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**在中国象棋中聚合一致的残局着法**

**摘 要**

作为中国象棋程序评价函数的一部分，我们经常将残局试探法纳入其中。为了有效地积累游戏的最终着法，我们提出了一种基于中国象棋残局着法的系统，构建了一套完整的残局启发式教学法，它被称为残局着法库，用于我们的程序，冥想。基于着法的系统包括采集模块、推理模块、查询模块和验证模块。这个系统实现了我们的图模型，它具有保持一致性和提高正确性的功能。实验结果表明，在此基础上，冥想的演奏强度有明显的增强。

**关键词：**计算机象棋，基于残局着法的系统解决冲突，点阵图，有效的算法

**Abstract**

We often incorporate endgame heuristics as part of the evaluation function for Chinese Chess programs. In order to aggregate endgame knowledge effectively, we propose a Chinese Chess endgame knowledgebased system to construct a large set of consistent endgame heuristics, called endgame knowledge base, which is used in our program, Contemplation. The knowledge-based system consists of the acquisition module, the inference module, the inquiry module and the verification module. This system implements our graph model that has the functionality of maintaining consistency and improving its correctness. The experimental results on self-play test show that the playing strength of Contemplation has a distinct enhancement with this knowledge base.

**Keywords:** Computer Chinese Chess,Endgame knowledge-based system,Conflict resolution,Lattice graph,Efficient algorithm

# 译文

1. **介绍**

Shannon[5]提出了一种将着法与类型相结合的体系结构，以寻找一个国际象棋程序。由Knuth和Moore在1975年改进的极小极大博弈树搜索算法，b修剪法，证明了对于完美的排序博弈树，搜索的时间复杂度是O(d1/2)，其中d是博弈树的深度，。在此之后，Reinefeld发现了在大多数情况下比b剪枝算法更好的NegaScout搜索方法，但是有时需要更多的时间来进行重新搜索。

国际象棋的状态空间复杂度和博弈树的复杂度分别是1046和10123。相对于最新的已解游戏，跳棋，它的复杂性是1021和1031，至少在近期的位来，它仍然被认为是已解的。因此，研究人员将游戏分为开场游戏、中间游戏和终局游戏。为了完成残局, van den Herik和Herschberg提出了逆向分析的概念，在1985年建立了残局着法库。汤普森利用逆向分析构建了残局着法库，并在残局中提供了完美的游戏。10年后，他的残局着法库可以包含6块残局。

每个游戏都有其重要的领域着法。虽然国际象棋和中国象棋都是棋盘游戏，但后者有几个不同的特点:(1)炮的各种战术，(2)限制国王机动性的宫殿，(3)不能被提升的卒。

在研究方面，中国象棋存在两个关键问题。第一个是关于职位重复的专门规则。亚洲规则是一种国际规则，相对于其他规则的重复，是相对一致的。这一特殊规则也增加了由于图形历史交互(GHI)问题而导致的残局着法库的复杂性。

中国象棋的第二个问题是在残局中一组剩余的棋子的材料组合的动态价值。由于没有对残局的精确定义，我们将残局定义为两个玩家都没有超过5个实力强打的棋子单位。车，马和炮。一个车被认为是两个强大的单位。这个问题使得在残局时很难评估一个正确的分数，从而残局棋子的位置变化和棋子交换导致一些不确定的情况。这个问题将在第2节中描述。

逆向分析也是计算机中国象棋残局的一个重要的解决问题的方法。这样的着法为比赛中基本提供了完美的走法，但是在真正的比赛中，由于中国象棋游戏的棋子比其他类似的棋类游戏(如国际象棋)所包含的棋子要多得多，所以在真正的比赛中是难以运用这些理想走法的。为了提高着法库在实践中的使用率，我们提出了一种系统化的方法来构建一个包含了2009年的材料组合启发式的大型一致着法库。逆行分析方法是一种以位置为基础的位置型配置。每个位置的价值是游戏的理论价值:胜利，平局和失利。我们的工作是收集材料组合，并将它们的值分配给评估函数。每种材料组合的价值反映了中国象棋大师的启发式，通常都能了解游戏的结局是否有利，或者不考虑棋子可能的极端位置。

