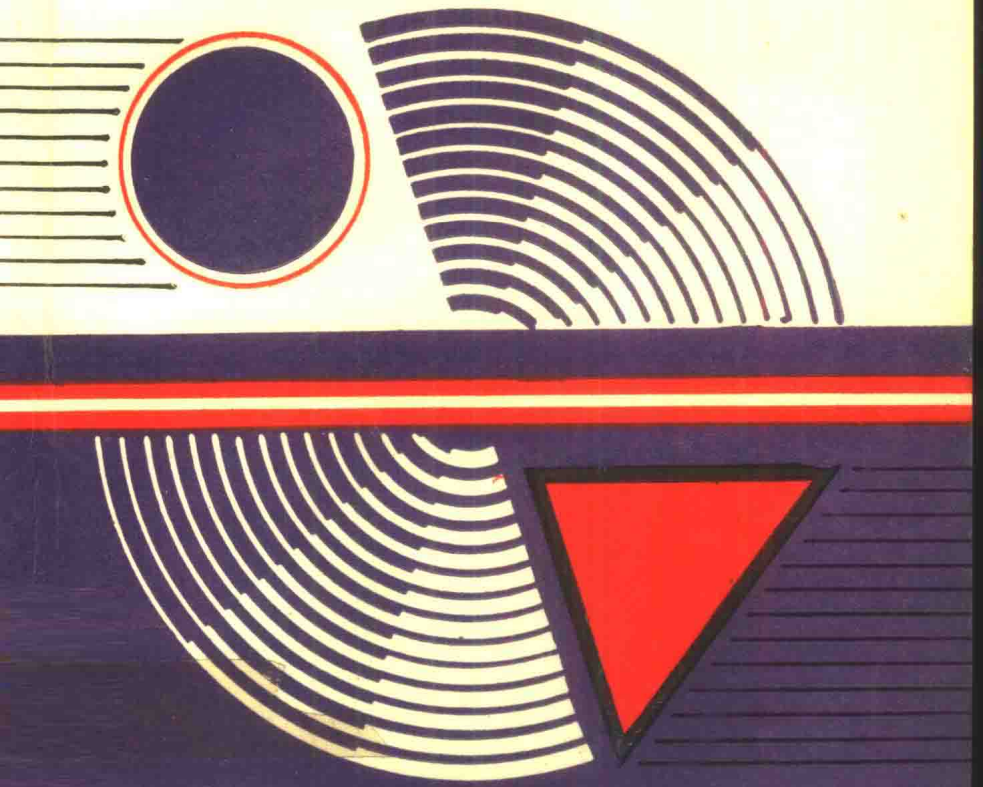
专家系统中的不确定推理
——模型、方法和理论

罗旭东　邱玉辉著



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前　言

专家系统是人工智能这门学科中主要的研究课题之一，在许多重要的领域里具有广泛的应用。知识不确定性的表示和处理，是专家系统中一个十分活跃的研究领域。本书总结了作者及合作者近年来的科研成果，其中部分内容是第一次发表。

不确定性知识的表示和处理，从有专家系统起就是最受重视的分支之一。有关的国际会议有两个，在有关刊物和会议上论文也是层出不穷的，还有许多专著研究这个问题，在国际上，这方面优秀的专家有Shotliffer，Duda，Shafer，Heckerman，Pearl，Dubois，Prade，Yager等等。国内最早涉及这方面工作的是吉林大学，他们先是在《计算机科学》上将国外的工作介绍到国内，随后又做了不少工作，在他们的带动下，国内许多学者也投入这项研究，并取得了一些好的成果。

作者开始这方面的研究源于1987年底在北京图书馆读到Heckerman那篇著名的论文〔Hec 86〕。受他影响，我们的思路也是从公理入手，试图为各种不确定推理模型建立一个类似于概率公理那样的基础，使有关工作能在其上展开。经过多年研究，从我们所建立的公理系统上，长出了许多分枝，经过修剪就形成了这本书。

本书的组织思路如下：从不确定性的估值情况来看，有

点估计型(包括Fuzzy点估计)、区间估计型和语言辞估计型。从这个角度出发，便有第一、二章。要不要给推理网络中结点赋先验概率，是不确定推理研究中的一个关键问题，由此而引发了第三、四、五、八章。从规则的不确定性的不同语义来考察，就产生了第六、七章；沿着多值逻辑、模糊逻辑和非单调逻辑这条线索，产生了第十二、十三章。从一专家到众专家的角度来看，应有多专家知识的融合和多专家推理的交互作用，第十一章可以视为是处理多专家的不确定知识的融合问题。

