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Overview and Vision of the NIST Engineering Design Technologies Group

Group Leader: Ram D. Sriram
Full Time Staff: Peter Hart, Kevin Jurrens, Kevin Lyons
Visiting Researchers: Scott Angster, Haeseong Jee, JungHyun Han, Russell Kirsch, Mike Pratt, PVM Rao, Rachuri Sudarsan, Peter Wilson
Post Doctoral Fellows: Scott Chase, Ronald Giachetti, Mark Schwabacher, Simon Szykman
Secretary: Tricia Stieren

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U. S. Department of Commerce
Michael Kantor, Secretary

Technology Administration
Mary L. Good, Under Secretary for Technology

National Institute of Standards and Technology
Arati Prabhakar, Director

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Engineering Design Technologies (EDT) Group
Manufacturing System Integration Division
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899
E-mail: sriram@cme.nist.gov

1. Introduction

The realization of an engineering artifact is a multistage process, which involves identifying a need for the artifact through market surveys, developing requirements or constraints, generating designs, manufacturing the artifact, testing for quality, marketing, and maintaining the artifact throughout its life cycle. Engineering design plays a critical role in the above iterative and collaborative process. Decisions made during engineering design stage govern life cycle costs. Various studies indicate that errors made during early stages of design tend to exponentially contribute to the cost of the final product. For example, an error which costs a thousand dollars to fix in the early design stage may require nearly a million dollars to rectify in the production stage. While there is a trend toward shifting manufacturing activities outside the U.S., we are still the world's leading innovator in designing products (as is evidenced by the number of patents issued). Hence, the ability of U.S. industry to compete in global markets may depend on how well we preserve and leverage our intellectual resources in engineering design technologies.

Roadmap to the document. A framework for collaborative design, described in Section 2, provides the current rationale for the technical focus of the design group. The vision and mission statements and our strategy for achieving our mission are provided in Section 3. Details of our technical approach and a five year plan are the subjects of Sections 4 and 5, respectively. Brief biographies of technical staff and the FY 95 publication list of the staff are included in Sections 6 and 7, respectively. Sections 8 and 9 detail our collaborations with academia and industry. Summaries of several ongoing projects are provided in Appendix A.

2. A Framework for Collaborative Design

Recent trends in computing environments and engineering methodologies indicate that the future engineering infrastructure will be distributed and collaborative, where designers, process planners, manufacturers, clients, and other related domain personnel communicate and coordinate using a global web-like network. Since the focus of the EDT group is design, we concentrate on the design environment,with an example of a future collaborative design framework shown in Figure 1. In this design environment, various designers (or agents) collaborate through a design net. Four representative design tasks are shown in Figure 1, where Synthesis involves generating various design alternatives; Visualization involves visual information processing, such as virtual reality applications, virtual shared workspaces, and issues related to the interfaces between humans and the computer; Simulation involves creating a representative computer-based model of a system, analyzing the system, and evaluating the predicted output for various input sets (e.g., solid/finite element analysis or physics-based modeling); Work flow/PRP focuses on task decomposition, task allocation, and product realization process (PRP) models.

The designers in the above framework may be using heterogeneous systems, data structures, or information models, whose form and content may not be the same across all disciplines. Hence, appropriate wrappers (as depicted by the black boxes) or standard exchange mechanisms are needed for realizing the full potential of sharing information models. An integral part of the design environment is the storage mechanism, which is envisioned as an object-oriented database. This storage mechanism is distributed and contains design histories, part data, design versions, and other related information. The data/information may reside in different databases. Access to the various databases and the application programs could be achieved through object request brokers or a similar mechanism.

3. Vision and Mission

The NIST Manufacturing Systems Integration Division established the Engineering Design Technologies (EDT) Group to identify the critical design needs of U.S. industry and to develop information models that address these needs. The vision of the EDT group is to *be a world leader in the development of technology and standards in support of mechanical/electromechanical design (product, process, and enterprise) environments needed for U.S. industry to maintain preeminence in the global market place.* To achieve the above vision our mission will be to: develop the enabling technologies for future design tools and the technical basis for future standards; participate in various design-related standards efforts; and establish an engineering design testbed for technology transfer.

Technology Development

Our efforts in technology development are directed toward working with the U.S. industry to solve complex design problems. We strive to achieve our goal by participating in leading research efforts that will eventually lead to novel design representations and problem solving techniques. This, in turn, may result in information models (product and process models) that will form the foundations for future standards. There are two tracks that the EDT group will follow in technology development: development track and research track. Our development track will focus on the following aspects of technology development: sponsored projects by other government agencies and industry consortia that are pertinent to NIST's mission; and projects leading to future design standards. Current projects in this area include virtual reality interfaces, product and process modeling, and engineering ontologies. Our research track will focus on projects related to the National Research Council (NRC) post-doctoral research program and related to NIST's core mission. Current interests and work within the research track are in design for assembly, assembly level tolerancing, constraints modeling, optimization, and representation issues in product modeling.

Standards

A computer supported distributed and collaborative design environment would involve the interaction of various heterogeneous applications. A key issue in achieving this will be the development of appropriate communication and representation mechanisms. Standards are very critical to these communication and representation mechanisms.

A standard of primary interest to EDT is ISO 10303, also known as STEP (Standard for the Exchange of Product Model Data) and developed by the ISO TC 184/SC4 standards committee. STEP has been under development for more than ten years, within both the U.S.-based Product Data Exchange Using STEP (PDES) effort and the ISO TC184/SC4 standards committee. Its intention is to enable the exchange of product model data between different modules of a product realization system, or the sharing of that data by different modules through the use of a common database. The first parts of STEP to achieve International Standard status were published recently (December 1994), but many other parts are under development and will eventually be added to the standard.

From the design point of view, the initial emphasis of STEP developers has been on shape description. Facilities have been provided for the capture, in standard format, of 2D drawings, 3D wireframes, surface models, and solid models. This reflects the state of CAD technology as it was when the STEP development effort commenced in the mid-1980s. However, CAD technology has progressed since that time, and most major CAD systems now provide facilities for parametric, variational, and/or feature-based design. These systems generate additional information, beyond the pure shape descriptions created by older systems, and STEP currently provides no means for capturing and transmitting this additional information. New efforts have recently started in ISO TC184/SC4 to remedy this situation, but there are substantial technical problems to be solved in finding satisfactory solutions. A related issue is the capture and exchange of engineering tolerance data. A partial solution to this issue is further advanced and the extensions (in certain areas) to STEP are approaching the International Standard status.

We envision working on standards development in several ways. Our near term goals are to: 1) develop, validate, and pursue standardization for information models which propose an electronic representation for manufacturing resources (e.g., machine tools, cutting tools, tool holders, inserts, tool assembles, etc.) within a defined scope; 2) develop appropriate interfaces between the design and planning activities of NIST's SIMA (System Integration for Manufacturing Applications) project; 3) help in the development of a capability for the handling of form feature information in STEP (this is required as a generic resource, useful for a range of applications beyond design itself), and 4) participate in technical discussions on extending STEP to cover parametric and variational models.

Looking further ahead, it is likely that a requirement will soon be formulated for the capture of design rationale information in STEP. EDT has a strong commitment toward understanding and modeling design rationale capture, in particular the types of representation needed to communicate rationale across collaborating applications. Additionally, a requirement is already emerging for a general means of interoperability of intelligent frameworks (or agents), such as knowledge-based systems. Some suggestions for means of achieving this exist (KIF, KQML), but much work remains to be done before a standard proposal can be made; Figure 2 shows a layered communication framework for supporting current and future information exchange standards. An additional area of interest is the representations for product realization process models. The EDT group will be addressing these and other related issues.

Testbed for Engineering Design

To achieve technology transfer, we are in the process of establishing a testbed for engineering design (see Figure 3). The goal of this testbed is to provide a platform for: testing and validating design methodologies, storing and accessing design case studies using appropriate standards (current and emerging), aiding in supplier-chain integration, and helping in various aspects of technology transfer. We are developing close partnerships with government, academia, and industry.

4. Technical Approach

The various technical issues that will be addressed by the EDT group are outlined below.

4.1 Help identify information access needs of small to mid-size design companies [*Technology Transfer*].

Recent changes in international trade pacts and the impetus given to the information highway might require a redefinition of product development boundaries. Large corporations may obtain goods and services from places which offer the best quality services in a cost effective manner. The United States can exploit this shift in product development strategies by developing a strong industrial base of small to mid-size companies. These companies would need to conduct their commerce on the information highway. Although these companies have the intellectual capabilities for performing design/manufacturing services, their use of the information highway for electronic commerce is hampered by a lack of adequate and cost-effective access mechanisms. Our goal is to conduct several workshops to study the needs of these companies for electronic commerce, as related to *engineering design*. We hope to collaborate with other NIST initiatives (such as the Manufacturing Extension Program) in this venture.

