COMPUTER CHINESE CHESS

Shi-Jim Yen[1], *Jr-Chang Chen*[2], *Tai-Ning Yang*[3], *Shun-Chin Hsu*[4]

Taipei, Taiwan

ABSTRACT

This article describes the current state of computer Chinese chess (Xiang Qi). For two reasons, Chinese-chess programming is important in the field of Artificial Intelligence. First, Chinese chess is one of the most popular and oldest board games worldwide; currently the strength of a Chinese-chess program can be compared to that of human players. Second, the complexity of Chinese chess is between that of chess and Go. We assume that after DEEP BLUE's victory over Kasparov in 1997, Chinese chess will be the next popular chess-like board game at which a program will defeat a human top player.
In the article we introduce some techniques for developing Chinese-chess programs. In the Computer Olympiads of 2001 and 2002, the programs ELP and SHIGA were the top Chinese-chess programs. Although these two programs roughly have the same strength, they were developed following completely different techniques, as described in the article. The improvements of the best Chinese-chess programs over the last twenty years suggest that a human top player will be defeated before 2010.

1. INTRODUCTION

Chinese chess (Xiang Qi) is one of the most popular board games worldwide, being played by approximately one billion people in China, Taiwan, and wherever Chinese have settled. Having a long history, the modern form of Chinese chess was popular during the Southern Song Dynasty (1127–1279 A.D.). The earliest record of a Chinese-chess game and a book on the theory of the game originates from that time.

Chinese chess is a two-player, zero-sum game with complete information. Chinese-chess expert knowledge started to be developed some 800 years ago. Nowadays, the world has many excellent human players. Yet, already now, the strength of the best Chinese-chess programs can be compared to that of human players notwithstanding the fact that the game is considered rather complex. Table 1 shows the state-space complexity and the game-tree complexity of chess, Chinese chess, Shogi, and Go. The state-space complexity of Western chess and Chinese chess was estimated by Allis (1994). The game-tree complexity of Chinese chess is based on a branching factor of 38 and an average game length of 95 plies (Hsu, 1990). The complexity of two other games has been estimated: by Bouzy and Cazenave (2001) for Go and by Iida, Sakuta, and Rollason (2002) for Shogi. The complexity of Chinese chess is between that of Western chess and Shogi.

Game	State-space complexity	Game-tree complexity
Chess	50	123
Chinese chess	48	150
Shogi	71	226
Go	160	400

Table 1: State-space complexity and game-tree complexity given by the power of 10.

[1] Department of Computer Science and Information Engineering, National Dong Hwa University, Taiwan. Email: sjyen@csie.ndhu.edu.tw.
[2] Department of Computer Science and Information Engineering, National Taiwan University, Taiwan. Email: d7526002@csie.ntu.edu.tw.
[3] Department of Computer Science, Chinese Culture University, Taiwan. Email: tnyang@faculty.pccu.edu.tw.
[4] Department of Information Management, Chang Jung Christian University, Taiwan. Email: schsu@csie.ntu.edu.tw.

After DEEP BLUE's victory over Kasparov, Chinese chess may become the next popular chess-like board game at which a program will defeat a human top player. In fact, the Chinese-chess programs ELP and SHIGA have already beaten a few 7-dan players in some human tournaments in Taiwan. The Taiwan Chinese-Chess Culture Association has qualified ELP as 6-dan and, in 2003, the Association qualified SHIGA also as 6-dan. We expect a program to defeat a human top player before 2010.

The course of the article is as follows. Section 2 introduces the characteristics of Chinese chess. Section 3 discusses the state of Chinese-chess programs. ELP and SHIGA were the top Chinese-chess programs at the 2001 and 2002 Computer Olympiads[5]. Although these two programs have similar strengths, they were developed using different techniques, which are described in Section 4. Section 5 considers the main challenges to the development of a Chinese-chess program. Finally, Section 6 provides conclusions.

2. CHARACTERISTICS OF CHINESE CHESS

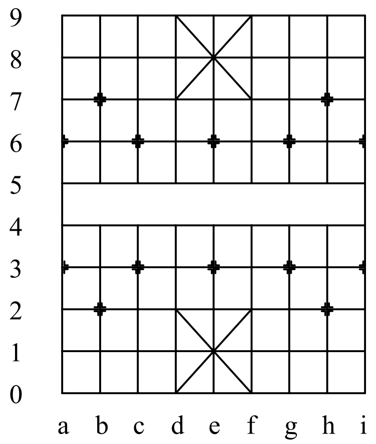
Below we describe the characteristics of Chinese chess by providing the basic rules (Subsection 2.1) and by presenting the key differences between Chinese chess and Western chess (Subsection 2.2).

2.1 Basic Rules of Chinese Chess

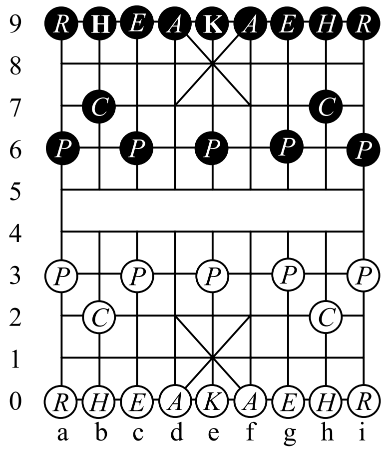
Our description of the basic rules of Chinese chess constists of four parts: the board (in 2.1.1), the rules that govern the pieces (in 2.1.2), the recording of the moves (in 2.1.3), and repetition rules (in 2.1.4).

2.1.1 The Board

The Chinese-chess set includes a board (Figure 1a) and 32 Chinese-chess pieces for two players (Figure 1b). The board has ten horizontal lines (ranks) and nine vertical lines (files). In the middle of the board the central seven files are interrupted by a horizontal space called the "River", which splits the board into two parts. Each side of the board has a "Palace" in the central squares marked with an "X" in Figure 1a. The pieces are placed on the intersections of the lines, including the "River banks" and move along the intersections (for precise rules, see 2.1.2). The two sides are usually distinguished by colour, being red or black. The goal of the game is the same as in chess, which is to checkmate the opponent.



