Beautiful Mates: Applying Principles of Beauty to Computer Chess Heuristics

by

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BEAUTIFUL MATES:

APPLYING PRINCIPLES OF BEAUTY TO COMPUTER CHESS HEURISTICS

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ABSTRACT

A synopsis of eminent computer chess programs reveal that they are designed around a 'brute force' approach. An argument is made that by continuing the 'brute force' search approach, computer chess development is moving away from human evaluation methods. Research is done into studies of evaluation methods, and a discovery is made that humans use a form of intuition, called their 'sense of beauty', to choose the best chess move. A paper by Margulies is cited which formulates principles of beauty which apply to chess. Three versions of a chess program are developed, using no heuristics, standard chess heuristics, and beauty heuristics formulated from Margulies principles. The performance of the three versions of the program are compared using chess puzzles, and rated for how quickly they find the solution, and how few nodes they evaluate. The results of these tests show that beauty heuristics are, on average, 15% faster at finding the solution, and evaluate 10% fewer nodes. An improvement is implemented in all versions of the program which biases the search towards better moves, resulting in the beauty heuristics success rising to an average of 25% faster to the solution, and evaluating 33% fewer nodes, than the other heuristics. It is concluded that the beauty heuristics are closer to the way that humans evaluate chess positions.

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Acknowledgements

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Chess Program

A DOS executable program was produced for this paper which plays a complete game of chess, in addition to solving chess puzzles. All the C++ source code and a DOS executable file are available from the Author. Email a request to the address on the title page.

1. INTRODUCTION

This paper concentrates on formulating heuristics for playing chess which ‘must be broad enough to encompass the best moves, yet selective enough to avoid wasting time on the absurd lines of play’ [8 p.158] These ‘broad yet selective’ heuristics are evidenced in human play, because studies show that the chess master subjects only a few moves to detailed analysis [7]. Particular attention will be focused on Margulies belief that the chess master ‘may use his sense of beauty as an additional guide to make the final choice’ [20].

Many Artificial Intelligence (AI) researchers believe that computer chess is a kind of benchmark for progress in AI research [3 p.227]. Research into game playing techniques reveal that chess is an appropriate environment for studying the affects of heuristics.

It is apparent from analysing the methods used by computers to play chess that they evaluate positions in a manner greatly dissimilar to humans. A synopsis of eminent computer chess programs reveals that since the early 1970’s they have been designed around a ‘brute force’ search approach. The designers of the current champion of chess computers, “Deeper Blue”, state that their efforts are focused on increasing the search ‘far enough to be sure it chooses wisely’ [19].

This paper demonstrates that an obsession with searching the game tree *farther* is moving the computer’s position evaluation away from human methods. Chess experts have lamented that the penetrating search performed by Deeper Blue, combined with it’s comprehensive database of past games, is squeezing the creativity out of chess.

Apart from Deeper Blue’s recent victory over the human world champion, the history of computer chess is littered with unfulfilled predictions of ‘machine dominance’. Reasons are stated for the failure of computers to play master level chess as ‘our lack of understanding of how the human chess player performs the task.’ [2 p.35]

It is clear that humans possess an intuition, called "Beauty" by Krantz [19], which acts as a guide to their play. Groot's results show that experts have a more 'discerning' evaluation function than average players - yet Newell and Simon prove this intuition is chess related and not a superior visual memory which certain people are born with.

Margulies demonstrates how heuristics help humans to limit the possible choices when evaluating a position. After consulting expert opinion on 'beautiful' chess positions, Margulies formulates eight principles of beauty which can be applied to chess heuristics. A program is designed for this paper which encodes Margulies principles into a set of heuristics, attempting to answer Krantz's question, 'why not teach the machine the building blocks of human intuition?'

Three versions of the program are developed to apply principles of beauty to chess puzzles. The first version does not employ any heuristics, the second employs the standard chess heuristics, and the final version combines standard heuristics with the beauty heuristics suggested by Margulies paper.

2. WHY GAMES AND WHY CHESS?

A game is a convenient vehicle for experimenting with heuristics, as many of the complications found in the real world are not evident. Games normally contain definite rules which operate in an enclosed environment, unaffected by capricious influences from outside that environment. AI author Crevier believes, "the success of game playing programs, and the nature of their reasoning processes, affect our understanding of what intelligence is".[3 p.217]

2.1 GAME CHARACTERISTICS

In a paper by Samuel [21], an investigation is made into the characteristics which a game must display to qualify as "an intellectual activity where the heuristic procedures and learning processes play a major role in evaluation." [21 p.1] He isolated five of these characteristics:

- The activity must not be deterministic in the practical sense - no 'solution' available.
- A definite goal must exist.
- The rules of the activity must be definite and they should be known.
- There should be a background knowledge against which the progress can be tested.
- The activity should be one that is familiar to a substantial body of people.

2.2 THE SUITABILITY OF CHESS

These characteristics are evident in the game of chess. Chess requires intelligence to play, has a detailed set of rules, and the goal state is well defined. There is no algorithm which will guarantee a win or a draw. Chess contains no element of chance[2] - it is theoretically possible to construct every conceivable position that could occur in the game tree. However, Shannon has estimated number of nodes in the complete chess tree to be 10^{120} [3 p.223], resulting in a search that would take decades. The shear number of permutations affords the use of heuristics to guide the search.

