A Survey of Engineering Framework Technology with Applications to Computer Aided Engineering

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Submission for Review

December 18, 1995

6th Int'l. Conference, Flexible Automation & Intelligent Manufacturing (FAIM 96), May 13-15, 1996, Atlanta.

Abstract

This paper surveys engineering framework technology and its potential benefits to collaborative engineering, with a particular focus on computer-aided engineering (CAE). A framework is a software infrastructure that enables engineering tools to interoperate (work together). Representative research and development efforts are overviewed, and their contributions to the key technologies are identified. While industry examples to date have been mostly pilot projects, it appears this field is developing rapidly and moving towards mainstream usage in the near future. Hence, this survey recommends becoming more acquainted with framework technology, and it identifies guidelines established by the National Industrial Information Information Protocols Consortium (NIIIP) as a suggested starting point.

An HTML version of this survey is available online that links to associated documents on the World Wide Web. Thus, as a secondary effect, this paper demonstrates how the Web can be used as a research tool.

Keywords

CAE, engineering framework, software infrastructure, interoperability, integration, collaborative engineering, agent, NIIIP, STEP, World Wide Web

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Notes to Reviewers: Whereas this version was printed directly from a Web browser, the final version will be formatted per the requirements and meet the page limit. The contents listing will not be included in the conference version.

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Because of the survey nature of this paper, it is also available as a World Wide Web document at the following address:

http://www.cad.gatech.edu/dai/pubs/conferences/faim96/

All underlined phrases are hypertext links to other documents containing more information. Thus, the best way to read this paper is from a Web browser. Select a link and the related document will be displayed. As many of the links are to Web documents on computers maintained by other organizations, I cannot guarantee they will always be available.

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1 Introduction

This paper overviews a trend that is likely to broadly impact computer aided engineering (CAE) in the near future. Rather than surveying traditional computational techniques, it focuses on engineering framework technology as a means to incorporate such techniques more effectively into the product development process.

Consider the following scenarios:

1. You have developed a specialized CAE system that will be used by a variety of internal and external customers. Some of those customers already have large investments in general purpose finite element analysis (FEA) software from different vendors. These customers tell you, "I want to use your system, but I don't want to buy another FEA program. Can I use Vendor A's FEA program with your system instead?" With framework technology, the answer would more likely be "yes".
2. You are developing a new CAE package that needs extensive geometric modeling

capabilities. Several geometric modelers already are available that will meet your needs. But how can you connect your new CAE program with these tools? With framework technology, a straightforward solution would be more likely.

3. A certain analysis problem needs to be solved using a sequence of several CAE tools. However, different versions of these tools are installed on a variety of computers. Because you will perform this analysis many times, you are wondering to what degree you can automate the solution process (i.e., the sequencing of tools and transfer of data). If a framework is used, full automation may be possible.

Much of the CAE effort to date has focused on the numerical computational aspects of engineering problems and the creation of individual tools. However, as the above examples indicate, applications that require the *information-intensive cooperation of these tools* are becoming increasingly apparent [Genesereth and Ketchpel, 1994]. The term **engineering frameworks** (FWs) is used here as the technology that enables such cooperation. The CAD Framework Initiative defines a framework as:

> *"... an infrastructure of software and interfaces that enable the integration and interoperability of [engineering] systems"* - CFI FAQ

Through engineering FWs, one can more easily take advantage of existing tools, as well as maximize the benefits of new tools.

Recent concepts such as concurrent engineering, collaborative engineering, virtual enterprises and agile manufacturing are the primary drivers behind much of the research and development in engineering frameworks. In the extreme, the goal of such trends is to enable the efficient development of products by geographically distributed, multi-company teams using diverse computer tools. However, the techniques used to solve this more general problem can benefit even small groups within the same company.

From another view, engineering frameworks are part of the answer to the question *"How do we connect people, their models, and their tools?"*. Olsen [1994] poses this question and overviews issues and current approaches. His proposed answer, summarized in the following figure, could be viewed as a kind of **agent-based engineering framework** [Huyn et al., 1993].

