

# Advances in Interfacing Production Systems with the Real World

*Franz Barachini, Toru Ishida, and Milind Tambe*

■ *The workshop "Advances in Interfacing Production Systems with the Real World" was designed to bring together researchers from around the world to focus on the problem of integrating production systems into industrial environments. It was held on 25 August 1991 in Sydney, Australia, in conjunction with the Twelfth International Joint Conference on Artificial Intelligence (IJCAI-91). Nine papers were accepted for the proceedings, and six of them were discussed at the workshop.*

The workshop "Advances in Interfacing Production Systems with the Real World" was designed to bring together researchers from around the world to focus on the problem of integrating production systems into industrial environments. It was held on 25

---

*...C is increasingly being used in many areas where production systems are applied.*

---

August 1991 in Sydney, Australia, in conjunction with the Twelfth International Joint Conference on Artificial Intelligence (IJCAI-91). Nine papers were accepted for the proceedings, and six of them were discussed at the workshop.

Real-time knowledge-based systems play a vital role in today's industry. The application areas of such systems include aerospace, robotics, telecommunications, transportation, and manufacturing. In these areas, production systems are increasingly being used as parts of process control systems. However, the production system paradigm was not originally designed with integration concerns in mind. In the past, production systems were mainly stand-alone systems,

which led to difficulties in integrating them with conventional computer systems.

In recent years, interest has intensified in increasing the power and utility of knowledge-based systems by integrating them with conventional software components. Unfortunately, although Lisp is still the language of choice in the AI community for building knowledge-based systems, C is increasingly being used in many areas where production systems are applied. Two papers at the workshop discussed the possibility of transferring a knowledge base from Lisp to C to ensure better run-time efficiency and ease of integration. The argument here is that one could use the expressive power of Lisp during prototyping and the efficiency of C during run time. Both papers showed that there was a performance gain of a factor of three on the average.

Antoine Mensch from Thompson-CSF, France, presented XIA, the Thomson-CSF environment for prototyping and producing expert modules and integrating them into conventional software components. He proposed a tool kit composed of a Lisp-based development environment and a C-based generator of run-time, procedural expert modules. Both the prototyping environment and the run-time modules can be coupled tightly to existing conventional applications written in C. The tool kit provides assistance for moving smoothly from the prototyping to the production environment, minimizing the amount of code that needs to be translated from Lisp to C.

The experiments show that the C-translated knowledge bases run three to four times faster than those in the Lisp prototype. Because the generated C expert module provides explicit memory management, the garbage collector, which can unpredictably interrupt the reasoning process, is

eliminated. Additionally, the total memory consumption is lowered. The executable file generated for the famous monkey and bananas problem has a size of 50 kilobytes, which is less than the size of any minimal Lisp executable file.

Takahiko Murayama from NTT Network Information Systems Laboratories Japan presented his experiences on translating Lisp-based production systems into C programs. He developed a translator from Lisp KBMS (knowledge-based management system), which is currently used at NTT to implement various telecommunication expert systems, to C. Based on the specific characteristics of the rules, working memory, and other data, the translator selects the most effective data types and sizes to decrease the frequency of garbage collection. The evaluation was done by applying the translator to various benchmarks, including a prototype expert system called ALICE (advanced power plants integrated maintenance control system), an advanced power plant integrated maintenance control system.

The result shows a threefold speedup in processing time. Furthermore, the system area for the standard kernel of Lisp and production systems, the expert system building environment, and system functions is reduced to just one-tenth of the original system. Finally, the frequency of garbage collection is also greatly reduced. He concluded that the overall effects of rewriting in C would make it easier to integrate expert systems into existing telecommunication applications.

An alternative development environment for knowledge-based systems, especially those with severe time constraints, is based on extending C with rule-based and object-oriented features. Tools on the market allow a tight coupling of these paradigms and then compiling the code into C. However, to the best of our knowledge, currently only two commercial tools offer a direct extension to C: PAMELA-C from ALCATEL-ELIN, Vienna, and RAL (rule-extended algorithmic language) from Charles L. Forgy of Production System Technologies, Pittsburgh, Pennsylvania. The latter was discussed in an abstract paper submitted to the workshop.

Forgy argues that in the real world, rule-based systems do not stand alone. They have to access system facilities, such as database interfaces and graphic user interfaces. Furthermore, pro-

grams are seldom best implemented in a purely rule-based style. A program might contain one or more important rule-based modules, but it will also contain conventional procedural modules for many tasks. Because C is a dominant system programming language, FORG invented RAL. RAL modules are able to use the same declarations as C modules (a strategy used in the PAMELA-C system as well); thus, functions and rules are able to operate on the same data, avoiding any consistency and update problems.

RAL extends C by a new scalar type, the NIL symbol, a new declaration for working memory elements and several new statements to handle working memory updates. All the extensions are completely integrated with standard C and, thus, are upwardly compatible. Additionally, RAL supports a new control strategy called generalized forward chaining (GFC). GFC adds the essential features of backward chaining to a forward-chaining architecture, but it is more powerful than either of the classic control architectures.