The facility to annotate a chess game provides a permanent record of previous games spanning several centuries which provides the background knowledge against which to record progress. Progress is rated in chess using the 'Elo' rating system [4]. The Elo rating numbers range from around 1000 for weaker players up to 2800 for a strong Grandmaster. Rating points are gained by beating higher ranked players in tournaments, with the difference of 200 points supposedly indicating that a player ranked 200 points higher will beat the weaker player 75% of the time.

2.3 CHECKERS

The development of computer checkers has many parallels with computer chess[3]. Samuel proved that checkers also contains all of the characteristics required. He created a initiatory program which contained "the ability to model the game as a tree and search it for judicious moves" [3 p.221. Checkers and chess are played on an identical 8x8 square board[4], yet chess contains more unique pieces[5]. This provides chess with more evaluation possibilities than checkers, and a more 'interesting' search tree to experiment with heuristics. Confirmation of checker's less challenging game tree can be drawn from the fact that the best checkers program, "Chinook", can repeatedly beat the human world champion[6].

2.4 GO

The game of 'Go' also contains fewer pieces than chess, but is played on a larger board accommodating 19x19 squares. The larger board results in an incredibly large game tree which is impossible to search beyond three moves ahead[7], and thus provides similarly remote

[2] Unlike, for example, Backgammon, which depends on rolling a pair of dice.
[3] Samuel began researching checkers in 1947, around the time Shannon was investigating chess.
[4] For a description of the chess board, and how the pieces are moved, see appendix A
[5] Pawn, Knight, Bishop, Rook, Queen, King, in chess, compared to Checker's one piece (although two pieces may combine to form a King).
[6] In 1995 'Chinook' beat the human world champion, Ron King, 7-0.
[7] After 3 moves you have 59,776,471 (391*391*391) possible boards. Quoted from [16]

chance of 'solving' the game. Keh-Hsun Chen[8] estimates that "To solve Go, a computer would have to analyse an absurd number of board positions - a number with 172 zeros" [quoted in 18].

The necessity for evaluation techniques to guide the search means that Go would provide an equally relevant environment to chess for experimenting with heuristics. However, computer Go is still in its infancy. Programmers have created extremely strong chess programs, yet computer Go games can not even beat experienced human amateurs [18]. This means that computer chess has a greater background for comparing results, (one of Samuel's 'required' game characteristics) than Go, and therefore is more suitable to this paper.

2.5 CHOSEN GAME

After considering the three suitable games, chess was chosen as an ideal example of a game which exhibits all of Samuel's required characteristics, for the reasons detailed above. An diagram of the chess board and a description of the moves is given in appendix A.

[8] Author of the program "Go Intellect", which won first place in the "Computer Olympiads"

3. A BRIEF HISTORY OF COMPUTER CHESS

In 1957 Herbert Simon predicted "Within 10 years a digital computer will be the world's Chess champion, unless the rules bar it from Competition." [quoted in 3 p.167] This opinion has since proved widely optimistic, with the strongest computer to date, "Deeper Blue" only just beating the world champion in an unofficial[9] match *thirty years* after Simon's predicted date.

A synopsis of the developments in computer chess in the forty years since Simon's prediction will show that considerable advances have been made in getting computers to play a strong game of chess. However, these advances have not followed the method of human chess playing strategy.

3.1 MACHACK

The first notable program to achieve a healthy Elo score (approx. 1400) was "Machack VI", by Richard Greenblatt in 1967. The mean rating of the United States Chess Federation players was 1500, so Greenblatt's program was "tantalisingly close" [3 p.226]. Figure 1 charts the increasing Elo rating of computer programs over the last thirty years.

[9] The match was under the auspices of the Association of Computing Machinery, a computer society, not any recognised Chess body.