(a) Empty board.



(b) Initial position.

Figure 1: Board and pieces of Chinese chess.

[5] In the 2003 Computer Olympiad in Graz, Austria, ZMBL and XIEXIE were the top Chinese-chess programs. However, it is hard to describe their techniques in this article, since as far as the authors of this article know there are no papers published by the program authors. Only a few personal discussions have been held. The characteristics of the two programs seem to be somewhere between ELP and SHIGA. (See Table 6)

2.1.2 Rules that Govern the Pieces

Chinese chess involves seven kinds of pieces. Each side has one King, two Advisors, two Elephants, two Rooks, two Horses, two Cannons, and five Pawns (Figure 1b), abbreviated as K, A, E, R, H, C, and P, respectively[1]. Kings can move only within the Palace. Kings move one space (move) at a time, only vertically or horizontally. Kings are not allowed to face each other directly. That is, if the two Kings are on the same file, at least one piece from either side must be in between, also on this file. A King will be captured if it moves into the "line of sight" of the other King. Advisors are also confined to the Palace. Advisors move one diagonal space at a time, they cannot move horizontally or vertically. Elephants can move only in their own territories, meaning that they cannot cross the River. Elephants move diagonally two spaces at a time, meaning that they always move up or down two spaces, and left or right two spaces. Elephants may be "blocked", meaning that if a piece stands in the space diagonally adjacent to the Elephant, then the Elephant cannot move in that direction. Rooks move horizontally or vertically to any empty space. Horses move one space horizontally or vertically and another space diagonally in either direction. Horses may also be blocked. A piece that stands right next to the Horse prevents the Horse from moving in that direction. Cannons can move sideways or vertically for any empty number of spaces, just like Rooks. However, to take a piece, a Cannon has to jump over some piece (which is called a Cannon mount) from either side. The number of empty spaces between a Cannon and a Cannon mount or between a Cannon mount and the piece that is being taken is unrestricted. Pawns move one space at a time. Before crossing the River, a Pawn can only move forward. Once having crossed the River, a Pawn can move forward or horizontally in either direction. Pawns can never move backward.

2.1.3 The Recording of the Moves

In the traditional system, the files of each side are numbered from 1 to 9 from right to left (Figure 2a). Moves are recorded using the syntax (name of piece, origin, direction, destination file or distance moved). When two pieces of the same kind are in the same file, the syntax is modified to (forward/rear, name of piece, direction, destination file or distance moved). This notation is sometimes ambiguous. For example, describing the Pawns' move in Figure 2b via the traditional system is extremely difficult. More examples can be found in Donnelly (2003).

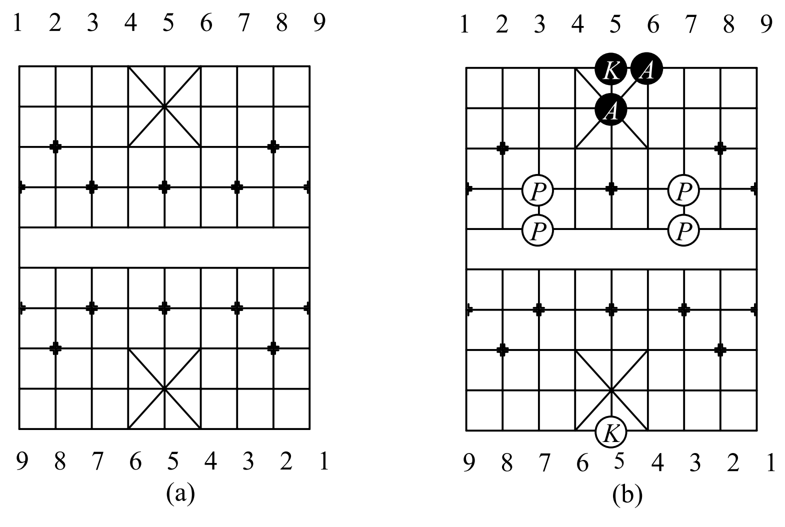


Figure 2: (a) Traditional system for recording moves. (b) Example that cannot be represented using the traditional system.

This article uses the "algebraic" notation for moves, suggested by Marsland (2002). It is a full algebraic triplet, (name of piece, source cofile, destination cofile). A cofile is a simple letter-digit pair, which specifies the position of a piece. In Figure 1b, for example, the black King is on position e9. Besides preventing ambiguity as in Figure 2b, this notation is more easily read by a computer program. Some game records using the algebraic notation and traditional notation can be found in Chen, Yen, and Hsu (2002).

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[1] The English translation of the Chinese names differs by author. The reader is referred to the Editorial to obtain some background information.

2.1.4 Repetition Rules

The rules that govern repetition of moves (moves that are repeated in the same situation) are quite different in China, Taiwan, and Hong Kong. In this article, move repetition will be discussed based on the Asian rules (Asian Xiangqi Federation, 2003; Hong Kong Chinese Chess Association, 2002). Asian rules are detailed in Lee (1989). An English translation of a part of the Asian rules can be found in Wu (2002). In Asian rules, forty rules govern the perpetual situations, some of which are quite complex for an amateur player.

Some simplified repetition rules are listed in Hsu (1990), Hsu and Liu (2002), and Ye and Marsland (1992b). A repetition is said to have occurred when the same position reappears on the board for the third time. Sometimes this occurs when both players are making non-attacking moves (perhaps aimless ones), in which case the game is drawn. More commonly, a repetition occurs because one side is perpetually attacking (threatening) a specific opponent piece (e.g., the King, but it could be almost any piece). Here these perpetually attacking moves are called *forcing*, and any third-time attacking move is “forbidden”. Appendix A lists a simple and almost complete summary of the repetition rules.