4.2 Aid in the dissemination of innovative computer-aided tools and techniques for engineering design [*Technology Development and Transfer*].

Some of these tasks will focus on the development of re-usable software modules, where each software module offers encapsulation and provides the necessary input/output interfaces. Other work will focus on the development of standards for capturing design rationale and the demonstration of a typical application.

Preliminary Design. Tools performing preliminary design take as input product specifications and produce as output a preliminary or conceptual layout. Making such tools available to industry would result in a significant increase in productivity during the initial design stages. EDT's role will be to implement a web-based infrastructure that will allow industry to explore preliminary design tools developed at various research organizations.

Simulation. Simulation (or modeling and analysis) tools determine the response of a system to various external and internal effects. EDT has been working with Washington and Purdue Universities in several cooperative ventures to study how virtual assembly simulation and physics-based modeling tools can be integrated into current design practice. Plans are underway to collaborate with other universities and to help in technology transfer to industry.

Databases. Computer-aided design environments are highly data (and knowledge) intensive and involve complex data representation to emulate the structure and behavior of complicated design entities. We believe that object oriented database management systems (OODBMS) have considerable potential for encoding engineering design information. We will install commercial (and other public domain) OODBMS and will develop appropriate metrics, test cases, and standard access mechanisms that will lead to efficient solutions for engineering design database needs. We plan to collaborate with other NIST laboratories, such as the Information Technology Laboratory, on these issues.

Evaluators. These are software-based critics which evaluate and validate designs and will be knowledge-based. We hope to acquire these evaluators from our collaborators and make them available to the design community through the Engineering Design Testbed. Our efforts will also focus on developing metrics for validating design methodologies.

Geometric modelers (Feature-based Modeling). Geometric modeling deals with the representation and manipulation of the geometric properties of a physical object and is an integral part of any CAE system. There is considerable difference in modeling requirements of various applications at different stages of product development, and we are yet to see a seamless integration of various geometric modeling tools and techniques throughout the product life cycle. There are several modelers in the research environment which claim to address the above problem. We hope to install a representative set and study issues related to incorporating innovative features from these geometric modelers in standards efforts, such as STEP.

Design rationale. Current CAD systems lack the ability to include information about engineering decisions. Encoding design rationale about both the overall process and the individual choice points should be a part of any future CAE tool. We will propose additions to current STEP standards for dealing with design rationale. We will also study how work on product realization process (PRP) can be incorporated in a design rationale framework.

Tools. EDT has acquired several state-of-the-art commercial computer-based design tools. Examples of these are: IDEAS Master Series, MicroStation, Pro-Engineer, etc. These tools can be used by visiting engineers from academia, government, and industry. We will be using these tools to study various standards related issues, in particular information transfer in a collaborative design environment.

Prototype Applications. We will select appropriate applications from industry and will develop prototypes to demonstrate some of the above concepts. These prototypes will also be used as the design application focus in our SIMA (System Integration for Manufacturing Applications) integration effort, which is a major integration thrust of the Manufacturing Systems Integration Division.

4.3 Participate in various national initiatives on design to help in standardization of design product and process models, with a particular focus on collaborative design [*Technology Development, Standards, Technology Transfer*].

There are several major initiatives in engineering design automation, a few of which are outlined below. The EDT group will actively participate in these efforts.

DARPA's Initiatives in Design. The IPPD (Integrated Product and Process Development), MADE (Manufacturing Automation and Design Engineering), SBD (Simulation Based Design), and AM3 (Affordable Multi-Missile Manufacturing) programs at DARPA (Defense Advanced Research Program Agency) focus on several aspects of design which are of interest to the EDT group. Of special interest are: tag team design which aims to develop design rationale and knowledge representation mechanisms for a smooth transition between successive teams of engineers; interoperability between various heterogeneous applications (ACORN, KIF/KQML, etc.); multi-level simulation and optimization; and physics-based modeling and virtual design environments.

TEAM. The Technologies Enabling Agile Manufacturing (TEAM) initiative of the Department of Energy strives to develop a set of computer-based tools to enhance the global competitiveness of the U.S. industry. The key thrust areas are: product design and enterprise concurrency, virtual manufacturing, manufacturing planning and control, intelligent closed-loop processing, and integration of various engineering activities. Of specific interest to EDT is the product design and enterprise concurrency thrust, in particular design product/process representation and knowledge interchange mechanisms for collaborative design.

ADAM. NASA's Affordable Design And Manufacturing (ADAM) initiative seeks to demonstrate various pre-competitive design and manufacturing technologies and the various integration mechanisms for these technologies. ADAM's specific domain is the aircraft industry. Another related effort at NASA is the Affordable System Optimization Program (ASOP).

National Science Foundation (NSF). NSF has several design-related programs, such as the Engineering Design Research Center at Carnegie Mellon University, the agile manufacturing initiative with DARPA, and a division dedicated to design and manufacturing tools, techniques, and integration.

Other Related Research. Various research efforts by academia can be found under the following world wide web locator: http://cs.wpi.edu/Research/aidg/AIinD-hotlist.html.

4.4 Participate in the development of appropriate storage structures for design case studies (or application notes) [*Technology Transfer and Standards*].

The Design Case Study Framework (DCSF) will involve the development of standard mechanisms for storing and accessing design product and process knowledge (see Figure 4). These standard mechanisms will be used to store design case studies, that we propose to acquire from various sources. DCSF will be developed as a layered structure, with the lowest layer being a database management system (most probably an object-oriented database management system) and the top layer consisting of various knowledge level editing utilities (e.g., store, edit, retrieve, etc.). The knowledge level structures will describe function, behavior, structure (including geometry), design rationale, and intended use.

4.5 Perform research toward the development of standards for the seamless interoperability of various CAD/CAE/CAM applications [*Technology Development and Standards*].

We envision the interoperability problems between heterogeneous engineering applications to occur at several levels. These levels are shown in Figure 2, and described below.
Physical: This level is concerned with the physical transmission medium, such as Ethernet, fiber optics, etc.
Object: At this level, the engineering objects are transported using appropriate object transfer modes, such as CORBA (Common Object Request Broker Architecture).
Content: This level deals with the communication of engineering artifacts, and should include feature, constraint, geometry, material, process, etc.
Knowledge/Design Rationale: This level deals with design rationale and design history issues, which provide additional information (including inference networks, plans, goals, justifications, etc.) about the engineering objects at the Content level.
Communication: This level provides additional detail to the Content and Knowledge/Design Rationale levels. Such details include the specification of engineering ontologies used, sender, recipient, etc., as defined by the KQML standard.
Negotiation: Any multi-agent activity will involve negotiation activity. The protocols needed to conduct such negotiations will be defined at this level.

The EDT's focus will be the content, knowledge/design rationale, and communication levels. The group aims to address information and knowledge transfer standards between various design applications, such as synthesis and simulation, and between design and other life cycle applications, such as process planning, production, etc. (see Figure 5). In particular, we will be working on the following areas: using IS0 10303-AP 203 to develop a proposed solid interchange format for CAD to solid freeform fabrication, activities of the ISO Parametrics Group, interfaces between augmented CAD, knowledge-based CAD, and traditional CAD for assembly modeling, and the development of engineering ontologies in KIF and EXPRESS.

4.6 Work closely with both industry and other government agencies in helping with design related needs [*Technology Development and Transfer*].

The EDT group is committed to working with industry and other government agencies in several modes: assist in developing future technology road-maps; help in technology transfer from research into practice; participate in national and international standards development; and develop an exchange visitor program with various agencies.

5. Five-Year Plan for Fiscal Years 1996 through 2000

The following activities constitute all design related programs within the Engineering Design Technologies group (see Table I).

5.1. Lead research activities related to engineering design, in particular Design Process Modeling, Design Rationale, Virtual Design Environments, Design for Environment, Modeling of Manufacturing Resource Data (as related to design) and Design for Assembly.

Current Projects: As listed in the appendices

Future Projects: Simulation-based design activities, Optimization, Geometric Modeling

5.2. Conduct research on object-oriented database needs for engineering design. (October 1996 - October 1997)

Current Projects: Grant to University of Minnesota.

Future Projects: Develop various layers of an object-oriented knowledge/data base management framework for the Design Case Studies project.

5.3. Participate in standards activities that support technology development efforts for engineering design representation.

Current Projects: RRM Manufacturing Resource Data, Augmented CAD, SO TC 184/SC4 Parametrics Working Group, Solid Freeform Interchange Format (SIF)

Future Projects: Joint Technical Committee (JTC) 1, SC 24 (Knowledge

5.4. Study at least one large scale design activity, such as complex electro-mechanical design, to assess the information modeling needs for collaborative design.

