VALIDATION AND VERIFICATION OF KNOWLEDGE BASED SYSTEMS: REPORT ON EUROVAV99

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1 INTRODUCTION

Knowledge-Base (KB) technology is being applied to complex problem solving and safety and business critical tasks in many application domains. Concerns have naturally arisen as to the dependability of knowledge base systems (KBS). As with any software, attention to quality and safety must be paid throughout development of a KBS and rigorous verification and validation (V&V) techniques must be employed. Research in V&V of KBS has emerged as a distinct field only in the last decade and is intended to address issues associated with quality and safety aspects of KBS and to provide such applications with the same degree of dependability as conventional applications. In recent years, V&V of KBS has been the topic of annual workshops associated with the main AI conferences, such as AAAI, IJCAI and ECAI.

In this paper we report on EUROVAV99 the Fifth European Symposium on Verification and Validation of Knowledge Based Systems and Components (EUROVAV99 `http://www.dnv.no/research/safekbs/eurovav99/`) which was held in Oslo in the summer of 1999, and was sponsored by Det Norske Veritas and the British Computer Societys Specialist Group on Expert Systems (SGES). EUROVAV is the leading European conference dedicated to the advancement of the theory and practice of V&V of KBS. Its objective is to bring together researchers from both academia and industry, not only from Europe, but also from all over the world, encouraging all styles of V&V approaches and a variety of application areas. EUROVAV99 was the fifth in a biannual series, with previous meetings in Cambridge, UK (91), Palma de Mallorca, Spain (93), Chambery, France (95), Leuven, Belgium (97).

The symposium successfully integrated two contrasting streams. On one side, the theoretical stream presented the best of recent developments in V&V of KBS, and their components, including database systems; covering a wide range of technical areas. On the other side, the applications stream presented papers describing practical applications of KBS and the associated V&V approaches. The symposium was opened by Professor Pal Bergan, director of research for Det Norske Veritas (DNV).

For each stream there were keynote addresses by acknowledged international experts in their field. For the theoretical stream, Trevor Bench- Capon from University of Liverpool, addressed the role of ontologies in the Verification and Validation of KBS. His presentation provided an excellent start point for EUROVAV'99 since the use of ontologies proved to be a theme that re-occured throughout the symposium. For the application stream there were two keynote speakers: the first was Jeffrey Voas fron the USA who talked about user participation-based software certification; the second was an invited speaker from DNV, Per Martinsen, who talked about the certification activities of software/knowledge based components integrated within programmable systems. The presentations were all followed by lively and fruitful discussions.

The symposium dealt with all apsects KB V&V, but broadly the presentations could be classified as follows:

- Theory and Techniques
- Ontologies
- Safety critical KBS (the Safe-KBS project)
- Knowledge Revision and Refinement
- Applications
- Certification
- The wider picture

A brief synopsis of each of the papers presented under each of these headings is presented in the following sections.

2 THEORY AND TECHNIQUES

In this first section five contributions were presented. The first was intended to carry out a certain amount of *scene setting*, while the remaining four were concerned with more detailed issues. The scene setting paper was given by Mieczyslaw Owoc of the Wroclaw University of Economics (Owoc et al. 1999), and provided an overview/insight into one aspect of KBS validation, i.e. the knowledge element. The authors presented a slightly unorthodox view of KBS and V&V with one considered to be a sub-component of the other. Owoc's principal concern was that of validating knowledge (rather than the structure of KBS). In this regard the authors suggest a number of guiding principles, dividing them into the more global set apart from specific guidelines oriented on the particular form of a knowledge base.

Eric Grégoire of the Universite d'Artois was concerned with the validation of KBS concentrating on the possibility of the KB containing contradictory knowledge (Grégoire et al. 1999). Grégoire noted that the checking of logical consistency of rulebases expressed in a clausal propositional logic form is a NP complete problem (see Cook 1971, or Garey and Johnson 1979 for proofs). To tackle this problem Grégoire suggested that consistency checking should be performed incrementally during the development of a KB rather than on completion, and then proposed a mechanism to achieve this based on a depth-limited instantiation schema. Grégoire developed this technique within a nonmonotonic representation formalism and exhibited various forms of inconsistencies that are linked to the progressive nature of his instantiation schema. The technique is implemented by means of a powerful and non-standard use of local search techniques, allowing very large rulebases to be checked for consistency and inconsistency.