2.2 Key Differences between Chinese Chess and Western Chess

Seven major differences between Chinese chess and Western chess are as follows.

1. Western chess is played on an 8×8 board with six different kinds of pieces, while Chinese chess is played on a 9×10 board with seven different kinds of pieces. The Chinese chessboard is more difficult to represent on a computer.
2. The board of Chinese chess is more like a “battlefield” than a chessboard is. The Chinese chessboard has two special territories. One is the Palace. The Kings and Advisors can move only within their Palace. The other is the River. Elephants cannot cross the River. These constraints seem to reduce the complexity of Chinese chess, since these pieces at first may appear not to be able to threaten pieces on the other side of the River, but this is a fallacy. These pieces can, in fact, directly threaten the other side’s pieces by being a Cannons mount and by the special rule that Kings should avoid seeing each other face to face.
3. Cannons are very special pieces. Cannons move like Rooks but have to jump over a piece to capture it. Thus, any piece co-operating with Cannons will have the same power as a Rook. Western chess has no similar piece.
4. Although Kings cannot leave the Palace, Chinese chess has a special rule that allows them to threaten their counterparts: Kings may not see each other face to face. Based on this rule, Kings sometimes have a power similar to that of Rooks, which is very useful in the endgame stage.
5. Blocking rules apply to Elephants and Horses. Western chess has no similar rule.
6. Pawns move one space at a time. When a Pawn reaches the opposite bottom line, it cannot be turned into another piece as it can be in Western chess.
7. Repetitive situations are relatively simple in Western chess. In Chinese chess, however, because of the larger board and the characteristics of certain pieces, repeating situations in which neither side wants to make a concession, is more likely to arise. Special rules are required to govern these situations. In some extreme situations, a referee must make a judgement. Therefore, resolving repeating situations is a challenge in computer Chinese chess. Section 4.2 discusses the related issues.

Chinese-chess rules differ markedly from those of Western chess, so the strategies differ. Strategies have an enormous influence on the writing of a Chinese-chess program. The most basic Chinese-chess strategies may be the ten strategies (Chang, 1985) summarized in appendix B.

3. STATE OF COMPUTER CHINESE CHESS

The first Chinese-chess program was likely written by Liao (1982). The first scientific paper on computer Chinese chess was published by Zhang (1981). The earliest (human-)computer Chinese-chess competition was the annual ACER cup, which was held in Taiwan from 1985 to 1990. The Computer Olympiad is another important (computer-computer) tournament. Since 1999 a regular human vs. computer competition has also been held in Taiwan. It allows a comparison of the strength of computer programs to that of human players. Moreover, sometimes computer programs were allowed to join human tournaments; some of the results are considered below. A few Chinese-chess associations have graded the performances of the computer programs in some of these tournaments. In this section, we briefly introduce the results of these competitions. For the latest information we refer to Yen, Chen, and Hsu (2004).

Obviously, the Chinese-chess rating system differs from that of Western chess. Traditionally, the strength in Chinese chess is rated in kyu and dan. The highest rating is the 9-dan. Recently, the Chinese-chess rating system was published on Internet. Here, China has begun to imitate the chess Elo-rating system. Generally, a rating of over 2550 points corresponds to 9-dan. At present, the most highly-ranked player is Xu Yin Chuan from China, with 2663 points. Table 2 compares the Chinese-chess Elo-rating system and the traditional Chinese-chess rating system.

Elo rating	1600	1700	1800	1900	2000	2100	2200	2300	2350	2400	2450	2500	2550
Traditional rating scale	4-kyu	3-kyu	2-kyu	1-kyu	1-dan	2-dan	3-dan	4-dan	5-dan	6-dan	7-dan	8-dan	9-dan

Table 2: Comparison between Chinese-chess Elo-rating system and traditional Chinese-chess rating system.

3.1 Computer versus Computer

The world's first computer Chinese-chess contest was the ACER Cup held in 1988 in Taiwan. Most competitors in the contest came from Taiwan. At that time, the computer programs were rated between 2-kyu and 1-dan. The internationalisation of computer Chinese chess began with the Computer Olympiad's international Chinese-chess contest in 1989. The programs in that contest came from various countries, including Canada, China, France, Taiwan, and the United States. Table 3 displays the first-place results over the years.

Computer Olympiad	**Place and Year**	**Winner**	**Author(s)**
1st	London, 1989	CHESS MASTER	C.S. Yu
2nd	London, 1990	ELP	S.C. Hsu, W.Y. Cheng
4th	London, 1992	MRSJ	R. Wu
6th	Maastricht, 2001	ELP	S.C. Hsu, W.Y. Cheng, J.C. Chen
7th	Maastricht, 2002	ELP	S.C. Hsu, W.Y. Cheng, J.C. Chen
8th	Graz, 2003	ZMBL	Zhijian Tu

Table 3: Results of Chinese-chess tournaments in the Computer Olympiads.

3.2 Computers versus Humans

From 1999 on, a human-computer Chinese-chess competition (H4C) was held each year at the National Taiwan University, Taipei, Taiwan (Lai, 2004). The purpose of this tournament was to compare the strength of the best Chinese-chess program to that of human players. Every year four players with a rating above 5-dan were invited. The representative Chinese-chess program in the first two Chinese-chess competitions was ELP. SHIGA joined the third competition. The official traditional rules and the usual time limit applied; each human played two games with a computer, which were simultaneously broadcast over the Internet. The referees determined the results according to the rules of the Taiwan Chinese-Chess Association. The winner of each game received US $ 270 and the loser received US $ 60 as an incentive for the human player to win. Table 4 presents the results of these competitions from 1999 to 2004.

