Analyzing the Intelligence of a Genetically Programmed Chess Player

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ABSTRACT

We investigate a strong chess endgame player, previously evolved by us through genetic programming [1]. Its performance is analyzed across four games, demonstrating the chess-playing capabilities developed through evolution. We end with a discussion of our GP-evolved player's pros and cons.

1. INTRODUCTION

Genetic programming (GP) has been shown to successfully produce solutions to hard problems from numerous domains, and yet an understanding of the evolved "spaghetti code" is usually lacking. Indeed, it seems a GPer must wear two hats: that of an evolutionary designer, and that of a molecular "biologist" [3].

We wore the first hat in [1] and presented highly successful chess endgame players, evolved via GP. In this paper we wish to wear the second hat—that of the molecular "biologist"—in an attempt to understand the resultant intelligence, hidden within the innards of our evolved programs. Although this paper is full of chess details, we believe the wearing of the second hat—not often seen in GP—presents an interesting exercise.

This paper is organized as follows: In the next section we summarize our previous work on evolving chess endgame strategies. Section 3 displays and analyzes the performance of one of our strongest evolved players, over four games. Finally, in Section 4 we discuss the capabilities of our evolved players in general.

2. PREVIOUS WORK

In a previous work we developed a chess endgame player using GP [1]. Our aim was to develop evaluation strategies that bear similarity to human board analysis. Thus, instead of looking deep into the game tree, we traverse less nodes, but consider each node more thoroughly. As such, our strategies use only limited lookahead.

The machine player receives as input all possible board configurations reachable from the current position by making one legal move (this is quite easy to compute). After these boards are evaluated, the one that received the highest score is selected, and that move is made. Thus, an artificial player is had by combining an (evolved) board evaluator with a program that generates all possible next moves. We used GP to evolve the board evaluator. The terminals and functions are shown in Figure 1. For full details see [1].

Our player was capable of drawing (and winning once in a while) against the CRAFTY engine (version 19.01) by Hyatt [1]. CRAFTY is a state-of-the-art chess engine, which uses a typical brute-force approach, with a fast evaluation function, NegaScout search, and all the standard enhancements [2]. CRAFTY finished *second* at the 12th World Computer Speed Chess Championship, held in Bar-Ilan University in July 2004. According to `www.chessbase.com`, CRAFTY has a rating of 2614 points, which places it at the human Grandmaster level. CRAFTY is thus, undoubtedly, a worthy opponent.

GP individuals were also pitted against MASTER: A strategy developed by consulting several highly skilled chess players, including an International Chess Master [2]. Against this strategy our evolved program was able to draw and sometimes win.

We challenged both CRAFTY and MASTER in fast-paced games (known as blitz games), playing 4 types of endgames: KRKR (i.e., King and Rook vs. King and Rook), KRRKRR, KQKQ, and KQRKQR. Strategies were first evolved to play one type of endgame, and then to play multiple endgames. The former means that the same pieces (one endgame type) were used as starting board, with their positions changing randomly, while the latter means that several combinations of pieces (several endgame types) were used, their placement also being random. Since random starting positions can sometimes be uneven (for example, allowing the starting player to attain a capture position), every starting position was played twice, each player playing both black and white. This way a better starting position could benefit both players and the tournament was less biased (this stratagem was adopted for both fitness evaluation and post-evolutionary

[1]CRAFTY's source code is available at `ftp://ftp.cis.uab.edu/pub/hyatt`.

[2]The highest-ranking player we consulted was Boris Gutkin, ELO 2400, International Master, and a fully qualified chess teacher.

