PANEL ON AI AND DESIGN

Saul Amarel (Organizer, Chair), Rutgers University
Alvin Despain, University of Southern California
Penny Nii, Stanford University
Louis Steinberg, Rutgers University
Marty Tenenbaum, Enterprise Integration Technologies Corp., and Stanford University
Peter Will. Hewlett Packard Laboratories

1 General Significance

Issues of industrial productivity are of major economic significance at present - not only in the US, but in all parts of the industrialized world By advancing the science of design, and by creating a broad computer-based methodology for automating the design of artifacts and of industrial processes, we can attain dramatic improvements in productivity.

Recent developments in computer science, especially in AI and in related areas of advance computing, provide us with a unique opportunity to push beyond the present level of computer aided automation technology and to attain substantial advances in the understanding and mechanization of design processes. To attain these goals, we need to build on top of the present state of AI, and to accelerate research and development in areas that are especially relevant to design problems of realistic complexity.

Work in design provides a unifying theme for collaborative research among subfields of AI, and also between AI and other parts of computer science - especially database systems and high performance computing applied to large scale modeling and simulation. Also, it provides an effective vehicle for establishing links between AI and computational science/engineering.

2 Relevance to AI Research

Design is the problem solving activity that results in the generation of a description of an artifact or process (in a given language of design structures) in some domain that satisfies given design specifications, i.e., goals and constraints. Typically, a designer reasons in two spaces - the space of design specifications and the space of design structures. Furthermore, in most engineering problems of realistic complexity the design process is multi-level (hierarchical) in nature - where high levels of the hierarchy correspond to conceptual design, with considerable amount of exploration taking place both in the space of structures and the space of specifications; and lower levels correspond to detailed technical design where specifications are fairly fixed, and complex searches take place in the space of structures.

Looking at basic work in AI from the perspective of design automation, we identify a number of research issues that need special attention, These can be organized in three major groupings: decision making; representations; and knowledge handling, including modeling and simulation.

In the area of decision making, the issues include how to handle poorly defined and incomplete design specification; how to handle multiple interacting goals and constraints, especially in tasks of concurrent design and in those involving tradeoff decisions; how to choose decompositions in various problem solving contexts; how to handle formation problems; how to organize hierarchical reasoning processes in design; and how to handle incremental design and redesign tasks. The complexity of realistic design problems is expected to stress current methods of problem solving (goal-directed, constraint-based, model-based, and case-based), and it is likely to induce the development of new methods.

In the area of representations, the issues include how to represent candidate design structures in ways that facilitate their evaluation and modification in light of given design specifications; how to represent design records so as to facilitate explanation and design reuse; how to represent designs from multiple viewpoints; and how to organize large reusable design knowledge bases. Much current work in Knowledge Representation and Reasoning, in Problem Formulation and Reformulation, and in the Organization of Large Knowledge Bases, is relevant to problems in this area.

In the area of knowledge handling, the issues include how to use domain knowledge for a priori guiding the generation of candidate solutions rather than (in addition to) the a posteriori evaluation of candidate solutions; how to find and exploit useful approximations to domain theories/models to enable reasoning from function to structure and to provide computationally tractable evaluations of solution candidates at various levels of solution construction; how to integrate qualitative and quantitative knowledge of a domain in the context of design problem solving; how to automatically acquire (or refine) domain knowledge; and how to learn from design experience, i.e., how to transform design experience into increased design expertise. Current research in approximate reasoning, qualitative physics, theory formation, and machine learning, is relevant to the concerns of this area.

Progress in handling these research problems will have major impact both on our understanding of design processes and their automation, and also on several fundamental questions that are of intrinsic concern to AI,

3 AI Activities in Design

AI work on specific design tasks has been increasing in scope and volume since the early eighties. Domains/tasks that received considerable attention include digital circuit design (especially, VLSI design), design of small electro-mechanical parts and assemblies, and design of materials.

Recently, AI methods are starting to be explored in the context of design tasks of increased complexity, e.g., design of computer architectures, design of ships, design of aircraft engines, conceptual design of aircraft, design of large static structures. Also, renewed attention is being given to the exploration of AI approaches in large-scale software design - a problem that has been of intense interest to AI since the early days of the field.

Together with the increased levels of research activity in AI and Design, there has been a substantial growth in professional activity in the field, in the form of papers, tutorials in national conferences, workshops, etc.

4 Immediate Background for the Panel

It is as a result of a recent seminal workshop in the field that the idea of the present panel has emerged. The workshop was held in Ithaca, N.Y. on August 14 to 16, 1990 - to assess research issues involved in the creation of a new generation of powerful computer aided systems for engineering design, to identify major research opportunities and difficulties in introducing AI methods and technology into significant design tasks, and to formulate recommendations for a major research program in this area [1].

The workshop, which was sponsored by DARPA, was co-organized by Saul Amarel (Rutgers) and John Hopcroft (Cornell). It had about 60 invited participants from acadtmia and industry, mostly from AI, but also from other areas of computing and from several engineering disciplines with strong interest in advanced approaches to computational design.