H4C	**Year**	**Strength of Human Players**	**ELP results (ELP-human players)**	**SHIGA results (SHIGA-human players)**
1st	1999	Five 5-dan players	6-4	None
2nd	2000	Two 6-dan players and two 5-dan players	4-4	None
3rd	2001	One 6-dan player and three 5-dan players	2.5-1.5	2-2
4th	2003	Four 6-dan players	0.5-3.5	2-2
5th	2004	One 7-dan player and three 6-dan players	3-1	3.5-0.5

Table 4: Results of H4C 1999-2004.

3.3 Computer Programs in Human Tournaments

In Taiwan, some human Chinese-chess tournaments allow the participation of Chinese-chess programs. Hence, some Chinese-chess programs have played in these competitions, and were given a grading certificate according to their results. ELP was qualified as 6-dan by the Taiwan Chinese-Chess Culture Association and as 5-dan by the Taiwan Chinese-Chess Association. SHIGA was qualified equal to 6-dan by the Taiwan Chinese-Chess Association in June 2003.

The strength of these programs is estimated from their records in tournaments. Figure 3 shows the average estimated playing strength of the strongest program over the years. Based on this table, the strongest program is expected to win against a human top player before 2010.

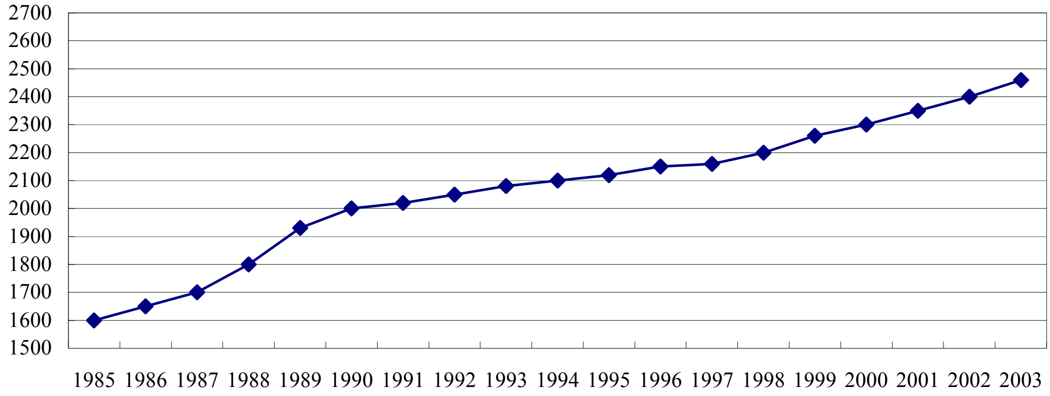


Figure 3: Strength of the strongest program over years.

4. TECHNIQUES USED IN CHINESE-CHESS PROGRAMS

This section describes the main structures of Chinese-chess programs, including move generation (4.1), handling perpetual situations (4.2), evaluating positions (4.3), the balance between search and knowledge (4.4), opening play (4.5), searching (4.6), and playing the endgame (4.7).

4.1 Move Generation

In an alpha-beta cut-off based program, determining the priorities for choosing the moves is very important, since a good choice will speed up the execution of the program. In Chinese-chess programs, the priorities for each move can be determined by the power of each piece. The sequence to be followed is: Rook, Horse, Cannon, Pawn, Elephant, Assistant, and King. If a move is a capture move, the move will have a higher priority according to the power of the captured piece. Based on the idea that a capture move and a stronger piece have higher priorities, ELP uses the following approach.

1. Positional moves and capture moves are processed separately. At the point of checkmate, the program may only generate a capture move.
2. Under the general conditions, capture moves are searched first.
3. The program produces feasible moves for the stronger pieces before the weaker ones are investigated.
4. Moves that capture more important pieces have higher priority.

For increasing the search speed, the following two rules are frequently added to the approach.

1. The Kings may not face each other directly; if the situation still arises, the program decides that the winner is the player who is to move next.
2. A King may not play for suicide. However, if the program still generates such moves, the searching procedure should handle them adequately.

Except for the movement of one piece, structures of several pieces are considered. Two simple ideas are as follows.

1. Continuously attacking: the attacking pieces are organized as a set; a queue is used to store the pieces that in turn continuously attack; after attacking, each piece is put into the queue again.
2. Generating local advantages: the chessboard is divided into four parts; each player has two parts. If the attacking is concentrated in one part, the local advantages are generated.

4.2 Processing Perpetual Situations

In 2.1.4 we introduced the perpetual situations in Chinese chess and stated that the related repetition rules are complex. Indeed, processing perpetual situations is very difficult. It is governed by complex rules. Therefore, perpetual situations can affect the efficiency of the search process, and may seriously affect their accuracy. Even if only one position is repeated, much time may be wasted for searching two levels in the tree. For instance, a useless check may not only waste precious time but also reduce the strength of the program, causing it to make mistakes. As a case in point, assume that Black moves Ra3e3 in Figure 3(a) (see Appendix), then the game will be drawn (Fang, 2001). However, if a computer program has no special procedure for checking repetition rules, the program will consider checking as follows: 1. Ra3a0 2. Kf0f1 3. Ra0a1 4. Kf1f0 5. Ra1a0.

Most Chinese-chess programs can examine perpetual situations but when encountering them repeatedly, they will forbid and ignore the move. Obviously, this procedure makes too many concessions to the opponent. A good human player can usually make the best use of the rules by compelling the opponent to make some concession. In an amateur tournament, such a concession may be unimportant, but a computer program that operates at grandmaster level must be able to process perpetual situations well.

The Chinese-chess rules that govern perpetual situations imply that moving forward a Pawn or capturing a piece never produce a repeated position. Accordingly, the current move can be tracked back to the latest move of a Pawn or a capture.

Processing perpetual situations is more complex than inspect them. The related ELP strategies are as follows.

1. Repetition of check is prohibited, including performing Cannon's mount move to cause check.
2. Repeatedly threatening the same piece is prohibited.
3. When the position is good, any move that causes a perpetual situation is prohibited.
4. Moves to avoid check are never prohibited.
5. If only a forbidden move can be played to avoid loss, then this forbidden move will not be prohibited.
6. A threatened piece can move, regardless of all prohibitions.