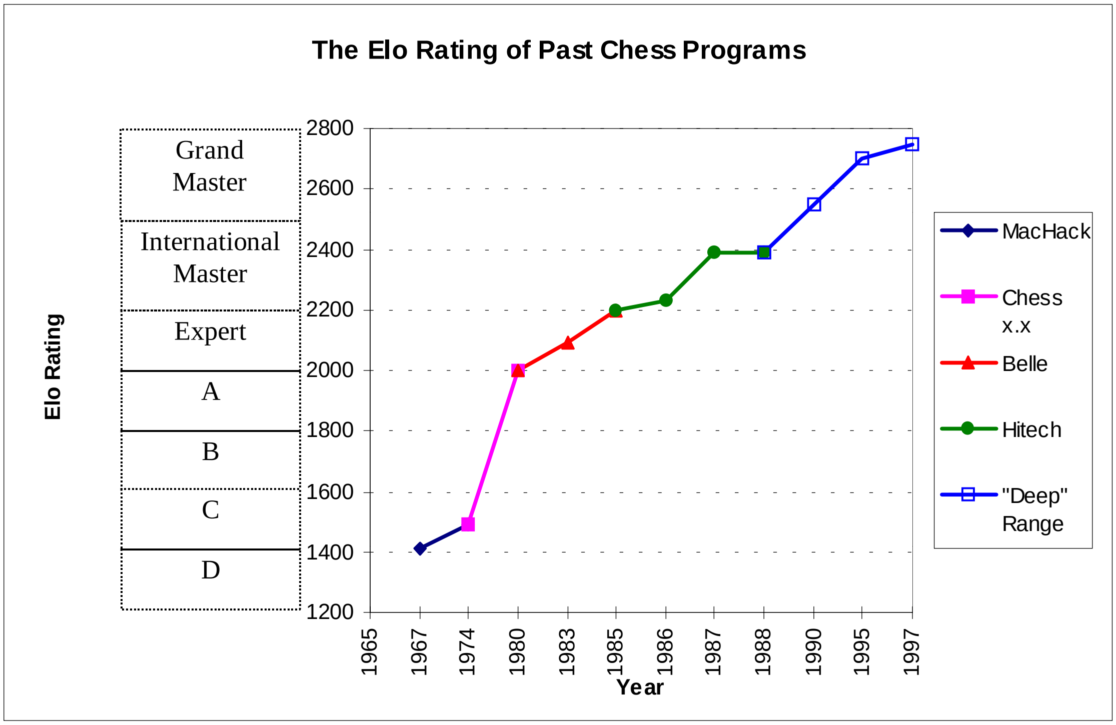

Figure 1. The Elo rating of past chess programs

The relative success of "Machack VI" and the publicity it generated during the 1960's "started a resurgence of interest in computer chess" [11 p.90]. By 1970 a greater availability of computer time at universities spawned enough programs to create a tournament in which the only players were computers. The first tournament was won by a program called "Chess 3.0" [3 p.227].

3.2 Chess 3.0

A key moment of computer chess development occurred in 1973, when the authors of Chess 3.0 redesigned their program around a 'brute force search' approach. By relying on efficient search procedures and ever faster computers, the new program searched the game tree to new depths [3 p.229]. Wright states that "by this time almost nobody doubted that computers may be able to perform some intelligent tasks, though perhaps by different means and ways to those used by humans." [23 p.2]

It is argued that all programmers initially approached computer chess with notion of mimicking the human playing process, but the advent of lucrative prize money[10] has introduced an overriding spirit of competition which forces programmers to cut corners.

The successor to Chess 3.0, "Chess 4.5" appeared in 1978, and followed the same 'brute force' approach. "The changes were made on the basis of specific performance weaknesses rather than on the basis of some general theoretical or conceptual model of human thinking or problem solving." [9 p.168]

3.3 CRAY BLITZ

A program called Cray Blitz was the last general-purpose computer to hold the title of 'world computer chess champion' in 1984. "After its demise, all world championships went to dedicated machines like 'Belle' who were, so to speak, to the trade born." [3 p.231] International master David Levy is renowned in the computer chess field for his wagers[11] against chess programs [11 p.90] However, after beating the Cray Blitz program 4 - 0 in 1984 he ceased betting on himself against computer opponents.

3.4 BELLE

The Belle program has been called one of the "biggest technical advances in computer chess" [4], because it consisted largely of electronic hardware able to perform, at great speed, tasks which are conventionally performed by software. It was designed by Ken Thompson at Bell Telephone Labs, signifying that computer chess had expanded from its university beginnings. BELLE was the first computer to reach the 'expert' level of chess, with an Elo rating of 2,200 [11 p.91]

[10] MIT professor Edward Fredkin has offered $100,000 to the authors of the first program to beat the world champion [3 p.227]
[11] In 1968 he bet £1000 with various computer science researchers that no program would beat him by 1978.

3.5 HITECH

Hans Berliner's research into the evaluation method for playing games was realised with the creation of the first chess program to gain the title "International Master". The program, called "Hitech", combined the innovative elements of Belle and Cray Blitz; "its dedicated circuits let it process 175,000 chess positions per second, yet it did so in a manner that could take elaborate chess knowledge into account" [3 p.231].

3.6 THE 'DEEP' RANGE

Thompson's work on special purpose hardware was taken one step further by Hsiung-Hsu, who designed a single silicon chip to perform all the functions of BELLE, but at speeds allowing one million position evaluations per second. The computer, called "Deep Thought", became the first computer to gain the title 'Grandmaster', and "relied on speed and clever search methods." It has been suggested that "Deep Search" might have been a more accurate name, because "it made absolutely no pretence at imitating human play." [3 p.232]

Deep Thought took the of reputation computer chess to an unprecedented level by becoming the first computer in history to challenge the human world champion. The champion, Kasparov, subsequently defeated Deep Thought 2 - 0 in 1989[12]. By the early 1990's IBM had employed Hsiung-Hsu and other programmers to develop a successor to Deep Thought containing 40 dedicated processors. In return match the supercomputer, called 'Deep Blue', surprised the world champion by winning the first game, but Kasparov went on to win the 10 game match by two clear games.

In May 1997 an improved version of Deep Blue "became the first computer to triumph over a reigning world champion in a classical chess match" [22 p.13] The latest version, called "Deeper Blue", employs 512 dedicated processors to increase it's board evaluation to 200

[12] But it did defeat David Levy 4 - 0.

million positions a second. It beat Kasparov by one game over a six game match. During play Deeper Blue consults a database of opening games played by every chess Grandmaster in the past hundred years, causing chess experts to "lament that the supercomputer is squeezing the creativity of the game into an ever-smaller section of the middle game" [22 p.13].

Berliner voiced a similar opinion when told about Deep Thought's methods. "Its designers did not believe in enhancing chess computers' performances by endowing them with humanlike chess knowledge … [they] knew little about chess." [3 p.232] Berliner did many important studies into the evaluation method for playing games with computers. This method "lies perhaps closer to how humans plan their play" [3 p.219].

In order to compare the contrasting approach between humans and computers, it is first necessary to examine how computers have been programmed to play chess.

4. HOW COMPUTERS PLAY CHESS

The foundation for chess programming lie in a seminal paper by Shannon[13]. The profundity of his ideas can be gauged from the fact that today virtually every chess program still employs the Shannon strategies in one form or another [4 p.48] .

