Verification and validation of Knowledge-Based Systems – Report on two 1997 events

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1 Introduction

This report gives an overview of two recent events on the validation and verification of Knowledge-Based Systems, namely EUROVAV’97 and AAAI-97 workshop on this topic. In order to give an integrated view of current research issues in this field, we have organised this report along thematical lines, unifying the reports of the two separate meetings. Our report focuses on the trends that we think will be important in the near future in this field.

EUROVAV is the bi-annual European Symposium on Verification and Validation of Knowledge-Based Systems. This 1997 edition of EUROVAV was already the fourth time that the symposium was held. It was chaired by Jan Vanthienen (University of Leuven, Belgium), and Frank van Harmelen (Vrije Universiteit, Amsterdam), and was organised in the beautiful city of Leuven. With 25 submissions (of which 16 were accepted), and with 35 attendants, this EUROVAV’97 was roughly the same size as EUROVAV meetings in recent years. Detailed information on the program, the participants, and on-line abstracts of all the papers can be found at http://www.econ.kuleuven.ac.be/congres/eurovav/eurovav97.htm. Under this address there is also an order form for the proceedings of the meeting.

Annual meetings on the Verification and Validation of Knowledge Based Systems have been organised in North America since 1988. The 1997 event took place in Providence in the form of a AAAI-97 workshop. It was chaired by Grigoris Antoniou (Griffith University, Australia) and Robert Plant (University of Miami, USA), and attracted around 20 participants from academia and industry. Selected (expanded) papers of this meeting will be published in a special issue of the journal Knowledge-Based Systems.

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2 Discussion of selected topics

2.1 Rule-based systems

Rule-based systems are still the most widely used representation method for the development of knowledge-based systems. In addition they have been around for many years, so it comes at no surprise that they have been studied extensively in the V&V community. Particular focus of earlier work regards redundancy, consistency, circularity etc.

One basic approach in the study of rule-based systems is the representation of the knowledge using matrices, which are then analyzed and manipulated to detect several anomalies. However, this approach has suffered from drawbacks both regarding the storage space and processing power required. In their EUROVAV’97 paper entitled “Verification and Validation of Rulebases using a Binary Encoded Incidence Matrix Technique”, Coenen and Dunne address these problems by introducing a binary representation of incident matrices. Their approach leads to reduced storage use and supports more efficient processing of the matrices using logical operations on the bit-level. Their system has been implemented.

In their AAAI-97 V&V paper “Performance Assessment and Incremental Evaluation of Rule-Based Systems”, Chander, Shinghal and Radhakrishnan argue that as a knowledge-based system evolves, its evaluation should be incremental. That means, system evaluation should be integrated in the system life-cycle. The reason is that redoing V&V work from scratch for the updated knowledge-based system can be very costly. The paper is based on providing a link that connects the conceptual, design, and implementation levels of a system. Knowledge is acquired using goal specification to capture the problem solving states. Based on the specified goals, the structure of the system at the implementation level is defined by a set of rule sequences which infer goals.

2.2 Formal Methods

In Software Engineering, the use of formal specification languages for the purposes of verification has long been advocated. In Knowledge Engineering, formal methods have not played a very prominent role until now. Recent years have seen a gradual increase in the use of formal methods in Knowledge Engineering, and they are also finding their way towards validation and verification. Fensel and Schönegge’s EUROVAV’97 paper “Specifying and Verifying Knowledge-Based Systems with KIV” reports on their work on formally specifying a KBS using KIV, the Karlsruhe Interactive Verifier, which was originally constructed for specifying classical programs. Using KIV, the structure and contents of a knowledge-base are specified using predicate logic, while the inference strategy of the KBS is expressed in dynamic logic. This allows them to prove properties such as termination and correctness of the KBS with the assistance of the KIV theorem prover.

Quite similar in aim, but rather different in approach was the EUROVAV’97 paper by Cornelissen, Jonker and Treur: “Compositional Verification of Knowledge-based Systems: a case study in Diagnostic Reasoning”. This paper proposes to use structural properties of a knowledge-based systems as the main guidance during verification. In particular, the authors concentrate on the hierarchical decomposition of the system into subcomponents as the main structure for their proofs. Their approach is to split up the proof of a required property into a number of lemmas, each of which can be proved separately. The
contribution of the authors lies in the guidelines they give for organising the required set of lemmas, namely (i) by strictly following the hierarchical decomposition of the system; (ii) by only formulating lemmas in terms of subcomponents of one level deeper in the decomposition hierarchy; and (iii) by formulating lemmas which only concern a single component.