Although these strategies are incomplete, they solve most problems. Further research is required on a mutual threat between a Rook and a Horse, or the mutual blocking of a Rook and a Cannon. Using these strategies, the program avoids violating the rules, while using them to compel the opponent to make some concessions.

4.3 Evaluating Positions

The evaluation of a position done by estimating the situation on a board, i.e., by determining the value that measures the advantage (or disadvantage). Such an evaluation is a part of Chinese chess that requires most intelligence; it is also the part at which humans are better than computers. Some special board situations are hard to determine even when the search trees are expanded to 15 or 20 moves. Moreover, some Chinese-chess endgames have a variety of conclusions. For instance, a side with three Pawns defeats the other side with two Advisors and two Elephants. Sending three Pawns across the River may take 30 moves or 40 moves, but if all pieces can be exchanged to create this situation, then a win is assured. Embedding this kind of judgement in the middle-game program engine increases its intelligence. The approach of embedding expert knowledge in the program may reduce the required search depth but it certainly increases the time required to calculate each evaluation function.

The evaluation of a position in Chinese chess has approximately five elements: (1) the strength of the pieces in play, (2) the important positions, (3) the flexibility of the pieces, (4) the threats between pieces and the protection of pieces from threats, and (5) a dynamic adjustment according to the situation (Hsu, 1990). Details of those elements are discussed below.

4.3.1 Strength of the pieces in play

Calculating the strength of the pieces is the simplest method to measure the current board status. Since different kinds of pieces have different attacking power and defensive power, their values are different. The King is the most important piece. Its value is much larger than the total power of all other pieces. The values of the other pieces are determined by heuristic rules. The power of one Rook is similar to one Horse plus one Cannon. The power of one Horse is similar to two Elephants. Based on these heuristic rules, ELP gives the following values to pieces (see Table 5).

Piece:	King	Assistant	Elephant	Rook	Horse	Cannon	Pawn
Value:	6000	120	120	600	270	285	30

Table 5: The value of each piece.

4.3.2 Important positions

Except of the summed values of the pieces, the position of each piece is very important. The place that can be occupied to threaten the enemy King is the best place. Since each kind of piece has a different way of movement, most programs are equipped with a table that stores the estimated importance of possible positions for each piece. The position value tables of the Rook, Horse, Cannon, and Pawn are given in the Figures 4 to 7.

14	**14**	**12**	**18**	**16**	**18**	**12**	**14**	**14**
16	**20**	**18**	**24**	**26**	**24**	**18**	**20**	**16**
12	**12**	**12**	**18**	**18**	**18**	**12**	**12**	**12**
12	**18**	**16**	**22**	**22**	**22**	**16**	**18**	**12**
12	**14**	**12**	**18**	**18**	**18**	**12**	**14**	**12**
12	**16**	**14**	**20**	**20**	**20**	**14**	**16**	**12**
6	**10**	**8**	**14**	**14**	**14**	**8**	**10**	**6**
4	**8**	**6**	**14**	**12**	**14**	**6**	**8**	**4**
8	**4**	**8**	**16**	**8**	**16**	**8**	**4**	**8**
-2	**10**	**6**	**14**	**12**	**14**	**6**	**10**	**-2**

Figure 4: Position values of a Rook.

4	**8**	**16**	**12**	**4**	**12**	**16**	**8**	**4**
4	**10**	**28**	**16**	**8**	**16**	**28**	**10**	**4**
12	**14**	**16**	**20**	**18**	**20**	**16**	**14**	**12**
8	**24**	**18**	**24**	**20**	**24**	**18**	**24**	**8**
6	**16**	**14**	**18**	**16**	**18**	**14**	**16**	**6**
4	**12**	**16**	**14**	**12**	**14**	**16**	**12**	**4**
2	**6**	**8**	**6**	**10**	**6**	**8**	**6**	**2**
4	**2**	**8**	**8**	**4**	**8**	**8**	**2**	**4**
0	**2**	**4**	**4**	**-2**	**4**	**4**	**2**	**0**
0	**-4**	**0**	**0**	**0**	**0**	**0**	**-4**	**0**

Figure 5: Position values of a Horse.

6	**4**	**0**	**-10**	**-12**	**-10**	**0**	**4**	**6**
2	**2**	**0**	**-4**	**-14**	**-4**	**0**	**2**	**2**
2	**2**	**0**	**-10**	**-8**	**-10**	**0**	**2**	**2**
0	**0**	**-2**	**4**	**10**	**4**	**-2**	**0**	**0**
0	**0**	**0**	**2**	**8**	**2**	**0**	**0**	**0**
-2	**0**	**4**	**2**	**6**	**2**	**4**	**0**	**-2**
0	**0**	**0**	**2**	**4**	**2**	**0**	**0**	**0**
4	**0**	**8**	**6**	**10**	**6**	**8**	**0**	**4**
0	**2**	**4**	**6**	**6**	**6**	**4**	**2**	**0**
0	**0**	**2**	**6**	**6**	**6**	**2**	**0**	**0**

Figure 6: Position values of a Cannon.

0	**3**	**6**	**9**	**12**	**9**	**6**	**3**	**0**
18	**36**	**56**	**80**	**120**	**80**	**56**	**36**	**18**
14	**26**	**42**	**60**	**80**	**60**	**42**	**26**	**14**
10	**20**	**30**	**34**	**40**	**34**	**30**	**20**	**10**
6	**12**	**18**	**18**	**20**	**18**	**18**	**12**	**6**
2	**0**	**8**	**0**	**8**	**0**	**8**	**0**	**2**
0	**0**	**-2**	**0**	**4**	**0**	**-2**	**0**	**0**
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 7: Position values of a Pawn.

