KNOWLEDGE BASED SYSTEMS

**Advanced Concepts
Techniques & Applications**

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Advanced Concepts
Techniques & Applications

edited by

Spyros G. Tzafestas

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PREFACE

The field of Artificial Intelligence (AI) has reached a high level of maturity with many important results, methods and tools being already available. AI is generally concerned with symbolic reasoning and problem solving. Knowledge-Based Systems (KBS) represent a subfield of AI which is concerned with the incorporation of symbolic knowledge into computer systems to solve problems that require human attention and intelligence. Typically, KBS are designed to replicate and autonomously apply human expertise (knowledge), which is suitably acquired and converted into industrial power. Knowledge acquisition is a central issue of KBS design, and in modern systems is structured according to some well-defined problem-solving method. KBS technology has received much popularity and acceptance in the engineering community, with applications ranging from design assistance, to automated planning, fault diagnosis / repair, and system supervision and control.

This book provides a set of selected contributions covering advanced theoretical and practical issues of knowledge-based systems, and is divided in two parts.

PART I (General Techniques and Tools) involves eleven chapters that present important methodologies and tools ranging from well-established to more fresh results. The topics covered in this part are : knowledge acquisition, machine learning, knowledge management, knowledge processing under uncertainty, design of structured models, computation of production systems, nonlinear planning, natural language communication in man-machine systems, and genetic-based learning.

PART II (Applications) contains eleven chapters, dealing with the following applications : simulation-based optimization, fault diagnosis, quality assessment, design for assembly, robotized arc welding, real time decision support, production management in manufacturing systems, reactive scheduling in manufacturing systems, concurrent design, and coordination of heterogeneous CIM data activities.

Taken together the twenty two chapters of the book, which have been prepared by leading experts in the field, constitute a well-balanced and long-standing reference source on knowledge-based systems and their applications. The book can be used as a reference book in graduate-level courses dealing with the theory and practice of KBS, and as a cohesive knowledge source for researchers and professionals.

I am indebted to all contributors for their high-level and timely contributions, and their cooperation and help throughout the lengthy editorial and publication procedure. I hope that their efforts integrated in this book will really meet the goal of providing an important addition to the current literature on knowledge-based systems. Finally, my special thanks go to the members of staff of the World Scientific's Editorial Department for their encouragement and support to this project.

Athens, October 1996

Spyros G. Tzafestas

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EDITORIAL

The purpose of this Editorial Introduction is to give a brief summary of the work described in the book. A wide repertory of theoretical topics on the analysis and design of knowledge-based systems are covered, along with practical implementation tools and important technological and non-technological applications. Chapters 1 through 11 deal with the methodological issues, and Chapters 12 through 22 present the applications.

Chapter 1 (by *S. G. Tzafestas* and *E. S. Tzafestas*) provides a thorough overview of the available knowledge acquisition techniques and interactive tools. The chapter starts with the general issues of knowledge acquisition, and then reviews the psychological methods, namely: interview, observation, multidimensional, and protocol analysis methods. Then, it discusses more advanced techniques such as concept learning, critical decision, analytical representation, and systems engineering knowledge acquisition techniques. Next, the chapter reviews the work done on knowledge acquisition as modelling and knowledge acquisition under uncertainty. Finally, a set of important automated knowledge acquisition tools are outlined, which employ symbol-level, method-based, and task-based conceptual models.

Chapter 2 (by *Cornuéjols* and *Moulet*) provides a survey of the major achievements in the area of machine learning. This includes the historical trajectory of the field, the basic concepts of typical use, the principal learning methods, and some current research topics. The learning methods discussed are methods for inductive generalization (symbolic and non symbolic), methods for unsupervised concept formation, methods for optimization goals, and methods for change of representation. The chapter concludes with an investigation of the relation between machine learning and the fields of statistics and knowledge acquisition, and a discussion of how machine learning is put into practice.

Chapter 3 (by *S. G. Tzafestas*, *Z. Ma* and *E. S. Tzafestas*) deals with three classes of inductive learning, namely version space learning, explanation-based learning and genetic algorithm-based learning. A general discussion of the basic

inductive learning models is first provided (definition networks, generality networks, causal networks, classification networks) together with a presentation of the structure of an ideal (learning) theory. Then the version space learning (VSL) family is considered, where the basic VSL, the polynomial VSL and the version space intersection methods are reviewed. Next, the explanation-based learning (EBL) methodology is presented (definition, imperfect theory problem, deep knowledge based learning, further progresses in EBL). Finally, the genetic algorithm based learning (GABL) family is discussed, including the basic genetic algorithm, the key issues of GABL, the COGIN search algorithm, and the parallel-stochastic induction algorithm.