NotMyKingInCheck()	Is the player's king not being checked?
IsOppKingInCheck()	Is the opponent's king being checked?
MyKingDistEdges()	The player's king's distance form the edges of the board
OppKingProximityToEdges()	The player's king's proximity to the edges of the board
NumMyPiecesNotAttacked()	The number of the player's pieces that are not attacked
NumOppPiecesAttacked()	The number of the opponent's attacked pieces
ValueMyPiecesAttacking()	The material value of the player's pieces which are attacking
ValueOppPiecesAttacking()	The material value of the opponent's pieces which are attacking
IsMyQueenNotAttacked()	Is the player's queen not attacked?
IsOppQueenAttacked()	Is the opponent's queen attacked?
IsMyFork()	Is the player creating a fork?
IsOppNotFork()	Is the opponent not creating a fork?
NumMovesMyKing()	The number of legal moves for the player's king
NumNotMovesOppKing()	The number of illegal moves for the opponent's king
MyKingProxRook()	Proximity of my king and rook(s)
OppKingDistRook()	Distance between opponent's king and rook(s)
MyPiecesSameLine()	Are two or more of the player's pieces protecting each other?
OppPiecesNotSameLine()	Are two or more of the opponent's pieces protecting each other?
IsOppKingProtectingPiece()	Is the opponent's king protecting one of his pieces?
IsMyKingProtectingPiece()	Is the player's king protecting one of his pieces?

(a)

EvaluateMaterial()	The material value of the board
IsMaterialIncrease()	Did the player capture a piece?
IsMate()	Is this a mate position?
IsMateInOne()	Can the opponent mate the player after this move?
OppPieceCanBeCaptured()	Is it possible to capture one of the opponent's pieces without retaliation?
MyPieceCannotBeCaptured()	Is it not possible to capture one of the player's pieces without retaliation?
IsOppKingStuck()	Do all legal moves for the opponent's king advance it closer to the edges?
IsMyKingNotStuck()	Is there a legal move for the player's king that advances it away from the edges?
IsOppKingBehindPiece()	Is the opponent's king two or more squares behind one of his pieces?
IsMyKingNotBehindPiece()	Is the player's king not two or more squares behind one of my pieces?
IsOppPiecePinned()	Is one or more of the opponent's pieces pinned?
IsMyPieceNotPinned()	Are all the player's pieces not pinned?

(b)

If(B, F, F)	If first argument evaluates to a non-zero value, return value of second argument, else return value of third argument
Smaller(F, F)	If first argument is smaller than second, return 1, else return 0
And(B, B)	If both arguments evaluate to a non-zero value, return 1, else return 0
And3(B, B, B)	If all arguments evaluate to a non-zero value, return 1, else return 0
Or(B, B)	If at least one of the arguments evaluates to a non-zero value, return 1, else return 0
Or3(B, B, B)	If at least one of the arguments evaluates to a non-zero value, return 1, else return 0
Not(B)	If argument evaluates to zero, return 1, else return 0

(c)

Figure 1: Chess representation. Opp: opponent, My: player. a) Simple terminals, which analyze relatively simple aspects of the board. b) Complex terminals, which check upon aspects a human player would. c) Function set (B: Boolean, F: Float).

Table 1: Percent of wins, advantages, and draws for best GP-EndChess player in tournament against two top competitors.

	%Wins	%Advs	%Draws
MASTER	6.00	2.00	68.00
CRAFTY	2.00	4.00	72.00

benchmarking).

Although individuals developed in multiple-endgame runs achieved slightly lower scores against our two opponents, scores were still close to draw, including some wins as well. In addition, GP individuals learned more generalized patterns, allowing them to compete successfully in several types of games. This suggests stronger learning has taken place. Table 1 summarizes the results attained.

3. ANALYSIS OF GAMES

We describe four games played between CRAFTY and a strong GP-Endchess individual, obtained at generation 190 (GPEC190 for short—see Figure 2). GPEC190 scored 0.42 points against CRAFTY on average (0.5 being a draw) in multiple-endgame runs. Table 2 summarizes the terminology used below.

In the games below GPEC plays against itself, with CRAFTY being used to analyze every move (i.e., CRAFTY also plays each board position of the game). The idea here is to see how GPEC fares both as Black and White, with CRAFTY serving as a superb yardstick.

3.1 Game 1

This game, as those that follow it, was played with a lookeahead of 1, i.e., the search tree is developed to a depth of 1. The starting position is given in Figure 3.