2.3 Abstract Knowledge Models

In the past decade, a gap has appeared between two areas within Knowledge Engineering, namely between Knowledge Acquisition and Knowledge Validation. The Knowledge Acquisition community has developed methods for modelling expertise in forms which are still close to the original knowledge as formulated by the expert, and which may therefore be still quite some way removed from an efficiently implementable form. The verification community on the other hand has mostly concentrated on efficient implementation forms such as production rules. Two EUROVA'97 papers aimed at closing this gap by trying to exploit the high level knowledge-acquisition models for the purposes of verification. Both the paper by Van Harmelen & Ten Teije and the paper by Marcos, Moisan & Pobil used KADS expertise models as the basis for verification. albeit for very different application areas. In their paper entitled “Validation and Verification of Diagnostic Systems” Van Harmelen & Ten Teije showed how a very general model of diagnostic reasoning could be used to prove properties of a KBS based on such a model. Marcos, Moisan & Pobil (“A Model-based Approach to the Verification of Program Supervision Systems”) showed similar results for a KBS that performed program supervision (ie. the automatic configuration and execution of existing pieces of software for a given task). Of course, such high level models can only be used as the basis of verification if they are sufficiently precise in both form and contents, so it is not surprising that both these papers were closely connected with the use of formal specification methods for KBS as mentioned above.

2.4 Modular Knowledge-Bases

When Knowledge-bases are large, it is not possible to verify all the knowledge simultaneously. In such cases, it is necessary to decompose them into smaller partitions in order to perform verification. Two EUROVA'97 papers proposed different approaches to this problem. Ramaswamy and Sarkar (“Global Verification of Knowledge Based Systems via Local Verification of Partitions”) used directed hypergraphs as a formalism to structure a KBS into partitions. Essentially, each hypernode correspond to a (set of) clauses used in conditions or conclusions of rules, and hyperlinks correspond sets of rules that comprise the inference path from on hypernode to another. This graph is then partitioned on the basis of a precedence ordering among the nodes (closely related to the dependency graph between the rules). Verification can then proceed by locally verifying individual partitions in the graph and subsequently propagating these local verification results through the dependency graph.

Whereas Ramaswamy and Sarkar used rules as their knowledge representation formalism, the paper by Vanthienen, Mues and Wets, entitled “Inter-tabular Verification in an Interactive Environment”, represents knowledge in tabular form, and separate tables form the modularisation mechanism in their case. However, one of the main drawback of those
systems is that anomalies which occur due to interaction of tables are neglected. Their paper investigates an approach to deal with these so-called inter-tabular anomalies. An interesting aspect of their work is that they make a very strong requirement that their techniques must be used on-line by a knowledge-engineer during KBS development. As a result, their approach uses heuristics in those cases where exhaustive checks would be too inefficient.

A second EUROVAV’97 paper dealing with modularity of tabular rule-bases was “Feature Construction for Verification and Validation of Tabular Knowledge-base Systems” by Piramuthu. His aim was to find techniques that would help in breaking up large tables into smaller and modular tables that are more easy to deal with. Machine-learning techniques for automatic feature construction were used for this purpose.

2.5 Machine Learning Techniques

Verification of a KBS must often be followed by an action to repair or improve the KBS. It has long been recognised that there is a close relation between such KB-repair actions and Machine Learning. In his excellent invited lecture at EUROVAV’97, Luc De Raedt showed how techniques from inductive logic programming (currently one of the most active and successful machine learning techniques) could be related to Validation and Verification of KBS.

A number of contributed papers at EUROVAV’97 also emphasised the connection with Machine Learning: In their paper “Inductive hypothesis validation and bias selection in unsupervised learning”, Talavera & Cortes proposed a framework for automatic validation of machine-induced KBS’s based on the capability of shifting the bias in the inductive learning system. Their experimental results could be seen as a contribution to both V&V and Machine Learning.

The paper entitled “The Selection of Training Cases for Automated Knowledge Refinement” by Palmer & Craw considered the role of training cases in KBS refinement. They showed how the choice of training cases has a crucial effect on the quality of the refined knowledge base, and argued that it is therefore unacceptable to select training cases at random. The described how training cases can be specially selected to validate specific refined knowledge bases, and they show how this leads to a higher quality of the knowledge base, while using a smaller number of training cases.

2.6 Multi-agent systems

Multi-agent systems are a quite recent development in artificial intelligence. They arose out of the realization that in order to solve certain kinds of problems it is useful to develop a system in which a number of knowledge-based systems cooperate and combine their problem-solving capabilities. Each KBS is constructed as a software agent which has autonomy and interacts with other agents to solve the given problem.

O’Leary gives in his AAAI-97 V&V paper “Verification of Multi Agent Knowledge-based Systems” an overview of correctness and verification issues for multi-agent systems. His work concentrated mainly on issues of inter-agent verification. In particular, it studies cases where verification is conducted on a meta rule base generated from the rules in each of the agent’s knowledge base. In these cases, existing knowledge base verification tools can be applied. Anomalies such as conflicts, circularity, subsumption, inconsistency and
completeness are studied in this context. Also, the paper identifies the problem of agent isolation.