Current Projects: Working with Black and Decker, Boeing

Future Projects: TBD

5.5. Install prototype systems that demonstrate new technologies.

Current Projects: Conceptual design

Future Projects: Work with DARPA MADE researchers.

5.6. Conduct various workshops for assessing various design automation needs.

Current Projects: None

Future Projects: Workshops to be conducted in Summer 96, Spring 1997, etc.

5.7. Help at least one small business (design company) in utilizing the national information infrastructure

Current Projects: Working with Thar Designs in Pittsburgh.

5.8. Interact with industry to provide support for effective design practices.

Current Projects: Working with Black and Decker, develop CRADA with other industries (e.g., Caterpillar Inc., Boeing, PACCAR Inc.)

Future Projects: Work with EDS, Xerox, IBM, etc.

5.9. Demonstrate a prototype virtual and distributed design environment, with cooperation from other groups/divisions at NIST.

Current Projects: Augmented Assembly, NAMT/SIMA

5.10. Publish in appropriate journals, conferences, and NIST internal reports.

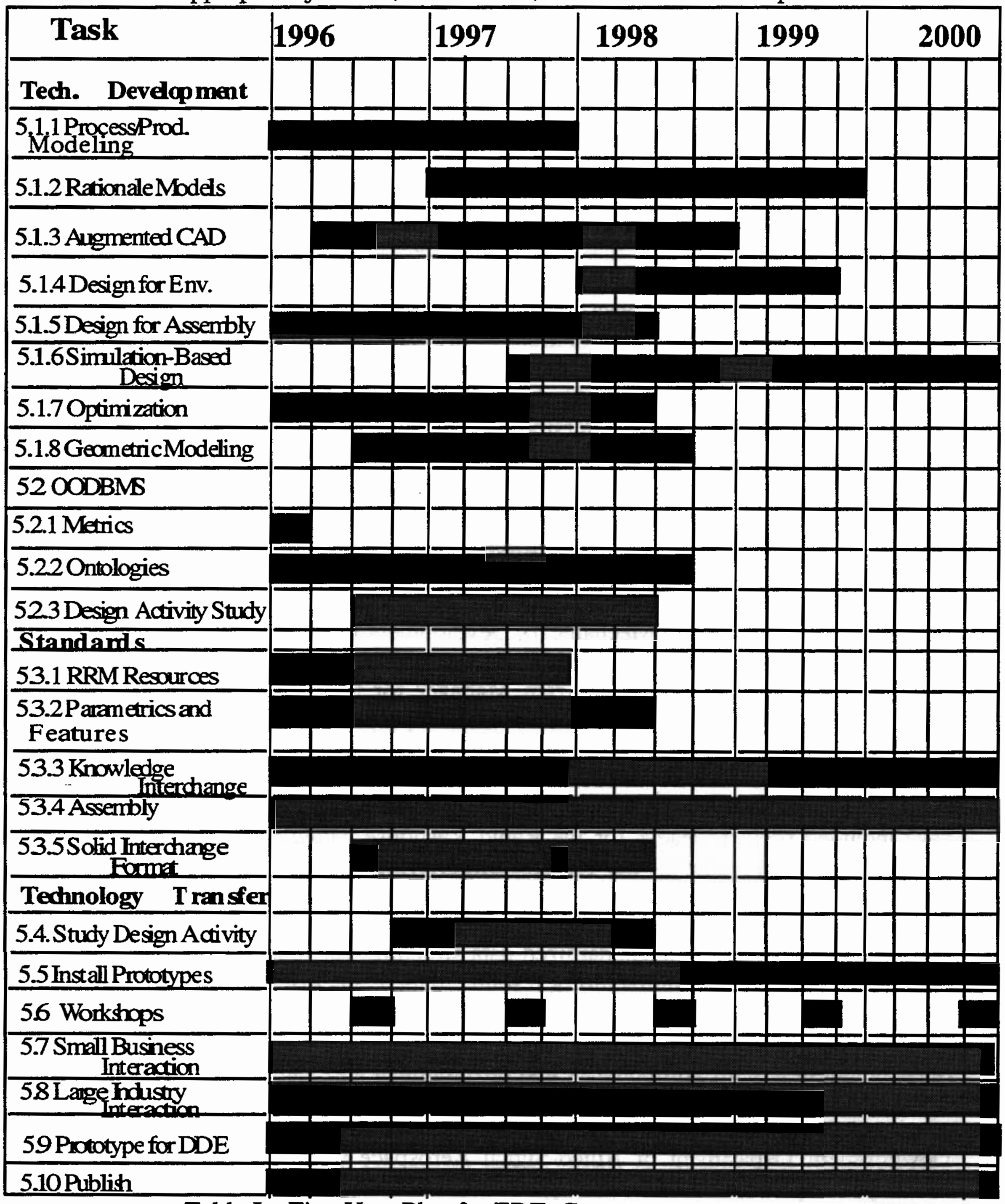

Table I: Five Year Plan for EDT Group

6. Resources

Our technical staff resources are as follows:

NIST Employees

Ram D. Sriram (Group Leader) is the group leader for the Engineering Design Technologies group. He joined NIST in October 1994. Prior to that he was on the engineering faculty at MIT and was instrumental in setting up the Intelligent Engineering Systems Laboratory. At MIT, Sriram initiated the DICE project, which was one of the pioneering projects in collaborative engineering. He has co-authored or authored nearly 100 papers, books, and reports in computer-aided engineering, including ten books. In 1989, he was awarded a Presidential Young Investigators Award from the National Science Foundation, U.S.A. Sriram has extensive experience in developing knowledge-based expert systems, natural language interfaces, object- oriented software development, geometrical modelers, and object-oriented databases for industrial applications. He has consulted for several leading corporations all over the world. He is also on the technical advisory board of Spectragraphics, which markets computer-based tools for collaborative engineering. Sriram received a B. Tech degree from I. I. T., Madras, India, an MS and a Ph.D. from Carnegie-Mellon University.

Kevin W. Lyons' current interests are in design methodology, modeling methodologies for product realization processes, assembly-based design, and design system integration in the domain of mechanical and electro-mechanical components, assemblies, and systems. Lyons came to NIST in 1992 with 15 years of industry experience with IBM. In IBM's Lexington, KY manufacturing facility he had assignments in Product Assurance, Quality Engineering (Electrical and Mechanical), Development Engineering, and Computer-Aided-Deign and Analysis Support, with key focus on assemblies. In FY 97, Kevin Lyons will be at DARPA, serving as the Program Manager for the Rapid Design Exploration and Optimization Program (a successor to the MADE program).

Kevin Jurrens is currently a member of the Engineering Design Technologies Group within the Manufacturing Systems Integration Division at NIST. Primary project roles have included project leader for the Rapid Response Manufacturing (RRM) Intramural Project, co-project leader for the Reverse Engineering Production System (REPS) Project, Test Team leader for the PDES, Inc. Sheet Metal Project CDIM SM1 effort, and technical staff roles for various other projects. Primary research activities within these projects have included development of a standardized data structure for representing machine tool and cutting tool data (i.e., "manufacturing resource data"), an assessment of the current state-of-the-art in rapid prototyping systems for mechanical parts, specification of system components and machine upgrades for a reverse engineering capability for repair and replacement of aircraft components, and development and validation efforts to assess the functionality of the STEP standard for the application of sheet metal die design. Prior to employment at NIST, Jurrens worked for the CAD/CAM Technology and Systems Development Department of Allied-Signal Aerospace Company, Kansas City Division. Primary responsibilities included general CAD/CAM system user support, software project management, software quality assurance and testing coordinator, plant-wide support for internal and external IGES CAD data translation, requirements and design for IGES flavoring software, and participation in the Department of Energy Data Exchange

Format (DOEDEF) Project. Jurrens received a BS degree (With High Distinction) in Mechanical Engineering from the University of Nebraska, Lincoln, and an MS degree in Mechanical Engineering from the University of Kansas, Lawrence.

Peter Hart is a Computer Scientist with primary interest in developing web-based services for engineering, such as the installation, analysis, testing, and maintenance of Internet related services that can be used to disseminate manufacturing related information and standards work to the public. Hart is also deeply involved with various aspects of the Engineering Design Testbed, and has taken the lead for EDT homepage development. His professional interests include CAD/CAE, Solid Modeling, Virtual Environments, Internet Resource and Service Utilization, Computer Graphics, C programming, Perl and shell script writing.

Post Doctoral Fellows

Scott Chase joined NIST with a fellowship from the National Research Council in January 1996. His research is in the area of computer-aided design, in which he has over sixteen years experience. His interests lie in feature modeling with formal logic and shape grammars. Dr. Chase holds degrees in Architecture from MIT and UCLA. He has worked in the fields of CAD and computer graphics development at Bechtel Civil, IBM, and Skidmore, Owings and Merrill, and has taught at the University of Southern California. He has been a researcher on the EDM project in product modeling at UCLA and the Technical University of Delft. Dr. Chase has published papers in journals such as Planning and Design, Research in Engineering Design, and Automation in Construction. He is a member of ACM and ACADIA.

