Computer Chinese Chess

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Abstract

- **An introduction to research problems and opportunities in Computer Games.**
  - **Using Computer Chinese chess (象棋) as examples.**
  - **Show how theoretical research can help in solving the problems.**
    - ▷ ***Data-intensive computing**: tradeoff between computing on the spot and using pre-stored knowledge.*
- **Phases of games**
  - **Open game (開局): database**
  - **Middle game (中局): Search**
  - **End game (殘局): knowledge**
- **Topics:**
  - **Introduction**
  - **Construction of a huge knowledge base that is consistent**
  - **Playing rules for repetition of positions**
  - **Construction of huge endgame databases**
  - **Benchmark**

Introduction

- **Why study Computer Games:**
  - **Intelligence requires *knowledge*.**
  - **Games hold an inexplicable fascination for many people, and the notion that computers might play games has existed at least as long as computers.**
  - **Reasons why games appeared to be a good domain in which to explore machine intelligence.**
    - ▷ *They provide a structured task in which it is very easy to measure success or failure.*
    - ▷ *They did not obviously require large amount of knowledge.*
- **A course on teaching computers to play games was introduced at NTU in 2007.**
  - ▷ 電腦對局理論

Predictions for 2010 – Status

- **My personal opinion about the status of Prediction-2010 [van den Herik 2002] at October, 2010, right after the Computer Olympiad held in Kanazawa, Japan.**

solved	over champion	world champion	grand master	amateur
Awari	Chess	Go ($9 * 9$)	Bridge	Go ($19 * 19$)
Othello	Draughts ($10 * 10$)	Chinese chess	Shogi	
Checkers ($8 * 8$)	Scrabble	Hex		
	Backgammon	Amazons		
	Lines of Action			

  - ▷ *Over champion means definitely over the best human player.*
  - ▷ *World champion means equaling to the best human player.*
  - ▷ *Grand master means beating most human players.*

- **color code**
  - **Red: right on the target.**
  - **Blue: not so.**
  - **Black: have some progress towards the target.**

Introduction

- **Western chess (西洋棋) programs.**
  - **One of the important areas since the dawn of computing research.**
    - ▷ *J. von Neumann, 1928, "Math. Annalen"*
    - ▷ *C.E. Shannon, 1950, Computer Chess paper*
    - ▷ *Alan Turing, 1953, chapter 25 of the book "Faster than thought", entitled "Digital Computers Applied to Games"*
  - **Beat the human champion at 1997.**
  - **Many techniques can be used in computer Chinese chess programs.**
- **Computer Chinese chess programs.**
  - **About 7-dan.**
  - **Computing research history: more than 30 years late.**
    - ▷ *Started from about 1981.*

Chess Related Researches

- **Chess related research:**
  - **Open game.**
    - ▷ ***Databases.***
    - ▷ ***Many pseudo theories with heavy human involvements.***
  - **Middle game searching.**
    - ▷ ***Traditional game tree searching.***
    - ▷ ***In search of a good evaluating function.***
  - **Endgame.**
    - ▷ ***Heuristics and knowledge.***
    - ▷ ***Computer constructed databases.***

Properties of Chinese Chess

- **Several unique characteristics about Chinese chess.**
  - **The usage of Cannon.**
    - ▷ *It is possible to attack or protect a piece at a longer range.*
  - **Categories of defending and attacking pieces.**
  - **The positions of Pawns.**
    - ▷ *The mobility of the pawn is limited before crossing the river.*
    - ▷ *It cannot move backward.*
  - **Complex Chinese chess rules (棋規).**
  - **Palace and the protection of kings.**
  - **The value of each piece (子力價值). is highly dynamic:**
    - ▷ *Although Knight*  *is roughly equal to Cannon* *,*

      Rook  *+ Knight*  *+ Cannon*  *is better than*

      Rook  *+ 2 Cannons*   *.*
    - ▷ *Knowledge inferencing among material combinations [Chen et al. 2007,2011].*

Research Opportunities

- **Some research opportunities.**
  - **Open game theories.**
    - ▷ *Learning form a vast amount of prior human knowledge.*
    - ▷ *In great need of some breakthrough.*
  - **Much larger searching space:**
    - ▷ *Western chess:* 10^{123}
    - ▷ *Chinese chess:* 10^{150}
    - ▷ *Deeper searching depth and longer game.*
  - **Game tree searching.**
    - ▷ *The usage of materials.*
    - ▷ *Knowledge inferencing among material combinations.*
  - **Endgame: contains lots of pieces.**
    - ▷ *The size of useful endgames is huge compared to that of Western chess.*
  - **Rules in facing of repetitions.**

Construction of a huge knowledge base that is consistent

Motivations

- **Computing of the material values is a crucial part of a good evaluating function for Chinese chess.**
- **Static material values:**
  - **King: 100**
  - **Guard/Minister: 2**
  - **Rook: 10**
  - **Knight/Cannon: 5**
  - **Pawn: 1**
- **Meanings:**
  - **A knight is about equal to a cannon.**
  - **A rook is about equal to two knights, two cannons, or a cannon plus a knight.**
  - **Three defending pieces are better than a knight, but two of them are as good.**

Dynamic piece value

- **Values of pieces are dynamic depending on the combination.**
  - **It is better to have different types of attacking pieces.**
    - ▷ *Cannons can "jump" over pieces, rooks can attack in straight-lines, and knights can attack in a very different way.*
    - ▷ *Guards are better in protecting the king in facing a rook attack.*
    - ▷ *Guards are not good in protecting the king in facing a cannon attack.*
- **Examples:**
  - **Example 1:**
    - ▷ *KCPGMMKGGMM is a red-win endgame.*
    - ▷ *KNPGMMKGGMM is a draw endgame.*
  - **Example 2:**
    - ▷ *KPPKGG and KPPKMM are red-win endgames.*
    - ▷ *KPPKGM is a draw endgame.*
  - **Example 3:**
    - ▷ *KNPKGM and KNPKGG are red-win endgames.*
    - ▷ *KNPKMM is a difficult endgame for red to win.*

Usage of Endgame Knowledge

- **Computer constructed endgame databases are too large to be loaded into the main memory during searching.**
  - **only useful at the very end of games.**
- **Human experts:**
  - **Studies the degree of "advantageous" by considering only positions of pawns and material combinations.**
  - **Lots of endgame books exist.**

Books

Format

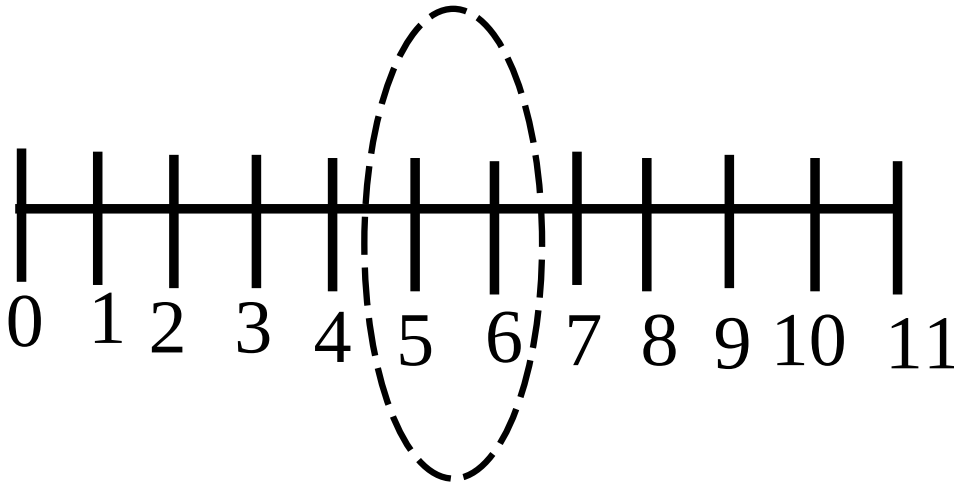
- **Granularity: 12 different levels by considering material combinations (子力組合) only.**
  - *紅必勝(0): The red side is almost sure to win.*
  - *紅大優(1): The red side is almost sure to win, but may be draw if the black side takes a very good position.*
  - *紅佔優(2): The red side has advantage, but has a chance to lose if the black side is in a very good position.*
  - *紅巧勝(3): The red side may win in some good positions, but in most cases it is a draw.*
  - *紅難勝(4): The red side has an advantage, but is very difficult to win.*
  - *均勢(5): Either side has a chance to win, i.e., tie.*
  - *必和(6): No side can win, i.e., draw.*
  - *黑難勝(7): The black side has an advantage, but is very difficult to win.*
  - *黑巧勝(8): The black side may win in some good positions, but in most cases it is a draw.*
  - *黑佔優(9): The black side has advantage, but has a chance to lose if the red side is in a very good position.*
  - *黑大優(10): The black side is almost sure to win, but may be draw if the red side takes a very good position.*
  - *黑必勝(11): The black side is almost sure to win.*

Motivations

- There are many existing heuristics about Chinese Chess endgames.
  - Books.
  - Computer records.
  - Annotations from human experts.
  - ...
- Previously, efforts are spent to collect heuristics.
- Now, our problem is to compile a consistent set of heuristics.
  - Granuality.
  - Errors and contradictions.
    - *Input error.*
    - *Cognition error.*
    - *Approximation and conversion error.*
- Questions:
  - How to compile a consistent set of heuristics?
  - How can you choose the "right" one when you have two different selections?
  - How can you easily detect a potential conflict?
    - *It is difficult to be 100% sure that there is no conflict.*

Comments

- **Numerical scale.**



- **We do not assume every endgame has a fixed value by simply considering its material combination.**
  - **Many critical endgames have different values according to their positions.**
- **It is an art to integrate the values from material combinations into the evaluating function.**

Sources (I)

- **Books: about 10,000 combinations**
  - 象棋實用殘局
  - 新殘棋例典1, 2, 3, 4, 5, 6
  - 象棋基本實用殘局詳解
  - 圖說象棋殘局
  - 象棋殘局基礎
  - 巧勢殘局
  - 馬兵專集
  - 馬兵專集增補
  - 炮兵專集
  - ...