4.1 MACHINE REPRESENTATION OF THE CHESS BOARD

Shannon suggested that the 8x8 squares on a Chess board be represented by 64 memory addresses. Each address in memory would act as a 'mailbox' for that square, containing either an 'empty' flag, or the identity of the piece residing in that square. He proposed that each piece be designated a unique number, positive for white, negative for black, which would identify it. The empty 'flag' consists of a zero.

The program written for this paper follows an improved representation, explained in appendix A, first used by Greenblatt to facilitate the 'edge of the board' detection. This version has extra squares storing a unique number, 99, representing 'off-the-board', which assist the program when formulating piece movement.

4.2 THE MOVE GENERATOR

A move is generated by the computer inspecting each square in turn and discovering which piece (if any) is in that square address. If the piece is a Rook, for example, a procedure listed below will be followed, according to the rules for moving a Rook.

[13] Shannon, C., "Programming a Computer for Playing Chess", 1949. Detailed in [4 p.48]

1) First check all the squares in a Northerly direction.
2) Add every square which contains an ‘empty’ value to a list of legal moves.
3) If encountering a square containing the value of an enemy piece, add the move to the list, note that a ‘capture’ is on this square, and stop searching in that direction (go to 5).
4) If the square contains either the value of a piece it’s own colour or the ‘off the board’ value, halt the search in this direction. Do not place the square in the list. Go to 5.
5) Repeat the process for all the squares in the East, West and Southerly directions

A computer can play Chess simply by generating moves at random, checking if they are valid according to the rules of chess, and playing any one of them. Programs using this approach have been tried and “were usually beaten in less than five moves.” [23]

4.3 EVALUATION

In an improvement to playing a randomly selected move, the computer can assess each move and make a judgement based on the best criteria. This appraisal, called the ‘Evaluation function’, was suggested by Shannon. He proposed that a move is selected by considering moves by white, replies by black, etc. until relatively static terminal positions are reached. He then proposed that “each terminal position be evaluated in a mechanical way.” [4 p.60]

Various criteria are defined that allow a move to be ‘valued’ and rated. Examples suggested by researchers (Shannon, Berliner, Greenblatt) include a ‘material balance’ procedure[14], a bonus for controlling the centre of the board, and a bonus for placing the enemy King in check.

Frey comments, “The idea was to weigh each of these factors according to its importance and then add all the items together to determine the value of the terminal position.” [5 p.60] Good moves, with a high value, are chosen above weaker moves with a low value. Minimax search utilises evaluation to find the move which increases the player’s score, and decreases the opponents, the greatest.

4.3.1 Piece Ratio Exchange

The previous section has shown how points are gained or lost for a captured piece. If the computer can take an opponent's piece without retaliation, then the move is encouraged. A move is discouraged if it will cause the opponent to gain a material advantage (i.e. it will take your piece on its next move).

Greenblatt introduced a procedure to determine whether the computer should exchange pieces[15] with it's opponent. This follows an established chess tactic [6] which dictates that a piece exchange favours the player with the higher material value

4.4 SEARCH

It is theoretically possible to search all of the available moves in chess, due to the finite number of pieces and the absence of any 'chance' element. However, with the complete chess tree comprising of 10^{120} nodes, searching even a minor part of it remains a tremendous undertaking.

In the first attempt to search part of the game tree Shannon devised the 'A' strategy. This was based on the concept of looking ahead to a fixed depth along all variations and evaluating all the positions at the resulting depth. The disadvantage is that a program would be prone to making errors of assessment when evaluating complex positions, such as piece exchanges, due to halting the search in the middle of the evaluation.

Shannon recognised the problem with this method, and proposed the 'B' strategy. Now the program would not always terminate its look-ahead at the same depth, but would sometimes continue searching until a 'quiescent' position was reached. This quiescent search helps the program find positions which can be safely evaluated and which are not too turbulent.

[14] A value is allocated to each piece, allowing an assessment of which side possesses a higher total value.
[15] For example, swap a Rook for a Rook, or a Knight for a Bishop.

4.5 PRUNING THE SEARCH

Greenblatt attempted to prune the branches of the game tree by only selecting the most promising moves for further evaluation, using techniques such as Alpha-beta pruning. Alpha-beta pruning consists of abandoning the investigation of a move when the opponent can respond with a countermove better than the best response already examined.

4.5.1 Horizon effect

The searching of a game tree has been described as "shining a searchlight into the unknown darkness of a game" [19]. A problem occurs at the limit of the "searchlight's" beam, known as the "horizon effect". Knowledgeable human players can outwit the computer by enticing it with a sacrifice or gambit, (eventually leading to a gain for the human), lying just beyond the machine's search horizon.

The programmers' response to the horizon effect is to enable the machine search to deeper levels [3 p.230]. This method does not solve the problem, as confirmed one of Deep Blue's designers; "When your opponent is Kasparov, though, it's (thus far)[16] impossible for even a 1.5 ton supercomputer to search far enough to be sure it chooses wisely" [19 p.87]. The problem with relying on search is that it sees everything in its search light very well, yet beyond that and Deep Blue has to guess, "And humans guess better".

4.6 TECHNIQUES FOR IMPROVING SEARCH

In an attempt to improve the tree searching method, the following improvements have been suggested by Levy, Harris and Botvinnik (in [11], [8] and [1]).

[16] In March 1997, two months before 'Deeper' Blue's victory over Kasparov.