Ronald Giachetti joined NIST with a fellowship from the National Research Council in September 1996, after receiving a Ph.D. in Industrial Engineering from North Carolina State University. His primary research interest is the development of a set-based design calculus to formally represent design imprecision. This is a continuation of research he conducted while a guest researcher at the Technical University of Aachen, Germany. He is also interested in design for manufacturing and tolerance analysis. He has three years experience as a production engineer in the defense electronics industry and has taught a manufacturing laboratory at NCSU. He has a B.S. in Mechanical Engineering from RPI and a M.S. in Manufacturing Engineering from Polytechnic University in Brooklyn, NY.

Mark Schwabacher joined NIST with a fellowship from the National Research Council in August 1996, after receiving a Ph.D. in Computer Science from Rutgers University. His Ph.D. dissertation is on the use of artificial intelligence to improve the numerical optimization of complex engineering designs. As part of his research at Rutgers, he tested his AI-augmented optimization techniques on several realistic engineering design problems, including the design of racing yachts of the type used in the America's Cup race, and the design of supersonic transport aircraft. He conducted this research as part of the Rutgers-based High Performance Computing and Design (HPCD) project, in collaboration with engineers at Lockheed Martin, United Technologies Research Center, and SAIC. Dr. Schwabacher received his B.A. from Rice University, where he completed a triple major in Computer Science, Mathematical Sciences, and Mathematical Economic Analysis.

Simon Szykman joined NIST with a fellowship from the National Research Council in August 1995, after receiving a Ph.D. in Mechanical Engineering from Carnegie Mellon University. The subject of Simon's doctoral dissertation was product layout optimization, which involved optimization of both component layout and pipe/wire routing. Simulated annealing, a stochastic optimization technique, is used for both layout and routing which can be performed either sequentially or concurrently. Simon's current work involves the development of a new generation of computational design tools that are able extract knowledge from stages of the iterative design process. By using this knowledge to build models of the process, these tools are able to improve their performance with experience and provide designers with knowledge that might not otherwise be available.

Guest Researchers

Scott Angster is a guest researcher on agreement from Washington State University where he completed his doctorate degree in Mechanical Engineering. His main area of interest is in the use of virtual reality techniques for computer-aided design and manufacturing applications. Scott received both his Bachelors degree and Masters degree in Mechanical Engineering from Virginia Polytechnic Institute and State University.

JungHyun Han received the B.S. degree in Computer Engineering from Seoul National University in 1988, the M.S. degree in Computer Science from the University of Cincinnati in 1991, and the Ph.D. degree in Computer Science from the University of Southern California (USC) in 1996. At USC, he worked in the Programmable Automation Lab, a research unit within the Institute for Robotics and Intelligent Systems at USC. With his advisor Prof. Aristides Requicha, he developed novel software systems for geometric reasoning that blend the techniques from both computational geometry and artificial intelligence. His Ph.D. dissertation is on feature recognition, which extracts features such as holes, slots and pockets from the CAD model. He designed and implemented a state-of-the-art system named Integrated Incremental Feature Finder. Han received the best paper award at the 15th International Computers in Engineering Conference for his work on feature recognition. His current research interests lie in geometric modeling, computer graphics, virtual reality, geometric reasoning in CAD/CAM, and computer vision.

Haeseong Jacob Jee joined as a guest researcher, after obtaining his Ph.D. From M.I.T. in 1996. His dissertation work, conducted under Prof. David C. Gossard and Prof. Emanuel Sachs, involved the development of a new solid model incorporating surface macro-texture, that can be fabricated by Three Dimensional Printing. Currently, he is studying techniques to replace current STL -- de facto standard file format for solid freeform fabrication -- with a new efficient standard format of representing complete geometries. Jee received a B.S. and an M.S. in Mechanical Design and Production Engineering from Seoul National University.

Russell A. Kirsch was a member of the group that first designed and built digital computers in the U.S. Federal Government at the National Bureau of Standards where he was responsible for computer design, operation, training, programming, and research since 1951. He published the results of his research in papers that started the computer fields of Image Processing, Syntactic Pattern Recognition, and Chemical Structure Searching. He was among the early workers in the use of computers in Natural Language Processing, Library Science,Time Sharing, Biomedicine, Artificial Intelligence, and Security Printing.

Mike Pratt is a Senior Research Associate in the Design and Manufacturing Institute at Rensselaer, currently working at NIST on an Intergovernmental Personnel Assignment (IPA). Until 1991 he was Professor of Computer Aided Engineering and Head of the Department of Applied Computing and Mathematics within the School of Mechanical Engineering at Cranfield Institute of Technology in England. He holds an MA in physics from Oxford University, an MSc in aeronautical engineering and a PhD in mechanical engineering from Cranfield. He has worked in computer-aided design and manufacture for more than 20 years, mainly in the context of mechanical engineering, and is co-author (with I. D. Faux) of the book "Computational Geometry for Design and Manufacture", Simon & Schuster (1979). His research interests include applications of geometry in many aspects of product design and manufacture, with particular emphasis on the use of form features in automating the interfaces between its various processes. He is also actively involved in CAD data exchange standards development in these areas. Pratt is on the editorial boards of the journals Computer Aided Geometric Design, Computer Aided Drafting Design and Manufacturing, and Engineering Applications of Artificial Intelligence. He is registered as a Practicing Engineer in both the UK and the European Union, and is a member of several professional organizations in the UK, the U.S., and internationally.

P.V.M. Rao joined as a guest researcher after obtaining a Ph.D. in Mechanical Engineering from Indian Institute of Technology, Kanpur, India. Prior to that he served as a Lecturer in Mechanical Engineering at Regional Engineering College, Allahabad, India for four years. The subject of Rao's Ph.D. thesis was a computational study of realizability of free-form shapes by shape conforming processes. His present research interests are in geometric modeling, feature based modeling and physically based modeling. He is a life member of Indian society for technical education.

Rachuri Sudarsan joined as a guest researcher after having worked at Computer Vision, India. His areas of interests include scientific computing, numerical and mathematical modeling, multibody dynamics, ODEs, aerospace simulation, symbolic computation, matrix computation, computational geometry, and NURBS. Sudarsan received a B.S (Mathematics) and an M.S (Applied Mathematics) from Madras University, an M.S (Aerospace Engineering), and a Ph.D. (Computer Science & Aerospace Engineering) from Indiain Institute of Science, India.

Peter Wilson is a Research Associate of the Catholic University of America, and is a guest researcher at NIST. He is a recognized international expert in information modeling and modeling languages, particularly as applied to the modeling and exchange of product data information. In previous careers Wilson has worked in both academia and industry in the USA and the UK and has been recogized as an expert in fields as diverse as semiconductor device physics, finite element modeling, and Computer Aided Design & Manufacture. He is the co-author of the book "Information Modeling the EXPRESS Way," Oxford University Press, 1994; the author of over a hundred research papers on semiconductors, CAD-CAM and information modeling; and a past Editor-in-Chief of IEEE Computer Graphics & Applications.

7. Publications of the EDT Group for FY96

Chase S C, "Design Modeling With Shape Algebras and Formal Logic," *ACADIA '96 Conference*, Tucson, AZ, Oct. 31-Nov. 3, 1996

Chase S C, "Modeling spatial reasoning systems with shape algebras and formal logic," *AIEDAM special issue on Geometric Representation and Reasoning in Design* (submitted)

Jurrens, Kevin K., Algeo, Mary Elizabeth A., and Fowler, James E., "Beyond Product Design Data: Data Standards for Manufacturing Resources," to appear in *Rapid Response Manufacturing: Contemporary Methodologies, Tools, and Techniques*, Dong, J. (ed.), Chapman and Hall, 1996.

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8. University Grants

George Washington University

Title: Methodologies for Modeling the Product Realization Process: International Practice and Research

Federal Program Officer:	Kevin W. Lyons
Recipient:	George Washington University Office of Sponsored Research 2121 I Street, N.W., 6th floor Washington, D.C. 20052
Technical Contact:	Prof. Michael R. Duffey
Project Duration:	4/95 -- 6/96

Abstract: Project will assess process modeling methodologies relevant to the product realization process (PRP), with an emphasis on new computer-based process modeling tools being used and under development at international industry sites. The evaluation effort will be targeted at those companies using state-of-the-art methodologies as identified by U.S. industries participating in an on-going NIST process modeling project. Efforts include sponsoring a workshop of both U.S. and foreign process modeling practitioners in Spring 1996 and interaction with researchers in Europe and Asia, including the Fraunhofer Institute at the University of Stuttgart. This study will help focus U.S. development efforts for new PRP modeling tools that can document "best practices;" identify bottlenecks (e.g., resource constraints) and task redundancy; provide "what if" analysis of design alternatives; risk assessment for schedule and cost; a tool for training; and other applications.

