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KNOWLEDGE-BASED SYSTEMS FOR MANAGING COMPLEXITY

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Knowledge-Based Systems for Managing Complexity

A Report from the Special Panel on KBS

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Background

For the 1993 DND Workshop on Advanced Technologies in Knowledge-Based Systems and Robotics, Ottawa, 14-17 November 1993, a special panel entitled **Knowledge-Based Systems for Managing Complexity** was conceived and chaired by the above author, with the following additional panel members-participants:

Mr. Stan Isbrandt - Emergency Preparedness Canada
MGen (Ret'd) George MacFarlane
Col Conrad Mialkowski, Assoc. DGRD Ops, CRAD
Dr. Zbigniew Mikolajuk, IDRC
Mr. Don Smith, DREV, and
Mr. Grant Thomas, RES Policy Research.

Messrs Isbrandt, MacFarlane, Mialkowski and Smith had already participated in two previous panels, on the "Applications of Expert Systems in DND, Present and Future" under the same chairman/moderator as in this case. Hence, for them it was very much a "follow-on" workshop with the testing of hypotheses already presented and the introduction of new findings and ideas based on the foregoing panel discussions. Dr. Mikolajuk and Mr. Thomas, both novices to this particular group, had prepared texts, submitted for publication, prior to having been selected for the KBS panel, hence their papers may be found elsewhere in this set of Proceedings.

Introduction

As has already been fully established within the context of this panel, the military uses of Knowledge-Based Systems (KBS) or Expert Systems are many and varied.[2] During the First Workshop on Applications of Expert Systems in DND, held at RMC, where the present panel was initiallly formed, many of the subsequent ideas were first introduced and discussed. Likewise, the initial conceptional modelling efforts were put forward within the context of that panel. We looked then, as now, at military as well as civilian uses of these systems and processes which make up KBS applications, since in the world of advanced technologies the civilian and military uses often blend. As anticipated then, developments and applications areas which may have been considered to be at the "outer edges" of the possible or even desirable, are now seen to have become imbedded in the general way of

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2 See, for example "Military Uses of Expert Systems: Some Future Perspectives" by Erik Solem, presented to the Symposium/Workshop on Applications of Expert Systems in DND, 2-3 March 1989, Royal Military College of Canada, Kingston, Ontario, published in its Proceedings.

doing things. Those with a particular interest in following the evolution of our concepts and ideas are encouraged to read the proceedings of these early ES Workshops/Symposia.

Findings and Results

Turning to the present panel, the aim of **Mr. Isbrandt's** particular contribution this time was to illustrate how an increasing level of complexity in computer applications can be handled with Knowledge Based Systems.

Coming from an Operational Research perspective, the particular focus was to discuss how Knowledge Based Systems can assist with the development and maintenance of a mathematical simulation. The discussion was based on lessons learned in the Directorate of Manpower Analysis (D Man A) in DND.

Several years ago, manpower modelling programs which were in use were relatively inflexible. The addition of one new feature to a model would often require changes throughout the application, requiring months to incorporate. New projects coming on line needed a much more flexible approach, in order to be able to incorporate needed changes within a reasonable time frame. This led to the development of a much more flexible model building utility, called GeM.

GeM has been successfully used as the basis for several different manpower models. It allows the building of complex mathematical simulation models from an object-oriented, menu-based interface. Model elements and dynamics are represented using objects such as nodes (which represent states) and links (which represent transformations of a resource from one state to another). Since standardized menus cannot foresee all eventualities, GeM allows the incorporation of a distinct Knowledge Based System in any link. This allows the model builder a high degree of freedom above and beyond the facilities provided by the GeM menus. A complex model may use a number of independent, compartmentalized Knowledge Based, or Expert Systems, in order to achieve a more accurate representation of real dynamic processes.

GeM has been successfully used to create several different models for manpower analysis. A typical model begins with a starting snapshot of an occupation, and projects 20 years or so, year by year, for an occupation of hundreds or thousands of individuals.

According to Isbrandt, the groundwork has been laid to continue on with functional models, where platform operations would be modelled in conjunction with occupational career progression and training. For instance, it would be feasible to create a model where operational cycles for naval platforms (duty periods, refit periods, etc) were modelled over a long period of time in conjunction with career progression, training, and sea-shore rotation for occupations which man the platforms. Such extra complexity is handled by incorporating individual sub-models in a larger GeM model, and then adding the interactions between sub-models using imbedded Knowledge Based Systems as necessary. Thus, more complex models are handled by aggregating sub-models, and modelling the interactions.

