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Artificial Intelligence and Marine Design

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In the last few years, interest has grown in exploring AI approaches to design problems, both because of the enormous potential impact on productivity of improved design tools and because of the interesting basic AI issues that these problems raise. In particular, a number of ship designers and AI researchers recently became interested in applying AI to the hydrodynamic design of ship hulls. A typical problem here is to design the shape of a ship's hull in response to desired hydrodynamic properties such as drag and stability, taking into consideration a variety of design constraints, such as total hull volume.

This problem differs in a number of ways from most previous work in AI and design. For instance, unlike circuit or program design, hull design involves designing a shape rather than a structure of discrete primitives. Furthermore, the underlying domain theory that permits a designer to reason about relationships between candidate designs and their physical (hydrodynamic) properties is extremely complex, so complex that the choice of appropriate simplifications and approximations is essential to make computations tractable. Because of these differences, hydrodynamic design has the potential to test and stretch our current ideas about how to do design.

Workshop Overview

In response to the interest in this research area, a workshop on AI and marine design was sponsored by the Defense Advanced Research Projects Agency (DARPA) and held at Rutgers University in New Brunswick, N.J., on 10–11 January 1989. The workshop was intended to provide planning support for research in the broad area of advanced computational approaches to design, with special emphasis on the exploration of AI methods in hydrodynamic ship design. The workshop was timely for ship designers, who, in recent years, have been trying to extend their computational tools to include means for effective support of experimentation with innovative designs as well as for (partial) automation of early conceptual design stages. It was also timely for AI researchers, who have been looking for complex, real-life design tasks as potential test beds for work in fundamental AI issues that are broadly relevant to design.

The workshop had two sets of goals: The first set involved (1) clarifying relationships between problems in hydrodynamic ship design and AI research issues, especially those related to the design and analysis of complex systems, and (2) facilitating communications (bringing down language-concept barriers) and helping establish collaborations between AI researchers and marine designer-analysts. The second set involved (1) formulating and assessing specific problems in the domain of marine design that are significant for ship designer-analysts and provide good test beds for research on critical issues in AI and design; (2) discussing methodological and technical approaches to these problems, including computer environments, data management methods, and system evolution; and (3) recommending research directions, with an emphasis on interdisciplinary collaborative efforts.

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The workshop brought together a group of about 45 participants, primarily from the computer science and marine hydrodynamics research communities. In the computer science field, the main areas represented were AI and design (participants were from Rutgers, the University of California at Berkeley, General Electric, Lockheed, Ohio State University, and Carnegie-Mellon University [CMU]) and large-scale symbolic and numeric computations and computational explorations of (and reasoning about) physical systems (participants were from the Massachusetts Institute of Technology [MIT], Rutgers, and FMC). In the marine hydrodynamics field, the areas represented were ship design (participants were from Science Applications International Corporation [SAIC], the U.S. Naval Academy, David Taylor Research Center, and the Netherlands Maritime Research Institute [MARIN]) and computational hydrodynamics (participants were from SAIC and MIT).

In addition, closely related viewpoints (and methodological developments) from the domain of aircraft design were brought to the workshop by researchers from NASA Langley Research Center, the Georgia Institute of Technology, and Lockheed. There were government participants from the Office of Naval Research, the Air Force Office of Scientific Research, and the National Science Foundation as well as from DARPA. Bob Simpson was the DARPA/Information Science and Technology Office coordinator for the workshop, and Saul Amarel, from the Department of Computer Science at Rutgers, was workshop organizer. The technical program was jointly planned by Saul Amarel and Nils Salvesen, director of the Marine Hydrodynamics Division at SAIC. Louis Steinberg, also from the Rutgers Department of Computer Science, was workshop coorganizer.