The contribution by Luis Laita from the Universidad Politecnica de Madrid (and his research team) dealt with the automated extraction of knowledge and verification of consistency in Rule-Based KBS (Laita et al. 1999). To achieve this objective they have defined an algebraic model that can be applied to many-valued logics which is incorporated into a software package written in the computer algebra language CoCoA. Luis Laita commenced by summarising the main idea of modelling propositional many valued logic with modal operators (interpreted over Lukasiewicz matrices) using polynomial residue class rings over an appropriate field (of integers modulo p, where p is the number of logical values). The crucial consequence of this construction is that tautological consequences and consistency can be expressed by the properties of ideals of the corresponding polynomial residue class rings. Given a KBS the system translates the rules and facts contained in the KBS, together with details of integrity constraints and any other additional information into polynomials. When dealing with these polynomials, to be a tautological consequence is equivalent to an ideal membership problem (that can be decided by checking whether a "Normal Form" is 0 or not) and the inconsistency of the KBS is equivalent to the degeneracy of an ideal (that can be decided by checking whether a certain "Groebner Basis" is 1 or not).

Silvie Spreeuwenberg and Rik Gerrits from LibRT Redeployment Technology (Netherlands) presented a tool (Spreeuwenberg and Gerrits 1999) to verify KB using meta-rules to be used within the object-oriented KBS development environment Aion8 from Platinum Technology. Besides OO, Aion8 supports Decision Tables, Rule Based Programming, Introspection, Code Generation and Component Based Development (CBD). (For further details on Aion see `http://www.platinum.com` and search for *Aion8* or *AionDS*). The V&V-tool is designed to be used both during and after the development of KBSs and focuses on the logical verification of such systems. The tool uses meta rules, meta information and the inference engine of Aion to accomplish this task. By using the same inference engine in the verification process as the inference engine used to evaluate and fire the rules to be verified, Spreeuwenberg and Gerrits suggest that there can be no discrepancy between the run time logic and the logic used in the validation process. This first version is developed in and for Aion, but the method and algorithms are applicable to any environment that supports rule based programming with an inference engine.

Much of the work described above is concerned with the standard rulebased representation of knowledge. Juliette Dibie-Barthlemy of University of Parix IX Dauphine, however, considered the semantic validation of conceptual graphs (Sowa 1984) used to represent knowledge based on constraints given by experts for validation purposes (Dibie-Barthlemy et al. 1999). Using this approach a KB is semantically valid if it satisfies all the given constraints (the authors use the term specification to describe expert knowledge given for validation purposes).

3 ONTOLOGIES

The ontologies concept, as applied to KBS, is a fairly recent innovation. Essentially an ontology, in the computer science sense of the word, is a set of definitions of (hierarchically ordered) classes, objects, attributes, relations, and/or constraints (axioms) whose main function is to provide a well defined vocabulary for the expression of domain knowledge. Thus an ontology is a knowledge-level description (Newell, 1982) in that it is independent of any representational formalism (Van Heijst, 1985). Also, an ontology is considered to be a meta- level description because it is a specification of a specification. It is often said that an ontology describes the domain knowledge that remains invariant over various knowledge bases in a certain domain (cf. Guarino and Giaretta 1995).

In general, we can say that ontologies may contribute to the following five KBS development areas.

1. Domain-theory development
2. Knowledge acquisition
3. Knowledge-system design
4. System documentation
5. Knowledge exchange

The role that the ontologies concept has to play in the evaluation of KBS was examined by the first of the invited speakers, Trevor Bench-Capon of the University of Liverpool (Bench-Capon and Jones 1999). The first half of the presentation was concerned with the motivation of ontologies — "an explicit specification of the conceptualisation of a domain". Bench-Capon emphasised that an ontology was not a model, "an ontology defines classes of concepts while models include instances of concepts" (Gruber, 1993). Bench-Capon then went on to state that ontologies describing KBS can be validated; and introduced a software tool, PRONTO, to support this approach to KBS evaluation. PRONTO operates by using the ontology to generate test cases which are then exectuted against the current knowledge base. If the test case fails, depending on the nature of the failure, and input from the expert, either the ontlogy or the knowledge base is refined.

The second talk in this category was given by Robert Engels of CognIT (Norway) whose presentation was "CORPORUM — An Automated Ontology Construction Tool". Robert Engels' talk focussed on the need to support knowledge companies who are in the business of capturing knowledge for Knowledge Management (KM). The talk included a demonstration of the CORPORUM tool which used the notion of an ontology to extract knowledge.