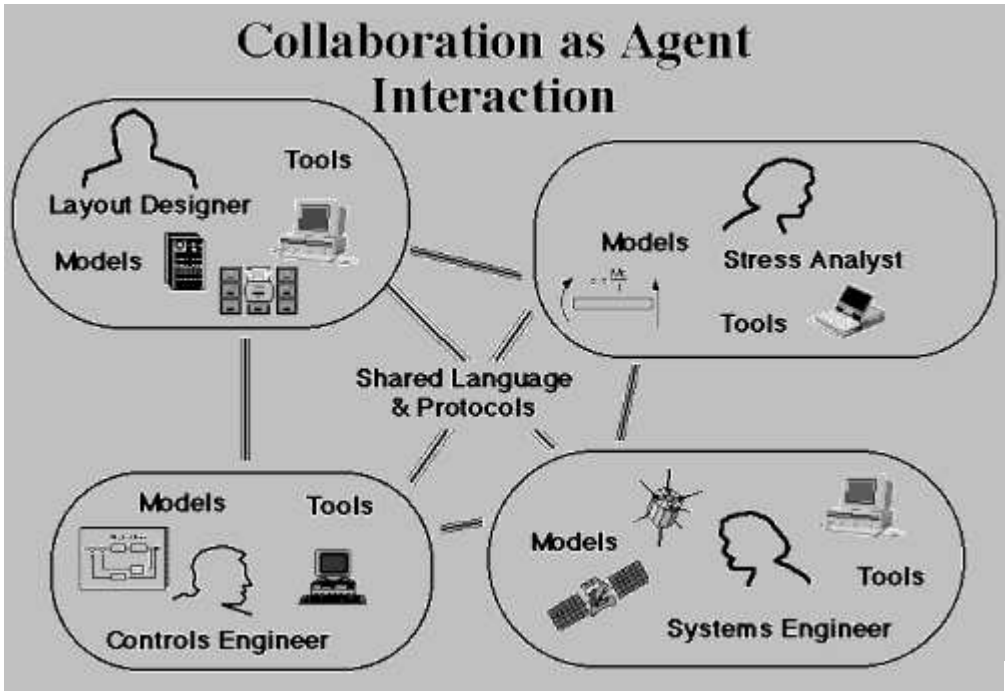

Figure 1 Agent Interaction [Olsen, 1994]

Based on Figure 1, engineering FW technology can roughly be divided into the following areas:

- **Tool Communication** - how to provide inputs to a tool and request outputs. Topics include interoperability, tool encapsulation, wrappers, and application programming interfaces (APIs).
- **Information Representation** - how to represent models in a computer-processable manner that can be shared among tools. Related areas are product modeling and knowledge representations like objects and constraints.
- **Control** - how to manage higher-level issues such as sequencing of multiple tools, coordination of multiple users, and consistency of shared information. Techniques include agents and knowledge-based management systems.

2 Representative Research & Development Efforts

This section highlights representative efforts of varying sizes as starting points to explore this emerging field. Some of the below descriptions come directly from the associated Web pages. Typically each Web server contains overviews, technical documents, and public domain software.

2.1 Electronic Commerce Resource Centers (ECRCs)

The U.S. Congress recently initiated the not-for-profit ECRC program under the direction of ARPA (Advanced Research Projects Agency). The program is a nationwide network of 11 regional

ECRCs coordinated by one national office. The main purpose of the ECRCs is to help companies implement electronic commerce and related technologies (including engineering frameworks, design-analysis integration, and STEP). A national Technology Hub reviews and develops needed technologies, and makes recommendations to the regional ECRCs.

The existence of this initiative illustrates the important role that information technology is believed to have in keeping companies competitive. It also emphasizes how information technologies like engineering frameworks are needed to help CAE fit better into a company's overall business purpose.

Examples - ECRC News [ECRC, 1995] reports a wide variety of industrial examples including manufacturing (Harley-Davidson) conversion of existing paper drawings and documents (a railroad equipment manufacturer, and the U.S. Air Force), and better CAE models (Trintex, a rubber tire manufacturer).