Research issues, opportunities and difficulties were viewed at the Ithaca workshop both from the perspective of core science/technology and of significant design domains. The bulk of the workshop activity was conducted in six working groups, each focusing on a specific set of issues. The discussion of AI (and, more generally, computer science) issues in design concentrated in the three areas of design decision making, design representations and information management, and modeling and simulation in design. The three design domains that received primary attention are: design of small electromechanical systems, design of large structures (ships, airplanes, engines), and design of software.

The general sense of the workshop was that the time is ripe to launch a major research program in computational design, with AI as a central component; and specific technical recommendations were formulated for such a program. Also, a set of fundamental issues for AI research surfaced at the workshop.

(i) The choice of representations and domain models strongly depend on the specific design task on hand and on the stage of design. This has strong implications on the development of comprehensive large knowledge bases for design that rely on fixed ontologies and representational conventions. A related issue is that certain problem solving methods are possible only if domain knowledge is available in certain forms and is represented/organized appropriately.

(ii) There is evidence that design (in particular, innovative and high level design) may be so completely dominated and determined by specific domain knowledge that it could not be effectively handled by generic methods and techniques. For example, experts agree that the reasoning involved in introducing an innovative hull configuration in ship design, or an innovative wing-tail configuration in aircraft design, are strongly tied to the physics of each specific situation. This point has important implications on AI methodology.

(iii) The concept of design record seems to be central to work in computational design. Advances in this area seem to be slow, despite progress in related areas of explanation and proof construction in AI, It is important to understand better the difficulties involved.

(iv) To identify critical problems and to test ideas, it is essential to build systems (and conduct experiments) in specific tasks/domains of realistic engineering significance. This implies the need for a substantial infrastructure to support the research, and an organization involving interdisciplinary teams from universities, research labs, and industry. Thus, serious progress in this area requires the commitment of resources that are above some "critical mass".

5 Panel Goals

The panel will review and discuss the scientific/technical assessments, the recommendations for research, and the fundamental AI issues that emerged from the August '90 Ithaca Design workshop.

A major goal is to increase the awareness of opportunities and problems in this area within the international AI community.

Another important goal is ID elicit views, and to stimulate discussion, on the open issues (of substance and of research methodology) that AI faces in the context of a major push in computational design. It is essential for this discussion to have participation by AI researchers as well as by researchers who are exploring AI approaches in a variety of engineering domains, and also by those who are concerned about design in the broader context of product development and manufacturing.

6 Outlines of Panel Presentations

Saul Amarel (Chair)

Introduction to the panel: general significance of AI in Design; relevance to AI research; summary of assessments, recommendations, and AI issues from the Ithaca Design Workshop. The case for a major program in AI and Design; features of such a program. Issues of collaborative research between AI and engineering disciplines.

Alvin Despain

Summary of AI approaches to VLSI design and to the design of computer architectures; needs and research ideas in these domains. Issues in hierarchical systems for design problem solving - languages, management of the design process, knowledge acquisition. Experience in applications of AI methods to VLSI design. Problems of complexity, and prospects of handling them via High Performance Computing and via AI methods.

Penny Nii

Summary of discussions/recommendations in the domain of software design from the Ithaca Design Workshop. The Workshop focused on problems associated with programming-in-the- large. There were three major recommendations with AI implications; (i) Build an infrastructure to cumulate and to use design information about both the process and the artifact of design; this has implications on the representation and use of design records. (ii)Build and disseminate domain-specific software architectures; this has implications on the acquisition and structuring of appropriate domain knowledge, (iii) Develop a technology for managing consistency, and for coordinating the efforts of multiple designers of large multi-version systems; this has implications on methods for handling domain and task-specific consistency in addition to syntactic consistency.

Louis Steinberg

Summary of AI research issues in decision-making, representations, and knowledge handling from the Ithaca Design Workshop. Emphasis on overall design frameworks, and their relationship to design tasks of various types. There are a number of dimensions along which a design task can be categorized; the position of the task along these dimensions determines the method which is appropriate for handling it. E.g., the degree of interaction between parts of a task specification affects whether and how a top-down decomposition method can be used. By considering where past and current research falls along some of these dimensions, we can get a good idea of what we know how to do, and where further work is needed.

Marty Tenenbaum

Summary of discussions/recommendations in the domain of small electromechanical parts design from the Ithaca Design Workshop. Needs and research ideas in areas of design knowledge capture and in the building of environments for support of human-machine collaboration in design, Issues in the handling of manufacturing constraints early in the process of designing an artifact. Current state and research directions in AI approaches for design of manufacturing processes.

Peter Will

Summary of research and development issues in the Product Development Process and in Enterprise Automation to support the total life cycle of a product. The issues include support for Design and Manufacturing as well as other functional areas, including: (i) capturing design intent, (ii) knowledge bases of components and sub-assemblies, (iii) simulation and modeling, and (iv) agent oriented manufacturing and distribution.

Reference

[1]Amarel, S. (1991). *Report on DARPA-sponsored Workshop on Design • held on 14-16 August, 1990, in Ithaca,* iV.K, Technical Report LCSR-TR-160, LCSR, Rutgers University, New Brunswick, N.J. 08903