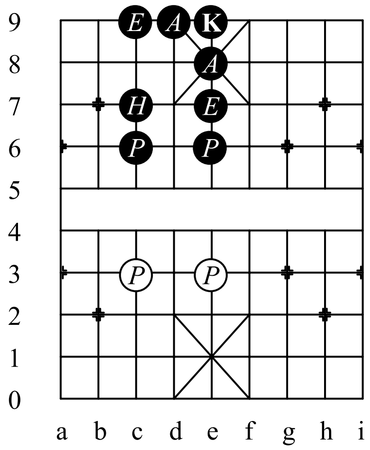
4.3.3 Flexibility of the pieces

If a piece could move freely, its attacking power is restricted. The possible positions of a piece except for the Cannons give the attacking range. The more flexible the piece is, the more attacking power it has. But estimating the flexibility of all pieces costs too much, ELP only considers the flexibility of Horses.

4.3.4 Threats between pieces and protection of pieces from threats

The number and kind of protectors and threatening enemies determine the security of a piece. A simple way to estimate the security is using a data structure to record the protecting and threatening relationships between pieces and following the killing principle to switch pieces. This method is fast, but prone to making wrong decisions. ELP uses quiescent search on terminal nodes until it reaches a static condition. This takes a great deal of computation time but leads to rather few wrong decisions.

4.3.5 A dynamic adjustment according to the situation



Dynamic adjustment uses the technique of pattern recognition to adjust dynamically the current values of pieces and the position-power table. In Figure 8, the Cannon positions c0, c1, c2, e0, e1 and e2 could threaten the enemy King or Horse indirectly such that these positions are adjusted as the optimal positions of the Cannon. When the enemy moves the King or Horse, the status of these positions have to be re-adjusted.

Figure 8: A Dynamic adjustment according to the situation.

4.4 Balance between search and knowledge

Chinese-chess programs are like Western-chess programs in that they can be divided into two types: knowledge-based and brute-force programs. A knowledge-based program emphasises the evaluation of positions. A brute-force program uses the ability to compute quickly and to explore the game tree deeply, so as to discover better moves. Even in Western-chess, the better approach has not been identified yet. Chinese chess has more different pieces and a larger board than chess, so knowledge-based programs are considered to have more potential. When SHIGA – a knowledge-based program – searches 13 to16 ply, the number of misjudgements of the position evaluation is greatly reduced and the benefits of the position evaluation are exploited.

ELP is a brute-force program. Interestingly, its strength is similar to that of SHIGA: both are around 6-dan. From past experience we know that ELP performs well in computer-computer competitions, and SHIGA performs better against humans. Table 6 shows the differences between the two programs.

	ELP	SHIGA
The strength of designers	1-dan	5-dan
Programming language	Assembly	Visual Basic
Program type	Brute-force	Knowledge-based
Playing style	Machine logic	Quasi-human style
Speed (ply/min)	12 to 14	10 to 11
Embedding Chinese-chess knowledge	Less	More
Misjudgements	Less	More

Table 6: Differences between ELP and SHIGA.

4.5 Opening Play

In Western-chess, some 20 plies (10 moves) are required (mostly stored in the form of knowledge) to be able to move the pieces to important positions, and thus lay the foundation for offence and defence during the middle game. For Chinese-chess programs search techniques alone do yield sufficient advantage but here too a massive opening database, which contains much expert knowledge, is necessary to develop an excellent Chinese-chess program.

The ELP development team built and maintained a Chinese-chess opening-game knowledge system since 1985 (Hsu and Huang, 1985; Hsu and Taso, 1991; Chen 1997). The existing knowledge database is composed of a tree structure and a hash function. The root of the tree is the current board, and the tree is descended with the next moves as a directed tree. This involves special processes for repeated boards – according to the rules described in Subsection 4.2. The space in the database is managed mainly by constructing a framework and using a hash function to map each board onto a slot. The program fetches the set of remaining pieces; masks the corresponding bits, and then executes an XOR operation based on these bits. The XOR-calculated value is the hash address of the board, and is mapped to some slot of the database.

After Chinese-chess game records have been input, the system relies on the judgement by combining the minimal backtracking method and considering the statistics of each board. Based on an information analysis including the score, the number of boards descending from it, and the conditions for a win, draw, or loss, ELP chooses those moves above a certain quality randomly, that is, after weeding out those moves with a low number of boards or a bad score; the program chooses one out of one-third of the moves depending on the utility rate and the formula "α× (number of draws plus the difference between the numbers of wins and losses)". The coefficient α may be given in the opening-phase behaviour as a more aggressive one or a more conservative one. Generally speaking, ELP with its fine-tuned opening database exceeds 7-dan in playing strength.

The knowledge base in ELP contains the records of most of the games in all Chinese-chess books in the world. Since 1995, Chinese-chess tournaments over the Internet have become popular, and nowadays form a reliable source of many game records. In 2002, when the 7th Computer Olympiad started, ELP contained around 40,000 games. At the actual combat, roughly the first 20 moves were from the opening database.

Most records in SHIGA's opening database are from the Internet Chinese-chess game servers. SHIGA has stored around 140,000 records. At the actual combat, roughly the first 24 moves are from the opening chess database. SHIGA does not always choose the move with the highest score but computes a weighted function, "one's own side good rate + power balance rate / 2". This number is used to weight the probability of choosing a candidate move. For example, if the present opening database is described by the statistical data in Table 7, then the next candidate move is computed as follows.

"Ch2e2": "Pg3g4" : "Eg0e2" = 99097*(42+18/2) : 19929*(42+20/2) : 13431* (41+24/2)

If a candidate move's evaluation is lower than one tenth of the maximum, it will be excluded from consideration. The program chooses one of the two moves with the highest scores in the opening game and one of the three moves with the highest scores in other stages. If some well-known bad or good move is encountered, the program is forced to make a predetermined move and avoids errors caused by the random number generator.