2.2 CAD Framework Initiative (CFI)

CFI is an international not-for-profit consortium seeking to provide industry-accepted standards and technology which enable interoperability of electronic design automation applications. CFI's membership consists of over 40 companies including CAD/E end-users and vendors, and workstation and semiconductor suppliers. Example members are electronics companies like AT&T, Hitachi, IBM, Motorola, Sony, and Toshiba, as well as electrical CAD vendors like Cadance and Mentor Graphics. While their primary focus is electrical engineering design automation, many of the techniques they are developing appear equally applicable to mechanical CAD/CAE (especially in the Tool Communication and Control areas identified in the Introduction).

CFI is developing public specifications which CAD/CAE vendors can use to create interoperable, engineering framework-based tools:

- Design Representation Programming Interface - basically product models for electrical design.
- Computing Environment Services
  - Extension Language:
    - Core Language Selection
    - Scheme-Based Extension Language
  - Base Networking Services Guidelines
  - Base System Services Guidelines
  - Base User Interface Guidelines
  - Error Handling Programming Interface
- Message Dictionary Specification (draft)
- Tool Encapsulation Specification (draft) - defines a standard way to wrap tools (including existing ones) so they can be used in a framework.
- Tool Manager
- Task & Session Model

Where possible, CFI is using or cooperatively extending existing standards and specifications (e.g.,

Common Open Systems Environment (COSE) and ToolTalk for inter-process and inter-application communication).

Combined, the above is similar to the Open Architecture in SDRC IDEAs and the Falcon Framework by Mentor Graphics; however, CFI standards are public and designed for wide-spread industrial use rather than being vendor-specific, quasi-proprietary interfaces. One aim is that vendors like SDRC and Mentor will adapt their tools to support CFI standards, thus enabling them to interoperate in a much broader framework.

Examples - The Web server at CFI has information about industrial examples to date, including an online interoperability demonstration.

Software - At present CFI sells a CFI DR Toolkit (supporting the Design Representation specification for electrical design). Toolkits for other specifications are planned.

2.3 STEP

STEP (Standard for the Exchange of Product Model Data) primarily plays a role in Information Representation - particularly for product models, which can form the basis for CAE models. STEP Part 104 addresses finite element (FE) meshes, and other STEP efforts exist related to engineering analysis.

Examples, Software, etc. - Appendix A overviews STEP and provide examples of industrial usage, available software, and references.

2.4 Enterprise Integration Technologies (EIT)

EIT is an R&D and consulting company specializing in information technology for electronic commerce, collaborative engineering, and agile manufacturing. Their past and present projects are often agent-based and include PACT [Cutkosky, et al., 1993], the ARPA Knowledge Sharing Effort (KSE) and ARPA Manufacturing Automation and Design Engineering (MADE). They collaborate with companies like General Motors, Lockheed, Martin Marietta, and Texas Instruments, as well as with universities and industry consortium like NIIIP.

Their server has publicly available information such as project descriptions, demonstrations, technical information, and software. They are the developers of SHTTP (secure hypertext transfer protocol), a more secure version of HTTP that can be used for Tool Communication over the Internet when proprietary issues are involved.

2.5 ARPA Knowledge Sharing Effort (KSE), et al.

KSE, an ARPA-sponsored consortium that includes the Stanford Knowledge Systems Lab and EIT, is aimed at enabling collaborative engineering. They are continuing to develop public-domain specifications and software implementations of supporting technology, as well as a reusable public library of proof-of-concept demonstrations. For example, they are the developers of KIF (Knowledge Interchange Format), ACL (Agent Communication Language), and KQML

(Knowledge Query and Manipulation Language) [Genesereth and Ketchpel, 1994]. KIF is an information representation language that appears more capable than STEP EXPRESS for representing knowledge such as constraints (general multidirectional relationships among objects).

Related projects are SHARE (part of MADE) and SHADE involving EIT, Lockheed, Xerox, and others. The latter reports the development of ontologies (information models) of engineering entities ranging from mathematics to physical laws to elevator components. They emphasize collaborative CAE; however, thus far they apparently have not dealt with problems that require discretized representations like finite element models (FEMs).

Their servers offer public domain tools and many online papers, including Olsen's Concur, and his overview of agents and their engineering applications [1994]. Genesereth and Ketchpel [1994] provide an overview of the agent-based framework theme that is common to much of the above work.