着法聚集是着法系统中的一个重要问题。这在中国象棋中也很重要。本文提出了一种基于着法的系统，可以获取、推理、查询、验证材料组合的着法。着法获取会自动生成材料组合，并执行一个分数预测方法来获得他们的分数值。推理技术解决了着法库中的冲突问题。探究是一种机制，使系统在存在不一致的情况下提出问题，以提高着法的质量。着法的验证有助于中国象棋专家验证和提高着法库的正确性。

本文的主要贡献在于，我们设计了一个图形模型来表示我们的数据，从而提供了保证一致性和提高着法库正确性的功能。第2节将讨论一致性和正确性问题。根据我们的实验，图形模型对于建立中国象棋的可靠着法库是有用的。

本文组织如下。第2节定义了我们的问题，并在图论中阐明了我们的概念。第3节描述了残局着法库系统的架构。第4节提供了我们的着法获取方法，并实现了系统的推理组件。第5节讨论了调查和验证过程。第6节通过自玩测试展示了基于着法的系统的整体实验。第7节为总结发言。

1. **理论基础**

在本节中，我们定义了块的符号，材料组合，以及材料组合的优势。然后我们根据保持一致性的图形模型讨论了动态材料组合的问题。主要使用的元着法包括块加性规则和具有其性质的格构模型。我们还将介绍一些关于图形模型的重要属性。

## 2.1 符号

中国象棋中有七个兵种:国王(K),士(G),象(M)、车(R),马(N),炮(C)和卒(P)。每种类型的静态材料价值的粗略定义如下:王(1),士(2),象(2)、车(10),马(5),炮(5),卒(1)。车,马和炮被认为强棋子，而卒是弱棋子。强而弱的棋子被称为进攻棋子，因为他们能够跨越将棋盘分成两界的河。士和象为防守棋子，他们负责保护国王。

一个材料组合被定义为一个位置上的一组块。我们用一线棋子来表示材料组合。线从红方国王开始，接着是其他红方棋子，接着是黑方棋子，然后是其他黑方棋子。例如，KCMKRP是一个材料组合，红方有一个国王，一个炮和一个象;黑方有一个国王，一个车和一个卒。在不失一般性的情况下，我们认为红方是进攻方，而黑方则是防守方。

## 2.2 元素的材料组合

一个材料组合附带有一个残局源标识符、一个优势分、一个不变标志和一个修改的标志。它们的描述如下:

结局源标识符。棋子着法来源，如教科书、人类注释或我们系统的自动生成。

优势分。材料组合的优点是在[0-9]范围内。值0(必赢)，1(较可能赢)，2(有利)，3(稍微有利)代表红方占优势的分数;4表示双方都有获胜的机会;5意思是平局，也就是说没人能赢;6是3的相反评价，7是2的相反评价，8是1的相反评价，9是0的相反评价。

不变标志。它被用于着法推断组件，以避免算法修改中国象棋专家手动分配的材料组合的分数。

修改标志。这个属性也被着法推断组件用来记录在迭代中被算法修改的信息。

图信息。我们将在第2.5节描述我们的图模型，这模型好比为推理模块维护的相邻节点和冲突相邻节点。

每一种材料的组合都有一个镜面的材料组合，这样红方和黑方就被交换了。对于对称的材料组合，红方和黑方包含相同的部分，它们的镜像材料组合反映了它们自己。相等实力的这种材料组合的分数只能是4或5。

## 2.3 动态材料组合的问题

攻击棋子和防守棋子的区别使得我们很难评估一个位置的正确得分。例如，KCPGMMKGGMM是一个红方可以获胜的残局。但在KNPGMMKGGMM 残局中，游戏通常以平局告终。图1所示的两个残局，相同评分价值中只有一个强棋子上有所不同，但它们的结论是不同的。不仅仅是进攻方棋子决定棋局，防守方棋子也在许多的棋局中至关重要。例如，在残局KPPKGG和KPPKMM中，红方有很多获胜的机会，但是KPPKGM通常是平局结束。因此，我们可以得出结论，KGM拥有比KGG和KMM更好的防御能力。然而，KNPKGM和KNPKGG通常是红方胜的残局，但在残局 KNPKMM中，黑方有更多的机会获得平局。KMM优于KGG和KGM的结论与前面的例子不一致。因此，在残局所有的特殊结果中很难找到一个一致的规则。