The final presentation in this category was by Henrik Giaever, of DNV, was entitled "Verification and Validation in Support of Knowledge Management". This was a very theoretical presentation concentrating on a philosophical discussion on the nature of knowledge, especially the differing views of information (consciousness). Perhaps the most interesting feature of the talk was Giaever's augmentation of the well known distinction between *knowing how* or *knowing that* by *knowing why*.

4 SAFETY-CRITICAL KBS (THE SAFE KBS PROJECT

The two presentations in this section described the work carried out as part of the Safe-KBS ESPRIT project, the aim of which is to define development and certification methodologies for KBS, especially embedded KBS used in safety critical domains. The particular result of this work has been the definition of a Safe-KBS life cycle, designed so that it can be integrated with formal methods and provide appropriate support for software certification methods.

The first presentation in this section (Dondossola 1999) was by Giovanna Dondossola from ENEL-SRI (Milan) and commenced by providing an overview of the results of the "Safe-KBS" project and the role of formal methods within that project. This was followed by a detailed discussion on the requirements for KBS formal methods within the context of both specification and V&V. Dondossola then continued to consider the impact of such methods on the KBS life cycle pointing out that life cycle models should be defined independently of specific development methods and techniques and then going on to consider the elements of such a life cycle based on that developed as part of the Safe-KBS project. Finally Dondossola gave consideration to the selection and evaluation of KBS methodologies, concluding that no optimum formal method exists appropriate to the full spectrum of KBS development requirements.

The contribution by Rune Steinberg of Computas (Norway) also described results founded on the Safe-KBS project, but concentrating on KBS design issues (Steinberg et al. 1999). Steinberg argued that, despite the fact that a well designed life cycle will contribute substantially to the confidence in a KBS, there is also a particular need to concentrate on design. Steinberg then went on to show how the Safe-KBS life cycle is supported by a catalogue of design patterns for safety critical KBS which describe design solutions that seek to increase the confidence of using KBS technology. The nature of these design patterns was therefore the main focus of this contribution.

5 KNOWLEDGE REVISION AND REFINEMENT

Having established that errors/anomalies exist in a KBS systems the practitioner will wish to revise/maintain the KBS in question. Given that it is possible automatically to detect errors in rulebases, the obvious next step is the automated refinement of such rulebases. Tools to achieve this end are usually labelled as knowledge refinement or knowledge revision tools. Such tools are typically used to assist knowledge engineers by automatically identifying the locations within a KB where the knowledge may need to be changed and (importantly) suggesting appropriate amendments (Craw 1998).

The first contribution in this section, by Robin Boswell of the Robert Gordon University, Aberdeen, described a suite of KB refinement tools under development as part of the KRUSTWorks project (Boswell and Craw 1999, Craw and Boswell 1999). These have been applied successfully to both artificial and real-world KBSs written in a variety of different languages. Central to this toolkit is a set of generic refinement operators and a hierarchical representation language for KBS rules. This knowledge hierarchy constitutes an ontology for KBS *rule-elements*; each KBS rule condition and conclusion is made up of one or more such elements. The ontology captures knowledge about the behaviour of rule-elements that is invariant over different shells and environments. Its purpose is to organise the refinement operators and apply them appropriately, in the same way that Fensel et al. (1997) use ontologies to organise problem solving methods and apply them to appropriate tasks.

The contribution by Nirmalie Wiratunga, also of the Robert Gordon University, looked at search techniques which enable KRUSTWorks to perform iterative knowledge refinement of faulty rule-bases. Incorporating backtracking into a best-first search solves the problem of getting caught in local maxima (Wiratunga and Craw 1999). Next, a re-ordering strategy can be used to make the best use of examples which when first encountered are correctly solved by the faulty rule-base, but may provide fault evidence for a subsequent modified rule-base. Finally, the search effort can be reduced by identifying pairs of examples providing fault evidence that result in conflicting repairs and re-ordering them next to each other so that such examples are processed in successive iterations.

The second contribution in this section, by Stephan Loiseau of the Universite de Angers, was a discussion of the distinction/overlap between KBS validation and KBS revision/refinement — i.e. maintenance (Dupin de Saint-Cyr and Loiseau 1999). This is a continuation of similar work studying the overlap between KBS verification and revision (see Bouali et al. 1997a and 1997b). In the presentation Loiseau defined refinement as a modification of an incoherent KB in order to restore its coherency. Revision in turn is the modification of an inconsistent KB to restore consistency. A coherent rulebase is one which if and only if with any valid input, contradictory results cannot be inferred.

