Analysis for 4×12 board of Othello

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Abstract

More than 20 years has passed since J. Feinstein (1993) found by using computer that perfect play on 6×6 board of Othello gives 16-20 loss for the first player. During this time, computers have improved drastically, however, standard 8×8 board remain unsolved. In our previous paper, we were able to obtain the perfect plays on 6×6 board and 4×10 board. In this paper, we challenge the unsolved problem of 4×12 board by dividing it into about 100 small distinct sub-problems.

Keywords: combinatorial theory, combinatorial optimization, perfect play, rectangular Othello

1. Introduction

Othello is a board game derived from Reversi by Goro Hasegawa (JPN) in 1973. Othello rules[1] are completely unified, whereas Reversi has many local rules. According to the Japan Othello Association established by Hasegawa, World Championship has been held every year since 1977, tournament is held in Japan, the United States and European countries.

Othello is categorized into two-player zero-sum finite deterministic games of perfect information[2]. Games in this class are possible to look ahead in theory, thus if both players choose constantly the best move, these are classified into win, loss or draw game for the first player[3] (the sequence obtained in this case is called perfect play). In 1993, Joel Feinstein reported that perfect play on 6×6 board of Othello gives 16-20 loss for the first player[4](Fig. 1); we confirmed that the sequence reported by him is one of the perfect plays[5]. Othello on standard 8×8 board has not been solved, since the number of positions is too large; according to some strong programs, it seems theory of becoming draw is strong[6]. In our previous paper[7], we were able to obtain some perfect plays on 6×6 board and 4×10 board. In this paper, we challenge the unsolved problem of 4×12 board by dividing it into about 100 small distinct sub-problems.

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28	9	8	7	31	32
22	14	1	4	17	16
27	13	○	●	6	15
19	2	●	○	5	12
24	23	3	10	26	29
21	18	20	11	25	30

Fig. 1. Feinstein's perfect play.

2. Othello

First of all, we will introduce the rules of Othello. The game always begins with the setup as shown in Fig. 2, however, since we deal with 4×12 board of Othello in this paper, the disposition such as shown in Fig. 3 is the starting position. One player uses the black side of the pieces (circular chips), the other the white side. Black always moves first.

Each player puts a piece of own color to an empty square in own turn. A player's move consists of outflanking his opponent's the pieces, he flips outflanked 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 any move, then he has to pass. If he is able to make a valid move, then passing is not allowed. The game ends when neither player can make any valid move. The winner is the player who has more pieces than his opponent.

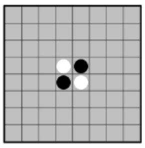

Fig. 2. Othello's setup.

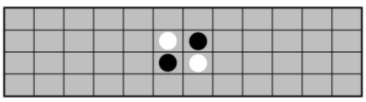

Fig. 3. The starting position on 4×12 board of Othello.

3. Computer Othello

For perfect analysis of strategy board game such as Othello, it is useful to refer thinking routines of game program. This is because end-game routine of game program is the perfect analysis exactly, and evaluation function in the middle-game routine is available for the ordering of the search in perfect analysis.

In addition, end-game routine is classified into solving for WLD (win/loss/draw) score and solving for exact score. Both are the perfect analysis, but there is a difference in the evaluation of the end. For an exact score solve, the end is evaluated with the piece difference. This routine can find best one move. For WLD score solve, the end is evaluated in three ways win, loss, and draw. It generates relatively many pruning (Alpha-Beta Pruning[8]) if the range of the evaluation value is small. Therefore, an execution time for the exact score is estimated to be several times of the execution time for the WLD score.

4. Perfect analysis for 4×2n board of Othello

Table 1 is the results that we analyzed from the starting position for 4×2n board of Othello. See Table 1, we see that rectangular Othello has the feature that gives the first player an advantage according to extended board size. Therefore, we suppose that there is a strong possibility that first move wins in 4×12 board of Othello.

Table 1. The analysis results for 4×2n board of Othello.

	Winner	Perfect Play
4×4	White	B: 03, W: 11
4×6	Black	B: 20, W: 04
4×8	Black	B: 28, W: 00
4×10	Black	B: 39, W: 00

5. Estimate the number of the final positions

See Fig. 4, it is changes in the number of the final positions for 4×2n board of Othello. By Fig. 4, the number of the final positions in 4×12 board seems to be about 10^{16}. However, in 4×12 board, since the white is often wiped out in the middle, it is assumed to be 10^{15}. Therefore, since execution time in 4×10 board is six days, we suppose that execution time in 4×12 board is about six thousand days. In this paper, by dividing it into about 100 distinct sub-problems, we solve each sub-problem in 4×12 board of Othello within sixty days.

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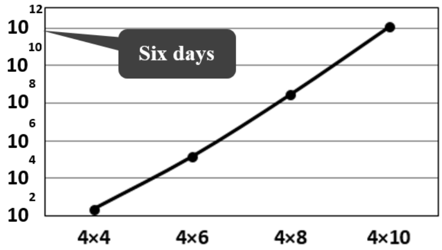

Fig. 4. Changes in the number of the final positions for $4\times2n$ board of Othello.

6. Perfect Analysis with the fixed moves

We found an initial position of 4×12 board as shown Fig. 5, which fixed from move 1 to move 6 in 4×12 board. This position gives win for the first player. This position is also the sequence of perfect play which is consistent with 4×8 board and 4×10 board. This is the reason why we choose this sequence. See Fig. 6, it is perfect play under starting position Fig. 6. If this sequence is the best move for both players, it shows that 4×12 board of Othello gives win for the first player. Therefore, it is necessary to check some positions which branched from white turn. Concretely, they are move 2, move 4 and move 6.

			❸	②	❶	④	❺				
					○	●					
					●	○					
					⑥						

Fig. 5. A fixed position from move 1 to move 6.

