The Engineering Design Repositories Project

William C. Regli, Lisa Anthony, Vincent Cicirello, Jon John, Xiaoli Qin, Yuriy Shapirshteyn, Vera Zaychik
Geometric and Intelligent Computing Laboratory
Department of Mathematics and Computer Science
Drexel University
Philadelphia, PA 19104

Abstract Under this NSF CAREER project, we are developing representations and algorithms to manage large digital libraries of complex engineering knowledge. The algorithms and data structures we are creating will integrate knowledge-bases of geometric information with systems for case-based reasoning and digital information retrieval. The research in this highly interdisciplinary project bridges several important fields: geometric reasoning, case-based reasoning, and digital libraries; it draws on the challenges presented by real-world problems from the domain of solid modeling and Computer-Aided Design (CAD) for engineering and manufacturing. This paper gives a brief overview of our progress during the 1998-1999 academic year.

Introduction Geometry and 3D solid models are ubiquitous in a diverse array of fields including architecture, graphic arts, entertainment, medical informatics, computer-aided design, and engineering and manufacturing. In engineering design, it is conservatively estimated that more than 75% of design activity comprises case-based design—designs that are variations and improvements upon previous design. This CAREER project involves the development of computational methods for reasoning about complex geometric and engineering information. In particular, we are focusing on:

1. **Collaborative Design Environments:** How can teams of designers, coordinating over information networks, share ideas and engage in creative activity? In particular, we are studying how this creative output can be archived and associated with the CAD and solid model data in Design Knowledge Repositories.

2. **Conceptual Design Environments:** How will designers interact with Design Knowledge Repositories? Given access to vast digital libraries of engineering knowledge, new forms of interaction and query interfaces will be required to navigate these knowledge-bases. We are building tools for specifying 3D conceptual product layouts and annotating structure-behavior-function descriptions of artifacts [5, 4].

This paper gives a brief overview of our progress in these areas and some of our current results, and provides a description of our plans for future work.

Collaborative Design Environments

Background The current generations of knowledge-based systems and collaborative work environments, coupled with the ascendency of the Internet and other IP-networks, have created a massive platform for deploying **Collaborative Knowledge Networks**. These networks are becoming vast in scope and immense in importance. In the context of engineering design, these collaboration networks provide a platform for capture and archival of design rationale and intent. This thrust of our CAREER research focuses on system building and prototyping tools to create rapidly configurable, domain specific collaborative knowledge networks—with a particular focus on integration of collaborative work tools, computer-aided design and knowledge-based systems.

Current Results We are currently working on two issues related to creating collaborative environments for engineering design:

1. **Knowledge Representation:** The essentials of the representation of collaborative knowledge networks are largely blurred amid ill-defined formats—the true knowledge still possessed primarily by the human agents in the enterprise. It has become increasingly evident that, while computing power is advancing exponentially, our models and representations of creativity and human knowledge have progressed very slowly.

   We are developing graph-based data structures for modeling the relationships between CAD data (e.g., parts and features) and collaborative activity (e.g., email, audio and video discussions). In addition, we have created a case-based representation and indexing schemes for problems in mechanical engineering design [7]. It is our belief that we will be able to use these structures for indexing and retrieval of CAD knowledge.

2. **Use of Advanced IP Networks:** We are also collaborating with AT&T Labs and using their advanced IP-network application middleware. Among the capabilities most relevant to this project,

the AT&T Labs IP middleware software provides mechanisms for tracking data flow in the network, security and encryption, development of network-aware software agents and services, multimedia messaging, network caching and, most importantly, tools for allowing these applications to leverage high-performance IP networks create interactive and high-fidelity collaborative applications.

Presently, we are integrating AT&T Labs' IP middleware with the I-DEAS CAD system and Metaphase Product Data Management system from Structural Dynamics Research Corporation (SDRC). As part of this integration, we are creating ways of linking collaboration tools (i.e., an email client) with the CAD environment so that communications (i.e., email messages) can be automatically tagged with a design context extracted from the CAD system.

Conceptual Design Environments

Background As noted above, much design activity is case-based or variational [10]. Over the past decade, 3D Solid Modeling has become a critical element of the product realization process—leading to successive generations of increasingly robust software tools for *detailed* design and engineering analysis.

The goal of this project activity is to develop novel techniques and tools to support *Conceptual Design*. Conceptual Design is the initial phase of product development, when product development teams, consisting of design engineers, manufacturing engineers, marketing and management personnel, determine the essence of a new product. As has been often documented, the design phase of the product realization process has a tremendous impact on the life-cycle cost of a product. However, there are few tools to support 3D conceptual design.

