Archiving Engineering Design Process, History, and Rationale

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Abstract

The aim of archiving engineering data for long term storage and for short term collaborative design remains blocked by numerous obstacles arising from the nature of engineering data and design processes. This paper introduces three research initiatives addressing these obstacles in the contexts of undergraduate education, cutting edge robotics, and industrial manufacturing.

Introduction

Imagine a world without any search engines, a shadowy Internet with inaccessible data. What you're imagining is largely the state of the engineering domains, worlds in which the information revolution has yet to sweep through. Engineers produce large volumes of data, often complex mathematical data in proprietary format. That is, data on which text searching is useless. This is but one of the problems faced by the effort to create an engineering internet, an engineering *cyber-infrastructure*.

The key piece in an engineering cyber-infrastructure is a digital archive[2, 3, 8, 11, 13]. The archive must be populated in a way that does not disrupt the engineer's design process. The collected data must be stored according to some model, which has proven to be challenging to create[9, 10]. Clever algorithms and techniques must be created to search the complex geometric data. And access controls must be designed in a way that protects intellectual property without crippling the system[14]. All these are issues of knowledge management.

Knowledge management in engineering domains is an increasingly important sub-activity in design. Artifact complexity and the diverse array of associated design, integration, and analysis tasks continue to grow even as design cycles shorten. Engineers are faced with using, maintaining, and building ever larger part catalogs, corporate histories, and project databases. Further, there is increasing interest in and need for using design knowledge to support the entire product lifecyle, particularly for long-lived artifacts.

Addressing these issues raises a number of difficult problems. Engineered parts and assemblies may be extremely complex, requiring large volumes of data that must not only be stored, but organized and made easily accessible. Design is also increasingly multi-disciplinary, producing artifacts that span domains such as mechanical, electrical, material, and biological engineering. The modern design process incorporates many different elements, including detailed geometric design, assembly design, visualization, process planning, and a number of simulation and analysis methods[4]. Each of these tasks are in turn associated with a bewildering array of software tools which are typically incompatible and reliant on specialized, proprietary digital file formats. Exacerbating these issues, product lifecycles may span decades or more, requiring storage, retrieval, and other archival tasks that will stay relevant, usable, and useful throughout many cycles of technological obsolescence in both design tools and archive infrastructure.

This paper overviews research addressing these challenges to developing digital archives for engineering data. It reports observations based on several archiving projects, and overviews basic research in support of engineering archives. Specific projects discussed range from archives for college-level education and engineering research to industrial design and manufacturing.

Research Initiatives

Engineering Repositories for Undergraduates

For future engineers to embrace fully the information revolution, they must be familiarized with the paradigm as they develop the practices they'll carry with them through their professional carers. That is, future engineers must be exposed to the technologies and practices of the information revolution as they receive their undergraduate education[12]. This is the goal of the Cyber-Infrastructure-Based Engineering Repositories for Undergraduates (CIBER-U) project, to demonstrate the viability of a small-scale, multi-university cyber-infrastructure for education and training.

The National Design Repository[1] of Drexel University will be used in the implementation of this infrastructure. For this undertaking, new archiving patterns and architectures will be developed to tackle the challenges posed by using collaborative engineering archives in an educational setting. Broadly these are challenges of informatics, issues relating to data entry, control, retrieval, and reuse.

The current interface to the National Design Repository allows case-by-case submissions, requiring a great deal of overhead work for the repository maintenance team as well as the group submitting the models. To be effective in an educational setting, this process must be streamlined so that students may enter material as it is developed; this raises a tension between administrative automation and quality control that must be addressed.

Once the data is entered and stored, the issues of searching, sharing, and securing the data become paramount. The applicable search techniques fall into two categories, artifact based searching and meta-data based searching[5, 6, 7]. When a user finds a desired item with one of these techniques, he must still have the proper authorization to view or use the content. The need for role-based viewing to allow a more nuanced approach to this information management will be explored.

The first iteration of this project is already underway, encompassing over one hundred students. The project will ultimately involve over 1,700 undergraduate students ranging from freshmen to seniors. For this undertaking, it will be necessary to identify the best practices for CAD model reuse in the freshmen-,

[1] http://edge.cs.drexel.edu/repository/frameset.html

sophomore-, junior-, and senior-level engineering design courses. These audience-dependent best practices also need to define how the students can design collaboratively, using the repository as a shared data interface. Ultimately, these best practices along with assessments of the educational experience will drive revisions to all other aspects of the cyber-infrastructure.

Engineering Informatics

Significant benefits in terms of quality, cost, and time can be obtained by replacing current engineering design practices with *in silico* substitutes. Such computer systems can radically reduce or eliminate the need for physical prototyping and can be used to automate some design tasks, freeing engineers to pursue higher level design issues and problems. However, these systems require a comprehensive, multi-disciplinary engineering model for any system in question. This project intends to create such an engineering model in the domain of snake-inspired robotics.