4.6.1 Opening Books

Centuries of human experience in chess have resulted in a set of initial moves, known as the opening, which have been shown to be optimal strategies for both players. Beyond the first fifteen moves the combinations become too varied to follow move for move. The set of moves are stored in a database and made available to the program during play. As has already been noted, Deeper Blue can consult the opening moves of every Grandmaster game played in the last hundred years.

4.6.2 Endgame database

The 'Endgame' is the final part of the game. The principle pieces have been exchanged and the player is left with their King and a few other pieces. A wide collection of ending positions have been accumulated and strategies for each are known. Many of the first computer chess games, such a Huberman's Ph.D. thesis[17] solely concentrated on the endgame, due to the fewer number of pieces to take into consideration and the fewer number moves needed to achieve the goal state, checkmate. In contrast to the opening, where computers borrow from human expertise, computers have made a contribution to the analysis of endgames. Levy said of Thompson's work with BELLE, "His work corrected a number of errors in the chess endgame literature." [11 p.49]

4.6.3 Killer Moves

The computer gives precedence to investigating opponent responses that killed, or refuted, other moves the computer has already considered. In this case, the killer moves are tried first by the Alpha-Beta heuristic, with an expected reduction in the number of positions to be considered.

[17] "A Program that plays Chess Endgames", 1967. Detailed in [11 p.132]

4.6.4 Transposition Tables

Often a sequence of moves can be made in any possible order and the final position is still the same. To avoid the superfluous computations resulting from reaching the same position in different nodes of the tree, a list of moves is kept in memory. When an equivalent node is reached the program realises, through the use of the tables, that the node has been previously studied in the tree of possible moves.

All of the search methods employed by computer chess programs show little or no resemblance to the methods employed by humans, which are analysed below.

5. HUMAN CHESS PLAYING METHODS

The argument for a more exact simulation of human chess players has been forcibly advanced by the former World Chess Champion, Mikhail Botvinnik. He suggested in 1970 that since humans are suited to solving ‘inexact’ tasks like choosing a move in a chess game, and computers are not, why not teach a computer to behave like a human [1 p.3].

In 1977 Charness warned that the failure to appreciate the complexity of analysing chess positions was due to “our lack of understanding of how the human chess player performs the task.” [2 p.35] He cited work by the psychologist Adrian de Groot [8] to answer the question “How does the human go about solving the problem of choosing a move?” [2 p.35]

5.1 PERCEPTION

Groot researched the processes used by a chess master when playing a game. His results showed that the average number of good moves for a given position is only 1.76, contrasting considerably with the 200 million positions a second studied by Deeper Blue. He also refuted the misconception, that chess masters examine hundreds of moves before selecting one, which was previously accepted by early researchers into chess skill[18].

Groot examined thought processes to determine why some players were better than others. To do this he showed ten subjects[19] unfamiliar positions and told them to think aloud when choosing a move. Although the Grandmasters chose the better move 34% more times than club players[20], the surprising result was that the ‘hundreds’ of moves supposedly explored had dropped to an average of 35 moves[21] in total [8 p.128]. This proved that although all players reviewed roughly the same number of moves, the Grandmasters perceived the problem differently to the Club players.

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18 Such as: Binet, A. “Psychologie des grands calculateurs et joueurs d’Echecs”, translated in [4]

19 Such as Grandmasters like Alekhine, Keres, Euwe - to club players rated as Class A - C on the Elo scale

20 Grandmasters chose the better move 86% of the time, compared to Club players 52%.

Groot continued his work to explore the role of perception by showing his subjects a chess position from an unfamiliar game. He asked them to recall the exact position of the pieces after only viewing the board for five seconds. The Grandmasters recalled 93% of the 22 pieces, yet Club players only recalled 51% correctly, confirming that Grandmasters have superior grasp of chess positions.

5.2 CHUNKS

Chase and Simon added an interesting post script to Groot's last results [14]. They replicated his experiment, but they scattered the pieces randomly around the chess board instead of placing them to form an game position. This time all the subjects recalled only 3 or 4 pieces correctly, prompting Chase and Simon to conclude that the superior performance of the Grandmaster was not due to extraordinary visual memory capacity, but rather to a chess-specific capacity.

Simon noted that "expert players have an instantaneous understanding of chess positions and a compelling sense of the winning move" [14 p.386]. He believes that chess masters are familiar with thousands of patterns involving small groups of pieces in certain relationships to each other, which he calls "chunks". Each chunk would suggest a desirable move or strategy, which would cut the need for extensive simulations of later moves [11]. The idea of human thought processes being represented as "chunks" was first suggested by the psychologist George Miller in his celebrated 1956 paper on short term memory.[22]

[21] The Grandmasters range was from 20 - 76.
[22] "The magical number seven, plus or minus two" Psychological Review, issue 63, pp. 81-97

6. CONTRASTING HUMAN AND COMPUTER METHODS

Chess researchers with a pragmatic approach, such as the designers of the 'Deep' range of computers, claim that regardless of the strategy adopted by the computer, if the computer plays good chess, then it is 'thinking'. The philosophy is explained by the phrase, "Much as aeroplanes do not fly be flapping their wings, chess computers do not have to imitate human thought processes to win games."[3 p.235]

Yet despite the well documented gains of computer chess there have been many criticisms of the brute force approach, and the reliance on faster processors to increase a program's power. Some experts offer a negative view on the 'intelligence' of chess-playing computers. Levy comments [11 p.234],

> *"[tree searching]produces a kind of monkey/typewriter situation...[The computer] appears to play moderately well, whereas it is actually playing very weak chess so much of the time that its best results resemble the moves of strong players"*.