Examples - PACT [Cutkosky, et al., 1993] demonstrates the multidisciplinary design of a robotic manipulator, including dynamics, controls, and electronics. Khedro, et al. [1993] show how agent-based frameworks can be applied to facility engineering (integrated structural design, architectural design, and project planning for buildings). The Concur pages highlight examples that use agents for Mathematica, MathCAD, and IDEAs.

Software - Tools for creating and manipulating KIF, ACL, and KQML are available, as well as a series of ontologies (written in KIF). SHADE offers the agents mentioned above.

2.6 Concurrent Engineering Research Center (CERC)

The Concurrent Engineering Research Center at West Virginia University is part of the DICE initiative begun in 1988. Their primary mission is "the advancement of enabling technologies for the collaborative enterprise." CERC concentrates on the development of generic computer technologies to help manufacturing organizations become collaborative enterprises. Validation of these generic approaches has been carried out using engineering applications (e.g, aircraft engine turbine blade design at General Electric and electronic system design at Westinghouse), and has continued in other arenas as well (e.g., real-time patient treatment for the National Library of Medicine). CERC's Web server contains *Concurrent Engineering Research in Review*, collections of concurrent engineering abstracts and references, and an archive of their technical reports.

Software - CERC's Information Sharing System (ISS) is aimed at the dissemination of heterogeneous information in a heterogeneous computing environment. In the Tool Communication area, this system uses the HTTP protocol to support client-end interoperability and OMG CORBA specifications for server-end interoperability. Web*, a major component of ISS, is a tool for publishing dynamic information.

2.7 CALS Technology Center

Initiated with a focus on the DoD CALS program, the Georgia Tech CALS Technology Center is aimed at the development and application of information technology to solve engineering problems in a wide variety of industrial contexts. Related projects include design-analysis

integration, multidisciplinary design optimization, and LEGEND (an experimental framework demonstrating how a "centralized definition" of design entities combined with "distributed instantiations" provides a balance between information control and efficiency [Stephens, 1993]). Peak, et al. [1995] utilize agents in an engineering framework to enable highly automated integration of design and analysis, with examples from solder joint fatigue.

Examples - Warner Robbins Air Force Base has been a major customer for several years with an emphasis on improved geometric data conversion via IGES. Recent additions to the Center include the Atlanta Regional ECRC, an aircraft maintenance program with the FCC, and an ARPA-sponsored project on printed circuit assembly design-analysis integration (being carried out jointly with companies that include Boeing and PDES, Inc.).

2.8 Object Management Group (OMG)

The OMG is a non-profit consortium dedicated to promoting the theory and practice of object technology for the development of distributed computing systems. OMG was formed to help reduce the complexity, lower the costs, and hasten the introduction of new software applications. Their goal is to provide a common architectural framework for object-oriented applications based on widely available interface specifications. International membership currently stands at over 500 software vendors, developers, and end users.

Thus far, OMG has developed the following guidelines and specifications to achieve the above goal based on member company recommendations.

- *The Object Management Architecture Guide* contains the central design guideline (the Reference Model) used by OMG to create a distributed object computing environment (Figure 2).

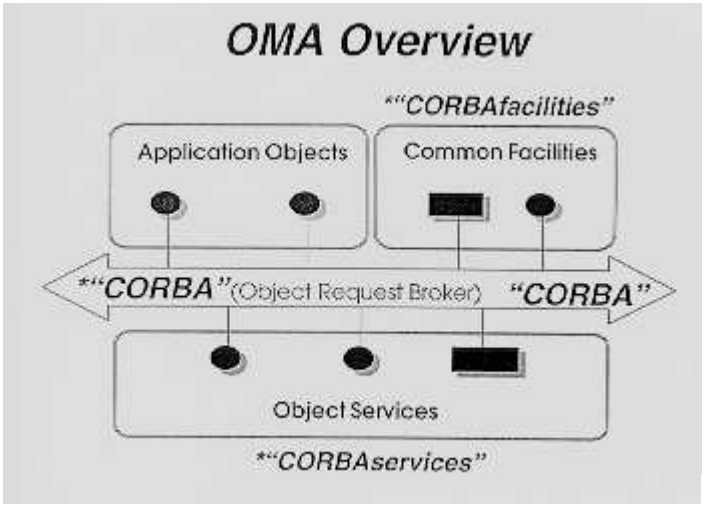

Figure 2 The Object Management Architecture [OMG]