Washington State University

Title: Virtual Assembly Using Virtual Reality Techniques

Federal Program Officer: Kevin W. Lyons
Recipient: Mechanical and Materials Engineering
Washington State University
201 Sloan Hall
Pullman, WA 99164-2920
Technical Contact: Dr. S. Jayaram
Project Duration: 5/95 -- 5/97

Abstract: The primary objective of this project is to demonstrate the feasibility of creating valued design information using virtual reality (VR) tools for virtual assembly and exchanging this information with other manufacturing applications such as a CAD application. A prototype "Virtual Assembly Design Environment" (VADE) will be defined and implemented to address a specific assembly scenario representative of actual issues facing an industry assembly facility. Since virtual assembly crosses multiple domains, it is important that the related technologies develop synchronously to enable industrial applications of virtual assembly. It is envisioned that the definition between CAD and VR systems will merge as new design systems will encompass features from each of the technologies. Data exchange is a significant barrier to development of prototype systems which demonstrate the application of VR technologies to design.

The project results and supporting documentation will assist in directing further research in virtual assembly and serve as the first step in the development of "next generation" CAE tools, methodologies, and technologies necessary to meet the criteria established for virtual assembly by DoD and commercial industries. The information disseminated at the end of this project should provide a "proof of concept" of the feasibility and usefulness of using virtual assembly techniques to reduce the overall product development cost and time.

Carnegie Mellon University

Title: Evaluation of Foreign Technology Plans in Manufacturing Systems as Related to the National Defense Manufacturing Technology Plan

Federal Program Officer: Kevin W. Lyons
Recipient: Carnegie Mellon University
Computer Science Department
5000 Forbes Road
Pittsburgh, PA 15213
Technical Contact: Dr. Stephen Cross
Project Duration: 3/95 -- 2/96

Abstract: The focus of this research is to study how advanced information processing technologies (for example, constraint directed planning and scheduling, agent-based electronic commerce, customizable internet services) are being, or could be, applied to manufacturing execution systems. In addition the mechanism for how this software is provided (on a per use basis vs. direct purchase) will be explored. The scope of the effort will be to develop an evolutionary strategy for introducing and enhancing new scheduling and control functionality into already running factories, especially focusing on small to medium size enterprises (SME's). Comparison with international competitors will be made to better understand the magnitude and speed at which U.S. industries mst adopt this new technology.

Workshop and site visits are planned to provide the depth and breadth of coverage of the technology assessment. Results will be made available through a variety of methods such as reports, World Wide Web (WWW), etc.

Purdue University

Title: PROXIMA: Geometric Support for Virtual Environments

Federal Program Officer:	Peter F. Hart
Recipient:	Purdue Research Foundation Division of Sponsored Programs, 1021 Hovde Hall West Lafayette, Indiana 47907-1021
Technical Contact:	Previous contact: Dr. George Vanecek, Jr. Present contact: Dr. Chandrajit Bajaj
Project Duration:	3/95 -- 2/96

Abstract: Purdue University is developing a suite of tools to support computer modeling of the assembly process. They will develop new computer software to improve the performance and fidelity of collision detection and contact analysis. These areas have been identified as key to the development of a new generation of CAD systems capable of supporting "digital" or "computational" assembly simulations as well as to allow "Virtual Environment" simulators to deal with large complex objects. Current work is focused on constraint management in distributed design.

University of Minnesota

Title: Object-Oriented Database Management Systems for supporting Multimedia

Federal Program Officer:	Ram D. Sriram
Recipient:	University of Minnesota 110 Washington Ave., South Minneapolis, MN 55455
Technical Contact:	Prof. Jaideep Srivastava/Paul Pazandak
Project Duration:	9/95 -- 5/96

Abstract. The purpose of the research is to develop a data model for multimedia extensions to object-oriented database management systems and to investigate metrics (requirements) for object database management systems for the support of this multimedia data. The scope will encompass software (class hierarchy support), architectures, and hardware.

Stanford University

Title: Multi-disciplinary Design Project

Federal Program Officer: Ram D. Sriram
Recipient: Stanford University
Stanford, CA 94305
Technical Contact: Dr. Richard Fikes
Project Duration: 3/96 - 4/96

Abstract. The purpose of the research is to demonstrate the role and power of ontologies in providing support for collaborative design. Specific goals are to develop ontologies for modeling and analyzing the structural, optical, and thermal properties of opto-mechanical devices and to provide recommendations needed to enhance the STEP standard to deal with engineering ontologies.

9. Industry Collaborations

EDT's current industrial collaborators are: Black and Decker; Boeing (three cooperative research agreements); PACCAR Inc.; Caterpillar Inc.; Perceptronics; Thar Designs; and the Rapid Response Manufacturing (RRM) Consortium (including National Center for Manufacturing Sciences, Ford Motor Company, General Motors, Texas Instruments, United Technologies Corporation, and Lockheed Martin). Efforts are being made to strengthen ties with other companies and industries (e.g., Xerox, IBM, EDS, ISR Inc., and IndustryNet) .

Small Business Innovation Research

Title: Integration Framework for Virtual Prototyping Software Tools

Federal Program Officer: Kevin W. Lyons
Recipient: Isothermal Systems Research, Inc.
P.O. Box 69
502 Steptoe
Colton, WA 99113
Technical Contact: Dr. Don Tilton
Project Duration: 8/95 -- 2/96

Abstract: The SBIR Phase 1 project is to investigate the development of an integration framework to enable concurrent engineering of mechanical components. The integration framework will allow the concurrent engineering of a mechanical system to be automated from customer input to the creation of complete virtual and physical prototypes. Different CAD/CAE/CAM, knowledge based engineering systems and virtual reality simulation utilities will be plugged into the framework, which provides a common database. The data in the database can be accessed as input to any specific software program integrated into the framework. A transformation may be performed upon the data through an interface translator.

The framework will be developed using object oriented analysis and object oriented design techniques. The framework will be easily expandable and allow reuse of object oriented code to the maximum possible extent. The data and files in the system, as well as the software programs integrated in the framework, can be located in physically different sites All data and file transfers will utilize Internet for standard communication between systems over both local and wide area networks.

Title: Computer Support System for Conceptual Design

Federal Program Officer:	Ram D. Sriram
Recipient:	IndustryNet Corporation 639 Alpha Drive Pittsburgh, PA 15238
Technical Contact:	Mr. David S. Mawhinney
Project Duration:	7/96 -- 11/96

Abstract: The SBIR Phase 1 project is to investigate the use of case-based retrieval for design. The key idea is that new design ideas often arise by reusing and adapting prior design ideas through direct recall and analogy. The current project aims to develop representation and indexing schemes for large casebases of designs. Using synthesis algorithms, the system will help the designer find appropriate products that can fulfill the required functions. The system will finally allow the user to order the products directly through on-line catalogs.

Appendix A: Overview of EDT Group Projects

A.1 TECHNOLOGY DEVELOPMENT

A.1.1 A Set-Based Representational Formalism for Preliminary Engineering Design

Staff
Ronald E. Giachetti

FY97 Funding Sources
National Research Council Postdoctoral Research Associateship

Project Objective
This work involves the development of a set-based design calculus to represent artifacts during the preliminary stages of the design process.

Need Addressed
Preliminary engineering design of mechanical products is not well supported by existing design tools. Preliminary design is characterized by high levels of imprecise knowledge and information. Standard product models define the product precisely. Therefore, during preliminary engineering design, designers are forced by these systems to arbitrarily assign precise values to parameters. The result can be that designers may select less than optimal values or impose unnecessary restrictions on the design. Furthermore, there exists no formal methodology for preceding from preliminary design to final design in a straightforward manner. Design is recognized to consist of stages of progressively finer detailed models but few systems can support this transition. Therefore, two problems are recognized. First how to represent an artifact model in the imprecise environment encountered during preliminary design. Second, there is a requirement to seamlessly integrate preliminary design with final detailed design. This implies a formal method is needed for reducing the imprecision in design.

The reason for focusing on preliminary design is that some of the most important decisions, those with the greatest effect on overall cost, are made during these stages. Hence, what is required are tools which can operate in the domain of the imprecise values and therefore allow analysis to be performed during preliminary design when many significant decisions are made. Fuzzy set theory applied to design is regarded as a promising approach. However, it lacks a formal methodology for system development and operation. One repercussion of this is that imprecision reduction is, at present, implemented in a relatively ad-hoc manner. In summary, the problem is how to represent the imprecision found in preliminary engineering design, what methodologies can be used to reduce the imprecision during the design process, and how can this research be integrated with existing design architectures.