Sources (II)

- **Computer constructed endgames: about 2,500.**
- **Endgames input by a human expert: about 17,000.**
  - **Using a web interface to manually input results of endgames with very few total number of attacking pieces.**
- **Using expert systems and rules to do inference: about 110,000.**
  - **Differ from collected endgames by one piece after removing some meaningless ones.**
  - **Bo-Nian Chen and Pangfeng Liu and Shun-Chin Hsu and Tsan-sheng Hsu, "Knowledge Inferencing on Chinese Chess Endgames,"** *Proceedings of the 6th International Conference on Computers and Games (CG)*, **Springer-Verlag LNCS# 5131, pages 180–191, 2008.**
- **Total: 140,320 out of the possible 2,125,764 feasible combinations.**

Problems

- **Human mistakes.**
  - **Different conclusions from different sources, e.g., books.**
    - ▷ *Different conclusions were made in different eras.*
    - ▷ *Different conclusions were made by different authors.*
    - ▷ *Some books discuss an endgame extensively with detailed positions, but have no general conclusions.*
- **Algorithmic mistakes.**
  - **Our algorithm for computer inferred endgame values has a roughly 90% of correctness.**
- **Granularity.**
  - **Some books only record results using a win-loss-draw format, not in 10 levels as we do.**
  - **Perfect endgame databases obtained by retrograde analysis contain winning rates, not a 12-level value.**
    - ▷ *How to convert rates to levels?*

How to detect conflicts – Basics

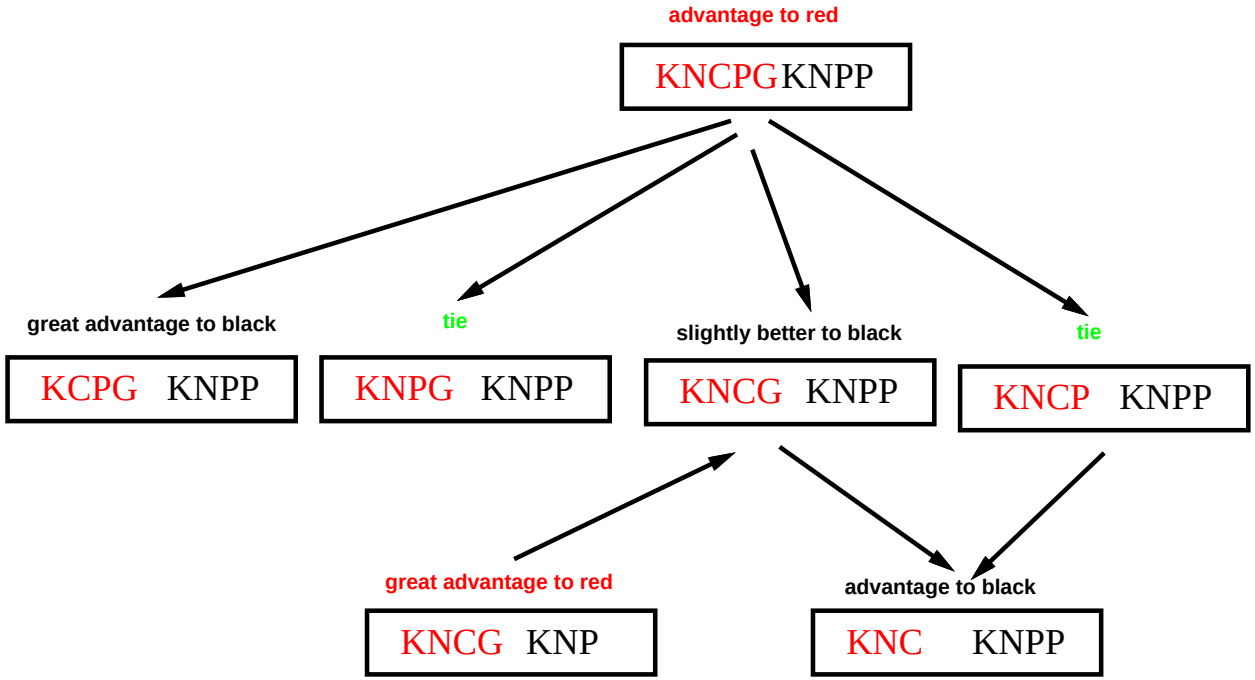
- **Piece additive rule:**
  - **The result of an endgame cannot get worse by**
    - ▷ *gaining extra pieces on your side;*
    - ▷ *losing pieces on your opponent's side.*
  - **The result of an endgame cannot get better**
    - ▷ *by losing pieces on your side;*
    - ▷ *if your opponent gains piece.*
- **Rule of defensive pieces, i.e., Elephant and Guard.**
  - **The result of an endgame cannot normally be greatly changed by gaining/losing an extra defensive piece.**
- **Rule of draw and tie:**
  - **It is a draw if no side can win.**
  - **It is a tie if either side can win.**
  - **An endgame cannot usually be turned from tie into draw by using the piece additive rule.**

How to detect conflicts – Process

- **Procedure: check rules for endgames that we have already collected.**
  - **Piece additive rule.**
  - **Rule of defensive pieces, i.e., Elephant and Guard.**
  - **Rule of draw and tie.**
- **Using relations between endgames, not just endgames themselves to check for potential conflicts.**
  - **Similar activities applied for human cognitive process.**

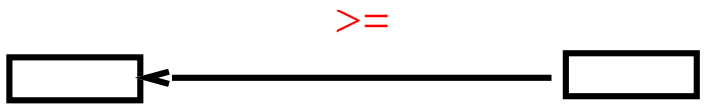
A graphic view

- **A graph theoretical model.**
  - **vertex: an endgame**
  - **edge: between two vertices u and v if they follow the piece additive rule.**
    - ▷ *the direction from u to v if the value of u must be no worse than that of v.*

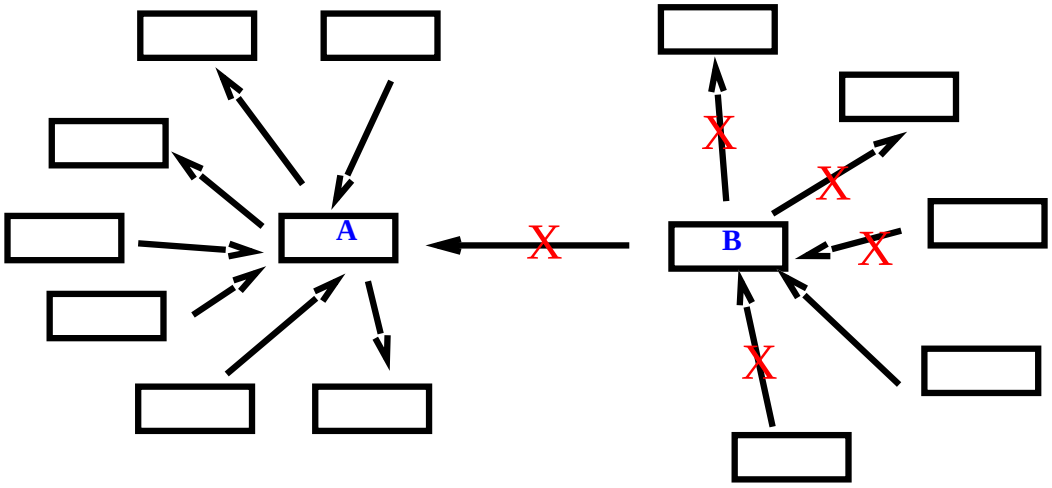


High level ideas

- Assume the major part of the heuristics are correct.
- A conflict is an edge such that the values between them does not follow the piece additive rule.

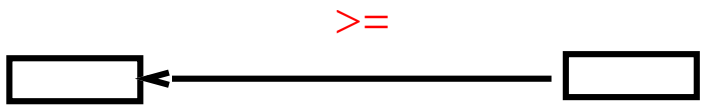


- The vertex who has a large percentage of conflicts is more likely to be incorrect.

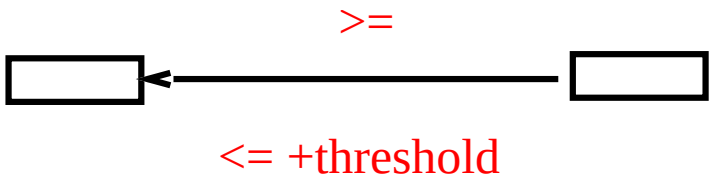


Enhanced ideas

- **A potential conflict is an edge such that the difference in values between the endpoints is more than a threshold, say 3, and the two connected endgames follow the rule of the defensive pieces.**
- **Original relation.**



- **Enhanced relation.**

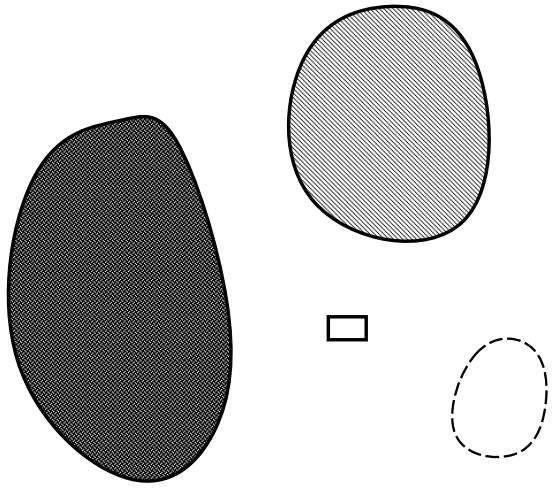


Algorithm

- **For each endgame, compute the percentage of conflicts, which is the ratio between the number of "corrected" relations and the number of total relations.**
- **Identify the ones with the large percentage of conflicts and either use human or an automatic procedure to re-assign its value.**

Potential problems for our approach

- A cluster of endgames all with consistent errors.
- A sparse or isolated cluster where inter-relation is few.
- A vertex can have a wide range of possible values due to the fact the values of its neighbors are much higher or lower than it.
- Solution: randomly select endgames in different clusters and verify them by human experts.



Remarks

- **Out of about 140,320 endgames, there are about 1/12 severe errors (ones whose corrected values differ from the original values by at least 3).**
- **A total of 1/3 endgames are revised.**
- **A period of 1 year is spent to obtain a consistent set of heuristics where it is almost impossible to manually check the consistency of the collection of endgames previously.**

Ongoing work

- More testing and analysis are needed.
- Using graph theoretical techniques to further process the data.
  - Assign a different weight to a different type of relations, and use the weight to find the ones that are most likely to be incorrect.
  - More inferencing rules that are not just between direct neighbors.
    - ▷ *Piece exchanges: you cannot get better by exchanging a stronger piece with a weaker piece.*
    - ▷ *Depending on the piece involved, assign a confidence factor, e.g., adding a rook and adding a knight have different levels of confidence.*
- Use expert system to do a better job in self-correcting.
- Test how much it can improve the performance of a Chinese chess program.
- Further usage:
  - Tutoring
  - E-learning
  - Knowledge abstraction

Rules for repetitions

Chinese Chess Special Rules (1/2)