由于材料组合的动态值问题，很难在中国象棋中交换棋子。例如，在KRKNGG 残局中，红方总是可以找到一个获胜的策略，但是在KRKNMM 残局中会有一些平局的情况。根据这一点，我们在特定的残局需要交换棋子并减少当前位置时，当且仅当选择KRKNGG可以确保红色的一方赢得比赛。KRKNMM有获得平局的风险，如图2所示.这种关于材料组合的着法在棋局中期和残局中是很重要的，但是要获得一致的着法是很难的，因为有超过一百万的着法。因此，我们提出了一种基于图论的方法来获取常用的残局材料组合的值。

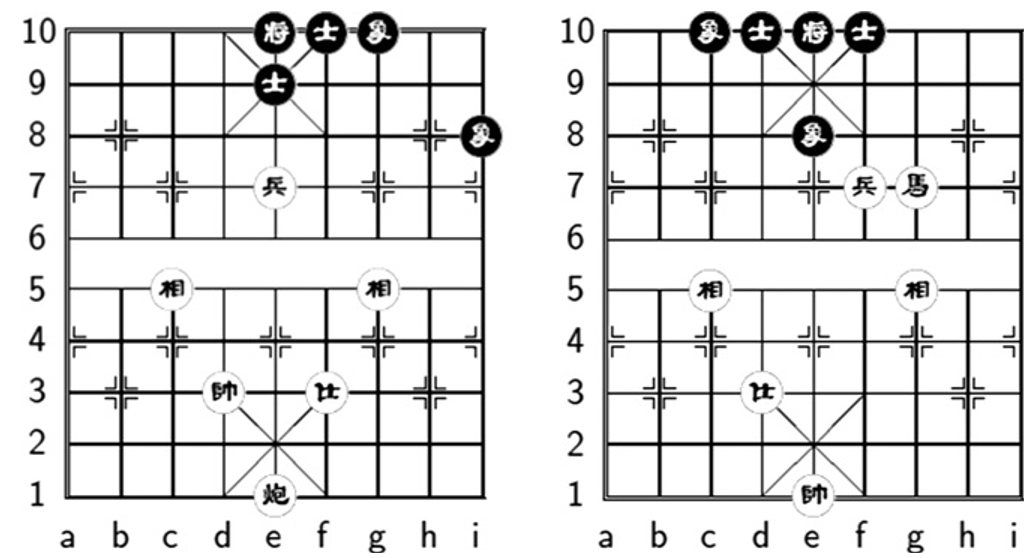


图1所示.材料组合KCPGMMKGGMM v.s . KNPGMMKGGMM。

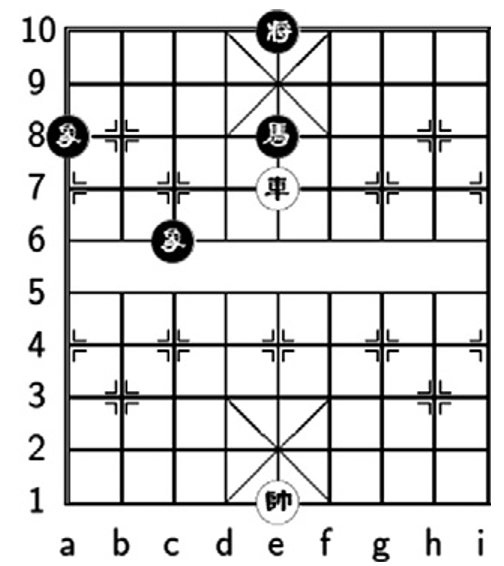


图2所示.KRKNMM的经典绘图配置。

## 2.4 主要的着法

在中国象棋中，所有的材料组合都遵循一种附加的规则，即对于一种材料组合，如果我们只考虑材料的组合，就不能使它比原来的更小。相反，从一方的材料组合中移除一个棋子不能使这一方比原来的更好。