In practice, an analyst might run and rerun a functional model as described above, continually changing model parameters until model behaviour exhibits some desired feature, or until the best result (measured with some yardstick of optimality) is obtained. Instead of an analyst choosing how to alter parameter values in this quest for an answer, it makes sense to use a computer, with a machine learning module, to change values and rerun the model. In D Man A a simple process of this type using a Genetic Algorithm has been tested as a proof of concept prototype.

Basically, this illustrates one process whereby Knowledge Based Systems can be used to handle increasing levels of complexity. GeM, as a model building utility, incorporating KBSs, has been used to create increasingly complex models which incorporate complexity which was impractical to consider previously. Isbrandt argued that the limits of GeM's ability to handle complexity have not yet been reached, so it can be used to create aggregate models of still more complexity. By incorporating GeM models within a machine learning loop, the computer may also be able to relieve the analyst of the complexity inherent in an iterative process of finding better or optimal model parameters.

In a generic sense, according to Isbrandt, the same approach can be used in other complex application areas. Sub-systems can be modelled independently, using their own Knowledge Based Systems or Artificial Intelligence features as appropriate. By providing a framework which is designed to accept and integrate generic modules, larger systems can be created. These aggregations may occur over several levels, and the interactions among modules may need to incorporate their own KBSs or other AI features. However, by designing the framework from the beginning to be amenable to a "mix and match" mode of combining and aggregating sub-systems, great flexibility can be attained in the handling of increasing levels of complexity.

MGen (Ret'd) George MacFarlane, a graduate of UBC (1954) and of the University of Michigan (1962), a former RCAF officer having retired as MGen, and subsequently Associate ADM(Mat), was most recently Executive Director of the Institute for Space and Terrestrial Sciences (ISTS). MacFarlane spoke on "Enabling Technologies".

The issues in the Information Age (which may be defined as instant communications, accelerated pace of invention and discovery, and rapid diffusion of knowledge) is that with a technological explosion there is simultaneously a population explosion (1990 - 5.4 Billion, 2030 - 10 Billion), with subsequent pollution and toxic waste. Global change itself presents problems of climatic change and more frequent, more severe storms; rising mean sea level; and implications for agriculture, forestry, fisheries, water supply and for society itself.

Discoveries and inventions build upon previous ones. However, in the pre-information age knowledge dissemination was slow, the discovery and invention rate sporadic and low and there was ample time for society to adjust itself. Not so with the coming of the information age. From now on, dissemination and diffusion will be **rapid**, discovery and invention rate **high** and **accelerating**, while the adjustment time only a few years to months.

MacFarlane then traced the development of the AI/Robotics/KBS discipline and gave examples of representative systems. These were Medical Diagnostics, e.g. MYCIN, EMYCIN. Decision Support and C^3I, self-paced Individual Student tutoring, On-condition Monitoring and Maintenance Advice, and others.

From this he moved to implications of Post-2000 demographics and technological advances. With fewer entrants to the (military) labor force there would be greater competition; the need for greater retention with subsequent greater job satisfaction required, and perhaps even a reduction in requirements.

The flood of new technologies, with new capabilities and faster diffusion worldwide should be seen in juxtaposition with increased likelihood of global unrest. However, our defence now really means few weapons systems, few war reserves and a weak defence industrial basis.

Key steps to at least partially counter these developments should be to select promising applications (which should be manpower intensive and reaction time critical). Secondly, we must try to convert theory to practice. This would, and should, be done by acquiring competence with regard to design, manufacturing, operations, maintenance and management. It would also mean acquiring understanding of the potential of new technologies. MacFarlane saw several promising military applications of technology, which he outlined.

The thrice-serving member of the panel, **Colonel Conrad Mialkowski** offered a presentation which he had entitled "Managing Complexity - A Soldier's Glimpse". Mialkowski, who had joined the Army in 1957 with two terms in Germany and three terms in NDHQ has been the Project Director of TCCCS and is presently Associate DGRD Ops of CRAD.

In a very useful overview, he surveyed the environmental impacts since the last conference. These were: continued world unrest, the increasing role of peacekeeping with what that entails; changing threats and (new) Canadian concerns, e.g. employment, debt and regionalization. This is all taking place within a situation of continued economic pressure, with fewer defence resources (people and money) and a decreasing national will for defence.