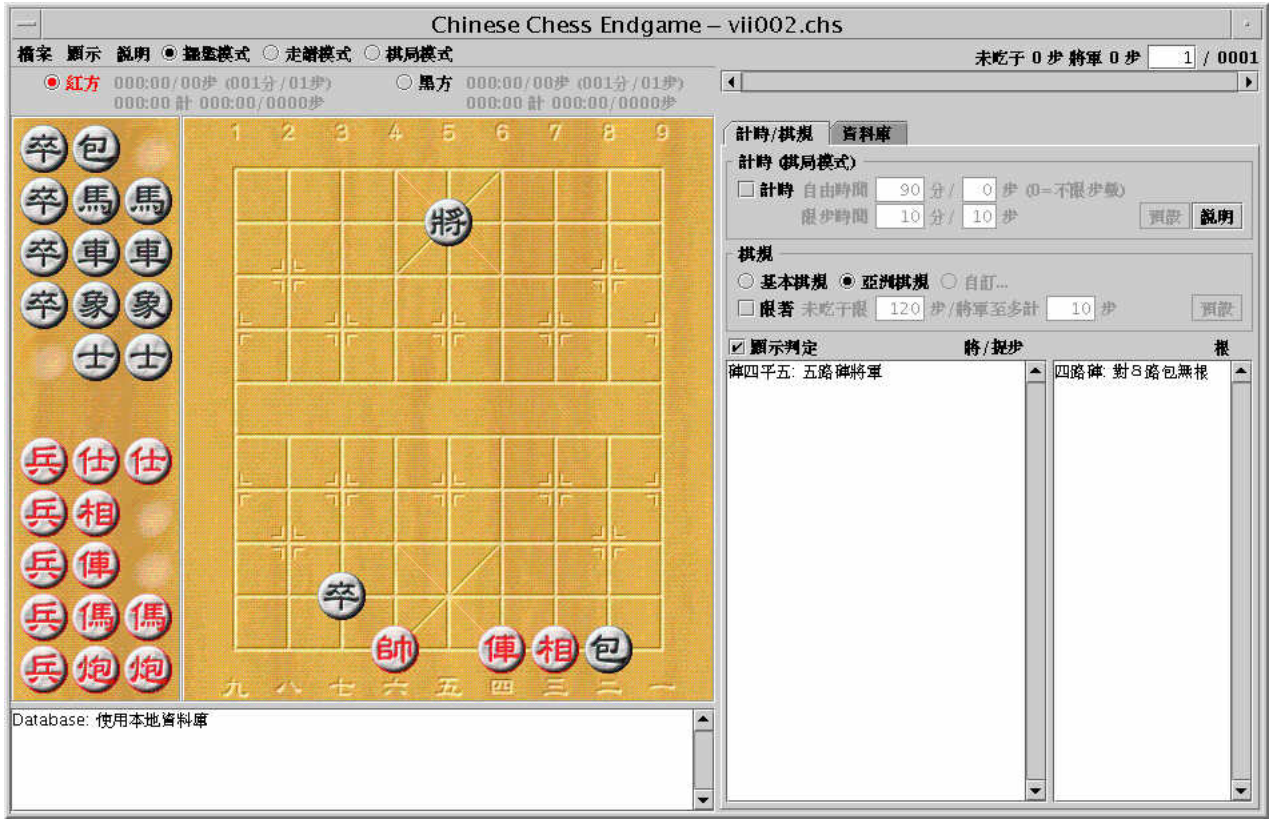
- **A player cannot avoid the losing of the game or important pieces by forcing the opponent to do repeated counter-moves.**
  - **Checking the opponent's king repetitively without chance of checkmate.**
    - ▷ ***Asia rule example #2.***
  - **Chasing an unprotected opponent's piece repetitively without chance of capturing it.**
    - ▷ ***Asia rule example #19.***
  - **Threatening (to checkmate) repetitively without chance of realizing the threat.**
    - ▷ ***Asia rule example #31.***
- **Not a problem for Western chess.**
  - **Cycles mean draw.**
  - **It is difficult to force a repetition when one side is not willing to do it.**
- **A big problem for Chinese chess.**
  - **The king cannot move out of the palace.**

Chinese Chess Special Rules (2/2)

- **You can always "chase" a protected opponent piece because the opponent can decide to exchange it with your attacking piece.**
- **Sometimes it is difficult to check whether a piece is $truly$ or $falsely$ protected.**
  - **Asia rule example #39.**
  - **Asia rule example #105.**

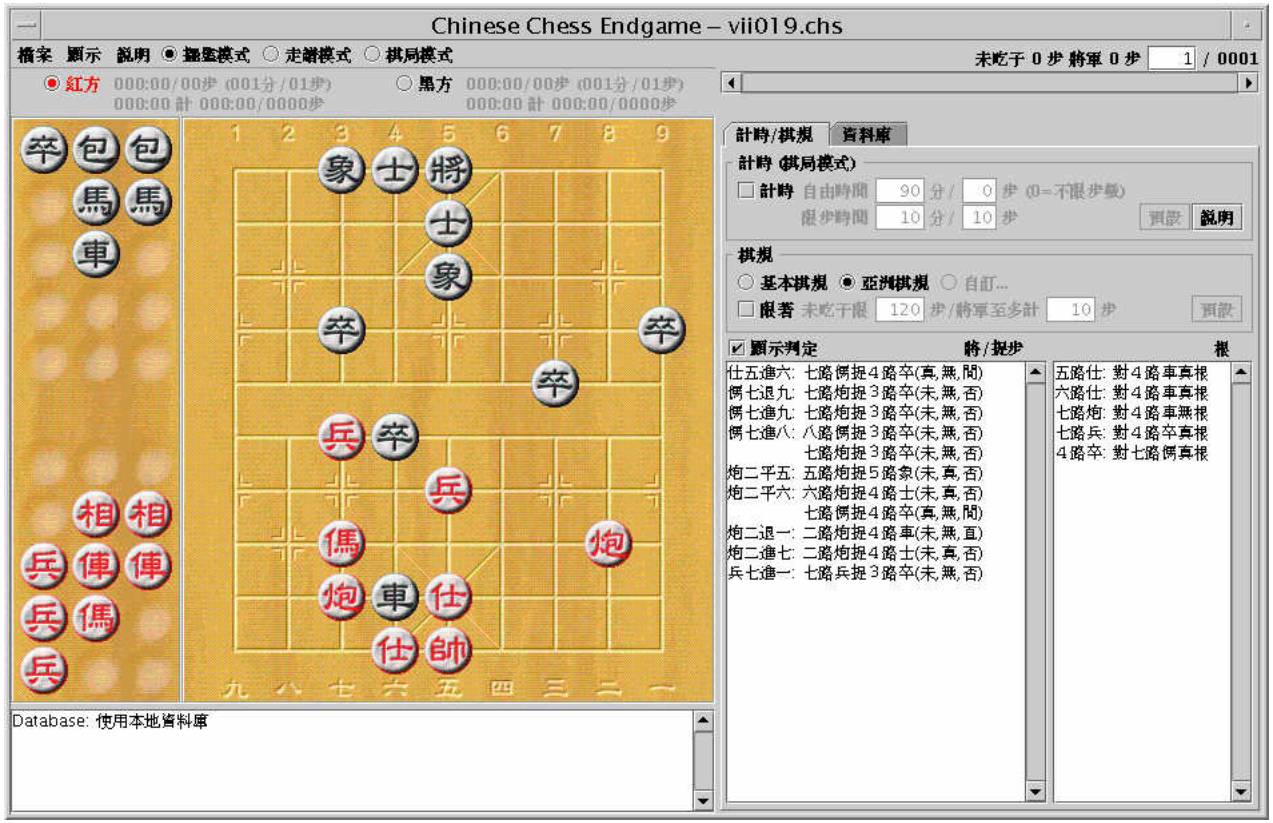
Asia Rule Example #2

- **Checking the opponent's king repetitively with no hope of checkmate.**
  - ***R4=5,K5=6,R5=4,K6=5,...***
  - ***Red Rook checks Black King.***



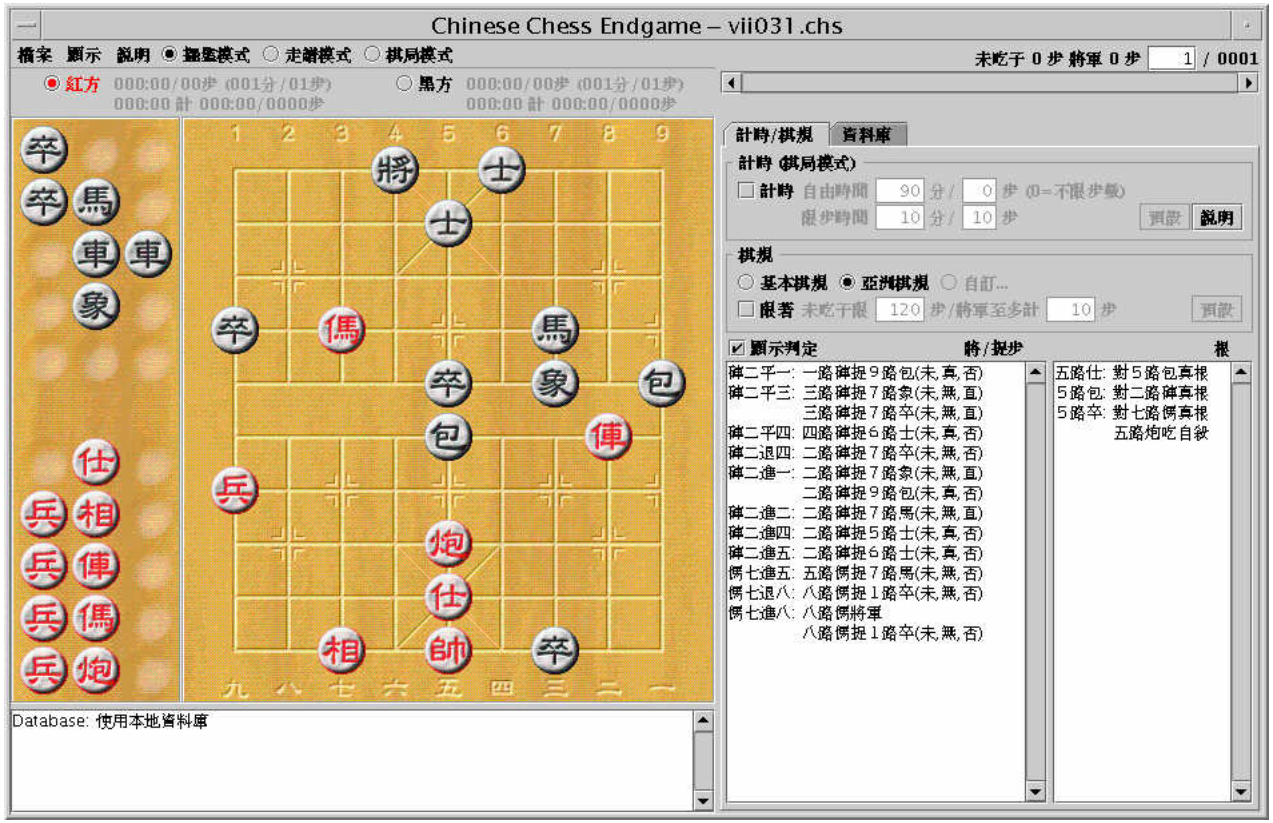
Asia Rule Example #19

- **Chasing an unprotected opponent's piece repetitively with no hope of capturing it.**
  - $C2-1,R4-2,C2+2,R4+2,...$
  - *Red Cannon at the 2nd column chases Black Rook.*