While the previous paper takes a fairly abstract view, Preece and Lamb study in their AAAI-97 V&V paper “Verifying Multi-Agent Knowledge-Based Systems using COVERAGE” a specific agent approach, the ARCHON architecture. This architecture distinguishes between two layers: the ARCHON layer which is concerned with interaction and communication, and Intelligent System layer which contains the knowledge of a particular agent; this layer can be a knowledge-based system. Within this architecture, Preece and Lamb study multi-agent systems which are realized as rule-based systems. They consider three types of knowledge: (i) domain knowledge DK, which corresponds to the Intelligent System layer; (ii) cooperation knowledge CK, which corresponds to the ARCHON layer; and (iii) monitoring unit, which defines the links between the two layers. The paper studies anomalies that can occur in the interaction of these different kinds of knowledge. It describes the COVERAGE tool which detects these anomalies and which is an extension of the COVER tool which validates classical rule-based systems. The paper concentrates mainly on intra-agent anomalies (that means, CK-DK anomalies), but work on CK-CK anomalies is in progress.

2.7 Uncertainty

From the development of the earliest knowledge-based systems it has been recognized that for various problems, it is necessary to represent and reason with uncertainty of the knowledge used. Approaches to uncertainty reasoning include probability theory, certainty factors, Dempster-Shafer theory, fuzzy logic etc. At the AAAI-97 V&V workshop there were two papers dealing with correctness and verification issues related to Bayesian networks.

In their paper “BVAL: Probabilistic Knowledge-Base Validation”, Santos, Gleason and Banks discuss the validation of Bayesian Knowledge Bases (BKB), a generalization of classical Bayesian networks capable of incorporating more detailed probabilistic dependencies and incomplete knowledge of states and dependencies. Their approach requires human involvement in the validation process. The authors argue that in the face of incomplete information, a major feature of BKBs, it is unrealistic to expect that validation will be conducted fully automatically. Rather a human needs to interact with the system during validation to correct errors stemming from incomplete information by modifying the knowledge in the knowledge base. The aim of their tool BVAL is to minimize the interaction required.

In “MACK: A Tool for Acquiring Consistent Knowledge Under Uncertainty”, Santos, Banks and Banks describe a tool for knowledge acquisition and maintenance in the framework of Bayesian Knowledge Bases. The tool, MACK, guarantees the consistency of the information stored in a BKB, both as it is acquired and later maintained. The system performs incremental checks and reports to the experts inconsistencies (both logical and probabilistic validity ones). MACK has been applied to NASA’s Post-Test Diagnostic System which supports the Space Shuttle main engine analysis.
2.8 Web sites

While the World Wide Web is constantly gaining importance, the tools supporting the Web still lack satisfactory functionality. For example, information retrieval is still based on syntactic criteria using search engines, while semantic search would be desirable. Another common problem are links pointing to non-existing pages.

It is the latter problem that Rousset analyzes in her EUROVAV-97 paper “Verifying the World Wide Web: a Position Statement”. She argues that this problem is mainly caused by updates, and that it can be addressed by adding more structure into Web pages. While this is impractical for the entire WWW, Rousset argues that it can be done on the level of Web sites, collections of Web pages under a common administration. The paper discusses how modelling the semantics of a Web site can be used to define integrity constraints which prevent the introduction of anomalies when the content of Web pages is updated.

3 Conclusion

In conclusion, we can say that in our opinion, the field of Validation and Verification of Knowledge-based Systems is in a state of transition. The problems that have been traditionally studied are now well understood, with feasible algorithms and theoretical underpinning. Although uptake of these techniques by industry still leaves a lot to be desired, the academic community is now moving on to new problems.

In particular, the use of formal specification techniques, the use of more abstract knowledge models, and new application areas such as multi-agent systems and the World Wide Web were prominent new directions at both of the KBS-V&V events described in this note.

We expect these themes to play an important role in the 1998 meetings on Validation and Verification of KBS. The annual European meeting on KBS V&V will be held on 1 June 1998 in Trento (Italy), in conjunction with the International Knowledge Representation Conference (KR'98). Information on this meeting can be found at http://www.cs.vu.nl/~frankh/VVKR98.html. The annual American V&V meeting will be held in Madison, Wisconsin, in the form of a AAAI-98 workshop. This meeting will celebrate the first 10 years of V&V meetings. More information can be found at http://www.aaai.org/Workshops/1998/wsparticipation-98.html. The next EUROVAV symposium will be held in 1999 in Oslo, organised by Alun Preece (apreece@csd.abdn.ac.uk) and Anca Vermesan (snf_av@debet.nhh.no).