REFLECTIONS

AI EDAM at 20: Artificial intelligence in designing

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1. INTRODUCTION

1.1. Designing as problem solving

From its inception the journal *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* recognized that designing is the precursor to analysis and manufacturing by placing it at the front of the list of areas it covers. Designing distinguishes itself from other aspects of engineering by its goal of changing the world within which it operates: designers are change agents. This characteristic makes designing a difficult task even for humans let alone for machines, because most of our knowledge and the means to acquire it assume that the world is given to us and what we need to do is characterize it. The Journal provided one of two continuing publication outlets for artificial intelligence (AI) in engineering at the time. This created the opportunity to have a focal point for the publication of archival research in the area, research that had previously appeared in disparate locations. It also offered the potential to develop a coherent research area where future research could build on previously published research.

In his 1967 Karl Taylor Compton lectures, Herbert Simon chose designing as the area to exemplify his ideas about the "sciences of the artificial." He treated designing as a class of problem solving, although he recognized that it was a special class that he labeled "ill-structured." This laid the foundation for AI in designing as a form of search. In 1987, at the inception of this Journal, designing as search was the predominant AI-inspired paradigm reflected in the papers of the time.

AI provided a fertile area for design researchers to draw inspiration. The research questions during the first decade of papers in *AI EDAM* focused on the issues of how to efficiently and effectively search design spaces. This often presented itself in the form of the application of the various technologies being developed in AI, for example, using expert systems, using constraint-based systems, using logic programming, using case-based reasoning, and more recently using genetic algorithms, using neural networks and fuzzy systems in designing. Designing as search mirrored earlier design research founded on concepts from operations research and optimization in particular. What AI did was to expand the domain of search computation from the numeric to the symbolic. This was an important and significant expansion of design computing as it allowed for a wider range of representations, and hence, a much wider range of design issues to be addressed. Through the use of symbolic representations and the associated symbolic computing, search was made directly applicable to a number of formulations of designing. It was used extensively in designing as configuration, which became explicitly and implicitly the representation for designing. This allowed for the integration of configuration concepts from related areas such as shape grammars.

1.2. Designing as designing

Designing as problem solving dominated the thinking of design researchers. There was a developing concern that this paradigmatic view did not adequately capture the distinctive and distinguishing characteristics of designing. What was inadequately represented in this paradigm were the results coming from cognitive studies of designers that indicated that designing involved not just search but a reformulation of the search space. Further, the intermediate results of designing affected what followed in a design session. This was not to imply that designing as problem solving would need to be discarded. What was implied was that the designing as problem-solving characterization was incomplete. Design research moved to designing as designing, with its unique characterization. AI techniques continued to play significant and dominant roles in this research that expanded, rather than displaced, the earlier research view.

Designing as designing brought with it problems, only some of which could be directly addressed by the "tradi-

tional" AI paradigm of problem solving. The major additions this demanded included how to deal with non-monotonicity in the way the design space changes over time, how to deal with the recursion that was implied by the notion that what has recently occurred during the current designing activity plays a role in shaping what is yet to come, how to deal with new knowledge that is learned as a consequence of the designing activity during that activity, and how to deal with changing requirements that are themselves a function of what has recently occurred during the current designing activity.

AI research in other areas than search are now used to attempt to deal with some of these issues: techniques from learning, techniques from associative and self-organizing memory systems, techniques from motivated agents, techniques from adaptive agents, and techniques from interaction systems all now play a role in developing research in designing as designing, in addition to novel techniques not drawn directly from AI.

2. WHERE ARE WE?

Surprisingly little of the AI-based research into designing has overtly found its way into industry compared to, say, the optimization-based research into designing. Much has, and some research in designing is used in industry without sourcing it to AI; for example, there is the use of rule-based systems that grew out of AI research. More recently, synthesis systems using neural networks have been used. Does this mean that some of the last 20 years of AI research has not been useful, or does it mean that it yet to be applied or does it mean that only the foundation has been laid? Presumably it is a mixture of all three of these. Much research repeated previous work now recast using symbolic computation but novel and significant research was published in *AI EDAM* that has yet to be taken up by industry and important research was published that laid the foundation for future research that has the potential to expand the scope of applicability of computation in designing.

The field of design research does not have as good a record of building on prior research as other well-established sciences do. This can be seen in the low citation rates, and hence, the low impact factors of the major journals in the field. We can peruse the publications in *AI EDAM* and pro-

duce a list of what was published. What is not obvious is what is missing from that list. There are gaps in papers on ontologies for designing and major review papers of both research areas and applications of techniques. In addition, there are gaps in papers that develop models of and processes of designing that are based on empirical studies of designers: both single designers and teams of designers.

3. WHERE ARE WE GOING?

Research areas follow both fashions and funding. The current fashions in AI research in design include agent-based systems, particularly multiagent systems and soft computing. These areas have yet to be explored to their fullest in the design field. There is an increasing interest in the interaction of hardware and software systems—sensate environments—that offers a new research direction for AI in design, a direction that has the potential to bring together a number of disparate research areas. There is an increasing interest in cognitively based AI in designing involving new kinds of concepts about memory, about access, about interactions, about learning, and about the role of the environment while designing. An important direction is research into ontologies in designing. Ontologies have been shown to play a significant role in the development of a field. Part of the difficulty of carrying out research in AI in designing has been the lack of an agreed ontology. In mature research fields, ontologies have been part of the significant research in general early in the field's development.

For a field to be a science it needs to have phenomena that require characterization through representation followed by modeling and then followed by theories with predictive capabilities. Designing is only now formally producing the phenomena that require characterization. The phenomena are being made accessible through cognitive studies of designers using such techniques as protocol studies. It may be that in the future we will see neurodesigning studies through a confluence of brain science and design science using techniques from neurophysiology. This would provide a neurological basis for designing phenomena and hence expand the reach of AI in designing research through the provision of a new kind of data. A journal such as *AI EDAM* should be at the forefront in publishing such groundbreaking research, in the same way as it has been in the past.