- *The Common Object Request Broker: Architecture and Specification* (CORBA) defines the mechanisms by which objects transparently make requests and receive responses, as defined

by OMG's ORB. The ORB provides interoperability between applications on different machines in heterogeneous distributed environments and seamlessly interconnects multiple object systems. It is the cornerstone of OMG's architecture.

- *CORBAservices* includes the first eight fundamental services needed to realize and maintain objects within a distributed computing environment.
- *CORBAfacilities* are a collection of higher level servicers broadly applicable to many applications or high value capabilities for specific domains or vertical markets.

Examples - Two engineering applications of OMG's CORBA are a recent NIIIP demo and the CERC ISS tool mentioned above.

2.9 National Industrial Information Infrastructure Protocols Consortium (NIIIP)

NIIIP is a team of organizations sponsored by the U.S. Government to develop open information infrastructure technology to support *virtual enterprises* (a temporary team of companies which come together to exploit worldwide product manufacturing opportunities). Rather than developing all the technology themselves, NIIIP is attempting to assemble existing industry software protocols to form their framework. Where needed, they propose extensions to such protocols if there are gaps in capability.

For example, their Reference Architecture (Figure 3) proposes a combined use of existing protocols from the Internet, OMG, STEP, and CFI efforts. Their document defines the four key technologies in their reference architecture, and discusses existing and needed solutions for each. Roughly, technologies #1 and #2 are what were identified in the Introduction as Tool Communication, while #3 corresponds to Information Representation, and #4 to Control.

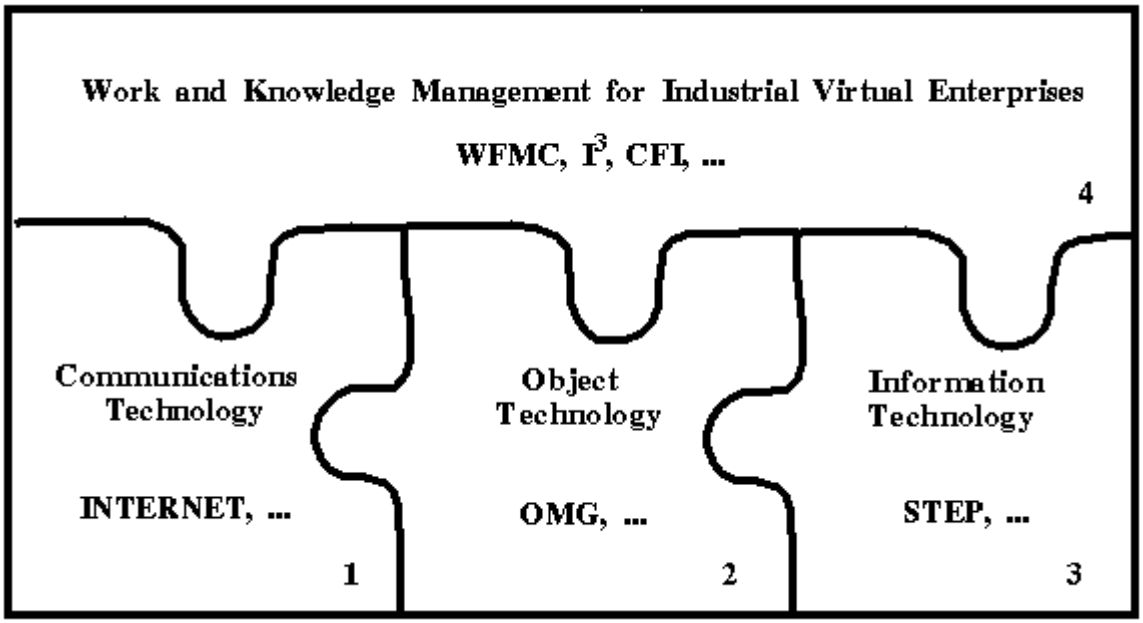

Figure 3 NIIIP Reference Architecture [NIIIP, 1995]

The NIIIP document can be considered as one reference for collaborative computing and engineering frameworks in general (it indirectly provides an overview of the state-of-the-art, and contains a glossary of terms and acronyms). It provides one view of how the technological pieces highlighted in the above R&D efforts can be brought together to "connect people, their models, and their tools."