White's first move—Qd3—is optimal (mate-in-7). Also, GPEC ascribed 6.0 points for moves Qf3 (Crft = 5.2) and Qg4 (Crft = 5.0); 5.0 points for Qe1 (Crft = 5.4); and 4.0 points for Qb1 (Crft = 0.0). All other moves (except for Qd7) lose, and all have been assigned a score of 0.0—which is correct (except for Qd7 which draws the game, and should have been given a higher score).

Black has only 2 options now: Kf4 (loses to Qf5#) and Ke5 (also loses but only in 7 moves); this latter was selected by GPEC.

White's second move: Now there are 2 best moves (establishing mate-in-6): Qf5+ and Ra5+. GPEC assigned 6.0 points to both moves Ra5+ and Qe3+. The latter move was randomly selected. It leads to a good position (Crft score above 9.0), but is not the optimal move; Qg3+ got a score of 4.0 (this move leads to a draw after Black captures White's queen and White captures Black's—Crft score 0.0). Qxc4 got 3.0 points—since this move captures the opponent's rook it leads to material advantage (without retaliation) and also wins the game. GPEC selected the second best move and identified several good moves (although one of the best moves was overlooked).

The current position, after 2 moves made by GPEC (now Black's turn) is shown in Figure 4.

Now Black has 3 possible moves: Kd6, Kd5, and Re4 (CRAFTY selected Kd6), which all lead to the same position for Black (disadvantage of 5 points). GPEC gave all a score

Table 2: Chess-game terminology.

a..h	columns
1..8	rows
K	King
Q	Queen
R	Rook
QxR	Queen captures Rook ("x" is a capture)
Qe4+	Queen moves to e4 and CHECKS ("+" is a check)
Qe4#	Queen moves to e4 and MATES ("#" is a mate)
Qe4! [Or !!]	Queen moves to e4; GOOD MOVE
Qe4? [Or ??]	Queen moves to e4; BAD MOVE
mate-in-n	Mate is unavoidable in n moves
Crft = 4.2	Score assigned by CRAFTY to given position
Positive scores	Favorable for White
Negative scores	Favorable for Black
9.0	(material) value of Queen
5.0	(material) value of Rook
1.5	If this is the score (or higher) the player is considered to be in a winning position

```
Tree 0:
 (If3 (Or2 (Not (Not OppKingInCheck)) (And2
     (Or3 (Or2 OppKingInCheck OppKingInCheck)
         (Or3 NotMyKingStuck MyFork OppPieceAttUnprotected)
         (Not MyFork)) (Not NotMyKingInCheck))) (If3
     (Or3 (Not (And3 OppPieceAttUnprotected NotMyPieceAttUnprotected
         OppKingInCheckPieceBehind)) (Or3 (And3 NotMyKingInCheck
         OppKingInCheckPieceBehind MyFork) (Or2 -1000*MateInOne
         NotMyKingInCheck) (And2 OppKingInCheck NotMyKingInCheck))
         (Or3 (Or3 (And3 NotMyKingInCheck OppKingInCheckPieceBehind
             MyFork) (Or2 -1000*MateInOne NotMyKingInCheck)
             (And2 OppKingInCheck NotMyKingInCheck)) (Or3
             MyFork NotMyKingStuck NotMyKingStuck) (And2
             OppKingStuck OppPieceAttUnprotected))) (If3
     (Not (And2 MyFork 1000*Mate?)) (If3 (And2
     100*Increase OppKingStuck) (If3 1000*Mate?
     NumMyPiecesUNATT #NotMovesOppKing) (If3 NotMyPieceAttUnprotected
     #NotMovesOppKing -1000*MateInOne)) (If3 OppKingInCheckPieceBehind
     -1000*MateInOne -1000*MateInOne)) (If3 NotMyKingStuck
     OppKingInCheckPieceBehind MyFork)) (If3 (Or2
     (Or3 (Or2 OppKingInCheck OppKingInCheck)
         (Or3 NotMyKingStuck MyFork OppPieceAttUnprotected)
         (Not MyFork)) (And2 OppKingInCheck NotMyKingInCheck))
     (If3 (And2 OppKingInCheck NotMyKingInCheck)
         (If3 1000*Mate? #NotMovesOppKing MyFork)
         (If3 -1000*MateInOne NotMyPieceATT OppKingInCheckPieceBehind))
     (If3 (Or3 (And2 NotMyKingStuck NotMyKingStuck)
         (Or3 OppKingInCheck OppPieceAttUnprotected
             MyFork) (And3 OppKingInCheck OppPieceAttUnprotected
         OppKingStuck)) (If3 -1000*MateInOne NotMyPieceATT
         OppKingInCheckPieceBehind) (If3 (< MyKingDistEdges
         NumMyPiecesUNATT) (If3 1000*Mate? #NotMovesOppKing
         MyFork) (If3 -1000*MateInOne NotMyPieceATT
         OppKingInCheckPieceBehind)))))
```