这个性质介绍了材料组合的图形表示，称为晶格。下一节中根据添加棋子元着法描述的格模型保持一致性。

## 2.5 点阵模型

我们采用的思想是将元着法应用为格模型。晶格是一个部分有序集(poset)，所有非空子集在数学顺序理论中都有一个接合点和一个集合。接合点是元素或子集的最小上限;集合是元素或子集的最大下界。将材料的组合规则应用到一个有向图的格子中。晶格中的节点表示一个材料组合。边缘接合点两种只有一个棋子不同的材料组合。我们定义晶格结构作为c，对于两个相邻节点x和y, x→y表示红方至少在x和y中是有利的，在晶格中，x →y表示x和y是可比性的，x的集合是y，晶格中的每一个节点都可以看作是着法的单一入口。两个节点之间的边表示对应的两个条目之间的关系。图3是点阵模型的一个例子。

1. **中国象棋残局知识体系**

中国象棋残局知识系统由采集模块、推理模块、查询模块和验证模块组成。获取模块将条目添加到残局知识库中。推理模块解决知识库之间的冲突。在推断过程之后，可能会出现一些无法使用现有规则解决的冲突。然后，查询模块会对这些“问题”进行排列，并根据它们的严重程度对它们进行排序，由中国象棋人类专家做出最终的判断。当知识库变得一致时，我们应用验证模块来帮助我们发现潜在的错误知识。构建的知识库被我们的程序“思考”使用，作为其评估功能的一个特征。除了在评价函数中使用片段和位置值外，关于材料组合的好处的信息也逐渐显著地接近尾声。

## 3.1 采集模块

获取模块使我们能够建立一个庞大的知识库。其工作流程包含三个步骤:(1)扩展现有结局知识库,称为扩展过程,(2)使用的方法预测未知材料组合自动分配分数为扩展节点,称为预测过程,(3)选择实例的结果值存储到知识库。图4展示了构建这样一个知识库的过程。第一个残局知识库被称为基本的残局知识。它是一个手工构建的小型知识库。扩展过程从当前知识库中检索一个实例i，并通过查找i的邻居对其进行扩展。中国象棋中有12种棋子，除了两位国王。因此，最多有12个添加，12个删除，总共有24个操作可以应用到新添加的节点上。对于每个新添加的节点，预测过程调用未知状态预测器为其分配一个分数。构建的残局知识库的可靠性取决于其一致性。目标知识库包含原始节点加上它们的邻居。

## 3.2 推理模块

推理模块需要晶格模型和的优点是能够找到所有的冲突通过重复以下四个步骤:(1)发现冲突,(2)选择一个候选人与冲突,(3)选择最佳的得分值为选定的候选人,和(4)修订的得分值选择的实例。第一步发现晶格中的所有冲突。如果格不一致，我们需要使用贪心算法来解决冲突。我们首先选择错误值最高的实例，然后尝试所有的分数值，找出最合适的分数，即。例如，它会导致最少的冲突。细节问题将在第4节讨论。在完成了获取模块和推理模块后，我们得到了一致的最终知识库。我们可以重复这个过程，将一致的知识库输入到自动扩展算法中，以获得更大的知识库。

1. **知识获取和推理**

知识获取模块的过程包括扩展过程和预测过程。在开始材料KRKNMM可以轻松获胜，但仍有一些图纸配置。然而，如果典当与两位黑人牧师交换，所得到的材料，将绝对是一场胜利。然而，与两个黑人侍卫交换一个小卒可能比与两个黑人牧师交换要容易。因此，KRPKNGGMM不太可能肯定会赢。由于正确地交换工件是重要的，我们的未知状态预测方法结合了材料还原的概念，使用材料交换表和碎片交换方法来评估材料组合的分数值。

我们设计了一个概率模型，通过交换块来预测未知材料状态的结果。两人可以在必要时交换棋子。引入了一个物质交换表来计算能够进行这种交换的概率。

零件的流动性是不同的。换一件衣服换另一种款式的衣服也不容易。一个助手块可以是任何没有被交换的块，但是它可以用来促进这样的交换。每个玩家可以选择一件作为助手件。主动玩家是想要进行某种交换的人。被动玩家是被迫进行交换的人。一般情况下，在辅助件的帮助下，积极地交换碎片会增加能够进行这种交换的机会。相反，被动地使用辅助部件交换碎片可能会减少交换碎片的机会。因此，我们通常构建一个二维材料交换表，在辅助件的帮助下记录每一种类型的交换的概率。