Workshop Program

About two-thirds of the program was devoted to invited technical presentations that concentrated on the current state of research and development in areas of interest to the workshop. In the area of computer science, the presentations covered current AI

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approaches to design problems and critical research issues in the field; current AI methods for reasoning with physics knowledge; research progress in computational methods for the exploration and analysis of physical systems; and experimental AI design systems in several domains —mechanical engineering, digital circuit design, and the design of special-purpose computer architectures. A progress report on the development of the Engineous design system at GE (which combines AI approaches and computational fluid dynamics [CFD] analysis tools) and its use in aircraft engine design provided an up-to-date view of the application of AI technology to problems that have many elements in common with ship hydrodynamic design.

Presentations in the general area of computational approaches to ship design and related work in computational hydrodynamics covered (1) detailed reconstructions of decisions and experience in the computer-aided design of racing yachts (in particular, the *Stars and Stripes*, whose victory in the 1987 America's Cup race owes much to the intensive use of computers in its design) and of small-waterplane-area twin-hull (SWATH) ships, (2) current research in computer-aided acquisition and analysis of hydrodynamic knowledge related to ship-wave motions, and (3) computer system requirements for ship design. A report on the HOSDES system for ship hydrodynamic design, which is currently in the advanced stages of development at MARIN, gave a good sense of the best computer environment for ship design that can be attained with current technology.

The last one-third of the program was devoted to brainstorming sessions that consisted of technical discussions about the nature of ship design problems, the requirements for advanced computer environments in this area, assessments of relevant AI research issues and possible AI approaches to hydrodynamic ship design, and ideas about future research.

To focus the discussion, a specific ship design problem was formulated by Nils Salvesen and Marty Fritts from SAIC. The problem provided a concrete basis for clarifying concepts and methods across disciplines and presenting specific ideas about AI approaches and open research issues. The problem was to design a SWATH ship whose primary purpose is to act as a helicopter platform for landings and take-offs at high seas; given characteristics of speed, range, and so on, had to be satisfied. The problem was presented as an example of realistic design situations that are significant for Navy planning and that can benefit from AI approaches. Also, it illustrated some of the challenges that problems in this area offer to AI researchers, in particular, developing a concurrent design with both hydrodynamic and structural considerations and acquiring and using new hydrodynamic knowledge about wave-ship motion, knowledge that is needed to provide insight into behavioral characteristics of proposed designs and to guide design decisions.

In a luncheon talk, Bob Simpson presented a DARPA perspective on research planning, with an emphasis on advances in AI and the related area of information science and on issues of industrial productivity and competitiveness. Dinner talks were given by Alexander Pond, executive vice president of Rutgers, and Raj Reddy, from CMU, then president of

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the American Association of Artificial Intelligence. Reddy's remarks focused on issues of computer-aided productivity, in particular, AI and design in rapid prototyping. Following the workshop dinner, a number of demonstrations were given of experimental AI design systems developed at Rutgers and ship design modules developed at SAIC.

In the course of the discussions, key AI research issues were identified that relate to the problems of ship design. These issues centered on four areas. The first area included the handling of multiple interacting goals and constraints, the effective control of concurrent design processes, methods for evaluating partially specified designs relative to various design goals and constraints, and strategies for solving constrained optimization problems with many variables. The second area included the issues of choosing problem decompositions and high-level representations of design configurations at various levels of abstraction and handling formation problems where the degree of coupling among design variables is high.

The third area included structuring and using design records, effectively tracing design decisions, designing from prototypical cases and by analogy, controlling redesign processes, and organizing large design knowledge bases. The fourth area included the issues of acquiring, transforming, and managing domain knowledge in ways that provide effective support for design decisions; choosing specialized models and approximations that are well tuned to specific kinds of design tasks; machine learning from design experience and learning from computational experiments in the domain; and coordinating mathematical modeling and numeric computing methods with symbolic methods used in AI.

Another important issue that surfaced during these discussions involved the changing nature of problem formulation in the early stages of conceptual design and implications for the system capabilities that would be needed to handle such dynamic situations. In these situations, design goals and constraints are in a state of flux; they are being shaped as the designer gains insight into the trade-offs between key performance parameters and cost relative to changes in the key structural parameters of possible designs. This issue brings forward methodological questions of how to compute reasonable estimates of performance-cost sensitivities with respect to various design decisions before complete designs are available and how to extend current AI problem-solving frameworks to effectively handle a set of closely related design problems, not just a single well-formulated problem.