Figure 2: GPEC190. As most chess players would agree, playing a winning position (e.g., with material advantage) is very different than playing a losing position, or an even one. For this reason, an individual board evaluator contains three trees: an advantage tree, an even tree, and a disadvantage tree. These trees are used according to the current status of the board. The disadvantage tree is smaller, since achieving a stalemate and avoiding exchanges requires less complicated reasoning. Shown above is GPEC190's even tree.

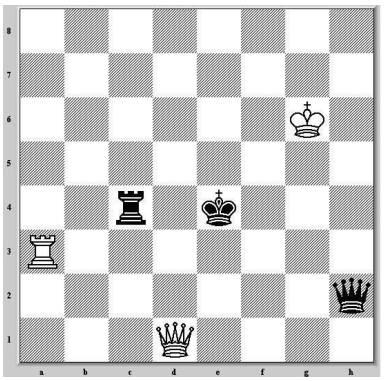

Figure 3: Game 1: Opening position.

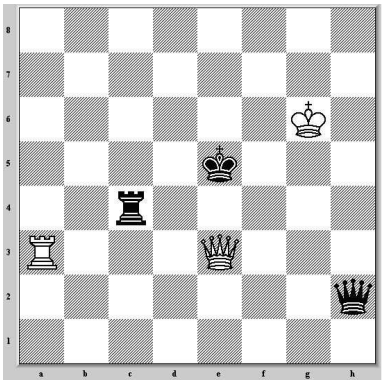

Figure 4: Game 1: After two moves by White.

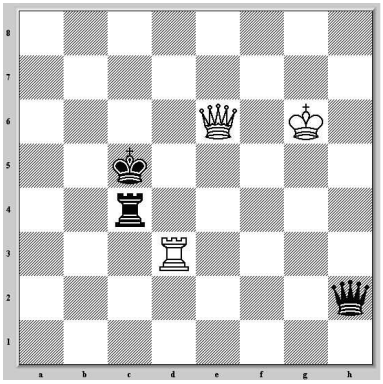

Figure 5: Game 1: After five moves.

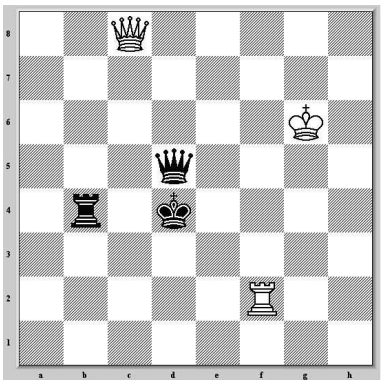

Figure 6: Game 2: Opening position.

of 0.0 and selected Kd6.

The optimal move for White is now Rd3+ (Crft = 5.5, move selected by CRAFTY). This move scored 6.0 points and was selected by GPEC. Other moves with high scores: Ra5+, 5.0 points (leads to Crft 0.0); Qb6+, 4.0 points—this is the second best move (Crft=5.0), and it received a good score; Qd3+, 2.0 points (Crft = 0.0)—this is not a fork since Black can play Kc5 and save his rook (GPEC did not assign this move a high score); Qg3+, 2.0 points—again a drawing move (Crft=0.0) was considered.