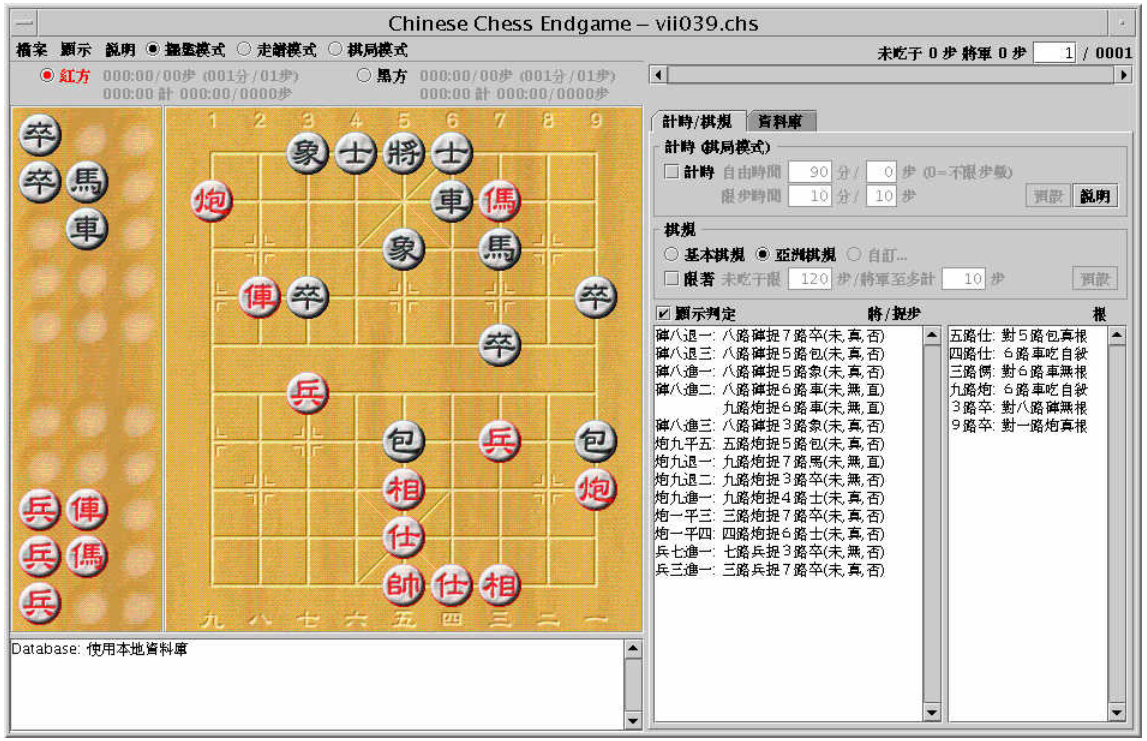
Asia Rule Example #31

- **Threatening (to checkmate) repetitively with no hope of realizing the threat.**
  - ***R2=1,C9=8,R1=2,C8=9,...***
  - ***Black Cannon at the 9th column threatens to checkmate.***



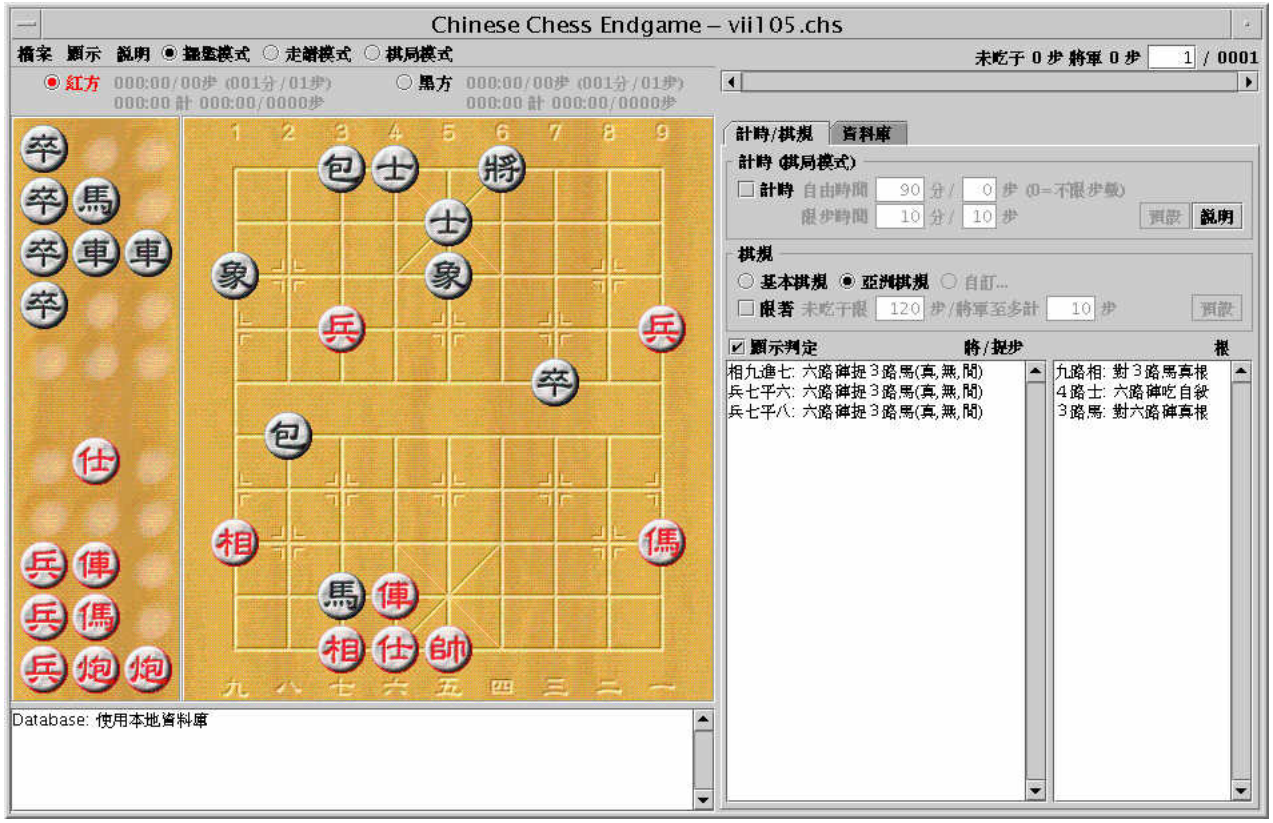
Asia Rule Example #39

- **Sometimes it is difficult to check whether a piece is *truly* or *falsely* protected: the definition of a protector is complicated.**
  - ***R8+2,G6+5,R8−3,G5−6,...***
  - ***Red Knight at the 2nd column is not protected.***
  - ***Black Rook at the 6th column cannot threaten.***



Asia Rule Example #105

- **Sometimes it is difficult to check whether a piece is *truly* or *falsely* protected: you can block a protector.**
  - ***P7=6,M1+3,P6=7,M3−1,...***
  - ***The protector of Black Knight at the 7th column is* blocked.**

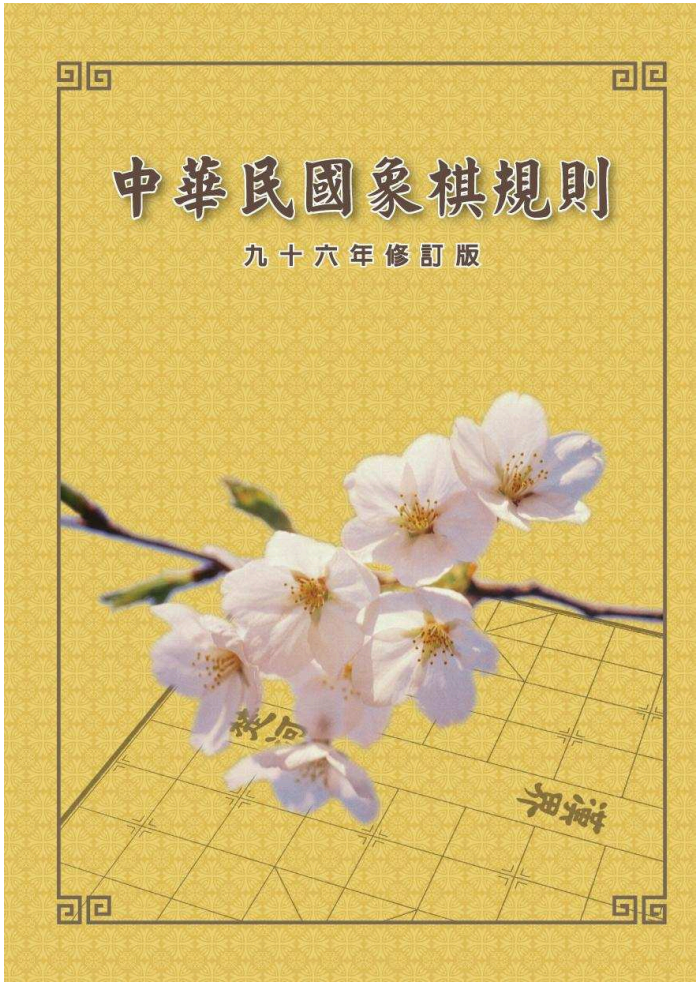


Types of rules

- **Two main categories:**
  - **Asian version (2003)**
    - ▷ *Supported by Asian Chinese Chess Association.*
    - ▷ *Simple and effective.*
    - ▷ *Is not really "fair" in certain complex cases.*
    - ▷ *Taiwan version (2007) is based on Asian version.*
  - **PRC version (1999)**
    - ▷ *Supported by the PRC Chinese Chess Association.*
    - ▷ *A national standard.*
    - ▷ *Developing still in progress: latest version dated 1999.*
    - ▷ *Try to be as complete and "fair" as possible.*
- **Problems in computer implementation:**
  - **"Rules" are vague.**
  - **Often illustrated with examples.**