Move	Total games	Used rate	Red is better	Draw	Black is better
Ch2e2	99097	66%	42%	18%	40%
Pg3g4	19929	13%	42%	20%	38%
Eg0e2	13431	9%	41%	24%	35%
Hh0g2	6465	4%	40%	20%	40%
Ch2h6	4993	3%	41%	14%	45%
Ch2f2	3918	3%	43%	17%	40%
Hh0i2	1162	1%	48%	20%	31%

Table 7: Statistics of the first move in SHIGA's opening database.

4.6 Searching

Because the games have similar complexities, the search method applied in Chinese chess is similar to that applied in Western chess (Hsu, 1990; Ye and Marsland 1992a,b). Basically, a Chinese-chess program builds minimal game trees searched by an alpha-beta search (Knuth and Moore, 1975). For example, the search engine in ELP is based on the principal variation search (PVS) structure that uses the following methods to enhance the search correctness and save computation time.

Quiescent search
A quiescence search explores all captures and checks from the current position, terminating at quiescent positions, defined as those in which no captures or checks are available (Beal, 1990).

Processing perpetual situations
As we described in Subsection 4.2, perpetual situations have to be identified during the search process. The influence of a check effect happens frequently. If the program only assesses at the first level, it may leads to a wrong board status that repeatedly tries to kill the King.

Computing and storing the results in advance
When the opponent is thinking, the program could make use of this “free time” to predict the opponent’s move and store the results. If the prediction is right, the results are fetched without further computation.

Forward pruning
This includes razoring, futility pruning, and null move (Ye and Marsland, 1992b).

Move ordering
This includes killer heuristic, history heuristic (Schaeffer, 1983), and internal iterative deepening.

Transposition table
Store position scores in a hash table for use if the same position is reached again (Marsland, 1986). The hash function used in ELP is described in Subsection 4.5.

Other speed-up methods
Iterative deepening and aspiration windows (Kaindl, Shams, and Horacek, 1991).

Before PVS begins, the program uses a threat-sequence search, in particular when the game tree is narrow and deep. It determines whether serial checking may be performed. In such a tree, only the checking of the King and avoiding having one’s own King checked, are considered. Comparing to the endgame stage, the middle game has fewer legal moves that can be played. Thus, more plies can be searched in the middle game. According to our development experience, ELP and SHIGA have a strength of about 6-dan in the middle game.

4.7 Endgame

In the endgame, few Pawns remain, so other strong pieces have more space to move. The search depth in this stage is limited owing to the freedom of the pieces and the large size of the Chinese chessboard. Since, human players can employ expert knowledge to help search in this stage, most Chinese-chess programs are inferior to human players in this stage. Hence, improving the endgame is key to defeating human top players.

The earliest retrograde algorithm is proposed by Ströhlein (1970). Subsequently Van den Herik and Herschberg (1985) have significantly contributed to the retrograde concept. Then Thompson (1986, 1996) has published his great contributions to Western-chess endgames. His endgame databases built on retrograde analysis succeeded to increase the playing strength of many chess-playing programs. Thereafter we have seen the contributions by Nalimov et al. (2001). In recent years, many people have shown interest in developing Chinese-chess endgame databases (Fang, 1996, 2001, 2003; Hsu and Liu, 2002; Wu and Beal, 2001a,b,c). Their essential procedure is using a retrograde algorithm to construct the basic endgame database and then constructing the more complex endgame database gradually. This kind of endgame system contains complete information. That is, it has knowledge on wins or losses, and it knows the optimal moves. Nowadays, a computer can automatically, without the help of expert knowledge, construct such endgame databases.

Rather than being built on retrograde analysis, an endgame database can also be built on massive experts’ knowledge (Chen, 1998). This kind of endgame database is smaller, more practical and easier to incorporate into the existing Chinese-chess programs.

5. CHALLENGES

Chinese-chess programs are still weaker than the human top players. Apart from increasing the computer speed, the following four research subjects will be helpful for achieving the goal to defeat human top players.

1. *Parallelisation of Chinese-chess programs* and *the development of customised hardware for deep look ahead*: before the release of the faster hardware, the parallel processing and dedicated hardware may improve the search process. Ke (1995) proposed for computer Chinese chess a parallel hardware architecture that applies global broadcasting to communicate and update the newest move dependence information among the search control subsystems. Simulation results show that up to a 179-fold increase of speed-up can be achieved by using 1444 search control subsystems.
2. *Endgame system improvement*: experience shows that when playing against a 6-dan human player, a Chinese-chess program will definitely lose if it enters the endgame with a power balance between the two sides. This fact indicates that the massive expert knowledge and the human intuition outperform the searching power of a program in the endgame. Therefore, establishing a more complete endgame database and using the massive expert knowledge will be an important challenge to improving Chinese-chess programs.
3. *Grandmaster opening*: Internet Chinese chess is in vogue, and so the opening database is growing very fast. However, if the database includes more than a certain number of records (approximately 100,000), increasing the number any further barely increases the strength. Perhaps, the reason is that most records extracted from the net are taken from games between players ranked from 3-dan to 5-dan. The strength after analysing these game records could not reach grandmaster level. The SHIGA team suggests the following ways of constructing an opening database. First, separate the records of steady variations and aggressive variations in different sets of game records. Second, separate records of the games between masters from those between the common players. Finally, makes minor variations in the opening game according to the style of the opponent. It conforms to the strategy that the human players use. This procedure can only be implemented, however, with the help of a human grandmaster.
4. *Another reasoning model*: Chen and Huang (1995a,b) proposed a dynamic fuzzy reasoning model for Chinese chess. This model is based on a fuzzy cognitive map and a rule-based system for deriving the best legal move. Based on this model, the effectiveness of the next move can be improved and the decision time will be much shorter than it is by game-tree searching according to the alpha-beta model.