Since Black is now in check there are 3 possible moves: Kc6, Kc7, and one block with the rook (a bad move, immediately losing the rook and leading to mate-in-4). CRAFTY chose Kc6. GPEC assigned all moves 0.0 points, and selected Kc6.

Out of 36 possible moves GPEC now identified the two strongest moves: 4.0 points to Qe8+ (mate-in-10, selected by CRAFTY); 4.0 points to Qe6+ (Crft = 5.5)—this move was selected. All other moves received 0.0 points. This time, GPEC did not separate a drawing move (Qg5) from other, bad moves. Still, the drawing move is bad here since it loses the advantage, so this is not a bad mistake. On the other hand, all other moves are very bad for White, and GPEC was correct not to assign any a score above 0.0.

Again, all five options for Black are now equally bad (with retreat toward the edge being the worst—leading to mate-in-8). GPEC assigned all a score of 0.0 and selected Kc5 , resulting in the situation shown in Figure 5.

Out of 40 possible moves, GPEC now selected the best move—Qd5+ (mate-in-7); this move received 6.0 points. Another high-scoring move is Qe3+, assigned 5.0 points. This score is better than CRAFTY's, which assigned this position 0.0 points (for some unknown reason), although the next move it selected was Kc6, and after that the position was evaluated as 5.2 again (and much later evaluated as mate-in-11). So the real score should be 5.0. Other high-scoring moves: 5.0 points for Qf7+ and Qc8+ (both good moves); 5.0 for Qf5+ (again, drawing the position); A bad score was 5.0 points for QxR+, which immediately loses the queen (KxQ). All other moves received 0.0, although, still, some are worse than others (for example, Rd1 loses the Rook in 2 moves).

Black's fifth move: Again, two bad options for black, both receiving 0.0 score—Kb6 (mate-in-4) and Kb4 (mate-in-6). GPEC selected the better one—Kb4.

White's sixth move: Out of 37 possible moves, the best one was selected again: Qg6+ (mate-in-6). This is an excellent move for a program with minimal lookahead.

Black now selected Kc5, leading to mate-in-1.

White could have mated with Rc5#, but this position received 0.0 points. Instead, Qd5+ (Crft = 0.0) was selected—a bad move.

To sum up the game (only White's move are commented upon since Black has far less options and all are bad):

1. Qd3+! (optimal move); Ke5
2. Qe3+! (second best move); Kd6
3. Rd3+! (optimal); Kc6
4. Qe6+ (good move); Kc5
5. Qe7+!; Kb4
6. Qg6+!; Kc5
7. Qd5+? (Bad move).

3.2 Game 2

In this second game we saw GPEC gaining an advantage, but not succeeding in using it. The scores were a bit more diverse (ranging from 0.0 to 8.0). Figure 6 shows the opening position.

White's first move: Out of 39 possible moves, GPEC selected the best move, Rd2+, which leads to the capturing of Black's queen (CRAFTY also made this move, but opted not to capture the queen). Other moves that were given a high score: 5.0 points for Rf4+ (White can capture Black's rook after Ke3); 3.0 points for Qh8, a drawing move; 3.0 points for Qg4+—this also draws. Perhaps GPEC perceived the King-behind-Rook element (one of the GP terminals) as favorable.

Black has only two options. GPEC selected the lesser good—Ke5 (mate-in-5), although the other option (Ke4) is also bad for Black (Crft = 14).

White can now capture the queen (RxQ), which is what GPEC selects. A better option, Qf5+ (mate-in-5), received 0 points.

Black's second move: GPEC captures the rook, which is the optimal move here.

White is now actually in a winning position but we analyze further to see if GPEC uses the advantage. The optimal

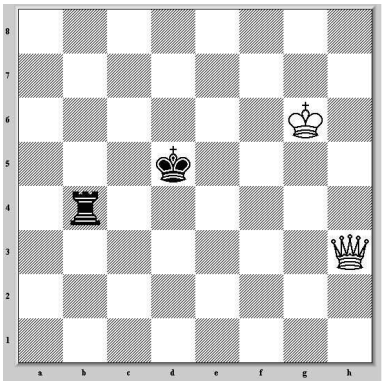

Figure 7: Game 2: After three moves.