Technical Approach
The research will include three main thrusts. The theoretical modeling of imprecision in design, manipulating imprecise design models, and how to integrate this with current design systems.

The first research thrust will be to develop a method for representing mechanical products during the preliminary design phases. Since the early phases of design are characterized by imprecision, the artifact model needs to represent imprecisely known variables, parameters, and constraints. Fuzzy set theory will be used for this representation. By fuzzy design calculus, it is meant, the formal syntactical vocabulary used to define a product model. We need to represent the design objectives, constraints, parameters, and other model attributes. The calculus will also formally define operations on the product model, based on possibility theory. This is necessary since, for instance, the operators used with linguistic variables are different than those used on fuzzy numbers. The calculus will make use of fuzzy numbers, intervals, and linguistic variables to represent both design imprecision and preference.

The second primary thrust of the research is to develop an algorithm for design imprecision reduction. This is a necessary condition to make the transition from preliminary design to final design. The algorithm provides a formal method to reduce imprecision. It consists of an ordered set of operators as defined by the fuzzy design calculus. Several methods will be researched for attaining imprecision reduction. One approach is to rely on the fuzzy intersection of variables and constraints. The intersection defines a smaller set (i.e. more precise) representation of the design parameter. A second method is to exploit the inherent characteristics of fuzzy mathematics. Non-linear operations on fuzzy quantities always increase the imprecision. Solving these equations backwards has the potential of reducing the imprecision.

The third thrust is to create a modeling environment for preliminary design. A fuzzy constraint modeling system seems an appropriate modeling paradigm for preliminary design. Further work is required in developing fuzzy constraint networks for design. Additionally, the design imprecision reduction algorithm must be supported. The overall design process will follow the top-down refinement strategy where, decisions made at higher levels in the hierarchy constrain lower level decisions. This approach maintains a consistent focus on the original functional requirements. The system architecture should support an intelligent user. It is not intended to replace the designers with a fully automated system, but to support a design team. Team members can make their concern known through constraints. This is one method for representing the life-cycle knowledge early in the design process, and provides a mechanism for identifying conflicts and reaching compromise solutions, which is a noted strength of fuzzy networks.

A.1.2. Reducing Design Costs by Predicting Downstream Values of Design Attributes

Staff
Simon Szykman

FY97 Funding Sources
National Research Council Postdoctoral Research Associateship

Project Objective
This work involves the development of a computational design tool that estimates downstream values of design attributes based on information available early on in the design process, such as design specifications.

Need Addressed
Experienced designers are often able to guide the design process toward promising designs from early on in the design process. This foresight is often referred to in the context of vague terms, such as intuition. One of the mechanisms that enables designers to look ahead in this manner is the building internal models that map design specifications to downstream design attributes. For instance, a designer may be able to provide relatively accurate estimates of the expected cost, performance, or efficiency of a design for a given set of specifications without having to produce the actual design. This comes not only from experience with doing design in a particular domain, but the ability to generalize information generated through design of earlier artifacts.

Because a large percentage of lifecycle costs are committed early on in the design process, such models can be of great benefit. The ability to predict downstream design attributes has potential benefits that include reduction of design iterations, avoiding wasted effort that occurs by exploring paths that lead to infeasible designs, and reducing the need for time-consuming analysis and simulation as well as physical prototyping. These advantages can translate to reduced design costs and time to market.

There are a variety of barriers that deter the use of these models in design practice. One common one is lack of expertise among designers that don't have the past experience from which to build these models. Because the models are represented internally, rather than explicitly, it is difficult for them to be articulated and passed on to less experienced designers. A second difficulty is that there are problems for which a mapping from specifications to downstream design attributes may exist, but that those relationships are too complex or multidimensional for a designer to be able to capture. A third barrier is that many designed artifacts span across multiple engineering domains. In these cases, building such a model may require more knowledge than a single designer may have. Lastly, although the use of concurrent engineering techniques is becoming more widespread, it is not uncommon for designs to be "thrown over the wall." In these cases, information is known about downstream attributes, but the lack of feedback to the designers makes it difficult for them build these models.

The goal of this research is to develop computational design tools that improve the design process by representing and constructing these models. The purpose of these tools is not to supplant any one part of the design process, but rather to create a tool that provides designers with knowledge that may not otherwise be available to them, thereby aiding them in guiding search in an iterative design process.

Technical Approach

The approach taken in this work is to use artificial neural networks (ANNs) to build these predictive models. An artificial neural network is able to represent a potentially complex functional relationship by producing an output for a given set of inputs The ANN can therefore be thought of as a response surface that takes as inputs values for a variety of preliminary or upstream design attributes, and outputs predicted values for downstream attributes.

Because ANNs are not a unique representation for a response surface alternative representational approaches can be used for these models including the more traditional polynomial functional representations as well as Bayesian surrogate models. Artificial neural networks were chosen for initial studies because of their ability to deal with characteristics that are typical of real design problems, including the ability to approximate discontinuities, represent relationships of high dimensionality, tolerance of noisy data, and the ability to interpolate and (to a lesser extent) extrapolate.

In order to build models that map specifications to downstream attributes, data corresponding to groups of related designs is required. Consequently, this methodology lends itself to problems where classes of similar artifacts have been previously designed (such as routine or variant design tasks), or problems where such data can be generated through simulation.

Current efforts are directed toward developing a prototype tool that can be applied to an industry design problem. One advantage of this approach is that it does not require any a priori knowledge about form of the design space or the domain of design. However, it may be possible to use these predictive models more effectively by using them in conjunction with approaches that include such knowledge when it is available. Long term issues include the ability to make use of additional knowledge as well as he characterization of the types of relationships that can be represented with this approach.

A.1.3 Modeling Features With Shape Algebras and Formal Logic

Staff
Scott C. Chase

FY97 Funding Source
National Research Council Postdoctoral Research Associateship

Project Objective
The work here involves the development of a feature based geometric reasoning system, with algebraic representations used in shape grammars and logic specifications of features.

Need Addressed
Research in the development of design modeling systems has identified the need for evolutionary models which support dynamic schema modification. However, the development of current design systems does not easily support such a goal. They tend to be constructed in a bottom-up manner, with the design of low level data structures and operations first. This can be seen as a "kit-of-parts" approach, and is often done in order to develop efficient operations for object manipulation. What this generally does is force the designer/user into a specific manner of representing and manipulating objects. Thus, the structure of a model must be decided at the start. Essentially this is akin to the philosophy of reductionism, which considers the universe to be composed of separate parts which, in various combinations, make up the whole.

The decision to classify and structure up front may preclude the possibility of other desirable forms and structures in the future. It is extremely difficult, if not impossible, to anticipate all possible ways in which one might wish to view or classify parts of a model. This often requires an unmanageable amount of information. The problems with this approach were among the causes of the failure of early CAD building modeling systems in the 1970's and early '80s, which often required the predetermination of all types of information of interest, and for this information to be stored in a single model.

On the other hand, the philosophy of holism considers the universe to be a whole rather than the sum of its parts. A system which forces no preconceived structure upon the user, but rather, allows one to find all sorts of emergent features and properties from within the whole, would be extremely desirable. This might enable an easier development path in a top-down fashion, from the abstract to the specific.

Technical Approach
The algebras of shape, as used in shape grammars, can support both holistic and reductionist views. By considering shapes as finite sets of elements which can carry fixed properties, a reductionist view is supported. The real power of such algebras, however, lies in the fact that the elements of a shape and their properties may be defined in such a manner as to enable the emergence of features which are not apparent in the initial formulation of a shape. In addition, the generality of their representations, their reliance upon a minimum of structure, and their use in combination can provide the semantic richness needed for design generation and analysis.
Representing shapes and features in first order predicate logic provides an easy way to develop complete computer systems for reasoning about designs. The use of logic

provides a natural, intuitive method of generating precise definitions of parametric shapes and high level spatial relations. And logic formulation serves as a powerful specification language for computer programs: classes of logic specifications can be easily transformed in working programs, with ongoing research seeking to improve these techniques.

The proposed work builds upon doctoral research recently completed, in which a model of shape, spatial relations and non-spatial properties was developed, constructed from first principles of geometry, topology and logic. A major effort here will consist of computer implementation of the modeling system described above. This involves the construction of a feature recognition system, with the features encoded from the dependency network of shape relations previously specified as logical expressions. The likely implementation platform will be a deductive database, which provides a simple mechanism for encoding facts and rules.

To date, the application domains tested have been architectural design and geographic information systems. Here, we intend to examine the applicability of the approach to the domain of mechanical engineered parts. This would involve the development of libraries of feature sets and a comparison to other work in feature-based modeling and reasoning.

A further look at non-geometric properties of shapes is also proposed. The existing model permits computations with labels (set based properties) and weights (properties that can combine), which can provide an additional richness for defining designs. An important question is, can properties such as functionality be captured using these constructs? In the future, an additional research goal is an investigation of how current STEP standards for product modeling can be extended to incorporate such emergent feature based representations.