Chapter 4 (by *Nilsen and Sivertsen*) provides a comprehensive discussion of the synergy between knowledge management and KBS V&V. The chapter starts with the fundamentals and the activities of knowledge management. The majority of knowledge based systems are not explicit with respect to the boundary conditions, and it is very difficult to reconstruct the preconditions for the systems' appropriate functioning. The chapter shows how this can be done through the use of a subclass of role independent models denoted ontologies. The requirements for this type of models are investigated and a detailed example, showing how ontological similarity can assist in the V&V process of knowledge-based systems (proof construction, proof re-use), is given.

Chapter 5 (by *Sridhar and Murty*) is concerned with the problem of knowledge acquisition under uncertainty. After an introduction to the problem, the role of probabilistic, fuzzy and nonmonotonic reasoning in handling knowledge under uncertainty is studied. The emphasis is put on a nonmonotonic reasoning system in belief revision. A model for belief revision is proposed which is demonstrated on the treatment of knowledge about the Indian disease Jaundice. The necessity of using suitable combinations of the probabilistic, fuzzy and nonmonotonic paradigms for dealing with real-life applications is revealed and discussed.

Chapter 6 (by *Dragoni*) is devoted to the problem of belief revision under uncertainty in multi-agent environments. First, some principal symbolic and numeric approaches to the problem are briefly reviewed. Then, the chapter gives two main guidelines to perform "belief revision" in a multi-agent environment, namely: (1) replacing the "priority to the incoming information principle" with the "recoverability principle": an anytime received piece of information must belong to the current cognitive state whenever it is possible. (2) dealing not just with pieces of

information but with couples <source, information>, since the reliability of the source affects the credibility of the information and vice-versa. A method that integrates symbolic techniques to check for maximal consistency, and numerical approaches to evaluate the credibility of the beliefs are proposed. The "belief-function" formalism provides a simple and intuitive way to transfer the sources' reliability to the information's credibility, but, along with its computational complexity, it suffers from the fact that the way it attaches a credibility to a set of beliefs is not satisfactory. Some methods for overcoming this problem are discussed.

Chapter 7 (by *Cuena and Molina*) presents and discusses an environment for the design of structural knowledge models, called KSM (Knowledge Structure Manager), starting with an overview of the state-of - art of the field. The KSM modeling concept provides a novel perspective of knowledge structuring based on an understanding of the model as a structured collection of knowledge bodies. The basic element of KSM structuring is the so-called "knowledge unit". The KSM methodology is illustrated with real examples from the traffic control field. The chapter ends with a summary of the KSM operation issues.

Chapter 8 (by *Sohn and Sato*) deals with the computation problem of production systems. Production system is one of the important products out of artificial intelligence. Its practical usage for real world problems however has been limited by long execution time due to its sequential nature. The chapter presents the first implementation of production systems on a large scale distributed-memory multiprocessor. A two-step approach to parallelize and implement production systems on the multiprocessor is taken. The first step parallelizes production systems within a production cycle by exploiting data-parallelism. The second step parallelizes production systems across production cycles by using *speculative computation* to break the dependence between production cycles. A parallel production system was successfully implemented on the 80-processor EM-4 distributed- memory multiprocessor. Preliminary experimental results indicate that production systems can indeed be parallelized not only within an iteration but more importantly across iterations.

Chapter 9 (by *Chung*) is concerned with the conflict detection and resolution problem in nonlinear planning. Conventional linear planners are believed to be potentially inefficient due to goal misordering. Nonlinear planners have therefore been developed by many researchers in AI planning community. Among the nonlinear planners, a strategy which detects and resolves conflicts among actions in parallel branches has been a central issue. This chapter presents a new

conflict detection and resolution scheme for nonlinear planning in which conflicts occurring among actions in a plan network are detected in resource reasoning. Compared to conventional state-level conflict detection and resolution, this scheme provides more efficient conflict detection and global conflict resolution. The proposed scheme keeps track of the usage of individual resources during planning, and constructs a Resource Usage Flow (RUF) structure for each resource. Conflicts among actions in a parallel plan network are detected by extracting the corresponding RUF structures and checking whether they compete for the same shared resource, and resolved based on reasoning about RUF structure. The RUF structure allows the planner to perform minimal and nonredundant operations for conflict detection and resolution. Finally, the proposed scheme is compared with those of the other planners.