Examples - Their approach appears promising based on a demonstration at a recent STEP meeting. They demonstrated collaborative access to axle information (including geometry and assembly) over the Web between CAD tools like AutoCAD and ProEngineer using STEP AP203, OMG CORBA, HTTP, and HTML protocols.

3 Recommendations & Potential Benefits

With the wide range of current developments, it is difficult to predict which techniques will prove successful in the long term. There are overlaps in current efforts (e.g., STEP EXPRESS vs. OMG IDL vs. KIF), as well as gaps (e.g., no standard representation of FE preprocessor models). Other challenges are identified by NIIIP [1995] such as security and how to take advantage of agents.

Suggested Approach

If a company is interested in learning more about framework technology, one approach is to evaluate the NIIIP Reference Architecture [NIIIP, 1995] and try out its recommendations where appropriate. As NIIIP membership includes a diverse group of significant players in this area (e.g., CFI, IBM, EIT, NIST, and STEP vendors), their approach is likely to be acceptable to a wide industrial audience.

A company could begin by reproducing a similar prototype framework internally and demonstrating it for a CAE application. This exercise would help a company become more familiar with the key technologies and better understand the benefits as well as challenges. Some of the software components are available in the public domain (e.g., Internet protocol daemons and STEP parsers).

Though agent technology has apparently not received as much industrial exposure as the above components, interested companies may do well to explore it also. The software and demonstrations mentioned from KSE, et al. provide a one starting point.

Possible Applications

After a prototype like the above is in place, a company could then build upon it to test applications such as:

- Creation of specialized CAE tools based on general purpose analysis tools.
- Design-analysis integration, including wrapping of existing FEA tools for highly automated use [Peak, et al., 1995] .

- Interaction of global/local or micro/macro models based on a common higher level description (e.g., via CIF, a kind of product model for LSI packages [Shepherd, et al., 1994]
- Creation of general CAE tools from functional parts (e.g., using existing geometric modeling tools).
- Development of CAE tools that can be used by other tools (i.e., tools that fit into a broader framework).

Overall, information technology, in general, and framework technology, in particular, could help a company better integrate its CAE tools into the product development process - linking CAE closer to the business of making high-quality products.

Since engineering framework technology is a rapidly growing field, it is easy to get lost in all the information available. It is helpful to keep in mind Olsen's basic question (how to connect people, their models, and their tools), and to consider solutions to the three basic areas identified: Tool Communication, Information Representation, and Control. One must be watchful for the general techniques that exist amidst the specific applications driving this technology - techniques that can be applied to CAE and benefit a company. The R&D efforts highlighted in this report can be used as starting points to learn more about such techniques.

4 Acknowledgements

The Internet resources made available by the above organizations greatly aided the creation of this survey. Special thanks goes to the following people at Hitachi, Ltd. for supporting this work: Ichiroo Nishigaki, Noriaki Okamoto, and Michihiro Watanabe.

The views expressed in this paper are those of the author and may or may not reflect the views of Hitachi, Ltd.

5 References

Some of the below references or related information are available on the World Wide Web at the indicated addresses (some are available both online and in printed publications). To see these and other Web addresses, please access them from the HTML version of this document using a Web browser.

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Appendix A - A STEP Sampler

What is STEP? How can it help me and my company? The aim of this Sampler is to point you in the right direction for answers to such questions. As the title implies, it is not a comprehensive guide, but hopefully it will assist you in getting started.

Sampler Contents

- Suggested Starting Points
- Internet Resources
- References
- Software Providers
- Industrial Usage Examples

Because this Sampler is long and contains numerous hyperlinks, it is available as a Web document at the following address:

http://www.cad.gatech.edu/dai/pubs/web/step-sampler/