除了国王，还有6种棋子。我们使用36个表来覆盖所有可能的组合。每个表包含指定活动块与所有可能的辅助块的交换概率，以及指定的被动块与所有可能的辅助块的交换概率。

1. **探究和验证**

## 5.1 探究

在执行冲突解决算法之后，它生成一个根据冲突节点的不一致性比率排序的冲突节点列表。人类专家只需要给出严重节点的分数值。然后，我们重新运行冲突解决算法，以减少更多的冲突。经过多次迭代，我们获得了超过12万的一致知识库，这是任何人类专家都不可能手动输入的。

## 5.2 正确性验证

在本节中，我们讨论了提高所获得的残局知识库正确性的两种方法，即随机抽样验证和高级算法的使用。

1. **实验结果和讨论**

在本节中，我们将评估我们在中国象棋游戏中使用的残局知识库，它的名称是冥想[12]。在修改数比较中，我们评估了不同版本知识库的修改数。在自玩实验中，我们使用不同版本的残局知识库进行自玩，以证明我们构建的知识库的有用性。

1. **总结**

我们的目标是收集知识，以确定哪些类型的最终游戏对搜索引擎有用。

为了保证知识库的一致性，提高知识库的正确性，提出了一种网格模型。我国象棋知识系统通过与推理模块和查询模块的协调，可以有效地获得大量一致的终局知识库。验证模块提供了一种有效提高知识库正确性的机制。

我们发现，如果我们拥有更多一致的知识，我们就不需要花费太多的精力来构建更大的一致的知识库，甚至可以进一步提高知识库的正确性。

这个知识库可以与我们的中国象棋程序——冥想相结合。自玩实验表明，END12CR是最好的版本，而END6C是最稳定的版本。总之，数量对于知识系统来说和质量一样重要。在未来，更多的实验可以在阅读比赛中进行，除了自我游戏。

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# 原文

**Aggregating consistent endgame knowledge in Chinese Chess**

# Introduction

Shannon [5] proposed an architecture to combine knowledge and the type A search for a Chess program. An improvement of minimax game tree search algorithm, a \_ b pruning, is proved that for perfect ordering game trees, the time complexity of the search is O(d1/2), where d is the depth of the game tree, by Knuth and Moore in 1975 [6]. After that, Reinefeld discovered the NegaScout searching method that perform better than a \_ b pruning algorithm in most cases, but sometimes takes more time to do the research [2].

The state-space complexity and the game-tree complexity of Chess is 1046 and 10123, respectively. Comparing to the latest solved game, Checkers, whose complexity is 1021 and 1031, it is still believed far from being solved in the near future [7]. Thus, the researchers divide a game into the opening game, the middle game, and the endgame. For the achievement of the endgame, van den Herik and Herschberg suggested the concept of the retrograde analysis to build endgame knowledge bases in 1985. Thompson [8] uses retrograde analysis to construct endgame knowledge bases and provide perfect play in endgame positions. Ten years later, his endgame knowledge bases can contain 6-piece endgames [9].

Each game has its significant domain knowledge. Although Chess and Chinese Chess are both the games of checkmates, the latter has several distinct features: (1) various tactics of cannon, (2) a palace that limits the mobility of kings, (3) pawns which cannot be promoted.

In the aspect of research, there are two critical problems in Chinese Chess. The first is the specialized rules for repetition of positions. The Asian rule is an international rule that is relatively consistent than other rules for repetition of positions. This special rule also increases the complexity of endgame knowledge bases due to the graph history interaction (GHI) problem [1].

The second problem in Chinese Chess is the dynamic values of material combinations, i.e., a set of remaining pieces, in the endgame. Since there is no precise definition of endgame, we define the endgame as the position set that both players have no more than five units of strong pieces, i.e., rooks, knights, and cannons. A rook is considered as two units of strong pieces. The problem makes it difficult to evaluate a correct score in the endgame and thus causes some uncertainty for transforming positions into endgames by piece exchanging. The problem will be described in Section 2.