Jan Vanthienen, of the Katholieke University of Leuven described a modularization approach to restructuring KBS founded on a decision table technique (Vanthienen and Moreno-Garcia 1999). Vanthienen is an internationally recognised expert of decision table techniques especially in the context of KBS. Modularization is an important concept with respect to verification, validation and maintenance, as it encapsulates knowledge into isolated modules which are easier to verify and maintain. By encapsulating knowledge and by avoiding redundant specification of knowledge, the risk of introducing incompleteness or inconsistencies during maintenance is minimized. The paper is illustrated with a specific KBS application (SEAR — Enterprise Human Resources Advisory System), the aim of which is to optimise human resource management in a social and juridical consultantship setting based on the Spanish Social Security General Regime Law. Vanthienen used his approach and the Prologa decision table tool to restructure the SEAR KBS into a decision table hierarchy while dealing with intratabular and intertabular verification.

6 APPLICATIONS

Much of the foregoing concentrates on the theory of KBS V&V. An important aspect of EUROVAV is also the practical application of V&V techniques.

To this end Francisco Ribeiro, of the Instituto Superior Tecnico in Lisbon, presented a discussion of V&V of a KBS system for supporting human experts in assessing applications for the house renovation grant system in Portugal (Ribeiro 1999). Ribeiro commenced by considering the development of the system (called HRGS) and then went on to consider the particular approach taken to verify and validate this system.

The contribution in this section by Jorge Santos, of the Polytechnic Institute of Porto, focussed on the V&V of intelligent applications software used by the electricity supply industry (Santos et al. 1999). In particular the presentation addressed the V&V of a KBS (called SPARSE) used to assist operators of Portuguese Transmission Control Centres in incident analysis and power restoration. Although this was the central theme, the contribution also provided a more general insight into the application of KBS V&V techniques.

Florence Sellini, of PSA Peugeot Citroen, presented a discussion of the verification of product modelling for design aid systems for mechanical sets based on the knowledge of expertise (Sellini and Yvars 1999). The talk described how knowledge used in a design system can be verified. A particular knowledge representation was described and additional constraints formulated which should conform to this knowledge. The presentation made a useful contribution as an example of what is/can be/must be done in a realistic KBS application.

The final contribution in this section (Schroeder 1999) was concerned with the formal verification of workflows and was by Michael Schroeder of City University London. Schroeder addressed the problem of formal verification of business processes. In the past few years, much research has been devoted to formal verification of business processes (van der Aalst 1998, Wodtke and Weikum 1997). As motivation, Wodtke and Weikum point out that the only validation techniques for workflows currently available are animation and simulation, and argue that symbolic verification is a mature field that provides a number of results and tools appropriate for workflow verification.

Guided by an example business process for a BT customer correspondance centre, in which work items are distributed, collected, possibly fixed, and then dispatched, Michael Schroeder showed how to translate a given process specification in the standardised PIF format into the calculus for concurrenct systems CCS. The main difficulty in the translation arises as PIF is underspecified and does not distinguish whether an activity has to wait for all preceding activities to finish or just for one. Schroeder's translation commits to the former intepretation based on pratical considerations for the application addressed.

Once the formal specification in CCS is given, one can use verification tools to check for a variety of interesting properties such as deadlocks, livelocks, liveness, and safety properties such as, for example, ensuring that jobs are sometimes fixed and always dispatched. Schroeder also addressed shortcomings of the tools, such as the inability to detect livelocks directly.

7 CERTIFICATION

The certification of software and the associated techniques is an area that is rapidly expanding. Much of the knowledge that has been developed over the past few years is now mature enough to be implemented in industry (Vermesam 1997). In this section, two papers were presented which dealt with software certification.

Jeffrey Voas (invited speaker), in the first paper (Voas 1999), noted that the most popular approaches to software certification are founded on publisher oaths and auditors (who carry out spot-checks to confirm such oaths) and suggests that this approach may be flawed — *Dirty water can run from clean pipes.* Voas went on to propose a certification methodology that does not employ auditors and publisher oaths, i.e. independent product certification. Voas is a recognized expert in the field of software assessment, having developed amongst other things the theory of inoculating programs against errors as a way to assess the safety of critical software systems.

The second talk, also invited, was presented by Per Martinsen, principal surveyor and head of the "Control Systems and Nautical Safety" department at DNV, who talked about "Software certification activities for programmable systems". The talk described the certification process in the wider context especially with respect to the practice of DNV.