Francois Terrier from CEA-DEIN, France, discussed the difficult problem of managing temporal facts according to the needs of an intelligent reasoner. Managing continuous data acquisition on an industrial installation reveals the problem of keeping information for a certain period and then removing it when it is not needed by the reasoner. For example, consider the rule "If a superpressure appears 5 hours after a fuel injection and if the temperature is too high 1 hour before a fuel injection, then ...." In this case, it is of no interest to the rule-based system to memorize fuel injection facts during a minimum period of five hours if "temperature is too high" does not appear at all. Therefore, an intelligent forgetting mechanism is proposed that is based on a temporal graph built from facts and rules.

This temporal graph represents the relative ordering of facts. It differs from Allen's networks or equivalent networks for time points because (1) it considers only numerically dated facts and (2) it defines only the sequence of facts, without taking other temporal relationships between facts into account. At run time, the expert system must update the graph with a propagating algorithm to find the facts that can be discarded. Terrier mentions that the proposed approach suffers from limitations in

knowledge representation that might not easily be overcome.

G. R. Prakash, Jaidev, N. Parameswaran, and H. N. Mahabala from the Indian Institute of Technology (Madras) presented OPS91, an architecture that enhances OPS5 with a reasoning maintenance system (RMS). In recent conference talks, different methods for coupling automatic truth maintenance systems (ATMSs) with production systems have been presented. These methods can roughly be classified into two categories: methods that adopt a loose coupling and those that adopt a tight coupling. The designers of OPS91 chose a compromise between these two strategies. RMS enhances the recognize-act cycle by introducing a dependency network (as a separate data structure) and a partitioned production memory. In the implementation, the dependency network is actually directly linked to alpha and beta memories of the RETE network. The reason for not choosing ATMS was to avoid maintaining multiple-world copies. Thus, there is hope that this approach is somewhat less run time intensive; however, run-time measurements were not presented.

David Goldstein from the University of Texas at Arlington discussed issues related to integrating knowledge bases into heterogeneous computer networks. Directed blackboard architectures play a major role in this area. They allow a combination of multiple knowledge sources in a hierarchical way by improving the control mechanisms, reducing the event scheduling required, and minimizing the amount of information that must be distributed through the blackboard. Goldstein discussed issues in parallelizing knowledge sources and described PRAIS (parallel real-time artificial intelligence system). PRAIS provides a mechanism for coarse-grained parallel processing over a heterogeneous network of machines. The system incorporates a modified version of the National Aeronautics and Space Administration's CLIPS (C language integrated production system) by supporting primitives for distributed processing.

Sophie Minault-Jousset from ALCATEL France presented a general distributed architecture for interfacing a production system with a real-time data-acquisition system. This architecture consists of two processors: one for real-time data management and the other for production system

reasoning. The architecture provides two-speed processing: The first processor operates quickly at the rate of data acquisition and reduces the amount of data input to the second processor. The second processor operates on its own as a background task, providing asynchronous feedback to the first processor.

This architecture was implemented in C and SPOKE ENGINE, an inferential system based on the object-oriented language SPOKE. The architecture is currently applied to an industrial real-time expert system for predictive maintenance of a gas turbine compressor.

Real time and distributed processing are two important issues in the production system area, and they are expected to assume increased importance in the future. Franz Barachini (ALCATEL) pointed out that run-time predictability for production systems should be improved, so that utility functions (in the decision-theoretic sense) can use more accurate values in high-level reasoning tasks. At the end of the workshop, Toru Ishida (NTT) presented his research activities on distributed production systems, where multiple production system agents cooperatively solve a single problem. Various new problems, such as transaction models for shared working memories and organizational issues of multiple production systems, were briefly introduced.

**Franz Barachini** received his M.S. in 1980 and his Ph.D. in 1983, both from the Technical University of Vienna. He spent six months at Stanford University as an invited researcher in his major area of interest, real-time knowledge-based systems. He is a member of the American Association for Artificial Intelligence and is currently head of the Knowledge-Based Systems Department at the ALCATEL-ELIN Research Laboratory in Vienna.

**Toru Ishida** received his B.S., M.S., and Ph.D. in engineering from Kyoto University, Kyoto, Japan, in 1976, 1978, and 1989, respectively. He is currently with NTT Communication Science Laboratories, Kyoto, Japan. From 1983 to 1984, he was a visiting research scientist at the Department of Computer Science, Columbia University. Since then, he has been working in the area of production systems and their applications. His current interests include parallel and distributed AI. He is a member of the Japanese Society for Artificial Intelligence and the American Association for Artificial Intelligence.

*Continued on page 30*

integrating AI and software engineering, a main goal of the KBSE community. After describing a success story from the Gulf War (the use of the dynamic analytic replanning tool [DART]), Boehm concluded with a description of the KBSE challenges. These challenges include knowledge capture (acquisition) for adding real value to intelligent systems, knowledge updating, knowledge representation choice guidelines to help spread the technology, and knowledge base-project database interoperability. The biggest challenge of all, according to Boehm, is the scalability challenge: making sure our techniques and technology can truly scale up to large, real-world problems.