沿着以上每一条线索的研究，都可以视为一棵树的一个分枝，而这棵树的根便是我们给不确定推理所建立的公理系统——NT-代数，这就是第九章介绍的内容。第十章着重研究NT-代数的数学性质。

作者愿借此机会向蔡经球教授、史忠植教授、李国杰研究员、祝明发教授、汪培庄教授、王遇科教授、王明亮教授、陆汝钤教授、徐泽同教授、韦梓楚教授、黄海涛高工、彭旭东先生、曹存根博士、吴发恩博士、张师超教授、白硕研究员、邱贵友先生、王能忠教授和张为群教授表示感谢，感谢他们的支持和帮助。

由于很多的内容尚属首次发表，疏漏、缺点在所难免，但作者愿以此书抛砖引玉，肯请同行赐教。

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Abstract

Expert systems have been popular for about twenty years and applied successfully in many domains. Nevertheless, problematic expert system design issues remain—uncertainty management is case in point. This book investigates the issue. We organize the book into the following five parts.

Part One MYCIN-Class Uncertain Reasonings

By forms of estimate for uncertainty, uncertain reasonings can be classified into three sorts:point-type, interval-type and linguistic-type. Strictly by fuzzy mathematics, this part derived an interval-type model and a linguistic-type model from MYCIN certainty factors method, which has been applied successfully in many expert systems. Clearly,their basis is sound,and they inherit the advatage of MYIN's,i.e. the ability of distinguish the belief from disbelief in a hypothesis referred to evidence. Of course, they have own advantages,e.g. the interval-type model can deal with the information about ignorance, and the linguistic-type model

can do fuzziness of linguistic terms. In addition, they can coexist in a single system, which offers some flexiblity for their application.

Part Two Uncertain Reasonings Based upon Probability

The subjective approach in PROSPECTOR is the earliest probability-based uncertain reasoning model used in expert systems. The main advantage of this sort of models is that they are built on a sound theoretic basis. But the values of prior probabilities of nodes in an inference net are needed to be supplied for, which is difficult very much for human experts. For the reason, they are employed in few expert system. In this part, very much space is devoted to discussing how to solve the problem. Concretely, discussed are the marriage between LS, LN and CF, and how to recover consistency between the definition of the certainty factors and the formulas for propagating their values through an inference net.

Another important issue is that different uncertainties have to be measured by different measures, and even the same uncertainty maybe need to use different measures to measure because of the difference between the characters of different experts. For the reason, we suggest eight kinds of measures

for various uncertainties. Natually, we consider the marriage between them in order to avoid supplying values for prior probabilities. All of these measures for uncertainties can be converted into corresponding probability values. Therefore, we develop a general framework for them, and explain some issues concerned with integrating them into a single system.

Part Three NT-Algebra: An Axiomtics of Uncertain Reasoning Models

On the basis of examining in detail many kinds of uncertain reasoning models in rule-based expert systems, by analysing the laws people must obey in reasonings under uncertain cases, and from the structure and constraint point of view, for uncertin reasonings in rule-based expert systems like MYCIN and PROSPECTOR, an axiomatics, NT-algebra, is proposed in this part. This part studies some basic properties of NT-algebra, and discusses issues involved in: 1) necessary and sufficient condition, intersection and union, and generating elements in respect to the subalgebra of a NT-algebra, and 2) relations between properties of product, quotient of NT-algebra models, productablity and quotientablity. In addition, this part defines homomorphism and isomorphism of NT-algebras, comes

to several conclusions including the basical homomorphism theorem,and discusses some algebra structures consisted of homomorphic mappings, e. g. semi-ring.

A model of NT-algebra needs to be defined on a sort of space different from a metric space. For this reason, this part introduces the concept of near degree space, a specific kind of topologic space,based on which the continuities of functions on a metric space, of fuzzy functions and of other types of functions can be considered uniformly. Moreover, in this part, the concepts of subspace, product and quotient of any near degree spaces are constructively introduced, on which continuities of the corresponding functions are discussed.