Thus, the workshop confirmed that many research issues that are intrinsic to the scientific development of AI can be profitably studied in the context of ship design problems.

Workshop Results

A number of strong recommendations emerged regarding promising technical approaches in the area. These recommendations involve the building of computer environments for AI-oriented system development and experimentation in ship design. In this regard, two areas must be emphasized: (1) the effective acquisition and management of new CFD analysis tools and their rapid assimilation into design processes, as well as support for the development of new models and analysis tools that are well tuned to the needs of specific ship design tasks, and (2) the effective control of design processes, emphasizing concurrent design and including approaches for exploring the space of feasible design configurations and storing and using design records. It was recognized that the development of these system environments can be largely based on current AI technology; however, the systems should have good evolutionary capabilities to provide a means for incorporating advanced features that derive from new results in related AI research.

An important outcome of the workshop was an improved sense of the potential impact on naval ship design of bringing AI approaches into the design process. Benefits are expected in the following areas: (1) rapid reaction to changes in operational requirements of ships and to relevant scientific and technological advances (for example, advances in remote sensing technology induce ship designs that minimize hydrodynamic disturbances left in their passage), (2) a rapid transition from design concept to operational prototype, (3) improved quality of designs and lower life-cycle costs, and (4) increased insight into design options and their hydrodynamic environment. The critical issues of speeding up the design cycle and accelerating the incorporation of new advances in hydrodynamic models and tools and new, promising technologies (for example, materials, controls) into the design process were repeatedly stressed by the marine designers. For example, it was pointed out that the development of new CFD analysis tools currently involves roughly 15 years from initial research to mature capability. This long delay puts us at an enormous competitive disadvantage. The use of AI approaches in this area, as well as in the control of concurrent design processes and the rapid exploration of the space of feasible design configurations, promises to provide speedup factors of 10 to 100. This speedup can have a dramatic impact on competitiveness and our ability to rapidly exploit innovative design ideas. Even the prospect of computer-aided innovation becomes realistic if powerful design environments become available to top-level designers and those responsible for deciding about main ship dimensions and parameters (top U.S. Navy officers) so that they can readily explore new design concepts.

It was observed during the discussions that many of the scientific and technical problems in ship design, as well as the challenge of rapidly and effectively handling innovative design concepts, are also encountered in the design of aircraft and aerospace vehicles. Thus, advances in AI and ship design are expected to have a substantial impact in these other areas.

Now that an AI and marine design community is emerging (and the workshop clearly contributed to this process), it is expected that a workshop in this area will become an annual event. This workshop marked an important step in the development of a major national research effort in advanced computational approaches to design, with an emphasis on AI and the related area of computer science. The marine design theme is of special scientific, engineering, defense, and economic significance. It provides a focus for research at the intersection of AI, large-scale numeric computing, and CFD, and it presents special challenges for the development of AI systems that can improve design productivity and competitiveness in an area of major national significance.

Saul Amarel is Alan M. Turing professor of computer science at Rutgers University. From 1985 to 1987, he was director of the Information Science and Technology Office at the Defense Advanced Research Projects Agency, on leave from Rutgers. In 1983, he was general chairman of the International Joint Conference on Artificial Intelligence. He has been active in AI research since the early sixties. His recent interests include problems in basic AI—representations in problem solving, theory formation processes, learning and expertise acquisition, design, and planning—and applications of computer science to the study and automation of design and manufacturing processes.

Louis Steinberg is associate professor of computer science at Rutgers University. He is principal investigator of the Rutgers AI/Design Group. His primary research interests lie in AI, especially AI applied to design and machine learning, and in developing a computationally based science of design. He served as chairman and organizer of the Rutgers Workshop on Knowledge-Based Design in July 1984, sponsored by the American Association for Artificial Intelligence (AAAI), and was co-presenter of the tutorials on AI and Design at AAAI-88 and the 1989 International Joint Conference on Artificial Intelligence.