During Conceptual Design, teams of designers may begin to develop a new product by sketching its general shape on paper. This "back of the envelope" approach is a key aspect of the creative thought process—once completed, one has a clearer idea of what is being created and can proceed to drafting or CAD activity. Previous research in areas such as conceptual design of graphical user interfaces (GUIs) [3] and cased-based reasoning and case-based design [8, 6, 2, 1] are relevant to our efforts. For example, much of the work in case-based reasoning has focused on developing symbolic representations for engineering knowledge about function and behavior, as well as algorithms for indexing, retrieving, and adapting design cases stored with these representations.

Current Results We have developed **CUP**, a 3D modeling tool for **Conceptual Understanding and Prototyping**. CUP allows teams of users, during the conceptual phase of design, to specify a spatial layout of components and sub-assemblies; it allows users to establish structural, functional, behavioral information about components and sub-assemblies; and it provides mechanisms for capturing textual information about the design's intent and designers' preferences.

CUP is primarily concerned with the creation of conceptual designs of *mechatronic systems*, electro-mechanical systems that combine electronics and information technology to form both functional interaction and spatial integration in components, modules, products, and systems. Typical examples of mechatronic systems include automatic cameras, miniature disk drives, missile seeker heads, and consumer products like CD players, camcorders, and VCRs. These designs include mechanical and electronic components—such as the CAD model (simplified) of a missile seeker assembly pictured in Figure 1, and related metadata (process and assembly plans, documentation, etc).

This simplified seeker assembly might be one of many dozens stored in a corporate design data/knowledge-base. A design team, faced with the task of creating a new seeker, might need to interrogate the CAD knowledge-base and examine previous design cases that could be relevant to this new problem. Examining this legacy data can prove time-consuming and tedious, unless the device required and its search parameters are known precisely beforehand.

As illustrated in Figure 1 (b), CUP allows a designer to quickly sketch out, in 3D, the major components and structural relationships in the assembly. Rather than performing detailed CAD to create a draft design (detailed CAD modeling for this model took several days), designers can, in a matter of minutes, build a conceptual design. This conceptual design can then be used as a starting point for further refinement or as a query to the design knowledge-base. CUP also, via its attributing, tagging and labeling features, helps designers capture the design intent and to build a structure-behavior-function (S-B-F) model of the artifact. Presently, we store the structure-behavior-function representation using XML and the S-B-F representation scheme developed by the National Institute of Standards and Technology (NIST) [9].

Conclusions and Future Work The work presented in this paper are the foundation of a multi-year effort at Drexel University to build large-scale engineering design repositories. These initial project activities have produced novel inter-disciplinary results cutting across engineering design, Internet computing, and artificial intelligence.

