Artificial Intelligence in Engineering: Personal Reflections[1]

The Beginnings of AI: 1950-1980

The field of artificial intelligence (AI), as we understand it now, got its impetus during a two-month workshop organized by John McCarthy (Stanford University), one of the founding fathers of AI, in Dartmouth in the summer of 1956. The term Artificial Intelligence was coined at this workshop. Massachusetts Institute of Technology (MIT), IBM, Princeton, Carnegie Mellon University (CMU) were well represented. Allen Newell and Herbert Simon from CMU showed a prototype of a program that emulated certain aspects of logical decision making. This generated considerable interest and hope for the future.

During the 1960s and 1970s much of the foundations for knowledge representation and problem solving were laid at CMU, Stanford, MIT, and IBM, to name a few. These efforts--except for possibly IBM's--were funded by the Defense Advanced Research Agency (DARPA). Herbert Simon's "Sciences of the Artificial" (MIT Press), Christopher Alexander's "Notes on the Synthesis of Form" (Harvard University Press), and Marvin Manheim's "Hierarchical Structure: A Model of Design and Planning Processes" (MIT Press) published during this period set the stage for future work on AI in design in the 1980s and 1990s.

Two notable applications of AI made their debut in the mid 1970s, which fueled the development of knowledge-based expert systems (KBES): MYCIN for internal medicine and PROSPECTOR for geological prospecting. These systems concentrated on classification-type problems, and led to the development of domain-independent tools for building diagnostic KBES. With the exception of Thanet Norabhoompipat, who, under the guidance of Prof. Steven Fenves, published a doctoral dissertation that discussed several AI problem-solving techniques needed for engineering problem solving, there was very little activity on the applications of AI to engineering problems.

Rise of AI in Engineering: The 1980s

The 1980s saw an emergence of AI applications in engineering, with the field primarily dominated by CMU, Stanford, and MIT in the United States. I was lucky to have been at CMU at this time, where I was exposed to lectures by the stalwarts in the field. I attribute my entry into this field to Prof. Raj Reddy, who was a pioneer in speech recognition and director of CMU's Robotics Institute, and Prof. Steven J. Fenves, a pioneer in the application of computing to civil engineering and a National Academy of Engineering member.

---

[1] Disclaimer: Commercial equipment and software, many of which are either registered or trademarked, are identified to illustrate certain concepts. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

My first exposure to KBES building started in the summer of 1981, when CMU was tasked with the development of a KBES to aid in trouble shooting of the Atlanta People Mover, an automated train at the Hartsfield International Airport, Atlanta, USA. The members of our team included Mary Lou Maher, Steven J. Fenves, Daniel Rehak, Jacobo Bielak, and myself. Mary Lou and I were graduate students at that time. After surveying various tools, we selected KAS as the KBES building tool, which was a domain independent version of PROSPECTOR. We divided the whole system into a hierarchy of modules, learned a lot about the functioning of the system, and then ventured into the knowledge-acquisition process with Westinghouse engineers who had designed the People Mover. We restricted ourselves to a small problem subset, principally the doors and the public announcement system. We did not publish our strategy of hierarchical diagnosis due to contractual requirements. Little did we realize that we had actually discovered a new way of doing diagnostic expert systems for complex electro-mechanical devices.

Most of the KBES in the early 1980s targeted the classification-type problems (or derivation problems as Saul Amarel from Rutgers put it). With the exception of R1, there were no commercial systems for formation-type problems or design. R1 configured computers for Digital Equipment Corporation (DEC) — a leading manufacturer of minicomputers at that time. R1 was built by John McDermott and colleagues at CMU in OPS5, a rule-based programming language designed and implemented by Charles Forgy. R1 (later called XCON) required considerable support, but the cost was justified as it saved DEC millions of dollars each year.

The mid-1980s saw the emergence of AI applications in engineering design. In the United States, CMU's Engineering Design Research Center pioneered applications in every engineering domain. The graduate students and other junior members at CMU's EDRC went on to assume various leadership roles in the academia and the industry.