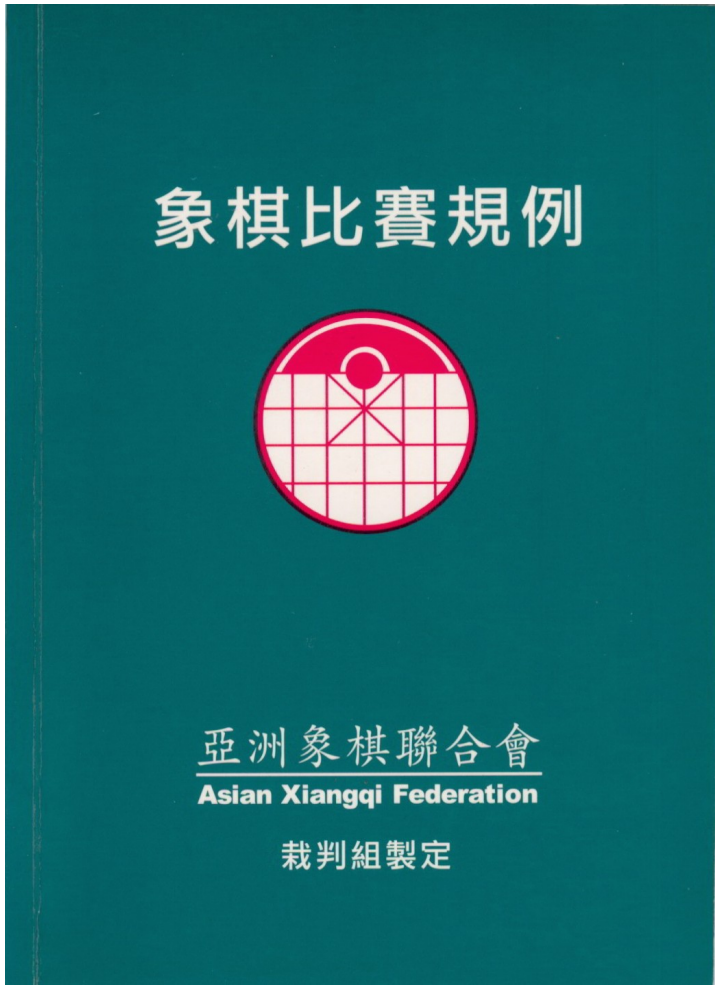
Rules: Taiwan Version

- **41 pages (2007).**



Rules: Asian Version

- **96 pages (2003).**



Rules: PRC Version

- **329 pages (1999).**

Rules: Problems About the PRC Version

- **317 pages (2000).**

Current solutions

- **Current treatment of special rules:**
  - **Avoid them at all: do not play repeated positions.**
    - ▷ *May lose advantage.*
    - ▷ *Must allow loops in endgame construction.*
  - **Special cases:**
    - ▷ *Only one side has attacking pieces: all are implemented.*
    - ▷ *One side has only a pawn and some defending pieces: can be affected by special rules.*
  - **Partial treatment:**
    - ▷ *Implement only the rules related to "checking."*
    - ▷ *Implement some "chasing" rules.*
    - ▷ *Verify whether special rules can affect an endgame.*
- **We need a throughout understanding of special rules to build larger endgame databases.**

Special Rules: Previous Results

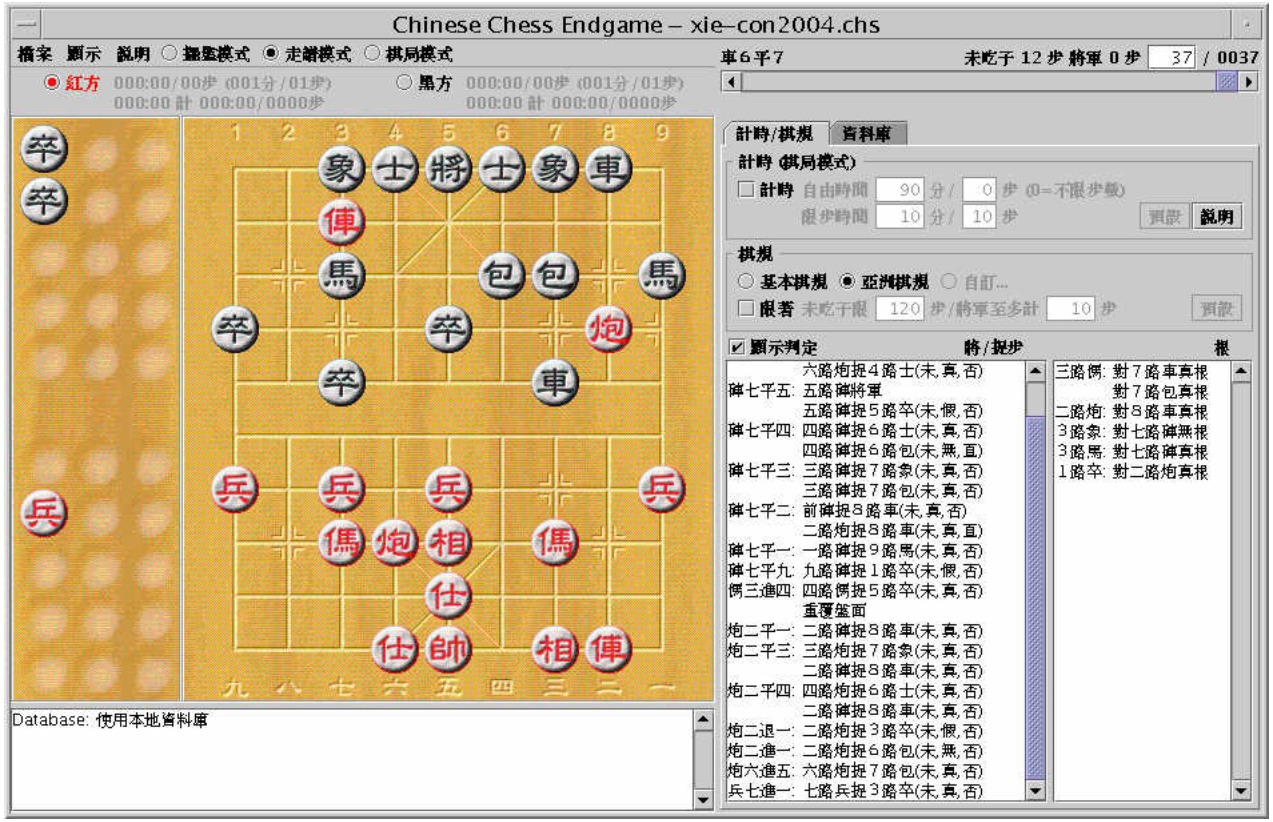
- **Partial treatment may build imperfect databases.**
  - **[Fang, Hsu & Hsu 2000].**
  - **Upto 17.3% for the checking rule in KRKNMM (**  **vs.**  **) [Fang, Hsu & Hsu 2002].**
  - **Jih-tung Pai [Private communication 2003] implemented a variation of [Fang, Hsu & Hsu 2002].**
- **Look for necessary conditions when databases can be stained by special rules.**
  - **Selected 50+ databases are verified [Fang 2004].**

Special Rules: Work in Progress

- **May affect the correctness of evaluation functions.**
  - **Xie Xie vs. Contemplation in the first WCCCC (Year 2004).**
    - ▷ ***Less than 3 % of the games played.***
  - **About 5% of the games played in the 10th Computer Olympiad (October 2005) need to utilize special rules.**
- **Usage of logic and graph theory in an algorithmic context to describe the Asian version.**
  - **To explain all examples.**
  - **To abstract hidden experts' knowledge.**
  - **To obtain fast computer implementations.**
- **Still a long way to go for the PRC version.**

Xie Xie vs. Contemplation at WCCCC 2004

- **Red: Contemplation.**
- **N3+4,R7−6,N4−3,R6−7,...**
  - ***Red Knight at 3rd column is protected.***
  - ***The game ended in a draw.***



Snapshot of the rules

any pieces in between; otherwise it is FALSE.

- $is\_stallmate(P)$ （困斃） $= (move\_gen(P) = \emptyset)$.

7. Let $R = (P_1, P_2)$ be a ply. Let $P_1 = (B_1, player)$.

   - $is\_suicide(R)$
     （自殺步：走之前沒有困斃、王見王或被將，但走之後對手可以一步之內使你困斃、王見王或被將，因此必輸）
     $= (\neg is\_stallmate(P_1) \wedge \exists m \in move\_gen(P_2), is\_stallmate((P_2, m))) \vee$
     $(\neg is\_\mathrm{KFK}(P_1) \wedge is\_\mathrm{KFK}(P_2)) \vee$
     ($\exists$ a piece p,
     $p \notin pieces\_attacking\_king((B_1, \neg player)) \wedge p \in pieces\_attacking\_king(P_2))$.

8. Let $R = (P_1 = (B_1, player), P_2 = (B_2, \neg player))$ be a ply. Let p and $kind(q) \neq$ KING be two pieces in B_1 where $capturing\_move(P_1, p, q) \in move\_gen(P_1)$.

   - $is\_forced\_capture(R)$
     （將軍抽子:走之前沒有將到對手的王，但走吃子步之後將軍）
     $= (pieces\_attacking\_king(P_1) = \emptyset) \wedge (is\_in\_check(P_2))$,

9. Let B_1 be a board configuration. Let p, q and r be three pieces in B_1, $capturing\_move(P_1, p, q) \in move\_gen(P_1)$, and $capturing\_move(P_2, r, p) \in move\_gen(P_2)$, where $owner(p) = player$, $P_1 = (B_1, player)$, and $P_2 = position\_after(capturing\_move(P_1, p, q))$. Let $P_2 = (B_2, \neg player)$ and let $P_3 = position\_after(capturing\_move(P_2, r, p))$.

   - $can\_be\_protected(B_1, p, q, r)$
     （在p 可以吃到q 的盤面組合B_1 中，若p 吃q，則r 可以自由離線回吃p; 目前自由離線的定義為：不能是自殺步。因此，若對手是將軍抽子，代表是可以自由離線。）

Construction of huge endgame databases

Endgame Databases

- **Chinese chess endgame database:**
  - **Indexed by a sublist of pieces S, including both Kings.**

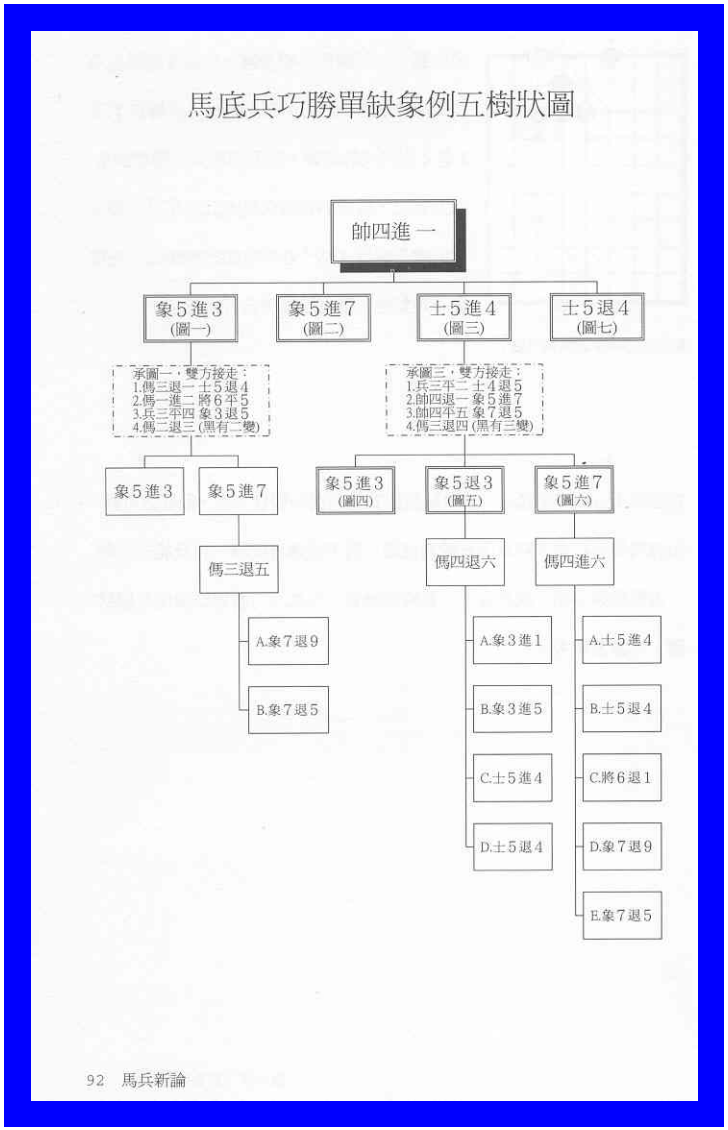
K	G	M	R	N	C	P
King	Guard	Minister	Rook	Knight	Cannon	Pawn
						