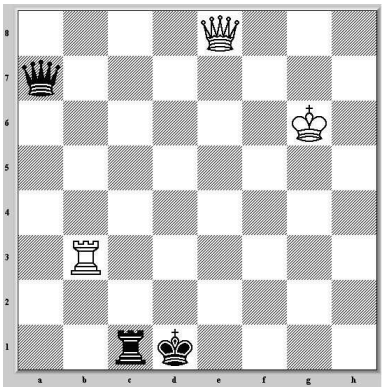

Figure 8: Game 3: Opening position.

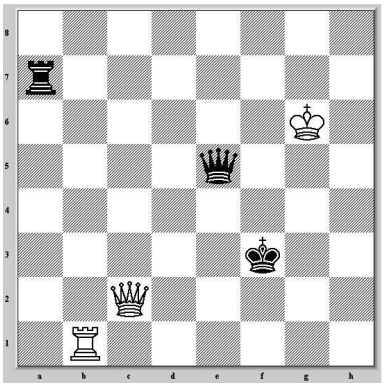

Figure 9: Game 4: Opening position.

move (Kf5, selected by CRAFTY) received only 3.0 points and was not selected. The highest-scoring move with the king was Kf7 (which CRAFTY rated as very close to the optimal Kf5), with 7.0 points, suggesting that GPEC has learned to position the king, but failed to do so since other moves seemed more favorable.

Many possible moves (for example Qa8) received 8.0 points. This is not the case with moves in which the queen can be captured by the opponent's rook—for example, Qb8 scored 0.0 points. On the other hand, Qc4+, in which the opponent's king can capture the queen, received 8.0 points. Perhaps this is because this position was perceived as some kind of fork (White's queen attacks both Black's king and rook). Qf5+, in which the queen is unattacked *and* checks the opponent's king received only 7.0 points, suggesting GPEC has not learned to attack the opponent's king when having distinct material advantage. Or, perhaps, this has indeed been learned, but is overshadowed by the elements giving high scores to mundane positions of the queen, while having the advantage. The current board is given in Figure 7.

Black's third move: CRAFTY suggests Re4, temporarily separating White's queen and king. GPEC assigned all Black's moves the same score—0.0—and selected Kc6.

During the next moves GPEC did not use its advantage. This is not surprising since it took CRAFTY more than 20 additional moves to win this position. In spite of that, GPEC did recognize the advantage, and did not win quickly since it did not make any mistakes (playing Black) in the next moves.

3.3 Game 3

This game started with mate-in-4 (see Figure 8).

White's first move—Rd3+—is optimal (mate-in-4). Out of 38 possible moves it received the highest score: 7.0. Qd6, also a good move (Crft = 4.22), received 5 points. All other moves received 0.0 points, which is correct since there are no other good moves for White.

Black's first move: only one possibility—Kc2.

GPEC now played Qe3 (Crft = -4.5), losing the advantage. This score received 1.0 points. The correct move was: Qe2+ (mate-in-3), which received 0.0 points. This game was played again, with a lookahead of 2, with much the same results.

Why did GPEC fail in this game? 1. Most obviously, mate-in-4 is not seen right now (not even with lookahead 2). However, this limitation did not interfere with selecting the correct move previously, so further reasoning is required. 2. The move leading to mate-in-2 does not appear to be distinct enough according to the known features: a. it only reduces the king's moves by one; b. it does not capture any piece; c. it does not create any (better) known formation, such as pieces supporting each other, or attacked, unprotected pieces (it has protection of pieces, but so do other possible moves).

3.4 Game 4

In this game, Black's king was exposed from the beginning (Figure 9).