Chapter 10 (by *Koenig*) presents an analysis that deals with knowledge structures and the generation of sentences for communicating the knowledge contained in the structures. Two knowledge structures are derived. The first knowledge structure is in the form of a graph tuple and is derived from a general automation graph described by thirteen basic automation variables. The second knowledge structure performs as an auxiliary structure and broadens the knowledge base in that it contains descriptive and relationship knowledge related to the thirteen basic automation variables of the first structure. Procedures are then developed for generating sentences with added mingled words for improving communications. The procedures are demonstrated by generating sentences pertaining to robot commands. Through the use of random techniques in the procedures, sentences generated at different times from the same knowledge structure may yield sets of sentences that are different but convey the same knowledge. The analysis presented in the chapter is based on previous work in the formal analysis of general automata with applications to robotic systems

Chapter 11 (by *Wah, Ieumwananonthachai and Yu*) presents a new approach to generalize heuristic methods (HMs) learned by evolutionary programming. The objective of generalization is to find a subset of HMs that are better than the current baseline HM over the entire problem domain, and to select the best HM among the subset. Generalization is difficult when performance values of HMs are characterized by multiple statistical distributions across subsets of test cases of an application. In this case, the ordering of heuristics by their performance values may depend on the baseline chosen for normalization. An evolutionary programming based approach to performance evaluation, learning and generalization of multiple HMs is proposed, and a new measure called *probability*

of win that can be used to calculate the fitness values of heuristics in learning is designed. Experimental results on new HMs found for circuits routing and branch-bound search are given.

Chapter 12 (by Zeigler, Kim and Moon) addresses the challenges presented by simulation-based optimization of models having a large number of parameters and requiring large, variable, completion times. Hierarchical Distributed Genetic Algorithms (HDGA) are discussed which tackle high complexity by performing successive approximation searches. In such a multi-level approach, higher level GA processes work in wide, but abstract, search spaces, whereas a lower level GA searches narrow, high resolution, spaces which seem to hold promise of finding the global optimum. All operations of Hierarchical GAs are executed in an asynchronous and distributed manner. This supports a high degree of control of computing resources to most effectively advance the search process. The approach is illustrated through its application to some challenging simulation-based optimizations.

Chapter 13 (by Torasso and Portinale) discusses the role of different representations of knowledge in diagnostic problem solving, the way these representations are used during reasoning, and the need of learning from experience for improving the capabilities of a diagnostic system. Diagnosis is considered as a complex activity involving many other subtasks, such as emission of diagnostic hypotheses on the basis of initial observations, request of additional data for discrimination among diagnostic hypotheses, and explanation of the solutions to the diagnostic problem. The emphasis of the chapter is on an experimental system which is able to combine model-based reasoning and case-based reasoning for diagnostic problem solving. In this system the domain knowledge is represented via a causal model, and basic mechanisms have been defined for solving complex diagnostic problems involving multiple faults. However, the model-based component has been supplemented with a case memory, and complex adaptation mechanisms have been developed in order to have a diagnostic system able to exploit past experience in solving new cases. Some initial experiments for evaluating the convenience of solving a new case by adapting a retrieved solution, rather than solving the new problem from scratch, are discussed.

Chapter 14 (by S.G. Tzafestas and Dalianis) considers the problem of diagnosing multiple simultaneous faults in complex technological systems. After a brief overview of the available diagnostic methodologies, a diagnostic inference engine is presented which is designed by integrating different techniques. This

inference engine is appropriate for using shallow knowledge, but it is also able to deal with deep knowledge when available. The resulting expert system was applied with success to the case of diagnosing multiple faults in a complex mechanical system where nonadequate deep knowledge is available. This case cannot be handled by first-generation expert systems.

Chapter 15 (by Vargas) describes a knowledge-based system designed to provide quality assessment within a complex manufacturing environment. This system uses Bayesian models of causal relationships to perform probabilistic inference in order to build cases for a case-based reasoner. The system can provide both quality assurance and quality assessment, because entries in the casebase can be used to detect intermediate process conditions which are likely to cause product defects at later stages of the process. It has the following components : (1) a network of data collection computers gathering standard statistical process measurements for quality assurance, (2) a database that integrates the entire manufacturing facility, (3) a set of Bayesian network representations of the process, which contain cause-effect relations between variables at various stages of the process, and (4) a case-based reasoner, which stores, in a casebase, instances of cases relating interesting observed events with product defects or potential product defects.