A.1.4 Engineering A La Carte: Improving The Interoperability Of Distributed Engineering Software Tools

Staff
Simon Szykman, Bill Regli

FY97 Funding Sources
National Research Council Post doctoral fellowship

Project Objective
To investigate the impact of emerging computer technologies on existing and future approaches toward integrating distributed CAD/CAM software tools.

Need Addressed
To date, integration of engineering software has been done predominantly (though not exclusively) on the "desktop". This has resulted in integrated packages of software tools that are beyond the reach of many smaller design and manufacturing companies due to the high cost of the software as well as the associated required hardware. For companies at the high-end of the user spectrum that can afford these tools, they provide the best integrated suite of tools but not necessarily the integration of the best tools available for a given application.

Predictions regarding the next generation of computational tools describe bringing higher capabilities within reach of smaller companies and allowing engineers to tailor a set of tools to an application through the use of distributed software tools which are accessed across networks. Achieving the envisioned engineering environment requires software integration at a different level. While currently-available integrated packages have addressed many issues that will arise in the development of new software tools, a new set of data and communication issues now arise.

Present computing capabilities provide a number of opportunities untapped by the engineering software community. The use of the emerging technologies that will enable new CAD/CAM environments is becoming more and more widespread. However, applications of these technologies are primarily still at the research stage and the area of integration of distributed software is still in its infancy.

Technical Approach
This project will investigate the use of emerging computer technology to improve the integration of engineering software tools. The types of technologies available exist at several different levels. At the first level are several varieties of network-savvy programming tools, such as Perl and Tcl/Expect. At a second level are programming languages and environments specifically designed for the exchange of executable software components (often in an interpreted language) over a network. The most notable of these is the Java language used over the World Wide Web. Included in a third level are some of the current application development environments in commercial software systems. Environments such as these can be used to create software modules to be shared, accessed or executed over the network from within a CAD environment.

Engineering A La Carte is an experiment in distributed engineering software integration and delivery. As part of this project, a prototype environment is being constructed using existing technologies and tools, such as those described above. This environment will be populated with several common and fundamental engineering tools (CAD engine, data translators, design repositories, manufacturing analysis and planning tools, etc.). Among the technical issues to be addressed are data sharing and encapsulation, data and communication standards, concurrency and parallelization of computation across networks.

This project does not involve the development of new computer technology, but rather will investigate the use of existing technologies to improve integration of existing tools and to map out approaches toward developing the next generation of integrated CAD/CAM software tools. Relevant emerging technologies include Java, CORBA, OLE, VRML and existing communication infrastructure such as the Internet and the World Wide Web.

A.1.5 AI-Augmented Engineering Design Optimization

Staff
Mark Schwabacher

FY97 Funding Source
National Research Council Postdoctoral Research Associateship

Project Objective
The objective of this project is to develop and test methods that augment conventional numerical optimization with artificial intelligence in order to successfully optimize engineering designs using existing simulators.

Need Addressed
The engineering design problem is to find quickly a good design in a complex engineering domain. Here ``good" can, for example, mean low cost or high quality. Examples of design problems include designing the fastest possible racing yacht, subject to the constraints that it satisfies the race committee's rules regarding what yachts can be entered in the race, and that its cost not exceed the available budget, or designing a supersonic aircraft with the lowest possible life-cycle cost, subject to the constraint that it be capable of carrying 70 passengers from New York to Tokyo at Mach 2.

Once a particular design problem has been stated formally, it can be attacked using nonlinear optimization. Nonlinear optimization works reasonably well when the objective and constraint functions defined by the simulator satisfy certain assumptions of continuity and smoothness. Unfortunately, these assumptions often do not hold for realistic simulators, because of what we call pathologies.

In realistic engineering domains, engineers often rely on legacy codes to simulate proposed designs. These codes are software programs that have generally been developed over many years, by many people. They often are based both on empirical data and theoretical equations. Engineers are reluctant to change or replace the legacy codes, because they have faith in the codes due to years of comparisons between the codes and physical experiments. Unfortunately, legacy codes tend to have many pathologies which make it difficult to use them within an automated design system. There are several types of pathologies. There can be multiple local optima, both physically meaningful, and caused by numerical noise. There can be nonsmoothness - that is, discontinuity in the objective or constraint functions or their derivatives. And there can be unevaluable points, which are designs for which the simulator is unable to produce a numerical evaluation - for example, designs which cause the simulator to crash or print an error message. The need addressed is performing design optimization reliably and efficiently in the presence of these pathologies in the simulators.

Technical Approach

My previous research focused on the use of artificial intelligence techniques, particularly machine learning, to improve the numerical optimization of complex engineering designs in the presence of pathologies in the simulators. In this work, several techniques to improve numerical optimization were developed. Prototype selection employs inductive learning to learn rules that select a previous design to use as a starting point for a new design optimization. Reformulation selection uses inductive learning to predict which of a set of constraints will be active at the optimum, then chooses a reformulation of the search space on the basis of these predictions. Knowledge-based gradients use a set of rules to compute gradients for use in numerical optimization in the presence of unevaluable points in the search space. Model Constraints are used to detect designs that violate the modeling assumptions of the simulator, and to communicate the severity of the violations to the optimizer. Each of these techniques has resulted in large improvements in the speed of optimization, and/or the quality of the resulting designs.

The current research will explore ways in which machine learning algorithms can be enhanced to improve their performance on the types of learning problems that arise in automated engineering design. The following tasks constitute the research plan for the associateship program.

Task 1: Integration of background knowledge. One approach for improving results is to integrate background knowledge into the learning process. One form of background knowledge that is often available in engineering domains is modality constraints - knowledge that expresses the modality of the learned class with respect to the attributes. Various techniques for integrating background knowledge into the learning process, including using it to filter the training data before running the inductive learner, or using it to constrain the tree that is built by a decision-tree learner, will be explored. Finally, learning problems that arise in engineering domains are often continuous-class learning problems - that is, the value being predicted is a number rather than a discrete value. How to use background knowledge in continuous-class learning is an interesting open question.

Task 2: Use of active learning. Another way to improve learning performance in engineering domains is to explore the use of active learning. The learning algorithm could decide to run specific additional simulations or optimizations in order to improve its understanding of the domain. It could use background knowledge (see Task 1) to aid in its selection of experiments to run.

Task 3: Improvements to the knowledge-based gradient technique. Here, how knowledge-based gradients can be improved through the addition of more rules will be explored.

Task 4: Testing and validation. Although the techniques developed in prvevious work have been tested in multiple realistic engineering domains, we would like to test them further in additional domains, and would like to perform further tests of how optimization performance is affected when using various combinations of my techniques.

A. 2. STANDARDS

A.2.1 Rapid Response Manufacturing (RRM) Intramural Project: Modeling of Manufacturing Resource (MR) Information

Staff
Kevin Jurrens and Mary Beth Algeo

FY96 Funding Sources
STRS (ATP)

Project Objective
The primary activity of the RRM Intramural Project over the past two years has been development of a proposed common representation for manufacturing resource (MR) data. Within this context, MR data includes information describing machine tools and other production tools, material handling equipment, cutting tools, tool holders, tool adaptors, fixtures, material inventories, and factory layouts. The RRM Intramural Project has addressed a limited scope of manufacturing resource data representation, including milling and turning machine tools; cutting tools appropriate to the processes of milling, drilling, boring, reaming, tapping, and turning; cutting tool inserts; and the tool holding and assembly components required to mount the cutting tools to the machines. Recent RRM Project results include development of a detailed Requirements Specification (NISTIR 5707) to describe the proposed MR data categories, attributes, and relationships, development of an EXPRESS information model based upon this specification, widespread distribution of the proposed data structure for industry review and feedback, and initial contact with standards bodies potentially interested in standardization of this type of manufacturing data.
Primary FY96 objectives for the RRM Intramural Project are to build upon recent project results in the area of a common representation for manufacturing resource information and to carry through with plans for validation, industry consensus, standardization, and technology transfer. The completeness, validity, and usability of the proposed data representation will be evaluated by implementing the information models in a single database to supply MR data to multiple engineering applications in a multi-vendor environment. Specific FY96 tasks will include:

- refinement of the MR requirements specification based upon industry review,
- validation and demonstration of the proposed data structure through database implementation (i.e., ODI Objectstore database) of the EXPRESS information model and integration of the resource database with commercial manufacturing software applications (i.e., IAMS MetCapp manufacturing process planning system and Cognition Cost Advantage manufacturing cost estimating system),
- development of appropriate machining application cost models with RRM collaborators for use in the MR Test Environment,
- industry consensus-building activities in support of a standardized MR representation,
- information dissemination and technology transfer through journal publications and

conference proceedings,

- interaction with national (ANSI) and international (ISO) standards bodies to initiate and facilitate standardization of a common representation for manufacturing resource data, and
- assessment of the ISO TC184/SC4/WG2 Parts Library specifications for potential application to electronic tooling catalogs.