The defence shifts are equally noticeable; with the closure of Canadian Forces Europe as of June 94; UN peacekeeping at an all time high; national sovereignty as a major forces mission and the question of world order peacemaking participation. With new roles for the CF, the military requirement remains **the ability to fight**. Since in the present decade increases are "out", cuts are "in", Mialkowski saw a clear need for affordable technology (also dual technology), fast change (faster, smarter, cheaper) (US battle labs); innovation, and a broad, technical research base (even if modest in size). Speaking generically about technology developments, Mialkowski saw the following as being of the essence:

- rapid change
- information technology
- communication technology impacts
- surveillance technologies
- trends to larger complex systems (e.g. smart weapons)
- micro technologies
- Knowledge Based Systems
- Robotics
- biotechnology growth
- industrial production capability/ markets.

As a result of the above considerations, Knowledge-Based Systems would have to be modest, simple, practical, domain specific, useful and cheap. New system means new problems and greater complexity.

DND has no choice but to invest in Knowledge-Based Systems to deal with upward spiralling complexity in emerging technology.

Donald L. Smith, who is the Director, Command and Control Division of the Defence Research Establishment Valcartier, and an active, previous participant on this KBS panel, spoke on "Challenges and Opportunities Managing Complexity with AI Technology in Command and Control Systems". In a very comprehensive presentation he dealt with the complexity in data/information fusion and in the planning/evaluation process. He discussed in some detail the challenges and opportunities implicit in the **co-ordination** of: human factors, computer science, and operational research activities as well as the **implementation** in: verification and validation, doctrinal and organizational changes, and life cycle management.

It is perhaps worth looking a little closer at this particular argument.

Command and control is the exercise of authority and direction by a designated commander over assigned forces in the accomplishment of his and/or the forces' mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities and procedures, which are employed by a commander in planning, directing coordinating and controlling forces and operations in the accomplishment of the mission.[3] Command and control can be viewed as a three-stage process:[4]

a. Picture compilation - accumulation and fusion of information to provide a tactical picture;

b. Situation assessment - assessment of the situation presented by the tactical picture in relation to the mission, and

c. Response - determination of options and selection of direct action as a result of the assessment.

The complexity of command and control systems arises from factors such as:

a. their distributed nature. Command and control systems tend to be distributed in both geographical and hierarchical terms.

b. temporal constraints. Typically, command and control systems must function within hard, real-time limits.

c. uncertainty and ambiguity. The information feeding the command and control system is more or less accurate, timely, and complete.

d. multi-agent architectures. Command and control systems consist of interacting combinations of human and machine agents.

The above factors combine to make the development, implementation and life cycle management of automated command and control systems ideally suited to the application of Artificial Intelligence.

Several papers presented at this workshop addressed specific aspects of these factors and there is reason to believe that, as AI technology advances, many of the individual problems will be solved. However, the ultimate challenge remains the integration of human and machine agents into effective, intelligent command and control systems. Achieving such integration will be the subject of research for many years to come.

Conclusions

In the discussion which followed all, or most, of the points raised were dealt with, and the complementanty of the presentations was recognized. As with the previous KBS panels at earlier workshops/symposia in this field, the present special KBS panel had been specifically requested; and the evolution of the ideas and findings followed its predecessors. These points were also stressed.

By now, Knowledge-Based Systems (KBS) are probably the best known, possibly also the most frequently emphasized area of research and application within the general field of Artificial Intelligence (AI).

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3 ABCA Definition.

4 Moon, J.R., Marriette, J.P. and Frampton, S.P. "Uncertainty in Command and Control Systems", Application of Artificial Intelligence to Command and Control Systems, IEE Computing Series 13, Peter Peregrinus Ltd, London, UK, 37-54.

Some years ago, Margaret Boden in a highly acclaimed work on AI postulated that, although the ability to solve complex problems in a wide variety of fields exist within AI, and in particular within ES, it was only relatively recently that the hardware costs had dropped to the point that such systems would be economically feasible.[5] This conference, and in particular the KBS panel, showed that time has in fact been compressed, and speeded up. By now these components are really becoming **embedded** in larger systems, much in the same way as electricity has become an obvious and regularized commodity of expanded usage. Nobody questions its general "validity" any more, and so it is - or should be - with Knowledge-Based Systems.

[5] Margaret Boden, Artificial Intelligence and Natural Man, Basic Books, N.Y. 1977.