Project plans for the intermediate and long term in-

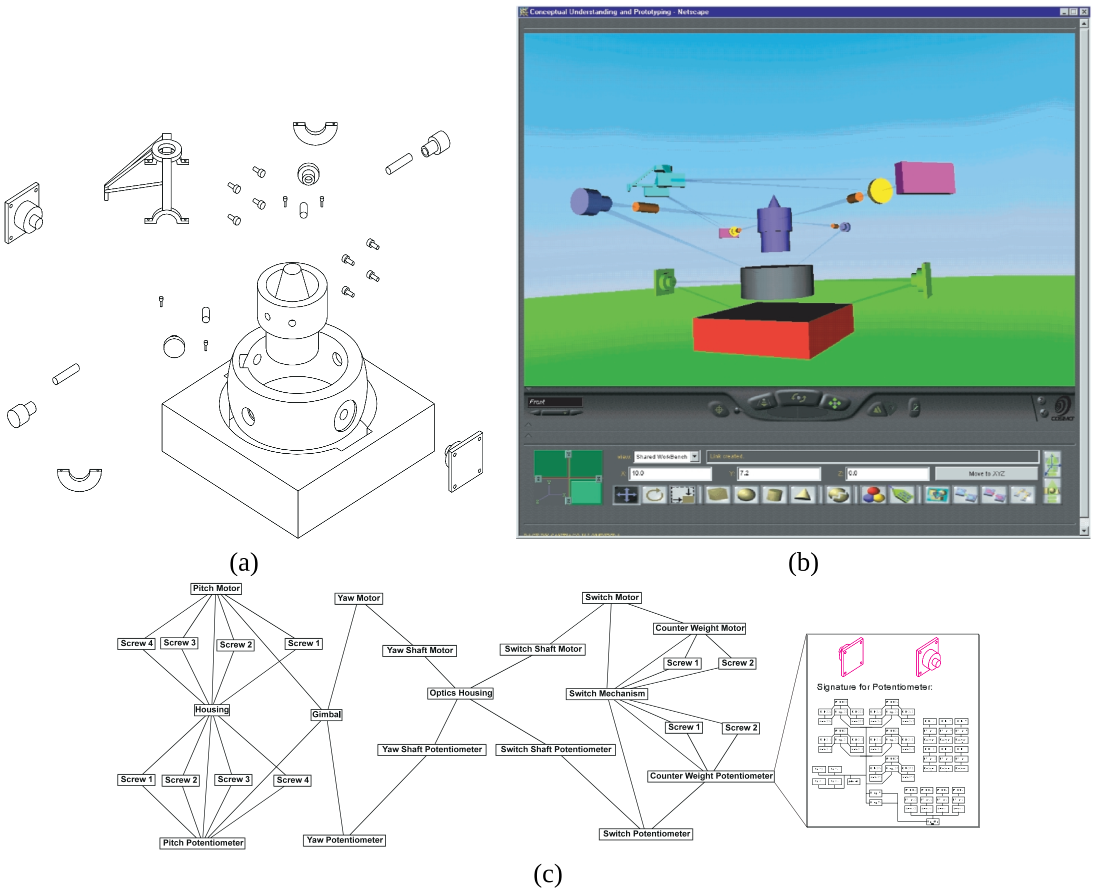

Figure 1: An example of a mechatronic system: simplified missile seeker assembly (a) along with its assembly structure (c). Figure (b) shows the conceptual design as sketched out with CUP.

clude:

- Deployment and testing of the integrated collaborative engineering environment in university courses on design and intelligent CAD.
- Extension of the conceptual design tool (CUP) to handle multi-user collaboration on conceptual design models.

Our ultimate goal is to integrate these tools with the National Design Repository (`http://repos.mcs.drexel.edu`) and build the foundation for large-scale digital libraries for engineering design and manufacturing.

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References

[1] S. Bhatta and A. Goel. Discovery of physical principles from design experiences. *International Journal of Artificial Intelligence in Engineering Design and Manufacturing*, 8(2), Spring 1994. Special issue on Machine Learning in Design.

[2] A. Goel and E. Stroulia. Functional device models and model-based diagnosis in adaptive design. *International Journal of Artificial Intelligence in Engineering Design and Manufacturing*, 10, 1996.

[3] Marti A. Hearst, Mark D. Gross, James A. Landay, and Thomas F. Stahovich. Sketching intelligent systems. *IEEE Intelligent Systems*, 13(3):10–19, May-June 1998.

[4] Santiago Lombeyda and William C. Regli. Conceptual design for assembly. In Satyandra K. Gupta, editor, *ASME Design Technical Conferences, Fourth Design for Manufacturing Conference*, New York, NY, USA, September 12-16 1999. ASME, ASME Press. Las Vegas, NV.

[5] Santiago Lombeyda and William C. Regli. Conceptual design for mechatronic assemblies. In David Anderson and Wim Bronsvoort, editors, *Fifth Symposium on Solid Modeling and Applications*, New York, NY, USA, June 8-11 1999. ACM, ACM Press. Ann Arbor, MI.

[6] M. L. Maher, M. B. Balachandran, and D. M. Zhang. *Case-Based Reasoning in Design*. Lawrence Erlbaum Associates, Mahwah, NJ, 1995.

[7] Xiaoli Qin. A case-based reasoning system for design of bearing assemblies. Master's thesis, Drexel University, Geometric and Intelligent Computing Laboratory, Department of Mathematics and Computer Science, Philadelphia, PA 19104, June 1999 1999.

[8] K. Sycara, D. NavinChandra, R. Guttal, J. Koning, and S. Narasimhan. Cadet: A case-based synthesis tool for engineering design. *International Journal of Expert Systems*, 4(2):157–188, 1992.

[9] S. Szykman, J. Senfaute, and R. D. Sriram. Using xml to describe function and taxonomies in computer-based design. In *ASME Design Technical Conferences, 19th Computers and Information in Engineering Conference*, New York, NY, USA, September 12-16, Las Vegas, NV 1999. ASME, ASME Press. DETC99/CIE-9025.

[10] David G. Ullman. *The Mechanical Design Process*. McGraw-Hill, Inc., 1992.