Other early notable contributions on AI in design came from John Gero (University of Sydney, Australia), George Stephanopoulos (MIT), Louis Steinberg and Chris Tong (Rutgers University), Dave Brown and Chandrasekaran (Ohio State University), Jack Dixon (University of Massachusetts), H. Yoshikawa and T. Tomiyama (University of Tokyo, Japan), Ken Preiss (Ben Gurion University, Israel), to name a few. Lyn Conway with her VLSI design work, Mark Stefik with his doctoral dissertation on planning, and Guy Steele with his constraint theory had significant influence on research on AI in design. Sanjay Mittal's work on PRIDE at Xerox PARC eventually led to the development of web-based configurators.

My own foray into design started with my doctoral dissertation under the tutelage of Prof. Steven Fenves. Inspired by Prof. Raj Reddy's work on Hearsay-II, I decided to focus on the development of an integrated structural analysis and design system using the blackboard problem solving paradigm. This led to the development of DESTINY for integrated design. May Lou Maher, at the same time, worked on HI-RISE, which was a pioneering effort in the development of KBES in structural design. HI-RISE's rules were

all coded in OPS5. It did not separate the control knowledge from design knowledge, in a similar manner to R1. I decided to extend HI-RISE and developed ALL-RISE in LISP (a very popular AI programming language at that time), one of the first domain independent shells for conceptual design.

The late 1980s also witnessed a plethora of tools – both commercial and open source -- targeted for building knowledge-based expert systems. These tools helped in diffusing AI technology to industry. A number of these tools are documented in my book entitled, "Intelligent Systems for Engineering: A Knowledge-based Approach" (Springer Verlag). Many of the tools developed in the 1980s are no longer in existence, or reincarnated in different forms. The only tool that survived over the past three decades is OPS5 and its variations, such as CLIPS and JESS.

The Birth and Transformation of the AI in Engineering Journal

In the summer of 1985, Bob Adey, who was the editor of *Advances in Engineering Software*, called me and asked me about the future of AI in engineering. Based on the bibliographies on AI on Engineering that Ross Joobbani and I put together for the *SIGART Newsletter*, I felt that the field had considerable growth potential. My response was very enthusiastic and I predicted that AI will play an increasing role in computer-aided engineering. Bob suggested that we organize a conference in that area and I agreed to do so. This was the birth of the *AI in Engineering Problem Solving* conferences. The first of these conferences was scheduled for April 1986. We also discussed the possibility of starting a journal dedicated solely to AI in engineering. Ken MacCallum of the University of Strathclyde and I were entrusted with forming an editorial board and getting the initial set of papers. We wanted to launch a journal entitled *Artificial Intelligence in Engineering* around the same time as the first *AI in Engineering Problem Solving* conference.

Ken and I were very successful in attracting world renowned researchers in the area to our editorial board. We got Laurence Leff to write a column describing "current activities" in the field. To our relief, the first issue of the journal, published by Computational Mechanics Limited, came out in July 1986, with several invited, but peer-reviewed, articles. Over the next several years, we worked hard on making the journal the best in its field. Two competing journals – *Engineering Applications of AI* and *AI for Engineering Design, Analysis and Manufacturing (AI EDAM)* – were started later. *AI in Engineering* kept its reputation at a very high level, due the diligent efforts of its editorial board.

Around 1989, I decided to resign from the *AI in Engineering* journal. Ken McCallum carried on as the sole editor for some time. Later on he was joined by several other editors. Ken resigned as the editor-in-chief in 1997 and George Rzevski was his successor until 2000. Finally, John Kunz, Ian Smith, and Testuo Tomiyama took over the leadership of the journal in 2000. I believe that Computational Mechanics Limited sold the journal rights to Elsevier Ltd. sometime in the mid-1990s. In 2002 the journal's name was changed to *Advanced Engineering Informatic*s, I handed over the chairmanship of

the *AI in Engineering Problem Solving* conferences to Prof. John Gero, of the University of Sydney. Later John decided to focus only on design aspects. He set up rigorous quality control standards, and made the conference series independent of the original publishers.

Expanding the Role of AI in Engineering Design: The 1990s

Soon after the launch of the journal, Chris Tong and I held a very successful workshop on AI in Engineering Design at the 1986 National Conference on AI. Based on the workshop proceedings, we edited a widely read three volume series entitled *Artificial Intelligence in Design*, published by Academic Press in 1992. Several pioneering contributions appeared in these volumes. Even today, most of the material that appeared in these volumes is state of the art.