    - *KCPGGMMKGGMM (*  *vs.*  *): the database consisting of RED Cannon and Pawn, and Guards and Ministers from both sides.*
  - **A *position* in a database S: A legal arrangement of pieces in S on the board and an indication of who the next player is.**
  - ***Perfect information* of a position:**
    - *What is the best possible outcome, i.e. win/loss/draw, that the player can achieve starting from this position?*
    - *What is a strategy to achieve the best possible outcome?*
  - **Given S, to be able to give the perfect information of all *legal positions* formed by placing pieces in S on the board.**
  - ***Partial information* of a position:**
    - *win/loss/draw; DTC; DTZ; DTR.*

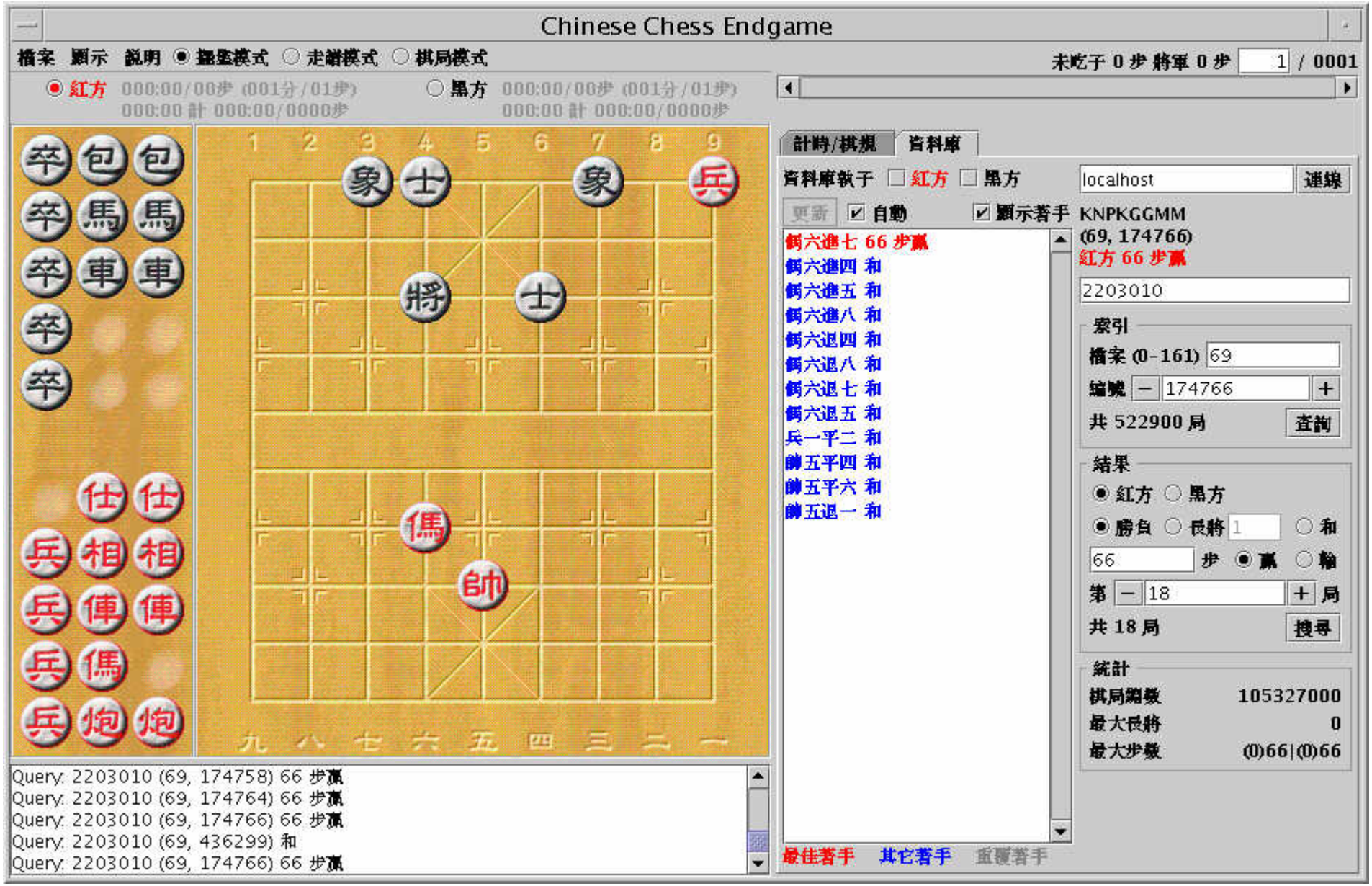
Usage of Endgame Databases

- **Improve the "skill" of Chinese chess computer programs.**
  - **KNPKGGMM (**  **vs.**  **)**
- **Educational:**
  - **Teach people to master endgames.**
- **Recreational.**

An Endgame Book



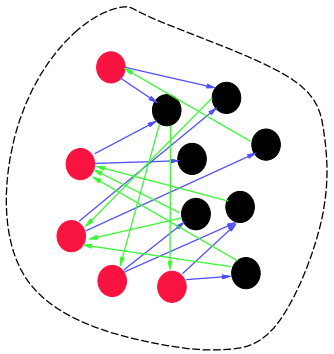
Books


Chinese Chess Endgame
檔案 顯示 說明 擺棋模式 走棋模式 棋局模式
未吃子 0 步 將軍 0 步 1 / 0001
紅方 000:00/00步 (001分/01步)
000:00 計 000:00/0000步
黑方 000:00/00步 (001分/01步)
000:00 計 000:00/0000步
計時/棋規 資料庫
資料庫執子 紅方 黑方 localhost 連線
更新 自動 顯示著手 KNPKGGMM
(69, 174766)
紅方 66 步贏
2203010
索引
檔案 (0-161) 69
編號 174766
共 522900 局 查詢
結果
紅方 黑方
勝負 長將 1 和
66 步 贏 輸
第 18 局
共 18 局 搜尋
統計
棋局總數 105327000
最大長將 0
最大步數 (0)66|(0)66
炮六進七 66 步贏
炮六進四 和
炮六進五 和
炮六進八 和
炮六退四 和
炮六退八 和
炮六退七 和
炮六退五 和
兵一平二 和
帥五平四 和
帥五平六 和
帥五退一 和
最佳著手 其它著手 重覆著手
Query: 2203010 (69, 174758) 66 步贏
Query: 2203010 (69, 174764) 66 步贏
Query: 2203010 (69, 174766) 66 步贏
Query: 2203010 (69, 436299) 和
Query: 2203010 (69, 174766) 66 步贏


Chinese Chess Endgame
檔案 顯示 說明 盤勢模式 走棋模式 棋局模式
未吃子 0 步 將軍 0 步 1 / 0001
紅方 000:00/00步 (001分/01步)
000:00 計 000:00/0000步
黑方 000:00/00步 (001分/01步)
000:00 計 000:00/0000步
計時/棋規 資料庫
資料庫執子 紅方 黑方
localhost
連線
更新 自動 顯示著手
KNPKGGMM
(69, 203899)
紅方 和
2203010
索引
檔案 (0-161) 69
編號 203899
共 522900 局
查詢
結果
紅方 黑方
勝負 長將 和
步 贏 輸
第 18 局
共 15527336 局
搜尋
統計
棋局總數 105327000
最大長將 0
最大步數 (0)66|(0)66
最佳著手 其它著手 重覆著手
Query: 2203010 (69, 174764) 66 步贏
Query: 2203010 (69, 174766) 66 步贏
Query: 2203010 (69, 436299) 和
Query: 2203010 (69, 174766) 66 步贏
Query: 2203010 (69, 203899) 和

Definitions

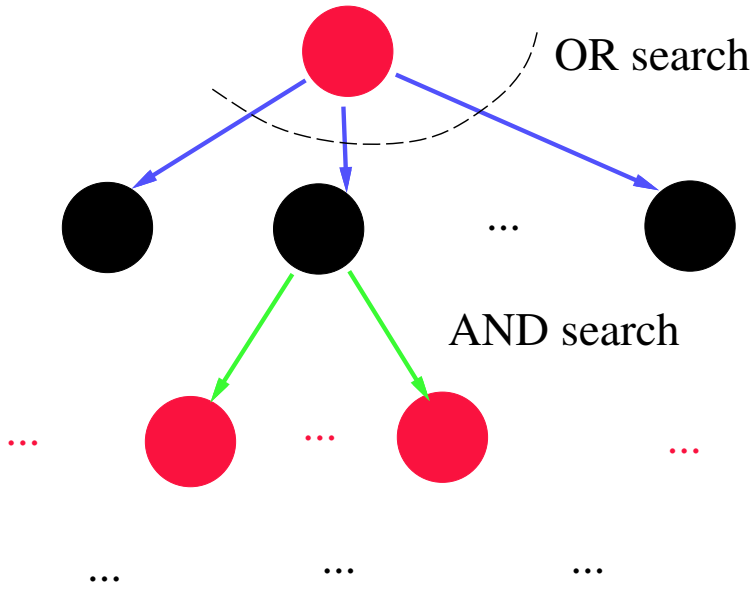
- **State graph for an endgame H:**
  - **Vertex: each legal placement of pieces in H and the indication of who the current player (Red/Black) is.**
    - ▷ ***Each vertex is called a* position.**
    - ▷ ***May want to remove symmetry positions.***
  - **Edge: directed, from a position x to a position y if x can reach y in one ply.**
  - **Characteristics:**
    - ▷ ***Bipartite.***
    - ▷ ***Huge number of vertices and edges for non-trivial endgames.***
    - ▷ ***Example: KCPGGMMKGGMM has $1.5 * 10^{10}$ positions and about $3.2 * 10^{11}$ edges.***



Overview of Algorithms

- **Forward searching: doesn't work for non-trivial endgames.**
  - **AND-OR game tree search.**
  - **Need to search to the terminal positions to reach a conclusion.**
  - **Runs in exponential time not to mention the amount of main memory.**
  - **Heuristics: A*, transposition table, move ordering, iterative deepening**

    . . .