This school of thought claims (Berliner, Botvinik) that thinking involves a particular set of procedures, which, if not employed, amount for nothing more than a brute force search.

It is suggested in section 3 that prizes, although providing funding and interest in computer chess, have ultimately contaminated the field. Labelled the "drosophilia" of artificial intelligence, computer chess was hoped to play the role in developing AI that fruit flies played in genetic research. This did not happen, "Carried away by sheer competition, many researchers started designing programs that won games instead of thinking like people" [3 p.236]

Chess authors are polarised regarding the style of play produced by the machines. One camp claims that despite the mechanical approach, it is often impossible to tell which is the human player when reviewing the moves from a game against a computer [18]. This amounts to a form of the 'Turing' test, with some computers, such as Deep Blue, producing "surprisingly humanlike chess" [18].

However, Krantz maintains that "The genius of chess lies in the sublime tension between logical analysis (call it Truth) and human intuition (call it beauty)." [19]. This implies that computers need to adopt a form of human intuition, in addition to their logical analysis, if they are to play like a human.

It is clear that humans possess an intuition, called "Beauty" by Krantz, which acts as a guide to their play. Groot's work is section 5 shows that experts have a more 'discerning' evaluation function than average players. Holding believes, "we may regard the judgement of chess beauty as an illustration of a different way in which cognitive factors may shape perception." [10 p.68]

In his paper "Principles of Beauty" [20], the psycologist, Margulies, consulted chess experts to explore the contradictions which appear when applying aesthetic principles, such as beauty, to chess moves. Hearst observed the need for this approach [9 p.168] ;

> *"Any promising attempt to create a computer program that plays superior chess will, in my opinion, have to be based on advice from master chess players and on significant advances in our understanding of relevant psychological principles and processes."*

From his research, Margulies concluded that beauty is functional in chess, particularly when applied to complex positions. "In complex positions the master may use his sense of beauty as an additional guide to make the final choice"[20 p.10]. This shows that his work on principles of beauty are closely linked with human methods for playing chess.

7. PRINCIPLES OF BEAUTY

Margulies researched aesthetic principles in chess by constructing twenty three pairs of example chess positions, and canvassing thirty expert[23] players to select the more beautiful move from each pair.

Although Margulies initially considered the judgement of players with a range of abilities, he restricted the report of his studies to expert players because "they are more consistent, and hence statistical significance can be obtained with a smaller N" [20 p.2]. Based on the judgements of the experts, he formulated eight principles related to beauty in Chess. These are summarised below.

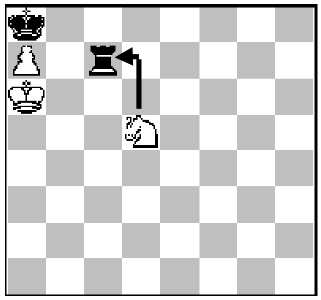
7.1 (1) SUCCESSFULLY VIOLATE HEURISTICS

Margulies cites the traditional strategies in chess to include "Keep the King safe, control the centre, capture enemy material, conserve your own material, etc." [20 p.4] He continues to say;

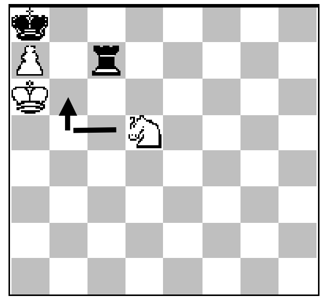
> *"Most moves which violate such heuristics are ineffective (and not judged beautiful, as I experimentally verified) but those few which are both contrary to usual strategy and also effective are beautiful."*

An example of this principle is illustrated in figure 2. Both the moves are effective, yet the usual heuristic concerning the capture of enemy material is violated in figure 2(b). This move was judged more beautiful by 90% of the experts.

[23] Chess Players with an ELO rating greater than 2000



2(a)



2(b)

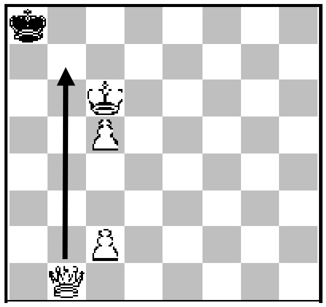
Figure 2(a) Checkmate by capture and, 2(b) checkmate without capture

7.2 (2) USE THE WEAKEST POSSIBLE PIECE

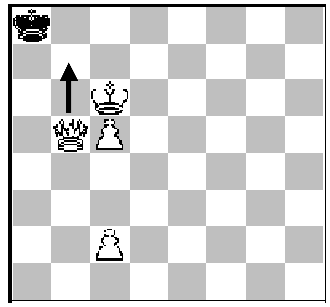
This principle states that where possible the weaker piece must be used in an attack. The position used to illustrate this principle gained the highest percentage of preference by the expert players. A move where a Rook gives check was selected as more beautiful than where a Queen gives check by 97% of the experts.

7.3 (3) USE ALL OF THE PIECE'S POWER

Figure 3 shows the illustration of this principle, which dictates that the Queen's movement across the board is using more of her power, and thus is more beautiful according to 93% of the experts, than the move where she only travels two squares.