Also in 1986, I joined the MIT's Civil Engineering Department as a faculty member in 1986. During my tenure there, I started collaborating with Prof. Bob Logcher.[2] Prof. Logcher and I extended the blackboard system to deal with both synchronous and asynchronous communication in collaborative design. We called our venture the DICE (Distributed and Integrated Collaborative Engineering) project. Several DARPA/National Science Foundation-funded projects at CMU, Stanford, and West Virginia University had similar goals.

The MIT-DICE project made several key contributions to both computer-aided engineering and AI, including a knowledge-based expert system building tool called COSMOS implemented in C++, an object-oriented blackboard, domain independent tools for design, constraint management tools, support for encoding design rationale and negotiation. The details of the DICE project can be found in my book entitled "Distributed and Integrated Collaborative Engineering Design" (Sarven Publishers). The influence of the MIT-DICE project can be clearly seen in the suite of collaborative design tools in vogue today. The success of our AI efforts and the DICE project at MIT is largely attributable to the intelligent and motivated students at MIT, with primary contributions from my doctoral students D. Navinchandra,[3] Albert Wong, Srinivasa Rao Gorti, and Feniosky Peña-Mora. I am very proud to note that all my students continue to make significant contributions to the computing field.

I left MIT to join the National Institute of Standards and Technology (NIST) in October 1994, to lead a program on engineering design. This program addresses many issues related to product representation and system interoperability for intelligent and distributed computer-aided design. Our work is significantly influenced by AI knowledge representation techniques, including the role of ontologies for semantic interoperability.

Much of the funding for AI in Design research in the 1990s was provided by the DARPA MADE (Manufacturing Automation and Design Engineering) and RaDEO (Rapid Design

---

[2] Prof. Bob Logcher, along with Prof. Fenves, wrote the first general purpose structural analysis program with a friendly user friendly interface in the early 1960s.
[3] D. Navinchandra passed away in 2004.

Exploration and Optimization) programs, under the able leadership of Pradeep Khosla (on detail from CMU) first and Kevin Lyons (on detail from NIST) later. The program managers ensured considerable involvement by the industry, in particular defense-related industry. Many of the projects initiated in the industry are still being pursued. My group at NIST provided programmatic and technical support to these programs.

Final Thoughts

The field of AI has continued to have considerable impact on computer software development and the practice of engineering over the past two decades, with themes changing every once in a while. Much of the work on blackboard systems has been reincarnated in the form of agent- and service-oriented architectures on the web. AI knowledge representation techniques have largely influenced the work on ontologies, RDF (resource description framework) and OWL (web ontology language). Ontologies will form the core of the emerging semantic web.

The industrial impact of AI has primarily been in the control and diagnosis-type applications. More than a decade ago Alan Mullaly, Chief Engineer for Boeing 777 aircraft, had this to say about AI's role in mechanical design: "Computers don't design airplanes. We have not put the knowledge that is in the airplane designer's head into AI that balances all these objectives. But, someday we will continue to probably move to that. Right now the knowledge to design airplanes is in the designer's head." Although AI has made some inroads into design automation—primarily very-large-scale integrated (VLSI) design, Mullaly's observations hold even today. There are two primary reasons for this: 1) the knowledge-acquisition bottleneck; and 2) the reluctance of CAD (computer-aided design) tool vendors to fully support KAD (knowledge-aided design) for fear of losing market place to traditional CAD tools.

Although not directly related to engineering, AI has made major strides in the video game and the word processing fields - two of the most widely used applications of computers. I am confident that artificial intelligence will continue to play an important role in the future of knowledge-based economies.

Dr Ram D. Sriram
Group Leader, Design and Process Group
Manager, Manufacturing Metrology and Standards for the Health Care Enterprise Program
National Institute of Standards and Technology
Mail Stop 8263, 100 Bureau Drive
Gaithersburg, MD 20899-0001, USA
Tel. (301) 975-3507
e-mail (official) sriram@nist.gov
Sriram's URL: http://www.nist.gov/msidstaff/sriram.ram.htm