Highly articulated, snake-inspired robotics represents an important new frontier in autonomous robotic systems. Traditional robotic systems are unsuited for a variety of important tasks, owing to difficult terrain or mission requirements. For example, search and rescue missions in complex urban environments require devices that can maneuver in collapsed buildings, through ductwork, and around other obstacles. Snake-inspired robots may also be useful for planetary surface exploration, minimally invasive surgery, and inspection of piping, ships, containers, and other structures too cramped for traditional robotic systems.

The domain of snake-inspired robots presents a number of multidisciplinary challenges. Mechanical engineers need to fit actuators and batteries into robot modules, which are volumetrically constrained due to the necessity for a small body diameter. Building these robots cost effectively requires innovative manufacturing practices, relying on chemical and materials engineering. The challenge of getting these mechanical structures to move and maneuver without active wheels or legs given a small area of terrain is another daunting task, requiring simulations, formalisms, and prototypes from computer scientists and mathematicians, complex control systems from electrical engineers, and innovative designs from mechanical engineers.

This multi-disciplinary domain is used in our Cyber-infrastructure demonstration project, Engineering Informatics, to show and explore how to more deeply connect different sub-fields of engineering and computer science. The main objective of this project is to create a comprehensive *engineering model* that will include semantic descriptions of robotic components, behavioral and simulation software, software for snake robot control and navigation, as well as the tools needed to perform analysis, component surrogation and mission assessment. (This effort will be undertaken as a coordinated set of multidisciplinary courses developed by the principle investigators and concurrently taught via eLearning systems across the partner institutions, the University of Wisconsin, the University of Maryland at College Park, the University of North Carolina, and Drexel University.) Another demonstration objective is to create an online archive for engineering models accessible through a "Source Forge"-like website. This will include tools for design collaboration and information sharing, as well as the distance learning and educational materials. The team will use this to define components and tools needed to advance the state of the art in snake-inspired robotic systems. This repository will be made available over the Internet and provided for use by educators and researchers around the country and the world.

Digital Engineering Archives

For many industries, engineering design and manufacturing data needs to be preserved over 50 to 75 year lifespans. Traditional digital data management techniques are usually dependent on the proprietary formats of commercial software systems and cannot guarantee the readability and utility of data over long periods. Hence, while 3D CAD modeling has become indispensable, the engineering part print (i.e., the 2D drawing) still remains a principal method of design knowledge archiving. The rich knowledge in 3D CAD about features, manufacturing processes and artifact behavior are simply lost in translation.

The Digital Engineering Archives project (DigArch) attempts to address this problem by developing representations and algorithms to archive 3D CAD objects. The approach is to augment shape-based representations with formal models of engineering semantics and domain-driven segmentation algorithms. The rationale is that low-level shape information is representationally straightforward, and easily preserved; whereas native CAD/CAM formats are proprietary and notoriously hard to "preserve," even across incremental product versions. Engineering semantics will be captured using emerging W3C, Semantic Web, ISO and NIST standards—formalisms that will need to be extended to handle new datatypes specific to complex engineering artifacts. These will be mathematical logics described in the non-proprietary syntax of international standards, and thus also easier to preserve than proprietary representations. Lastly, techniques from databases will be extended to extract and populate these representations from existing design tools and engineering documentation.

This approach forms the basis of a toolkit to create and search engineering archives, a set of tools to be developed and tested in collaboration with the government/industrial partner Honeywell FM&T. This project will include close cooperation with the Department of Energy's Advanced Design and Production Technologies Initiative (ADAPT) team to apply techniques developed in this research to indexing and storage of engineering data used at the Kansas City Plant (KCP). The objective is to extract data to create Digitial Engineering Archives, enable answers to meaningful engineering queries on archives of 3D engineering knowledge, and support long-term engineering knowledge preservation. The relationships among shape and form, structure and function, and behavior and semantics are among the most fundamental questions studied by science and engineering. It is precisely these relationships that must be captured in Digital Engineering Archives. While these problems are large in scope, by focusing on the vital domain of discrete part manufacturing, this project is poised to produce theoretical results, novel techniques, and prototype systems. The aggregate output of the proposed project includes advancements in representation and retrieval algorithms, as well as contributions in basic computer science and engineering design and manufacturing.

Conclusion

This paper presents the above three projects, exploring the basic issues and problems along with the approaches and research taken toward their resolution. By relating these initiatives it is hoped this paper will contribute to an understanding of the need for archiving in engineering design, the many challenges encountered therein, and potential solutions.

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