3(a)



3(b)

Figure 3(a) To checkmate the Queen travels 6 squares and 3(b) the Queen moves 2

This principle is dismissed by Grandmaster Fine as “rather dubious, since the differences between the two Queen moves do not seem too important.” [17 p.1] He neglects to mention that Margulies later includes this principle in his summary “Don’t waste any power” [20 p.7]. There is a definite correlation between Margulies summary and Fine’s summary, “beauty derives from the concealment of aggression”, which warrents the inclusion of this principle, and thus weakens Fine’s objection to it.

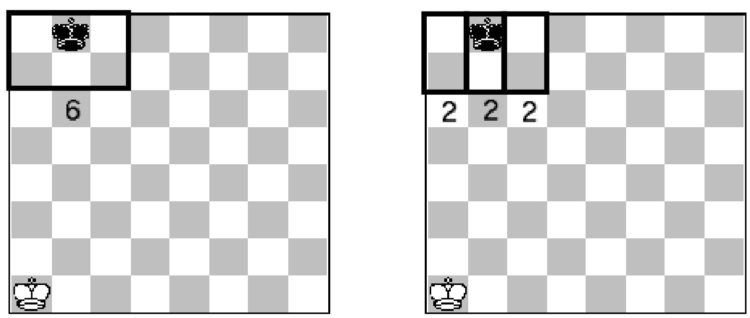
7.4 (4) Give More Aesthetic Weight to the Critical Pieces

This principle considers pieces which are critical to a move, and the ones which stand idle. Margulies constructs a position where a white Bishop checks the enemy King and a white Queen stands idle, and a position where the Queen checks the King and the Bishop stands idle. He believes “the Bishop is clearly aesthetically preferable to the Queen” [20 p.6] and 93% of the experts agree and select the first position as more beautiful.

Although this principle seems identical to the second principle (Use the weakest piece), Margulies constructs two more positions to illustrate that the idle non-critical piece is important to give more weight to the critical piece. For example, if a player has only a King and a Pawn on the board and uses the weakest piece to check, it is because it is the only piece available[24]. If, however, the player used a Pawn to check when there was also a Queen on the board, then more weight should be given to the fact the weaker piece is consciously being used when a stronger one is available.

7.5 (5) USE ONE GIANT PIECE IN PLACE OF SEVERAL MINOR PIECES

For this principle Margulies invents two new Chess pieces to illustrate that consolidating all power into one piece is more beautiful than using several pieces. He invents a piece which covers six squares, shown in figure 4(a) and three pieces which cover two squares, figure 4(b).



4(a) 4(b)

Figure 4(a) Checkmate by the single 6-squared piece, and 4(b) By three 2 squared pieces

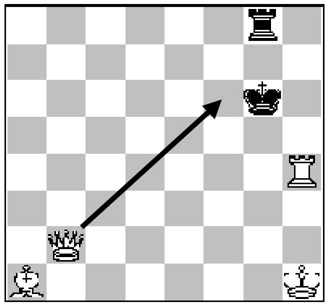
Margulies believe that the first position is an demonstration of the "preference to reduce everything to a single statement" [20 p.7], and 73% of the experts believe that it is more beautiful.

7.6 (6) EMPLOY THEMES

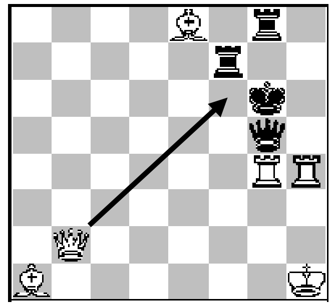
Margulies shows the experts the mating position in figure 5(a), which he describes as the "most sparse". He then develops this position along a theme which, after two more positions,

[24] A King can not check another King, as it would place itself in check at the time, which is illegal.

becomes "fully developed" in figure 5(b). This principle had the lowest percentage of experts, 70%, choose the latter position as the 'more beautiful'.



5(a)

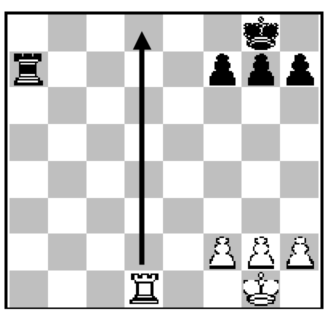


5(b)

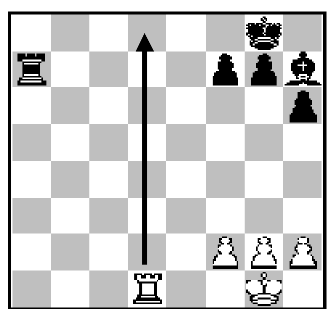
Figure 5(a) Theme is not fully developed, and 5(b) Theme is fully developed

7.7 (7) AVOID BLAND STEREOTOPY

Margulies constructs a checkmate position which he describes as "commonplace", shown in figure 6(a). He then alters this position slightly to make it less 'stereotyped', and 90% of the experts judge it is more beautiful.



6(a)



6(b)

Figure 6(a) A commonplace position, and 6(b) A less common position

7.8 (8) NEITHER STRANGENESS NOR DIFFICULTY PRODUCE BEAUTY

Developing the previous principle Margulies produces a position similar to figure 6(a), replacing the three black Pawns in front of the King, with three black Rooks. Although this position could legally arise[25], he states "it would never occur in an actual game" [20 p.9]. This position is not judged beautiful by the experts, so Margulies observes that "Wildly improbable positions are a far cry from bland sterotopy but they do not lead to judgements of beauty" [20 p.9].