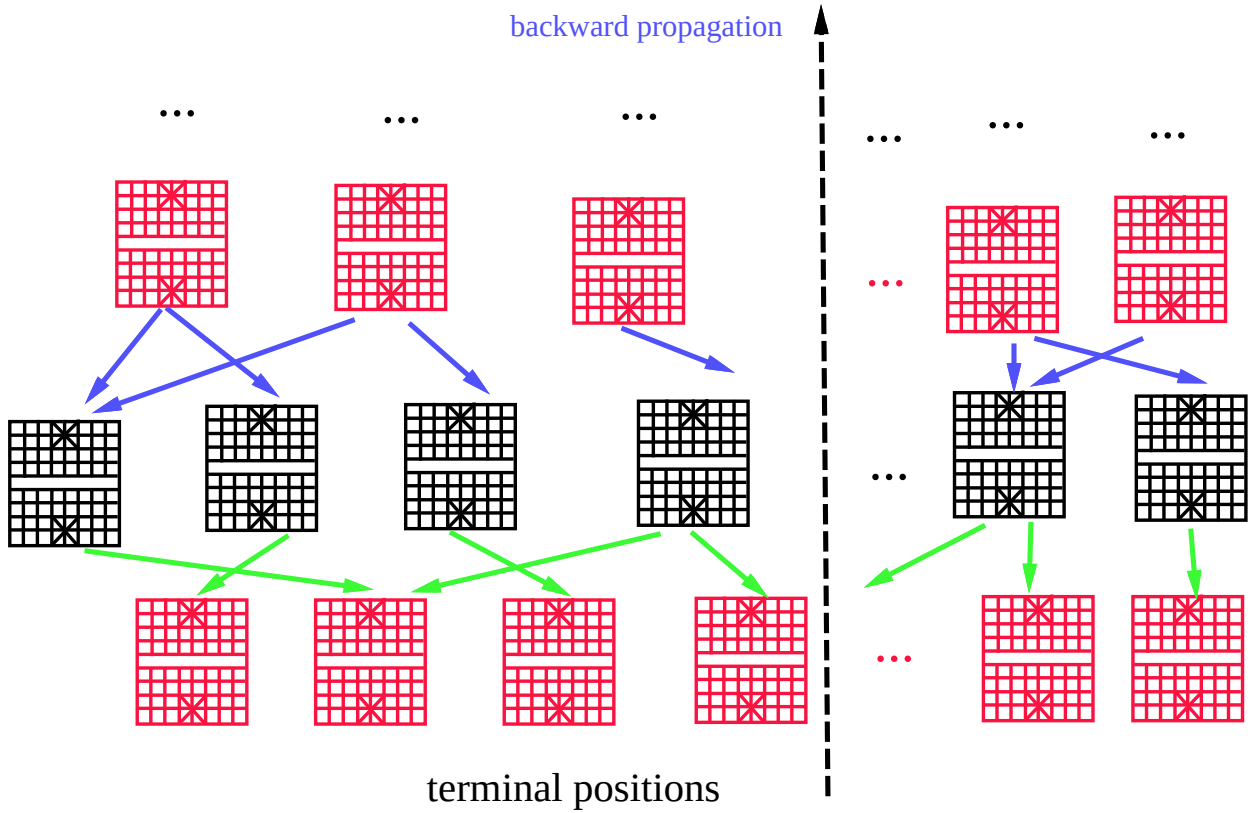


Retrograde Analysis (1/2)

- **First systematic study by Ken Thompson in 1986 for Western chess.**
  - **Retrograde analysis (回溯分析)**
- **Algorithm:**
  - **List all positions.**
  - **Find all positions that are initially "stable", i.e., solved.**
  - **Propagate the values of stable positions backward to the positions that can reach the stable positions in one ply.**
    - ▷ ***Watch out the and-or rules.***
  - **Repeat this process until no more changes is found.**

Retrograde Analysis (2/2)

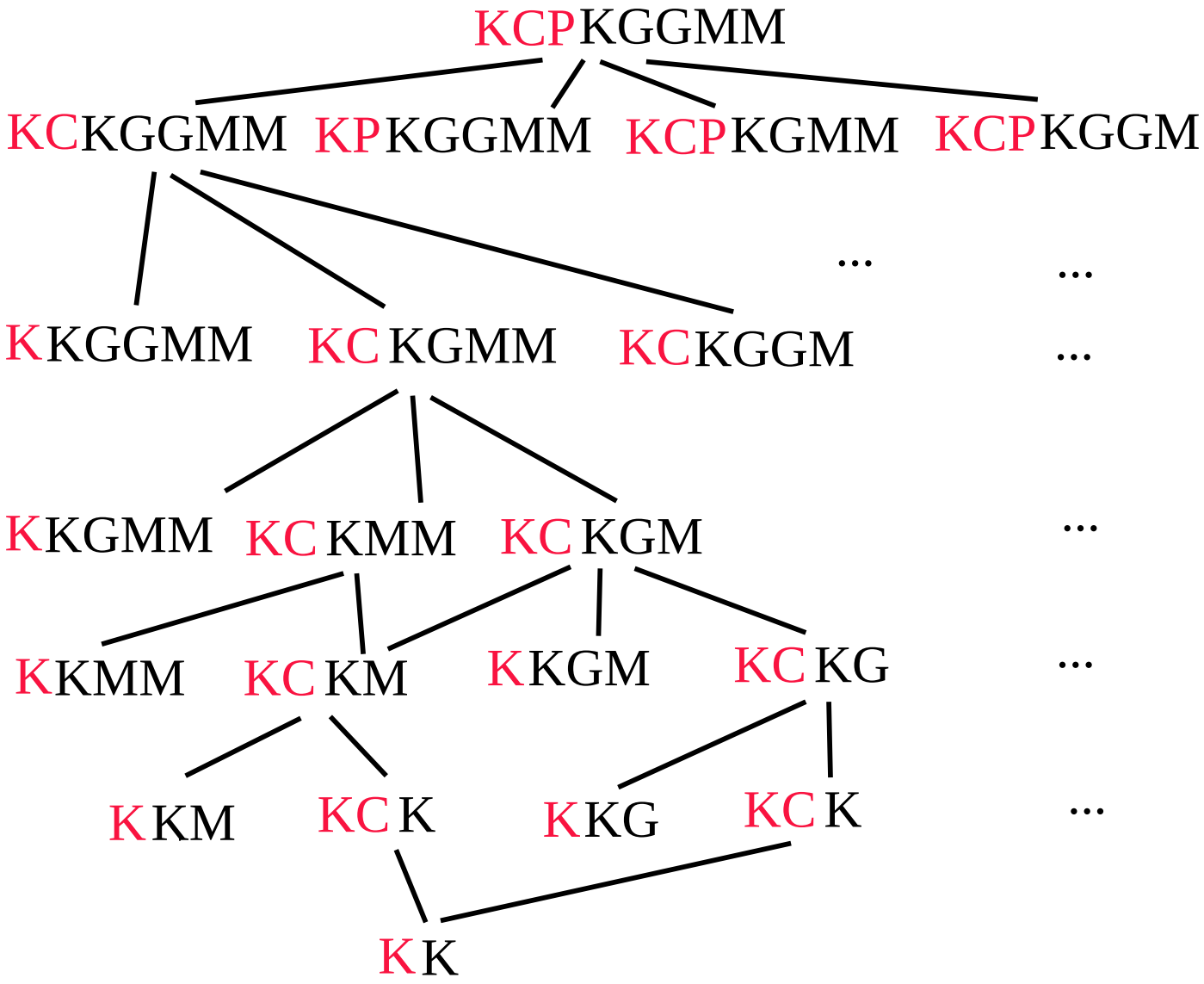
- **Critical issues: time and space trade off.**
  - **Information stored in each vertex can be compressed.**
  - **Store only vertices, generate the edges on demand.**
  - **Try not to propagate the same information.**



Stable Positions

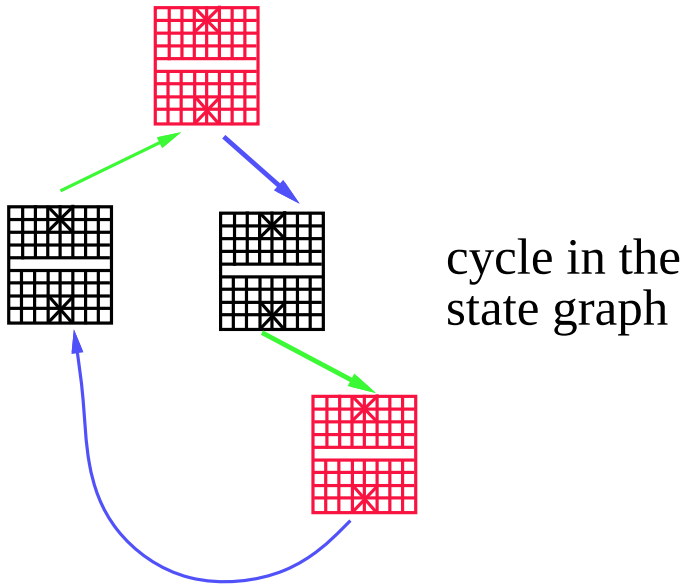
- **Another critical issue: how to find stable positions?**
  - **Checkmate, stalemate, King facing King.**
  - **It maybe the case the best move is to capture an opponent's piece and then win.**
    - ▷ *so called "distance-to-capture" (DTC);*
    - ▷ *the traditional metric is "distance-to-mate" (DTM).*
- **Need to access values of positions in other endgames. For example,**
  - **KCPKGGMM needs to access**
    - ▷ *KCKGGMM*
    - ▷ *KPKGGMM*
    - ▷ *KCPKGMM, KCPKGGM*
  - **A lattice structure for endgame accesses.**
  - **Need to access lots of huge databases at the same time.**
- **[Hsu & Liu, 2002] uses a simple graph partitioning scheme to solve this problem with good practical results.**

An Example of the Lattice Structure



Cycles in the State Graph (1/2)

- **Yet another critical issue: cycles in the state graph.**
  - **Can never be stable.**
  - **In terms of graph theory,**
    - ▷ *a stable position is a pendant in the current state graph;*
    - ▷ *a propagated position is removed from the sate graph;*
    - ▷ *no vertex in a cycle can be a pendant.*



Cycles in the State Graph (2/2)

- **For most games, a cyclic sequence of moves means draw.**
  - **Positions in cycles are stable.**
  - **Only need to propagate positions in cycles once.**
- **For Chinese chess, a cyclic sequence of moves can mean win/loss/draw.**
  - **Special cases: only one side has attacking pieces.**
    - ***Threaten the opponent and fall into a repeated sequence is illegal.***
    - ***You can threaten the opponent only if you have attacking pieces.***
    - ***The stronger side does not need to threaten an opponent without attacking pieces.***
    - ***All positions in cycles are draws.***
  - **General cases: very complicated.**