By comparison with other related works, it is concluded that NT-algebra as an axiomatics is superior to those proposed by other people in the following aspects: 1)its reflecting the different more cases of human brain's estimating uncertainties of evidence and rules,and 2) its reflecting more laws of human brain's uncertain resonings, i.e. more laws of the propagations of uncertainty through a reasoning network.

Part Four Logic Relative Multi-Ary Uncertain Reasoning Models and Second-Order

Uncertain Reasoning Models

The first object of this part is to study how to handle uncertainty distributions over truth set of a multi-valued logic, every component of which measures absolutely belief or change in belief on taking the corresponding truth value. The conception of logical relative multi-ary uncertain reasoning models handling such distributions are introduced in this part. To build such kinds of models, the general theory and methodology of algebra-base based on NT-algebra is developed. From our proving, the D-S evidence theory can be viewed as a special algebra-base, and by the constructions of our some concrete models, it can be concluded that our theory and methodology of algebra-base is superior to D-S evidence theory. Hence, further research on algebra-base is well worth doing. Besides, it is stressed that the previous researches published in respect with uncertain reasonings are mainly directed against two-valued logic, while ours in the part is directed against any multi-valued logic.

The second object of this part is to study how to handle people confindence-degree for a estimate of some uncertainty. For this, the concept of second-order uncertainty is introduced in this part. For any uncertain reasoning models corresponding a NT-algebra model, a general framework for the second-order

uncertain reasoning model is built up. In particular, two second-order uncertain reasoning models corresponding respectively to MYCIN's certainty factor model and PROSPECTOR's subjective Bayesian approach are discussed. For any logic relative multi-ary uncertain reasoning model, two kinds of general frameworks for the corresponding second-order uncertain reasoning models are developed. In addition, this part discusses the following issues associated with the application of these second-order uncertain reasoning model: coexistence of first-order and second-order uncertainties, efficiency of inference and so-called semi-second-order models. Few research on second-order uncertainty has been published by other authors, which foundations are very poor, while ours in this part is more systemical and has a good foundation.

Part Five Uncertain Default Reasonings

In reality, for a piece of default rule, perhaps we can not enumerate all of rerequisition and justification. In some case, the correlation between the rerequisition, justification and conclusion, which is revealed by a default rule, may be uncertain. Moreover, its rerequisition may not always be completely certain or negative, its justification may not always completely consist with what is known

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and so its conclusion maynot always be absolutely certain. In addition, evidence also may not always be completely certain or negative. Therefore, in default reasonings, uncertainty should be take into account further. on the other hand, people usually prefer use linguistic terms rather than numerical values to estimate uncertainty. For this reason, this part employs linguistic terms to estimate basic uncertainty and develops a framework for default resoning based on linguistic terms. In this framework,both the first-order and second-order uncertainty are taken into account, and both crisp and fuzzy propositions are involved in.If we view previous research on uncertain reasoning as the work associated with monotonic uncertain reasonings,ours in the part can be viewed as one about nonmonotonic uncertain reasonings.

内 容 简 介

本专著分为五篇．第一篇根据可能性理论，发展了MYCIN确定因子模型，使其能够在一定程度上处理“不知道”的信息和模糊性。第二篇根据概率论，讨论类MYCIN和类PROSPECTOR模型，建立了一般框架，定义了几种新度量，并讨论约束、扩张、结合、转换和选择等相关问题。重要的是不要求对推理网络结点赋先验概率．第三篇提出了一个不确定推理模型的公理系统：NT-代数，并讨论了其基本性质、子代数、积代数、商代数、理想以及同态等．其中同态映射在分布式专家系统中会涉及到．第四篇为多元相关模型和二阶模型．前者的不确定性变量是多值逻辑真值集上的分布，后者可用于处理多专家知识的融合或重用．第五篇提出了一套能同时处理不确定性、非单调性和模糊性的方法．

本书可供有关专业科研人员参考，可作专家系统开发和应用人员的工具书，亦可供计算机、应用数学和模糊数学等专业的高年级本科生和研究生学习．

目　录

绪论……（1）
§0.1　专家系统中为什么需要不确定推理……（1）
§0.2　不确定推理研究成果的回顾……（3）

第一篇　MYCIN 族不确定推理……（8）
第一章　基于区间估计的确定因子模型……（8）
§1.0　引言……（8）
§1.1　〔0，1〕区间上的 MYCIN 确定因子模型……（10）
§1.2　不确定性的表示……（11）
§1.3　不确定性的传播……（13）
§1.4　封闭性和平坦化……（17）
§1.5　平行组合的结合性……（19）
§1.6　推理链的压缩性定理……（21）
§1.7　例子……（23）
§1.8　小结……（26）
第二章　基于梯形模糊数的确定因子模型……（27）
§2.0　引言……（27）
§2.1　预备知识……（28）
§2.2　基于梯形模糊数的模型……（30）
§2.3　例子……（37）
§2.4　小结……（40）