White's first move—Rb3+ (Crft = 14.00)—scored 6.0 points. CRAFTY suggested Rf1+ (Crft = 14.2) but this move leads to quite identical results (GPEC assigned this move 5.0). 4.0 points were given to Qd4+ (Crft = 9.0). Black has to block with the queen, but White can play Rf1+, maintaining the advantage. 2.0 points were given to Qc6+ (Crft = 0.0 since Black can block with his queen and white has to exchange).

It is quite remarkable to see that GPEC's scores here highly resemble CRAFTY's, although GPEC uses *no* lookeahead (except for scoring each possible move separately). The scoring scheme developed here by evolution is thus far from trivial: GPEC managed to distinguish between the last two options not only on the basis of the opponent's capability of blocking the threat (one move ahead), but also

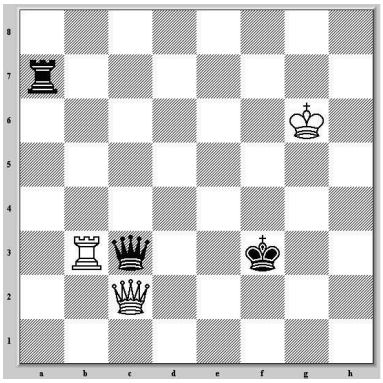

Figure 10: Game 4: Black must block threat.

considering the player's ability of generating a new threat (two moves ahead), which was *never* taught directly via the chess terminals. This can truly be seen as emergent tactical considerations—surpassing even the chess capabilities of the authors.

Black now has to block the imminent threat. GPEC selected Qc3 (mate-in-2), which is not a good move, although none of Black's options are good. See Figure 10 for the current position.

White's task is relatively easy now: it can mate Black in two moves. Out of 27 possible moves, GPEC assigned both the optimal move (RxQ, mate-in-1) and the near-optimal move (QxQ, mate-in-3) 5.0 points, and selected the latter; other moves received 0.0 points.

Black's second move: The best move here is Ke4—the king moves to the center trying to delay the mate (other moves lead to faster mates). GPEC did not distinguish between any of the five possible moves, assigning all 0.0 points. The move selected was Kf4 (mate in 1 by Rb4#).

White's third move: Again, GPEC missed the opportunity to mate, selecting the move Qc4+ (which scored 3.0 points). The mate move (Rb4#) also received 3.0 points.

4. DISCUSSION

GPEC190 has shown strong chess endgame skills. Achieving near-draw scores against CRAFTY on several types of endgames in previous experiments, it continued to amaze the authors of this article, selecting sophisticated moves in the games above. It has shown several good capabilities:

- GPEC never misses a capture. While this may seem trivial, coevolving individuals sometimes tend to lose their ability to take advantage of the opponent's blunders, since less mistakes are made as evolution progresses, and that knowledge can be lost [4].
- GPEC has demonstrated, time and again, the ability to drive the opponent towards a mate. Even when several options exist, it usually selects the best, fastest one.
- GPEC has also learned to use several of the advanced terminals in a correct way, usually avoiding partial (and thus disastrous) forks.
- Even when the optimal move was not selected, it was given a high score in most cases, indicating the move had at least been considered.
- GPEC has demonstrated these capabilities over numerous games (only some of them analyzed here), meaning proper generalization has taken place, over various positions, and not only in specific cases.
- All these achievements were attained with extremely limited (typically 1) lookahead, which may be interpreted, at least to some extent, as evolution being successful in finding principles underlying the endgames we played, in a way more reminiscent of human thinking than of exhaustive search.

On the downside, the evolved program exhibited some important limitations. First, near-mate positions were often reached, but very few mates occurred. Second, bad moves were usually not distinguished from each other; typically, all received a zero score. Third, some seemingly haphazard moves were still made. Especially after an advantage was gained, most moves received high scores, including moves in which the player's pieces were about to be captured. Fourth, the scoring range was limited (in spite of its resemblance to real scores). A strong chess program should use more diverse scores, especially for bad positions (negative or at least distinct scores), to separate them from even positions.

The analysis carried out in this paper clearly indicates that we have evolved "intelligent" chess players, and our findings—both positive and negative—point the way toward improving our evolutionary setup.

5. REFERENCES

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