Retrograde analysis is also an important problem solving method for computer Chinese Chess endgames [13]. Such knowledge bases provide perfect play in tournaments, but it is not easy to go into these pre-created endgames during a real tournament due to the fact that Chinese Chess endgames contain much more pieces than other similar games such as Chess. In order to increase the usage rate of knowledge bases in practice, we proposed a systematic method to construct a large consistent knowledge base that contains heuristics about material combinations in 2009 [4]. The retrograde analysis method is the position-wise configuration whose knowledge base consists of positions. The value of each position is the game-theoretical value: win, draw or loss. Our work is to collect material combinations and to assign their values to be used in an evaluation function. The value of each material combination reflects the heuristic a Chinese Chess master usually understand whether the endgame is advantageous or not without considering possible extreme positions of the pieces.

Knowledge aggregation is an important problem in knowledgebased systems [11]. It is also critical in Chinese Chess. In this paper, we propose a knowledge-based system that can acquire, inference, inquire, verify on the knowledge of material combinations. Knowledge acquisition automatically generates material combinations and perform a score prediction method to obtain their score values. The inferencing technique resolves conflicts in the knowledge base. Inquiry is a mechanism for the system to ask questions when there is inconsistency to improve the quality of knowledge. Verification of knowledge facilitates Chinese Chess human experts to verify and improve the correctness of knowledge base.

The main contribution of the paper is thatwedesign a graphmodel to represent our data and thus provide the functionality to ensure the consistency and to improve the correctness of the knowledge base. The consistency versus correctness problem will be discussed in Section 2. According to our experiments, the graph model is useful in building a reliable knowledge base for Chinese Chess.

This paper is organized as follows. Section 2 defines our problem and illustrates our concept in graph theory. Section 3 describes the architecture of the endgame knowledge-based system. Section 4 provides our methods for knowledge acquisition and implements the inference component of the system. Section 5 discusses the inquiry and verification process. Section 6 shows the overall experiment of the knowledge-based system by a self play test. In Section 7, we make concluding remarks.

# Theoretical foundations

In this section, we define the notations of pieces, material combinations, and advantage scores of material combinations. We then discuss the problem of dynamic material combinations, followed by our graph model for maintaining consistency. The main metaknowledge used includes the piece additive rule and the lattice model with its properties. We will also state some important properties about the graph model.

**2.1 Notations**

There are seven types of pieces in Chinese Chess: king (K), guard (G), minister (M), rook (R), knight (N), cannon (C) and pawn (P). The static material value of each type of pieces is roughly defined as follows: king (1), guard (2), minister (2), rook (10), knight (5), cannon (5), pawn (1). Rooks, knights and cannons are called strong pieces and pawns are weak pieces. Strong and weak pieces are called attacking pieces because they are able to cross the river which divides the board into two territories. Guards and ministers are defending pieces. Their mission is to protect the king.

A material combination is defined as the set of pieces in a position. We use a string of pieces to denote a material combination. The string starts from the red king, followed by the other red pieces, followed by the black king, and followed by other black pieces. For example, KCMKRP is a material combination that the red side has a king, a cannon and a minister; the black side has a king, a rook and a pawn. Without loss of generality, we consider the red side as the attacking player and the black side as the defending player.

**2.2 Elements of material combinations**

A material combination is attached with an endgame source identifier, an advantage score, an invariable flag and a modified flag. They are described as follows:

Endgame source identifier. The source where the piece of knowledge comes from, such as text books, human annotations or automatic generation by our system.

Advantage score. The advantage score of a material combination is in the range of [0–9]. The values 0 (sure win), 1 (mostly win), 2 (advantageous), 3 (slightly advantageous) represent the scores that the red side is in advantage; 4 represents that any one player has a chance to win; 5 means draw, which says no one can win; 6 is the opposite of 3, 7 is the opposite of 2, 8 is the opposite of 1, and 9 is the opposite of 0.

Invariable flag. It is used in the knowledge inferencing component to avoid the algorithm to modify the scores of the material combinations assigned manually by Chinese Chess human experts.

Modified flag. This attribute is also used by the knowledge inferencing component to record entries that are modified by the algorithm in an iteration.

Graph information.We will describe our graph model in Section 2.5. The information such as the neighbors of a node and the conflict neighbors of a node are maintained for the inference module.

Each material combination has exactly one mirrored material combination such that the red pieces and the black pieces are swapped. For symmetric material combinations that the red side and the black side contain same pieces, their mirrored material combinations reflect to themselves. The scores of such material combinations of equal power can only be either 4 or 5.