Previous Results — Retrograde Analysis

- **Western chess: general approach.**
  - **Complete 3- to 5-piece, pawn-less 6-piece endgames are built.**
  - **Selected 6-piece endgames, e.g., KQQKQP.**
    - ***Roughly*** $7.75 * 10^9$ ***positions per endgame.***
    - ***Perfect information.***
    - ***1.5 – 3*** $*10^{12}$ ***bytes for all 3- to 6-piece endgames.***
- **Awari: machine and game dependent approach.**
  - **Solved in the year 2002.**
  - $2.04 * 10^{11}$ **positions in an endgame.**
    - ***Using parallel machines.***
    - ***Win/loss/draw.***
- **Checkers: game dependent approach.**
  - $1.7 * 10^{11}$ **positions in an endgame.**
    - ***Currently the largest endgame database of any games using a sequential machine.***
    - ***Win/loss/draw.***
    - ***Solved in the year 2007 with a total endgame size of*** $3.9 * 10^{13}$.
- **Many other games.**

Results — Chinese Chess

- **Earlier work by Prof. S. C. Hsu (許舜欽) and his students, and some other researchers in Taiwan.**
  - **KRKGGMM (俥 vs. 士 士 象 象) [Fang 1997; master thesis]**
    - ▷ *About* $4 * 10^6$ *positions; Perfect information.*
- **Memory-efficient implementation: general approach.**
  - **KCPGMKGGMM (炮 兵 仕 相 vs. 士 士 象 象) [Wu & Beal 2001]**
    - ▷ *About* $2 * 10^9$ *positions; Perfect information.*
  - **KCPGGMMKGGMM (炮 兵 仕 仕 相 相 vs. 士 士 象 象) [Wu, Liu & Hsu 2006]**
    - ▷ *About* $8.8 * 10^9$ *positions;* $2.6 * 10^{-5}$ *seconds per position; Perfect information.*
    - ▷ *The largest single endgame database and the largest collection reported.*
  - **Verification [Hsu & Liu 2002]**
- **Special rules: more likely to be affected when endgames get larger.**

Problems and Solutions

- **Need to solve the problem of finding cycles in a graph.**
  - **Modeling using graph theory.**
  - **Using previous knowledge from graph theory.**
- **Need to solve the problem of requiring a huge space o store the database being constructed.**
  - **Carefully partition the database into disjoint portions so that only only the needed parts are loaded into the memory.**
  - **Using combinatorial properties to do the partition.**

Benchmarking

Introduction

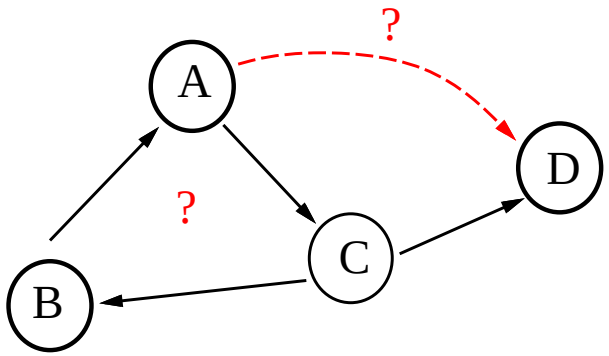
- **It is inevitable to revise your Chinese chess program during development.**
- **There are many stable versions, P_{t_1}, $P_{t_2}, \ldots$, indexed by time stamp t_i.**
  - **Stable means bug-free, namely the code does exactly what you intend to do as far as you know.**
- **Question:**
  - **How can you be sure that P_{t_i} is better than one of its previous versions P_{t_j} for some $j < i$?**
  - **Notation:**
    - $P_i > P_j$ *means* P_i *is better than* P_j.
    - $P_i = P_j$ *means* P_i *is about the same as* P_j.
    - $P_i \geq P_j$ *means* P_i *is no worse than* P_j.
- **Easy solution:**
  - **Conduct some games between the two versions and see who wins the most games.**
- **Is the solution satisfactory?**

Potential problems

- **Is the relation transitive?**
  - **Thats is, if $P_i > P_j$ and $P_j > P_k$, then can you be sure that $P_i > P_k$?**
- **Is the relation platform independent?**
  - **CPU speed, memory bandwidth, ...**
  - **Both versions use the same platform.**
  - **Both versions use different platforms.**
  - **Platform may differ over time.**
- **Is the relation rule independent?**
  - **Fast game (5 seconds per ply), Normal game (60 seconds per ply), ...**
  - **Chinese chess rules for repetitions.**
- **Without knowing answers to these potential problems, we do not know which version is "the" best.**

Motivation and related work

- **Scenario:**
  - **Suppose you have a "great idea" M and a current version P_i.**
  - **By patching P_i with M, you obtain the next version P_{i+1}.**
    - ▷ ***Let*** $P_{i+1} = P_i + M$.
- **Questions:**
  - **Is M really a "great idea"?**
  - **What version shall I use during a competition?**
  - **How to compare the "strength" of P_i and P_{i+1}?**



Related work

- **The Swiss system for a tournament.**
- **Rating systems, such as ELO, over a period of time.**
  - ***It has been estimated by Levy and Newborn that doubling the computer speed gains approximately fifty to seventy ELO points in playing strength for chess.***
  - ***However, this applies mainly to computer-vs-computer matches, and not to computer-vs-human matches.***
  - ***Remark: cited from Wiki.***
- . . .

Our little experiment

- **Two versions of Contemplation.**
  - **Version 814:**
    - ***The version we used for Computer Olympiad 11 (May 2006).***
    - ***Searching speed: 5.5 M nodes per second during middle game.***
  - **Version 903:**
    - ***The latest version (upto May 2007).***
    - ***Adding 6000+ lines of code (for the evaluation function) to version 814.***
    - ***Searching speed: 2.8 M nodes per second during middle game.***
  - **Version 814 is faster, but version 903 has more domain knowledge.**
- **Platform:**
  - **Free BSD 6.2 + GCC 4.1.2**
  - **Xeon 5160 3.0 GHZ CPU + 4GB DDR II 677 memory**
    - ***This CPU has two cores.***
    - ***Each version uses one core.***

Testing setup

- **Games played:**
  - 22 fixed openings.
  - No endgame databases.
  - Testing of middle games.
  - Each program plays first alternatively for each opening.
  - A total of 44 games played in each round.
- **Each round:**
  - With pondering.
  - Fix the time used in each ply.
    - *From 5 seconds, 10 seconds, . . . , 60 seconds.*
  - Time that is not used in a ply can be saved to be used in the plys thereafter.
- **A total of 12 rounds, i.e., 528 games, were played in four weeks during May 2007.**

Results

seconds	v903 vs v814			scores	difference
	win	draw	loss	v903:v814	
5	19	7	18	45:43	+2
10	19	7	18	45:43	+2
15	15	13	16	43:45	−2
20	16	8	20	40:48	−8
25	21	10	13	52:36	+16
30	21	9	14	51:37	+14
35	21	11	12	53:35	+18
40	20	7	17	47:41	+6
45	19	8	17	46:42	+4
50	20	11	13	51:37	+14
55	18	13	13	49:37	+12
60	22	12	10	56:32	+24

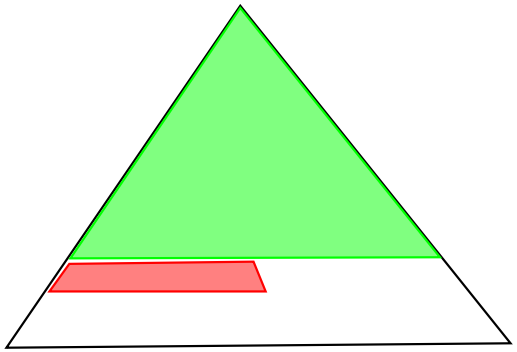
- ***Each win: 2 points.***
- ***Each draw: 1 point.***
- ***Each loss: 0 point.***

Observation I

- **Observation I:**
  - **v814 roughly equals to v903 at rounds that took time less than 20 seconds.**
  - **v814 beats v903 at the 15-second and the 20-second rounds, but loses all other rounds.**
- **Comments:**
  - **When time is limited, searching deeper and searching smarter is about the same for Contemplation.**
  - **20-second round is the best "competing environment" for v814 as compared to v903.**
- **Conjecture:**
  - **Expect a similar behavior on a 40-second round for a platform that is twice slower.**

Observation II

- **Observation II:**
  - **The performance of v814 improves on rounds of 40 and 45 seconds.**
- **Comments:**
  - **The performance curse of v903 vs. v814 is stair-cased.**
  - **The average branching factor B_{avg}(v814) is about 2 to 3.**
    - ▷ ***Need 2 to 3 more times of running time in order for the search depth to increase 1.***
  - **It is only useful to search the entire layer of nodes of the same depth.**



Observation II – conjecture

- **Conjecture:**
  - **Relatively speaking, the performance of v903 is more stable.**
  - **If the additional computational power is less than B_{avg}, then it is better to spend the extra power on the evaluation function.**
  - **Extra power may come from**
    - ***multi-threading;***
    - ***faster architecture, CPU or RAM;***
    - $\ldots$

Observation III

- **Observation III:**
  - **v903 out-scores v814 at a large margin for rounds of 25, 30, 35, 50, 55 and 60 seconds.**
- **Comments:**
  - **Searching depth may not be a dominating factor for playing strange when the depth is "enough."**
  - **The law of diminishing returns (效益遞減) in searching.**
- **Conjecture:**
  - **Need to balance the time used in searching deeper and the time used in searching smarter.**

Remarks

- **Need to fix the "competing environment" E to define $P_{i+1} > P_i$.**
  - **Revised definition: $P_{i+1} >_E P_i$.**
- **Whether a newly coded M is a great idea or not depends on the platform and "competing environment" you are using.**
  - **If M slows you down too much at the current platform, then your testing score may be worse.**
  - **Some times later, say next year, if a faster platform is available, then your testing score may become better.**
  - **You may observe a zig-zag effect on a series of versions.**
    - ***It becomes bad for a while, then it becomes good again.***
- **Do not abandon M easily!**
- **You are a winner of a competition does not guarantee you will be the winner later even if all programs stay unchanged.**
  - **Faster platforms may be invented.**
  - **Rules may change.**
  - **Luck is always part of a game with fun, such as Chinese chess.**

Future work

- More testing and analysis are needed.
  - The growth of games win/draw/loss.
  - The behavior when one plays first/last.
  - The length, time elapsed or plys played, of games.
  - What kinds of games are easily win by a particular version?
  - Are the results stable?
  - ...
- Compare results across different platforms.
  - For example, AMD v.s. INTEL.
- With opening databases.
- With endgame databases.

Concluding Remarks

- **Many open problems.**
- **Research opportunities:**
  - **Algorithm and complexity.**
  - **Algorithmic engineering.**
  - **External memory algorithms.**
  - **System implementation.**
  - **Parallel computing.**
  - **A.I.**
    - ***Knowledge extracting.***
    - ***Data mining.***
    - . . .
  - **Discrete Math., e.g., Graph theory.**
- **Commercial opportunities.**
- **Fun.**

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