The third paper in this section, presented by Anca Vermesan, DNV Norway, presented an approach to certifying software contained within systems where its functionality is considered critical within the environment in which it is placed (Vermessan et al. 1999). Two certification methods were described in detail, and the role of V&V in certification of KB components emphasised. Vermesan argued that as techniques for the evaluation of software systems develop in parallel with the systems themselves, certification bodies must constantly review the requirements that are required from software components in order to achieve safe and dependable systems. The approach presented here is also based on the findings of the Safe-KBS European project.

8 THE WIDER PICTURE

In this final section some wider aspects of KBS V&V were considered, in particular:

1. The possible application of KBS V&V to recent database models.
2. The contribution that integrity checking techniques current within the database community may have to play with respect to KBS V&V
3. The application of conventional software V&V techniques to KBS V&V.

Frans Coenen, of the University of Liverpool, considered possible future directions for rule base V&V on the presumption that many techniques developed by the rule base V&V community have come out of the research domain into what might be described as the main stream (Bench-Capon et al. 1998). In particular Coenen considered opportunities for possible cross-overs between database integrity checking techniques and a number of rule base V&V strands (Coenen et al. 1998). Collectively they refer to these techniques as VVI (Validation Verification and Integrity) techniques. The presentation commenced by giving an overview of integrity issues, then went on to consider overlaps between database and rule base systems and finished with a discussion of future directions in VVI.

Continuing in this theme the second paper in this section, presented by Antoni Ligęza of the Institute of Automatics of the AGH in Cracow, Poland, was concerned with the analysis and verification of data and knowledge (D&K) using a common model founded on an extension of the relational database model (Ligęza 1999). The model basically takes the tabular form based on attributes; appropriate logical interpretation allows for common model for both data and knowledge. Similarities and difference between data and knowledge item were discussed and it was claimed that within the model data can be considered to be the part of knowledge expressed with the finest granularity and unconditional.

The main focus of the paper was the meta-level analysis of D&K tables to identify and define problems associated with adequate data and knowledge representation. In the paper seven top-level problems were identified; the proposed taxonomy considered the following ones: adequacy of D&K representation, sufficiency, constraints satisfaction and consistency, correctness, equivalency and manipulation (an “algebra” of KBS), similarity and analogy, and classification (including inductive generalization). Logical definitions were proposed within a unifying logic-based perspective. Influence of selected issues on system reliability, safety and quality was analyzed and a uniform logical framework for discussion was put forward. An important final note was that although the problems above are specified with logical definitions, for the simplified, tabular D&K model they can be approached with algebraic methods, which seems to move them closer to engineering applications. Ligęza also went on to consider various technical problems encountered during implementation of verification procedures.

The third paper in this section was by Barry Eaglestone of the University of Shefield, described some of the V&V issues of concern in the database community in the context of schema integration of federated databases (Masood and Eaglestone 1999). Eaglestone also briefly overviewed a semi-automated methodology for the schema analysis phase of schema integration based upon the ontology-based conceptualisation of schema semantics. In this approach semantics of schema elements are made explicit by mapping them into an ontology, as an aid to verifying correctness of schema integrations and the validity of schema designs.

The final paper in this section was by Frode Hgberg, also of DNV Norway, who considered the application of conventional software V&V techniques to KBS V&V (Vermesan and Hgberg 1999). Hgberg presented an experimental framework, founded on the Safe-KBS project, to determine whether a technique is applicable or not, based on concepts found in mutation testing. The framework itself consisted of a number of steps guiding the researcher/practitioner in the assessment process. Mutation testing is used to simulate faults in an example program to determine the techniques ability to detect them. The paper concludes that the framework gives basis for qualitative assessment of the applicability and efficiency of applying specific traditional V&V and testing techniques to KBS components. To illustrate these ideas Vermesan and Hgberg seeded a sample KBS with faults through a mutation process, and then used a number of traditional V&V methods to find these faults.

9 CONCLUSIONS

The main themes of EUROVAV'99 the conference were:

- The role of ontologies in KBS V&V and their components.
- Certification of KBS.
- The V&V of KBS founded on the object-oriented paradigm.
- V&V of multiple KBS.
- The effect that KBS V&V "know how" might have on other disciplines.

As with previous meetings EUROVAV'99 provided a valuable opportunity to keep up to date with developments in V&V of KBS and to share experiences in the practical issues of developing and certifying knowledge based systems in particular, and software systems in general.

The proceedings are published by Kluwer Academic Publishing (Vermesan and Coenen 1999). Anyone wishing to obtain a copy should contact Anca Vermessan (`Anca.Vermesan@dnv.com`) at DNV, Oslo. Plans are currently underway for EUROVAV 2001.

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