**2.3 The problem of dynamic material combinations**

The distinction of attacking pieces and defending pieces makes it hard to evaluate the correct score of a position. For example, KCPGMMKGGMM is an endgame that the red side can force a win, but in KNPGMMKGGMM endgame, the game generally ends in a draw. The two endgames, shown in Fig. 1, only differ by one strong piece of the same material value, but their conclusions are different. Not only attacking pieces are critical for endgames, defending pieces are also critical in many endgames. For example, in the endgames KPPKGG and KPPKMM, the red side has many chances to win, but KPPKGM is generally a draw endgame. Thus, we may conclude that KGM has better defensive power than KGG and KMM. However, KNPKGM and KNPKGG are generally red-win endgames but in the endgame KNPKMM, the black side has more chance to achieve a draw. A conclusion that KMM is better than KGG and KGM is inconsistent with that of the previous example. Therefore, it is hard to find a consistent rule for all of the peculiar results in endgames.

The problem of having dynamic values for material combinations makes it difficult to exchange pieces in Chinese Chess. For example, the red side can always find a winning strategy in KRKNGG endgame, but there are some drawing cases in KRKNMM endgame. According to this, when we need to exchange pieces and reduce the current position into certain endgames, choosing KRKNGG ensures the red side to win the game, but choosing KRKNMM has some risk of getting a draw, as shown in Fig. 2. Such knowledge about material combinations is important in the middle game and the endgame, but it is hard to acquire a consistent set of knowledge since there are more than one million of them. As a result, we propose a method based on graph theory to obtain values of commonly used endgame material combinations.

**2.4 The main meta-knowledge**

All material combinations in Chinese Chess follow the piece additive rule that for a material combination, adding pieces to a player cannot make it to be less advantageous than the original one if we only consider material combinations. Conversely, removing a piece from a player in a material combination cannot make this player to be be better than that was in the original one.

This property introduces the graph representation for material combinations, called a lattice. The lattice model described in the next section maintains consistency according to the piece additive meta-knowledge.

**2.5 The lattice model**

The idea we adopted is to apply meta-knowledge as a lattice model [10]. A lattice is a partially ordered set (poset) that all non-empty subsets have a join and a meet in mathematical order theory. A join is the least upper bound of an element or a subset; a meet is the greatest lower bound of an element or a subset. By applying the piece additive rule, material combinations can be transformed into a lattice which is a directed graph. The node in the lattice represents a material combination. The edge connects two material combinations that differ only one piece. We define

# Chinese Chess endgame knowledge-based system

The Chinese Chess endgame knowledge-based system consists of an acquisition module, an inference module, an inquiry module and a verification module. The acquisition module adds entries into the endgame knowledge base. The inference module resolves conflicts among the knowledge base. After the inferencing process, there might be some conflicts that cannot be resolved using existing rules. The inquiry module then arranges these ‘‘questions’’ and ranks them according to their severeness for Chinese Chess human experts to make the final judgement. When the knowledge base becomes consistent, we then apply the verification module to help us finding out potentially incorrect knowledge. The constructed knowledge base is used by our program, Contemplation, as one feature in its evaluation function. In addition to using piece and location values in the evaluation function, information about the benefit of material combinations gradually significant near endgame.

**3.1 The acquisition module**

The acquisition module enables us to build a large knowledge base. Its working flow contains three steps: (1) extend an existing endgame knowledge base, called the extending procedure, (2) use the method of predicting unknown material combinations to automatically assign scores for extended nodes, called the predicting procedure, and (3) store the resulting value of the selected instance into the knowledge base. Fig. 4 shows the process of building such a knowledge base.The first endgame knowledge base is called an elementary endgame knowledge. It is a small knowledge base that is constructed manually. The extending procedure retrieves an instance i from the current knowledge base, and extends it by finding the neighbors of i. By definition in Section 2, the neighbors of a node are those nodes of either adding a piece or deleting a piece from the original node. There are 12 types of pieces in Chinese Chess, excepting the two kings. As a result, there are at most twelve additions, twelve deletions, totally up to 24 operations that can be applied to a newly added node. For each newly added node, the predicting procedure calls the unknown state predictor to assign a score for it. The reliability of the constructed endgame knowledge base relies on its consistency. The target knowledge base contains the original nodes plus their neighbors.