第二篇　基于概率的不确定推理……（41）
第三章　基于概率的不确定推理模型的基本原理……（42）
§3.0　引言……（42）
§3.1　PROSPECTOR模型……（42）
§3.2　知识不确定性的一般表示……（44）
§3.3　RS(H|E)、P(H)和P(E)间的关系……（44）
§3.4　概率传播公式……（45）
§3.5　小结……（49）
第四章　结合PROSPECTOR的和MYCIN的方法的不必赋先验概率的不确定推理……（49）
§4.0　引言……（49）
§4.1　不一致性问题……（50）
§4.2　三元规则强度……（52）
§4.3　例子……（57）
§4.4　讨论……（64）
§4.5　小结……（65）
第五章　恢复确定因子定义与其值传播公式间的一致性……（66）
§5.0　引言……（66）
§5.1　基本理论……（67）
§5.2　规则强度的一致性赋值……（72）
§5.3　例子……（77）
§5.4　小结……（88）
第六章　几种新的类PROSPECTOR规则强度……（89）
§6.0　引言……（89）
§6.1　四种新的类PROSPECTOR规则不确定性度量……（89）
§6.2　组合规则强度……（95）
§6.3　讨论……（99）

§6.4 例子……(103)
§6.5 小结……(106)
第七章 几种新的类MYCIN规则强度……(107)
§7.0 引言……(107)
§7.1 逆确定因子……(108)
§7.2 几率确定因子……(110)
§7.3 支持确定因子……(115)
§7.4 小结……(116)
第八章 类PROSPECTOR和类MYCIN规则强度间的结合和转换……(118)
§8.0 引言……(118)
§8.1 MYCIN确定因子与类PROSPECTOR规则强度结合…(118)
§8.2 规则强度的转换……(122)
§8.3 例子……(128)
§8.4 小结……(132)

第三篇 不确定推理模型的公理系统——NT-代数…(133)
第九章 NT-代数的基本概念……(134)
§9.0 引言……(134)
§9.1 贴近度空间的概念……(135)
§9.2 NT-代数的定义……(141)
§9.3 MYCIN和PROSPECTOR的不确定推理模型都分别对应于一个好NT-代数模型……(150)
§9.4 有限NT-代数的存在性……(152)
§9.5 NT-代数的一些基本性质……(153)
§9.6 小结……(160)
第十章 新空间、新代数制作及同态映射……(160)
§10.0 引言……(160)
§10.1 子空间和子代数……(161)

§10.2 积空间和积代数 ……(164)
§10.3 商空间、商代数和理想 ……(170)
§10.4 同态映射 ……(177)
§10.5 小结 ……(186)

第四篇 多元相关的不确定推理模型和二阶不确定推理模型 ……(187)
第十一章 多元逻辑相关不确定推理模型 ……(188)
§11.0 引言 ……(183)
§11.1 代数基 ……(188)
§11.2 基于三值逻辑的三元相关模型 ……(197)
§11.3 基于四值逻辑的四元相关模型 ……(205)
§11.4 语言概率辞多元相关模型 ……(207)
§11.5 基于概率的多元逻辑相关不确定因子模型 ……(213)
§11.6 小结 ……(219)
第十二章 二阶不确定推理 ……(220)
§12.0 引言 ……(220)
§12.1 二阶对应于NT-代数的不确定推理模型 ……(220)
§12.2 二阶多元相关模型 ……(229)
§12.3 语言辞MYCIN确定因子模型及其二阶模型 ……(235)
§12.4 讨论 ……(242)
§12.5 小结 ……(244)

第五篇 不确定的缺省推理 ……(246)
第十三章 基于语言辞的缺省推理的框架 ……(246)
§13.0 引言 ……(246)
§13.1 预备知识 ……(248)
§13.2 一阶模型 ……(253)
§13.3 二阶模型 ……(261)

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