During the rest of the conference, 25 papers were presented in nine sessions: General Design Issues, Requirements, Automatic Programming, Reuse, KBSA, Debugging, Reverse Engineering, Learning, and Process Support. These papers were selected from 56 that were submitted to the conference and reflected the state of the field as follows: First, there is a lot of activity in the support of requirement and specification activity. Second, domain modeling and domain knowledge are increasingly viewed as important (this fact was revealed in a panel presentation as well). Third, although the lack of maturity of the field is reflected in the "toyiness" of many of the problems, there are now some significant success stories. Rather than report on some or all of these presentations in detail, the reader is invited to examine the proceedings (Proceedings 1992).

Panels and demonstrations were also part of the conference. The three panels were "Domain Modeling," moderated by Neil Iscoe of EDS, Incorporated; "Encouraging Adaptation of KBSA and KBSE Technology," moderated by Bill Sasso of Andersen Consulting; and "Knowledge-Based Design," moderated by Michael Lowry of the Kestrel Institute. The panels were a combination of presentations by the panel members and questions from the audience. Demonstrations included both academic prototypes and commercially available systems.

The final day of the conference featured a plenary address by Thomas Cheatham of Software Options and Harvard University. Cheatham, one of the authors of the original KBSA report, described computing in the 1990s as being characterized by networks of workstations, with an occa-

sional supercomputer; multiple simultaneous users; life-cycle support; and, finally, activity coordination or process support. He then described an artifact-based software engineering environment being developed at Software Options called the E-L (environment language) system. The E-L system is based on the management of small typed artifacts, which, along with a coarse structure of relations of reference, predecessor, and successor, can describe both a software system and the process and environment used to generate it. The E-L system coordinates activity by multiple users over a large, interrelated base of artifacts and projects to provide activity distribution, communication, persistence, modularity, viewing, and extensibility.

KBSE-91 ended with an open discussion of the conference and the goals and status of the KBSE community. A number of suggestions were raised, from generating better publicity and getting wider European participation to having more formal tutorials and thinking hard about the education issues in generating and using KBSE technology. The primary technical concern was the maturing of KBSE work into more realistic domains so that knowledge-based techniques and technology could be evaluated properly.

Planning, organization, and implementation of future KBSE conferences will be facilitated by the formation of a permanent KBSE steering committee. Lewis Johnson of USC Information Sciences Institute is both next year's conference chair and program chair. Donald Yu of UNISYS will serve as local arrangement chair. The conference will be held in the Washington, D.C., area in mid- to late September 1992. For more information about this conference, send electronic mail to kbse7-request@cs.rpi.edu.

*IEEE Expert* started a special track on KBSE. This special track should appear early in 1992 with a number of the best papers from KBSE-91; subsequently, the track will be open to general submissions. For more information, contact Peter G. Selfridge, AT&T Bell Laboratories, Murray Hill NJ 07974, pgs@research.att.com.

## References

Green, C.; Luckham, D.; Balzer, R.; Cheatham, T.; and Rich, C. 1986. Report on a Knowledge-Based Software Assistant.

In *Readings on Artificial Intelligence and Software Engineering*, eds. C. Rich and R. Waters, 377-428. San Mateo, Calif.: Morgan Kaufmann.

Proceedings of the Sixth Knowledge-Based Software Engineering Conference (KBSE-91). 1992. Washington, D.C.: IEEE Computer Society.

**Peter G. Selfridge** received his Ph.D. in computer science from the University of Rochester in 1982. Since then, he has been at AT&T Bell Laboratories and is currently in the AI Principles Research Department. Selfridge's main interest is in the application of knowledge representation technology to problems in large-scale software development, maintenance, and understanding.

---

## Advances in Interfacing...

*Continued from page 26*

**Milind Tambe** received his M.S. in computer science from the Birla Institute of Technology and Science, Pilani, India, in 1986 and his Ph.D. in computer science from Carnegie Mellon University (CMU) in May 1991. He is currently a research associate at CMU's School of Computer Science. His interests are in the areas of integrated AI architectures and efficiency and parallelism of AI programs. He is a member of the American Association for Artificial Intelligence.

---

## Processing Declarative Knowledge

*Continued from page 27*

restaurant where the conference banquet took place.

Proceeding preprints were available at the workshop, and book proceedings will be published as part of Springer-Verlag's Lecture Notes on Artificial Intelligence (Boley, H., and Richter, M. M., eds. 1992. *Processing Declarative Knowledge International Workshop (PDK '91)*. Berlin: Springer-Verlag. Forthcoming.

---

**Cristina Ribeiro** has a B.S. in electrical engineering from Porto University and an M.S. in electrical engineering from IST, Lisbon Technical University. She is currently working on a Ph.D. in AI at Lisbon New University. Her current research interests are temporal reasoning, logic programming, and constraint solving.