ISSUES IN BUILDING AND EVALUATING NETWORKED ENGINEERING ENVIRONMENTS

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Abstract This paper describes recent results from the National Design Repository Project (`http://www.designrepository.org`). The Repository is a growing digital library of publicly available Computer-Aided Design data from a wide variety of application domains (Mechanical, AEC, GIS, etc). The long-term goal of this project is to create a flexible infrastructure for managing the relationships between CAD data (designs, geometry, topology, etc) and metadata (documentation, collaborative work, simulation, etc.). Further, based on this infrastructure, we are creating new data structures and algorithms for knowledge indexing and case-based retrieval of engineering data.

Keywords: Design Repositories, Collaborative Design, Computer Supported Collaborative Work, Computer-Aided Design.

1. Introduction

This paper describes recent results from the National Design Repository Project (`http://www.designrepository.org`). The Repository is a growing digital library of publicly available Computer-Aided Design data from a wide variety of application domains (Mechanical, AEC, GIS, etc) [Regli and Gaines, 1997; Regli and Cicirello, 2000]. The long-term goal of this project is to create a flexible infrastructure for managing the relationships between CAD data (designs, geometry, topology, etc) and metadata (documentation, collaborative work, simulation, etc.). Further, based on this infrastructure, we are creating new data structures and algorithms for knowledge indexing and case-based retrieval of engineering data.

The National Design Repository Project is entering its third year. In this time, to has grown to include over 50,000 solid models and assemblies and occupy ten gigabytes of storage. In the course of this explosion in data, we have begun to address the following issues:

1 **Integrating Collaborative Work with Design Metadata:** Great advances have been made in the representation and sharing of design, simulation, manufacturing and analysis data. We are examining a how CAD can better support collaboration by integrating CAD with collaborative work.

2 **Sharable Ontologies for Collaborative Design Knowledge:** Ontologies are needed for the digital storage of collaborative work along with traditional engineering data. ,

3 **Data Indexing Schemes for Collaborative CAD:** New forms of data indexing are needed to search for patterns in design databases that represent problem solving methods or design parameters.

4 **Evaluation Methods for Collaborative Engineering Environments:** Lastly, we are developing evaluation methodologies for assessing human performance in next-generation networked engineering environments.

This extended abstract provides a high-level overview of our current research efforts in these areas.

2. Research Components

Collaborative Work as Design Metadata. A Design Repository is not a static entity holding a snapshot of the state of the world. We are building a Collaboration Message Model to link engineering data (such as geometry, topology and features) with the collaborative exchange of the designers as captured by collaborative work tools. In this way, the design enterprise can be recorded and archived in its raw form. While the signal-to-noise ratio of the initial raw capture will be low, this creates a platform for extraction of design intent as well as for automated indexing of design process.

We believe that integrating collaboration tools with Computer-Aided Design (CAD) tools and archiving the resulting context-rich communication will enable us to preserve the design knowledge acquired during the design process. As part of the Networked Engineering Project at Drexel University, we are creating an environment that integrates Computer-Supported Collaborative Work (CSCW) with CAD (shown in Figure 1). We believe that this research testbed will enable us to advance the understanding of how collaborative work tools can be effectively applied to the engineering design process. This will become more important as an increasing amount of design activity occurs asynchronously over distance and time using network-based collaboration tools.

Sharable Ontologies for Design Knowledge. Different design domains, even different projects, have different representational needs [Szykman et al.,

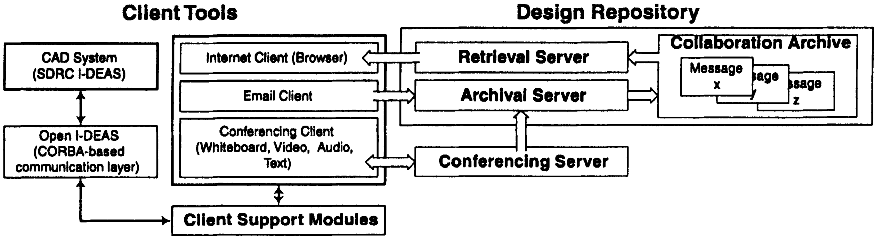

Figure 1. Architecture for integrating collaborative work with computer-aided design.

1999b; Szykman et al., 1999a; Schlenoff et al., 1999]. Sharing knowledge across design activities requires constructing sharable ontologies that can describe the semantics of specific design problems. We address this problem at two levels: representation and sharing of design data; and indexing and reuse of design experience as captured during collaborative work.

We are currently developing a *message model* for representing communication and collaboration during engineering design. Our goal is to create a knowledge infrastructure to describe inter-agent collaboration and its context within the design lifecycle. The message model will serve as a basis for archiving the evolution of both the artifacts being designed and the design activity, as well as a basis for indexing and retrieval of this experience. The *message model* represents one such classification schema—covering various types of typical design communication (shown in Figure 2). Based on this analysis, we define a message model document type definition (DTD) using the Extensible Markup Language (XML). Our message document type can represent different kinds of collaboration (such as email exchange, video/audio conferencing and text-based chat sessions) and the design information that is discussed (design data such as parts, assemblies, features). This creates a uniform way to structure the information communicated during design collaboration and capture the context and the contents of the messages exchanged. With this representation schema, the collaboration that occurs during engineering design can be captured and indexed for later reuse in design databases and design knowledge repositories.

