysis in each Othello board. P means number of the positions, T means execution time and R means results.

| | 4×4 | 6×6 |
|---|---|---|
| P | 218 | 884,392,099,420 |
| T | 0.001s | 5d12h16m |
| R | LOSS(-8)<br>B:3,W:11 | LOSS(-4)<br>B:16,W:20 |

| | 4×6 | 4×8 | 4×10 |
|---|---|---|---|
| P | 139,803 | 294,430,331 | 1,195,804,922,641 |
| T | 0.1s | 2m15s | 6d6h22m |
| R | WIN(+16)<br>B:20,W:4 | WIN(+32)<br>B: 28, W: 0 | WIN(+40)<br>B: 39, W: 0 |

It turned out that the result of 6×6 board is consistent with the result of Feinstein. However, we have took about one week to perfect analysis because number of the positions was about 890 billion. Second, see Table 2.

Table 2. Execution results of perfect analysis in each Reversi board.

| | 4×4 | 6×6 |
|---|---|---|
| P | 524 | 1,628,664,185,199 |
| T | 0.001s | 8d12h42m |
| R | LOSS(-3)<br>B:6,W:9 | LOSS(-2)<br>B:17,W:19 |

| | 4×6 | 4×8 | 4×10 |
|---|---|---|---|
| P | 274,549 | 299,987,758 | 842,204,125,277 |
| T | 0.15s | 2m12sec | 4d12h22m |
| R | WIN(+18)<br>B:21,W:3 | WIN(+32)<br>B: 28, W: 0 | WIN(+40)<br>B: 32, W: 0 |

We ran a similar experiment in Reversi version (starting position is parallel). However, we obtained similar experimental results.

## 6. Conclusion

See Figure 2 and Figure 3. The horizontal axis shows each board and the vertical one shows the ration number of the pieces acquired by the first move relative to the total number of the pieces. The central dashed line shows the boundary of the win/loss. Figure 2 shows the ration is increased in the transition from the 4×4 board to the 6×6 board. Figure 3 shows the feature that the first move becomes advantageous along with the expansion of the board in rectangular Othello.

From these, we guess that the first move will become advantageous along with the expansion of the board in square Othello.

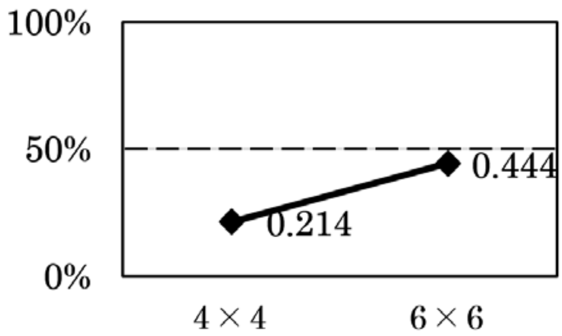


Fig. 2. Ration number of the pieces by first move (square).

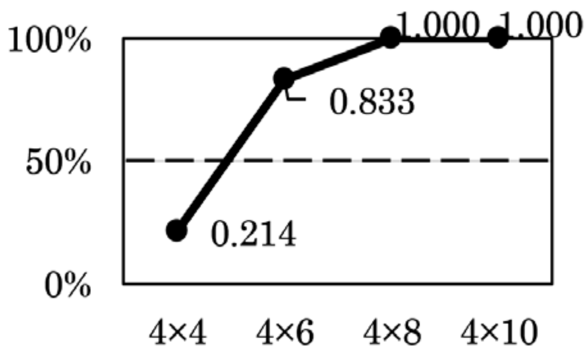


Fig. 3. Ration number of the pieces by first move (rectangle).

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Also, considering the increased range in Figure 2, we consider the standard 8×8 board is likely to be a win for the first move or draw. Moreover, there is a high possibility that first move wins in 10×10 or more board.

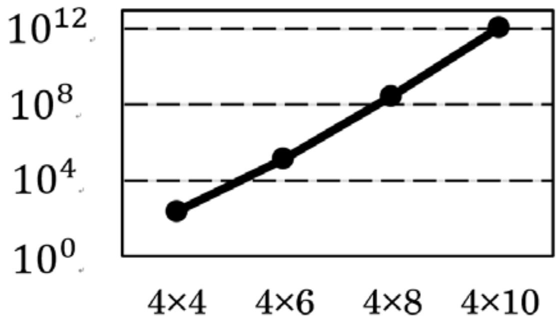


Fig. 4. Number of the positions in rectangular Othello.

Besides, Figure 4 shows the transition in number of the positions in rectangular board. The horizontal axis shows each board size and the vertical one represents number of the positions by the exponent. From this graph, we can see that number of the positions increases curvedly. Additionally, it can be guessed that number of the positions of 4×12 board is about $10^4$ times of 4×10 board.

## 7. Future work

In this paper, we were able to obtain the perfect play of 6×6 board and 4×10. We confirm that this consideration is correct by continue to challenge the perfect analysis which extended this (4×12, 4×14 and 6×8 boards). In addition, in 8×8 board, we continue to further consideration by the perfect analysis of some advanced boards from starting position to occur well in between the high-level players.

### 7.1. *Improvement*

Alpha-Beta Pruning becomes more effective by the move ordering. Because our program is low this quality, it is necessary to improve.

We have to implement a hash table in order to cut the boards with duplicate and symmetry. However, it will slow down the search to take the access time to it.

In addition, we improve the Bid Board mentioned in Section 3.1 and the drawbacks mentioned in Section 4.

## Acknowledgements

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