In an attempt to test difficulty the experts were shown three positions from an actual game.[26] They were asked to judge the most beautiful move, the move requiring most calculation, and the move most difficult to 'see'. Although the experts were split on the 'most calculation' and 'difficult to see' moves, nearly all of them selected the same position as beautiful. Margulies concludes that, "Difficult moves do not enhance beauty". [20 p.10]

[25] By one of black's Pawns being promoted to a Rook.
[26] Fischer v Benko, 1963 U.S. Chess Championship.

8. A DISCUSSION OF MARGULIES' PAPER

The former world champion, Vasily Smyslov, states that he only became champion, "only after overcoming the need to play beautifully". [Quoted in 20 p.10] Although this suggests that applying principles of beauty will not make a world champion, it does confirm that chess masters use 'beauty' as a heuristic to guide their evaluation.

Margulies principles hypothesise that beauty can perform a similar function to human intuition when evaluating chess positions. He is careful, however, to qualify his belief that it does not take the place of analysis, "The beautiful move is likely to be the better move, but analysis is necessary" [20 p.10]

In a reply to Margulies paper, Fine observed that "it is clear that, in every case, what is considered more beautiful is the move which uses the least amount of force" [17 p.1] Fine reduces Margulies eight principles to the singular, "beauty derives from the concealment of aggression." [17 p.1]

Holding accepts the conclusions of Fine's analysis, observing that, "Fine makes a good case for the idea that in the majority of the comparisons the preferred solution is the move that uses the least amount of force" [10 p.69].

The functionality of Margulies principles when applied to chess puzzles can be assessed by implementing them into a chess program. The program uses heuristics formulated from certain beauty principles to guide it to a more efficient search. If a program evaluates fewer nodes it displays a better evaluation method, which, according to Berliner, 'lies closer to how humans play'.

It is also expected that a correlation can be proven between 'beautiful' play and Fine's theory concerning the "lack of aggression".

9. APPLYING MARGULIES PRINCIPLES TO CHESS PUZZLES

Chess puzzles known as 'mating problems' involve finding the 'winning move' which will lead to checkmate in a given number of moves. Out of Margulies eight principles, only four are implemented in the program that accompanies this paper. The reasons for selecting certain principles concern their suitability to solving mating problems, and are discussed in detail below.

9.1 ACCEPTED PRINCIPLES

The first principle is accepted in a reduced form. The 'successfully violate heuristics" has been reduced to 'successfully violate heuristics which apply to mating problems'. This ensures the heuristics being violated are applicable to mating problems, because standard heuristics can apply to many different areas of the game, yet mating problems concentrate on the end of the game.

Margulies summarises the second, third and forth principles, "Use the weakest possible piece", "Use all of the piece's power" and "Give more aesthetic weight to the critical pieces", as "Don't waste any power". These encapsulate aesthetic principles such as "economy", "parsimony" and "simplicity" which were initially discussed by Margulies.

These principles were implemented in the *"Beauty"* version because they offer no direct advantage over the standard heuristics, yet they do form an additional guide to assist the choice of a move. Frey observed from Groot's research that Grandmasters had more discerning perception of a move than the average players. It is possible that these principles will increase the program's perception of the 'correct move', enforcing Margulies belief that masters may use their sense of beauty as an additional guide.

The fifth principle, "Use one giant piece in place of several minor pieces" was investigated in a modified form. Obviously the regulation chess game does not contain the pieces invented by

Margulies, and thus it would be difficult to apply to mating problems. However, by examining the implication behind his example, that six squares attacked by one piece, $\frac{6}{1}$, is more efficient than six squares attacked by three pieces, $\frac{6}{3}$, appears to consolidate the summation "Don't waste any power".

Margulies admits that "traditional principles of economy could be invoked to support findings in either directions" [20 p.10] An analysis of the fifth principle suggests it can be applied in either 'direction', with the situation arising where the using all of the pieces is more economical because it wastes less of the power contained on the board. The fifth principle was not implemented in the program, but it was used to propose a new principle, "use all of the pieces". The remaining principles could not be applied to mating problems for the reasons outlined below.

9.2 REJECTED PRINCIPLES

The sixth principle favours elaborate 'themes', contrasting with the previous 'economy' orientated principles, and thus does not lend itself to being used in mating problems. The solutions to mating problems find the move which leads to checkmate in the fewest resulting moves. For this reason, 'themes' can not be developed because they hinder the search for the quickest checkmate by examining a superfluous search area.

The seventh and eighth principles were also not implemented for a similar reason. When examining a checkmate puzzle the computer does not have the luxury of being able to change the opponent's pieces to present a less stereotyped position. The problem with Margulies example in figure 6, is that the white player uses the same move in both cases. White's position would not be benefited by following the "Avoid bland stereotopy" heuristic, because it advises against the most effective move for that position (which was the move taken). The move would, however, be judged beautiful under principle three, because it uses all of the Rook's power.

9.3 ALL PIECES

An analysis of the fifth principle suggests a new principle can be formed which is the opposite of it. Called "use all of the pieces", it encourages the computer to use a move where all of its the pieces on the board are utilised. An attack where *all* of its pieces are involved is more efficient than an attack where only a proportion are involved, because it wastes less power.

This principle was experimentally adopted with the other heuristics. Problems were encountered when it was implemented, and thus the heuristic yielded poor results. Frey states [5 p.60];

> *"For each new term which is added to the evaluation function one must ask if the Chess information gained is worth the cost in computation time that this additional assessment will require."*

It is clear in the case of this heuristic that the substantial cost in computation time far outweighed any benefits it provided the search.