**3.2 The inference module**

The inference module takes the advantage of the lattice model and is able to find all the conflicts by repeating the following four steps: (1) discovering conflicts, (2) selecting a candidate with conflicts, (3) selecting the best score value for the selected candidate, and (4) revising the score value of the selected instance. The first step discovers all conflicts in the lattice. If the lattice is not consistent, we need to apply our greedy algorithm to resolve the conflicts. We first select the instance with the highest error value, and then try all score values to find out the most suitable score, i.e., the one that causes the least amount of conflicts, for the instance. Detail issues will be discussed in Section 4. After performing the acquisition module and the inference module, we obtain a consistent end-game knowledge base. We can repeat the process by feeding the consistent knowledge base into the automatic extending algorithm to obtain a larger knowledge base.

# Knowledge acquisition and inference

The process of the knowledge acquisition module includes the extending procedure and the predicting procedure. In the begin material KRKNMM can win easily, but there are still some drawing configurations. However, if the pawn is exchanged with two black ministers, the resulting material, KRKNGG would absolutely be a win. However, it may be easy for a pawn with a rook to exchange with two black guards than exchanging with two black ministers. Thus KRPKNGGMM is not likely to be a sure win. Since exchanging piece correctly is important, our unknown state predictor method incorporates the concept of material reduction that uses a material exchange table and piece-exchange method to evaluate the score value of a material combination.

We design a probabilistic model that predicts the results of unknown material states by exchanging pieces. Both players can exchange pieces when necessary. A material exchange table is introduced to compute the probabilities of being able to carry out such an exchange.

The mobility of pieces are different. The easiness to exchange a certain piece for pieces of another type is also different.Ahelper piece can be any piece that is not being exchanged, but it can be used to facilitate such an exchange. Each player can select one piece as a helper piece. An active player is the one who wants to make a certain exchange happens. A passive player is the one who is forced to make an exchange. Generally, actively exchanging pieces with the assistance of a helper piece increases the chance of being able to carry out such an exchange. Contrarily, passively exchanging pieces with the aid of a helper piece may reduce the chance of pieces being exchanged. Hence,wemanually construct a two-dimensional material exchange table to record the probability of exchanging for each type of piece with the assistance of helper pieces.

There are 6 types of pieces besides to the king.Weuse 36 tables to cover all possible combinations. Each table contains the exchange probabilities of the specified active piece with all possible helper pieces and the specified passive piece with all possible helper pieces.

# Inquiry and verification

**5.1 Inquiry**

After performing the conflict resolution algorithm, it produces a list of conflict nodes sorted according to their inconsistency ratios. Human experts only need to give the score values for severe nodes. Then, we rerun the conflict resolution algorithm again to reduce more conflicts. After several iterations, we obtain a consistent knowledge base of size more than 120 thousands, which is impossible for any human expert to manually enter.

**5.2 Correctness verification**

In this section, we discuss two types of methods to improve the correctness of the obtained endgame knowledge base, namely the random sampling verification and the usage of advanced metaknowledge.

# Experimental results and discussions

In this section, we evaluate our endgame knowledge base used in a Chinese Chess playing program, Contemplation [12]. In the modification number comparison, we evaluate the number of modifications between several versions of knowledge bases. In the self-play experiment, we perform self-play by using different versions of endgame knowledge base to demonstrate the usefulness of our constructed knowledge base.

# Conclusions

Our goal is to aggregate knowledge to identify which kinds of endgames are useful to a search engine.

In this paper, we proposed a lattice model to ensure consistency and to improve the correctness of the knowledge base. Our Chinese Chess knowledge-based system can effectively acquire a large amount of consistent endgame knowledge base by coordinating with the inference module and the inquiry module. The verification module provides a mechanism that efficiently improves the correctness of the knowledge base.

We discover that if we have more consistent knowledge, we need less effort to build a larger consistent knowledge base, and even to further improve the correctness of the knowledge base.

The knowledge base can be integrated with our Chinese Chess program, Contemplation. The self-play experiment shows that END12CR is the best version, and END6C is the most stable version. In summary, quantity is as important as quality for knowledgebased systems. In the future, more experiments can be carried out in read tournaments in addition to the self-play ones.

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