29	19	18	●	●	●	●	●	13	32	41	
30	24	17	16	14	○	●	10	20	31		
35	36	21	23	15	○	○	22	33	34	39	
37	25	26	8	7	○	11	9	12	27		

Fig. 6. Perfect play fixed from move 1 to move 6 in 4×12 board. The black wins 48-0. PASS is 28. 30. and 40.

7. Experiments

We use six computers with quad-core to solve the sub-problems for 4×12 board. Our solver has the exact score as evaluation value for perfect analysis.

Fig. 7, Fig. 8 and Fig. 9 are three positions that must be checked in order to prove that gives win for the first player on 4×12 board. The Greek alphabets in these figures mean all of places that the second player can put in his turn. 'F' in each figure means 'Finish', this is a place which already finished the search when we check in descending order (Depth 6, Depth 4, and Depth 2).

			●	●	●	●	●				
					○	●	(β)				
				(α)	●	○					
					F						

Fig. 7. Depth 6.

			●	●	●	F					
					○	●	(ε)				
				(γ)	●	○					
					(δ)						

Fig. 8. Depth 4.

				F	●	(η)					
					●	●					
				(ζ)	●	○					

Fig. 9. Depth 2.

Table 2 shows a part of the position that is fixed from move 1 to move 6 in 4×12 board of Othello. These are currently analyzing sub-problems for this board. For every element in Table 2, the first Greek alphabets show the places as mentioned above. The following character strings are a sequence to move 6 corresponding to the coordinates in Fig. 10. For further details on the sub-problems, refer to Appendix Table 3.

Table 2. Currently checking problems for each position.

Depth 6	Depth 4	Depth 2
(α)	**(γ)e4g1**	**(ζ)f4e1d1g1**
(β)	**(γ)e4h2**	**(ζ)f4e1d1h2**
	(γ)e4f4	**(ζ)f4g1h1h2**
	(γ)f4g1	**(η)h1e1d1e3**
	(δ)h4h1	**(η)h1e1d1f4**
	(δ)h4h2	**(η)h1e1d1h2**
	(δ)h4h3	**(η)h1e3g4h3**
	(ε)h3f4	**(η)h1e3h4h3**
	(ε)h3h4	
	(ε)h4e2	
	(ε)h4e4	
	(ε)h4g4	
	(ε)h1g1	

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a1	b1	c1	d1	e1	f1	g1	h1	i1	j1	k1	l1
a2	b2	c2	d2	e2	○	●	h2	i2	j2	k2	l2
a3	b3	c3	d3	e3	●	○	h3	i3	j3	k3	l3
a4	b4	c4	d4	e4	f4	g4	h4	i4	j4	k4	l4

Fig. 10. Coordinates on 4×12 board.

8. Consideration

(ζ)f4e1d1g1, **(γ)e4g1** and **(η)h1e1d1f4** in Table 2 have already finished. Both results are the black win 48-0. When all of the execution given in Table 2 are over, if their results are the black win, it is proven that the first player wins in 4×12 board of Othello. Moreover, if all of them are complete victories of the first player, it is proven that a sequence given in Fig. 6 is one of the perfect plays on 4×12 board of Othello.

9. Future work

The next challenge is the analysis for 6×8 board of Othello. It is necessary to estimate the size of game tree in the 6×8 board accurately. After that, we will implement the distributed processing for transferring to the cloud servers.

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Appendix

Table 3. The other problems fixed to move 6 on 4×12 board.

Depth 4	Depth 2		
(γ)e2g1	(ζ)f4e1e2g1	(ζ)f4g1d3e4	(η)h1e1h3h2
(γ)e2h1	(ζ)f4e1d3d4	(ζ)f4g1h2e1	(η)h1e1h3h4
(γ)g4h1	(ζ)f4e1d3g1	(ζ)f4g1h2e4	(η)h1e1h3i1
(γ)g4h2	(ζ)f4e1d3h2	(ζ)f4g1h2g4	(η)h1e3d4d3
(γ)g4h2	(ζ)f4e1g4g1	(ζ)f4g1h2h3	(η)h1e3d4e1
(γ)g4h3	(ζ)f4e1g4h2	(ζ)f4g1h2h4	(η)h1e3e4e1
(γ)g4h4	(ζ)f4e1g4h3	(ζ)f4g1h2i2	(η)h1e3f4e1
(γ)h4g1	(ζ)f4e1g4h4	(ζ)f4g1h2i3	
(γ)h4h1	(ζ)f4e1h2g1	(ζ)f4g1h3e1	
(γ)h4h3	(ζ)f4e1h2h3	(ζ)f4g1h3g4	
(δ)e2g1	(ζ)f4e1h2h4	(ζ)f4g1h3h2	
(δ)e2h1	(ζ)f4e1h2i2	(ζ)f4g1h3h4	
(δ)e4g1	(ζ)f4e1h3g1	(ζ)f4g1h3i3	
(δ)e4h2	(ζ)f4e1h3h2	(η)h1e1e2e3	
(δ)e4e3	(ζ)f4e1h3h4	(η)h1e1e2i1	
(δ)e4d4	(ζ)f4e1h3i3	(η)h1e1e3d3	
(δ)g4h1	(ζ)f4g1d2d3	(η)h1e1e3i1	
(δ)g4h2	(ζ)f4g1d2d4	(η)h1e1g4f4	
(δ)g4h3	(ζ)f4g1d2e1	(η)h1e1g4h2	
(δ)g4h4	(ζ)f4g1d3c3	(η)h1e1g4h4	
(ε)h1e3	(ζ)f4g1d3d4	(η)h1e1g4i1	
(ε)h1f4	(ζ)f4g1d3e1	(η)h1e1h3f4	