Chapter 16 (by Billatos) is concerned with the application of the axiomatic design principle to the "Design for Assembly" (DFA) methodology, which is a methodology that should be considered in the early design stage in order to cope with increasing demands of lower costs, improved working environment, and higher wages. When Axiomatic Design (AD) is implemented with DFA in an intelligent way, a new area of design concepts would be realized. This study examines some elements of intelligent design systems to assess manufacturability of a product through the development of a knowledge-based expert system (KBES) for assembly. The knowledge base has been acquired from DFA along with AD concepts with emphasis on the conceptual design stage where the structure of the product as a whole is considered. These concepts have been implemented in a case study illustrating its applicability.

Chapter 17 (by Bolmsjo) reviews the complexity of the arc welding process and highlights problem areas for robotic arc welding to be solved in terms of observability and controllability. The three main phases in a welding operation are: (1) welding procedure specification, (2) welding process, and (3) post weld inspection. For these activities different solutions to develop knowledge-based systems are described in the chapter, and rather short but complete solutions on the

problems are given for each case, with emphasis on expert systems and neural networks technology. The conclusions drawn are that the arc welding process is a complex application for knowledge-based systems, but there are many driving forces to realize such systems within specific domains.

Chapter 18 (by Cuenca and Hernandez) presents knowledge oriented design principles for producing a knowledge structure sufficiently general to deal with real-time decision support systems. The approach considered is based on the concept of "Problem Solving Method" (PSM). A suitable structure of composite PSMs is proposed which is based on other subtasks performed by more elementary PSMs up to the level of the basic PSMs (called "mechanisms"). This PSM structure is then used to specify the corresponding KSM (Knowledge Structure Manager) model that relates the different PSMs with their associated domain perspectives as described in Chapter 7. The efficiency and reliability of this KSM framework for application development is comparable to the traditional approach via information structures and programs supported by well known programming languages.

Chapter 19 (by Villa and Nicolich) deals with production management in integrated manufacturing systems using the knowledge-based approach. It proposes a highly adaptive integrated shop-floor control framework which is based on the concepts of real-time negotiation and object-oriented programming, and is implemented by knowledge-based tools. Production management involves two problems, namely the family grouping problem and the dynamic scheduling problem. The chapter addresses both problems. The multi-agent shop-floor control scheme proposed is very flexible, robust and adaptive, since instead of machines processing jobs according to a plan established by a local controller, a population of knowledge-based controllers operate cooperatively to achieve both individual goals and the overall system goal.

Chapter 20 (by Costello, Jordan and Browne) considers the reactive scheduling problem, and describes the work carried out during the development of a knowledge-based decision support tool which incorporates the element of a planner's experience or informal knowledge. The foundation for the incorporation of informal knowledge into a decision support tool is the reuse of knowledge within an organization which has the potential to grow from within, continuously learning and reapplying solutions which have been proven to work in the past. If a repository of informal knowledge is developed, then the valuable experiences of the expert human scheduler are never lost to the system. Of course, a major difficulty for

utilizing such a knowledge-based reactive scheduling support tool is the acquisition of the knowledge required for its successful functioning.

Chapter 21 (by S. G. Tzafestas, Vavatsikos and Levendis) outlines the architectural and functional issues of a generic decision support expert system for the concurrent design problem. After an overview of the available results on the decision support systems used in the design domain, a set of high-level scenarios for the retrieval and presentation of manufacturing information according to the designer's requirements are specified, along with the relevant criteria and specifications for a system to support concurrent product design. The role of case-base of manufacturing cases, based on collected manufacturing experience tested in the existing shop-floor environment, is clarified for retrieval purposes related to several design questions and scenarios.

Finally, **Chapter 22** (by Kim and Nof) presents coordination and integrated models for distributed and heterogeneous CIM information. For concurrently coordinated CIM data activities, an advanced workflow model called *Data Activity Flow Net* (DAF-Net) is developed. For executing the coordination model and integrating heterogeneous information systems, a multi-agent based model called *Agent-Based Integration Model of Information Systems* (AIMIS) is proposed. To test the implementation logic of the two models, Parallel Virtual Machine (PVM) software is applied. In this research, PVM has been proven to be a highly effective tool for testing the implementation logic of DAF-Net and AIMIS.

The theoretical and practical results presented in the book provide a good representative picture of the current status of the knowledge-based systems and applications field. In addition to the surveys and how-to-do issues involved, many new techniques are described which are not available elsewhere.