6. CONCLUSION

Compared to other games such as Checkers, Othello, and Go, the complexity of Chinese chess can be said to be similar to that of Western chess. Computer Chinese chess should benefit from using many technologies developed for Western chess. A game of Chinese chess can usually be divided into three stages – the opening, the middle game, and the endgame. In the opening, Chinese-chess programs currently use an opening database to support computation. An opening database is enlarged by Chinese-chess game records from tournaments on the Internet and by the results of Chinese-chess tournaments. According to the results of the competition between human and computer, the best program with an adequate opening database is currently above 7-dan and the program that implements adequate searches in the middle game can exceed 6-dan. These ratings may be improved as hardware advances. The endgame is the weakest part of the present Chinese-chess programs. A massive memory is necessary to combine endgame database and the search system. The development of hardware may overcome this difficulty. Finally, according to the above analysis, the authors estimate that a computer will defeat the human World Champion before 2010.

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APPENDIX A: A SIMPLE REPETITION RULE OF CHINESE CHESS

The following is a simple and almost complete summary of the repetition rules as they pertain to forcing moves.

1. If only one side attempts to repeat a position with a forbidden move, then they are judged to have lost (i.e., a forbidden move is illegal).
2. If both sides repeat the position using forcing moves, the game is ruled a draw at the third repetition.
3. If both sides repeat non-forcing (non-threatening) moves, the game is ruled a draw at the third repetition.
4. Sometimes a move can be judged in two ways (as, for example, being both a threat move and a threat to checkmate by continual checks in the following moves). Then the move that is forbidden is selected.
5. A side can ask the referee to adjudicate a draw if no piece has been taken, and no more than ten checks have been made by the opponent within the last 40 moves.

Forbidden forcing moves are defined as follows.

1. Perpetual checks on the King are forbidden.
2. Perpetual threats on an unprotected piece (except on a Pawn that has not crossed the River) are forbidden.
3. Perpetual threats on a Rook by Cannons and/or Horses are forbidden.

These rules simply cover most perpetual situations. In Figure 3a, after moves 1. Ra3a0 2. Kf0f1 3. Ra0a1 4. Kf1f0 5. Ra1a0, the move Kf0f1 will be forbidden by forbidden perpetual moves rule 1. However, sometimes determining which perpetual move is forbidden is difficult. In Figure 3b, after moves 1. Rg6i6 2. Ri9h9 3. Ri6h6 4. Rh9g9 5. Rh6g6 6. Rg9h9 7. Rg6h6 8. Rh9i9 9. Rh6i6 10. Ri9g9 …, forbidden perpetual move rule 2 dictates that Red is forbidden to threaten perpetually the Black Rook. However, this game is drawn by the 24th rule in the Asian rules: “when a Rook threatens on a Rook, if neither is pinned down, the threatening move is not forbidden”.

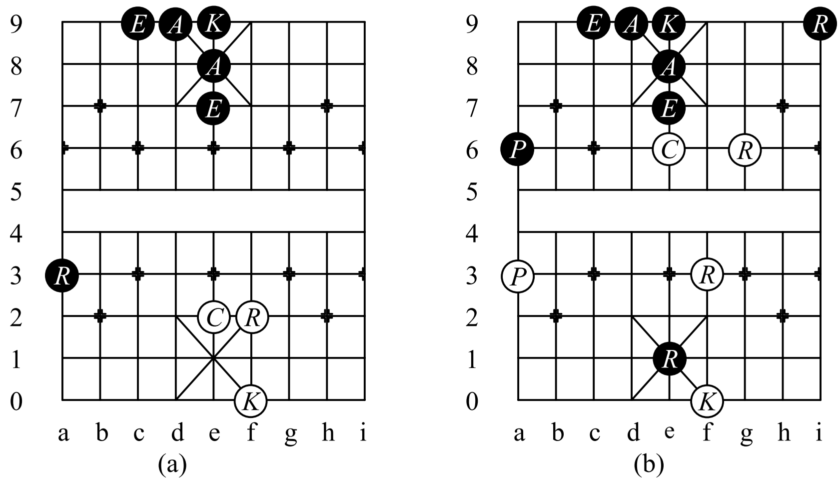

Figure 3: (a) Simple example of perpetual situation. (b) Complex example of perpetual situation.

APPENDIX B: TEN STRATEGIES FOR PLAYING CHINESE CHESS

1. *Open the game normally*: starting the game normally is usually better, especially against a unknown opponent. Carelessness at the start may cause immediate defeat.
2. *Playing variably in the middle game*: in Chinese chess, most variations arise in the middle game. The winner has usually played extraordinarily in the middle game. Most of the interest in Chinese chess is in the middle game.
3. *Ending the game steadily and carefully*: the situation is clear in the end game. The side with more pieces may exchange some pieces for those of opponent to reduce the opponent's strength.
4. *Examining the overall situation*: two factors are extremely important in estimating the current board situation. The first is the number of pieces in play. The second is the positions of these pieces on the board and their relationship with each other. Examining the overall situation reveals potential danger.
5. *Occupying the strategic points with the Rook*: usually files d, f, e, b and h, and ranks 1 and 8 are most important for the Rooks.
6. *Decrease mobility of the Horse*: Horses are powerful when they can move freely but they can be blocked easily; therefore, the paths of Horses must be carefully considered.
7. *Mobilising Cannons*: positioning Cannons on ranks 0 and 9 is inferior to positioning them on file e. Mobility is also important. Cannons become more offensive if they are put in the same file or rank.
8. *Sending Pawns aggressively*: Pawns should enter the enemy's territory quickly. The ancient players clearly taught that the power of a Pawn is no less than that of the Rook when it reaches the opponent's King. They have a similar influence power to Horses or Cannons when they reach the boundary of the Palace.
9. *Stopping opponents with Advisors and Elephants*: suitably placed Advisors and Elephants can block attacks from the opponent and provide a base for Horses, Cannons and Rooks.
10. *Intelligently attacking with the King*: the stronger player attacks intelligently with the King while the weaker player treats the King as a burden.