Indexing Schemes. Given large archives of design knowledge, how will this data be searched and harvested? Traditional search methodologies are rooted in database technologies, pattern matching and analysis and text search. These search methods are poorly equipped to handle the complex interactions between form and function that would be the basis for search of design knowledge-bases. Design Repositories require new kinds of search algorithms that can

Message Model Document Type Definition

```
<!ELEMENT communication (context, contents)>
<!ELEMENT context (date, users, designdata)>
<!ELEMENT contents (subject, text, file?, attachment*)>
<!ELEMENT date (#PCDATA)>
<!ELEMENT users (initiator, participant+)>
<!ELEMENT initiator (firstname, lastname, email?)>
<!ELEMENT participant (firstname, lastname, email?)>
<!ELEMENT firstname (#PCDATA)>
          (etc)
```

Example XML Message

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE COMMUNICATION SYSTEM "http://edge...
<COMMUNICATION type="email">
 <CONTEXT>
   <DATE>February 11, 2000</DATE>
   <USERS>
    <INITIATOR>
     <FIRSTNAME>Vera</FIRSTNAME>
     <LASTNAME>Zaychik</LASTNAME>
          (etc)
```

Figure 2. Simple fragment from the collaborative design message model.

query over geometric and topological constraints as well as structure, behavior and function.

Our current work has focused on developing graph-based representations for CAD data, CAD features and features relationships [Regli and Cicirello, 2000; Cicirello and Regli, 1999; Cicirello, 1999]. We are able to query based on feature data in order to look for manufacturing process similarity as well as topological and design similarity. We are expanding these efforts to develop more general methods of including collaborative work relationships in order to fully model the knowledge networks that engage in design activity.

Evaluation Methods. In the current world of distributed design and manufacturing, designers have access to an overwhelming array of software tools for authoring, analysis, simulation and collaboration. As part of this research, we are developing user-centered evaluation techniques for doing formative and summative evaluation of collaborative design environments. Our approach is beginning to detail how to apply these generic principles to the evaluation of collaborative engineering systems and Design Repositories [Hewett and DePaul, 2000; Regli et al., 1999a; Regli et al., 1999b]. In particular, we break the evaluation activity into several components:

1 **Task Analysis and User Studies:** In order to enable designers to work more effectively using new computer tools and resources, such as the Design Repository, task analysis and data modeling needs to be performed. First, we are investigating how designers do their work now (i.e., what type of archiving of design rationale is currently conducted), and how they would like to do it to obtain maximum benefit. Furthermore, design is a social process, involving continual communication among individuals proficient in a range of disciplines. That process needs to be studied as a part of developing any useful applications.

2 **Creation of Specifications and Requirements:** Specifications and requirements will be developed on the basis of the goals discovered during the task analysis and user study. For example, for the Design Repository project, one of the requirements is to archive email and video conferencing communication and store it using a message model developed in the previous stage of the project. Another requirement is to be able to search the repository for a particular part, project, designer, date or problem.

3 **Implementation and Prototypes:** In the context of evaluation, it is helpful to be able to evaluate the design of the project and preempt some of the problems that would otherwise surface only after the implementation is almost done. It is in fact helpful to devise some kind of a mental model or a simulation from the design to be able to evaluate it. Although not recommended, implementation for many projects starts before work on prior stages is completed. This approach can still be successful if the developers are reasonably knowledgeable about the problem domain and realize that design choices should be reversible in light of new constraints or information.

4 **Summative Evaluation—Establishing Goals and Metrics:** Once the users are identified and their tasks are defined, goals need to be determined. When the goals are defined, metrics of evaluation of success can be set in place. For example, throughout successive steps of a design project, we can examine current state and activities and compare them to the goal state. We are striving to make the metrics of evaluation should be as detailed and as quantifiable precise as possible.

For example, in the Design Repository project, the main goal is to provide designers with knowledge relevant to their current task in a simple manner. The subgoals are to gather knowledge from on-going projects in a number of different media, store thus accumulated knowledge in a structured way, provide tools for easy retrieval and browsing. Metrics of evaluation could be as follows:

- Is more relevant information available to a designer through the use of the Design Repository, as compared to previous practices?
- When searching for information on some prior project, was the designer able to find relevant information, if any. Why or Why not?
- Percentage of relevant/irrelevant information: is there really any benefit in archiving informal media?

3. Conclusions

This paper has provided an overview our latest research activities to develop and evaluate environments for Networked Engineering. We see this research as building a platform that can examine next-generation Collaborative CAD and Product Data Management tools—as well as creating novel ways of interacting with design knowledge. Managing large-scale design knowledge-bases poses unique technical challenges that span academic disciplines of computer science, information retrieval, information science, and human-computer interaction. A better understanding of these issues will serve to greatly advance our ability to create testbeds, such as the National Design Repository, to enable communities of researchers to collectively address these problems.

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