Description of Candidate IMES

The work of the RRM Intramural Project will be used as the basis for a candidate Initial Manufacturing Exchange Specification (IMES) as defined by the NIST Manufacturing Systems Integration Division. The technical scope of the planned IMES can be described as follows:

Standardized electronic representation for a limited scope of manufacturing resource data, including milling and turning machine tools; cutting tools appropriate to the processes of milling, drilling, boring, reaming, tapping, and turning; cutting tool inserts; and the tool holding and assembly components required to mount the cutting tools to the machines.

Industry Need / Problem Statement

In the domain of mechanical design and manufacturing, information sharing between computer aided (CAx) applications is typically synonymous with product design data exchange. Other information elements which are relevant to and necessary for the functions performed by CAx applications are frequently overlooked. For example, computer-interpretable representations of manufacturing resources (machine tools, cutting tools, etc.) are employed within a variety of manufacturing software applications, including software to perform manufacturing process planning, manufacturing simulation, tool selection, manufacturing cost estimation, and machine tool programming. Manufacturing enterprises often rely on multiple software systems, purchased from different vendors, each of which requires access to different representations of the manufacturing resources used by that facility. This situation results in resource data stored and maintained multiple times in multiple formats for different applications within a given facility. This in turn causes much duplicate work for maintaining the information, redundant data stores of manufacturing resource data which may or may not contain the most recent and accurate information, and longer lead times for implementing new systems which require this data. System integration or sharing of resource data between systems or engineering functions is not possible without information loss in the current environment.

A single representation for manufacturing resource information that is common to a variety of software applications and engineering functions would reduce or eliminate these problems. This common representation would shorten product cycle time by enabling system integration and sharing of resource data, reduce software operating costs by eliminating costly maintenance of multiple data stores, increase usability and applicability of existing corporate databases, lower manufacturing costs through less duplication of effort and more efficient engineering functions, and increase product quality by allowing ready access to the facility's most current and accurate manufacturing resource data. Common representations of manufacturing resources can also enable the manufacturing resource vendors themselves to offer documentation of their products via mechanisms consistent with state-of-the-art computing and networking technologies, including integrated databases, CD-ROM disks, on-line services, or electronic vendor updates.

Several efforts have been initiated within industry to develop information constructs (e.g., databases, information models) that describe manufacturing resource data. Existing efforts have typically resulted in company-specific data structures and system implementations. The implementations are frequently applicable to only a single application within the organization, with much duplicated effort required to implement systems for additional application areas.

The work of the RRM Intramural Project addresses these concerns by developing a publicly available representation for manufacturing resource data, that attempts to satisfy the various perspectives and requirements from manufacturing resource vendors, manufacturing software vendors, and mechanical parts manufacturers. The solution proposed by the RRM Intramural Project is based upon a thorough analysis of current representations from the various perspectives. It is expected that project results will provide a catalyst for a standardized manufacturing resource data structure by providing proven results and a working strawman to appropriate standards organizations.

Standardization

Standards organizations that could potentially play a role in the standardization of manufacturing resource data are indicated below. Current prospects are primarily centered around ISO TC29/WG34 for cutting tool information (in collaboration with ISO TC184/SC4/WG2). The RRM Intramural Project anticipates that standardization of this type of manufacturing data will ultimately include participation and/or liaison by ISO TC29 (small tools), ISO TC39 (machine tools), and ISO TC184 (industrial data).

- ISO TC29 (Small Tools)
  - WG34 - Computerized Machining Data Exchange
- ISO TC39 (Machine Tools)
  - SC2 - Test Conditions for Metal Cutting Machine Tools
  - SC3 - Modular Units for Machine Tools
  - SC8 - Work Holding Spindles and Chucks
- ISO TC184 (Industrial Data and Manufacturing Languages)
  - SC4 - STEP Product Data
  - SC4/WG2 - Parts Library
  - SC4/WG8 - Manufacturing Management Data
- ANSI/Cemented Carbide Producers Association B212 (Carbide Cutting Tools, Tool Holders, Indexable Inserts)
  - B212 U.S. Advisory group to ISO TC29
- ANSI/ASME B94 (Cutting Tools, Holders, Drivers, and Bushings)
- ANSI/ASME B5 (Machine Tools and Performance Evaluation)
  - TC 45 - Spindle Noses and Tool Shanks for Machining Centers

TC 51 - Manufacturing Systems and Components
TC 52 - Machining Centers

Association for Manufacturing Technology (AMT) (formerly National Machine Tool Builders Association - NMTBA)

United States Cutting Tool Institute (US-CTI)

Collaborators

NATIONAL PROGRAMS: Primary interactions have been with the National Center for Manufacturing Sciences (NCMS) Rapid Response Manufacturing (RRM) consortium and the Department of Energy Technologies Enabling Agile Manufacturing (TEAM) consortium. The RRM consortium views this work as one component of the product and process representation required to build an Integrated Product & Process Model (IPPM). The TEAM program has stated their intention to use the results of this NIST work as the basis for their manufacturing resource database.

OTHER INTERACTIONS: The project is currently pursuing collaboration with Texas Instruments in the area of machining application cost models for the Cognition Cost Advantage software. The project will continue participation with an industry user group (Ford, General Motors, Chrysler, Caterpillar Inc., cutting tool vendors, etc.) in the area of electronic tooling catalogs. The project has discussed possible collaboration with several companies for integration of a machine tool simulation application with the proposed manufacturing resource database. The project will continue interactions with the Institute of Advanced Manufacturing Sciences (IAMS) during integration of the MetCapp application with the manufacturing resource database.

Related Developments

The Rapid Response Manufacturing (RRM) consortium is organized through NCMS. Consortium members include General Motors, Texas Instruments, United Technologies, Ford Motor, Lockheed Martin Energy Systems, and several manufacturing software vendors. A principal objective of the NIST RRM Intramural Project is to establish collaborations with the RRM consortium to support RRM program efforts and to leverage NIST skills and technologies. With this support role in mind, activities of the RRM Intramural Project are selected based upon needs of consortium member companies.

A. 2. 2. Enhanced Integration of CAD with Design Support and Manufacturing Engineering Systems

Staff
Kevin Lyons, Ram. D. Sriram, Michael Pratt, Peter Hart, JungHyun Han

FY97 Funding Sources
STRS (SIMA) and DARPA

Project Objective
Enhance the interoperability and performance of design systems through identification of functional, data, and integration requirements, and development of prototype system extensions and enhancements which implement HPCC and integration technology solutions.

Within this broad scope, the project will be focused on achieving results in the following two areas; 1) understanding the design process and how design systems aid in product design (process modeling), and 2) developing data exchange mechanisms between traditional CAD (Computer Aided Design), Augmented CAD (e.g., Analysis, Virtual Reality), Knowledge-based CAD (Design for Assembly) and manufacturing engineering systems such as process planning. The project's benefit to industry are a result of addressing the needs specified below.

Need Addressed
Many industries are struggling to identify new methods to remain competitive with U.S. and foreign companies. Design processes have received little attention, yet are of significant importance to the industrial product realization process. Effective engineering design is key to matching the company's product to its customer demands and to providing improved quality, reduced costs, and reduced time to market. Specific needs related to project focus are further discussed below.

The emergence of new design support systems has introduced interoperability issues in that these new systems are not tightly coupled with current traditional CAD applications. An example of this is VR (virtual reality) systems, which are being viewed as a natural extension or enhancement to current CAD systems; hence are also known as Augmented CAD systems. Yet, today very different methods to visualize and manipulate the underlying product model are used. This results in data and information that cannot be shared by other engineering and manufacturing systems. This incompatibility is highlighted when engineers, working with a product model within a VR application, generate important information that assists in defining assembly processes or results in modifications to the product model. In addition to these concerns, successful application of new design support tools and technologies in industry where significant impact can be shown, is lacking. Until these barriers are addressed and solved there is little likelihood of industries acceptance of these tools and technologies.

Technical Approach
This project will develop a prototype information exchange mechanism to demonstrate the transfer of data created in a CAD environment to other manufacturing systems (e.g., process planning system) utilizing state-of-the-art support technologies. The project is divided into several tasks as described below (see Figure 5).

Design to Process Planning: This task involves the exchange of information between traditional CAD systems and process planning systems. Our goal to develop various extensions to AP 203 and assist in final stages of standardization to AP 224 (which is in draft stage), which are STEP standards.

Knowledge-Based Design to Assembly Analysis: This task involves the exchange of information between knowledge-based design systems and assembly analysis programs, such as stability analysis, augmented assembly modeling, etc.

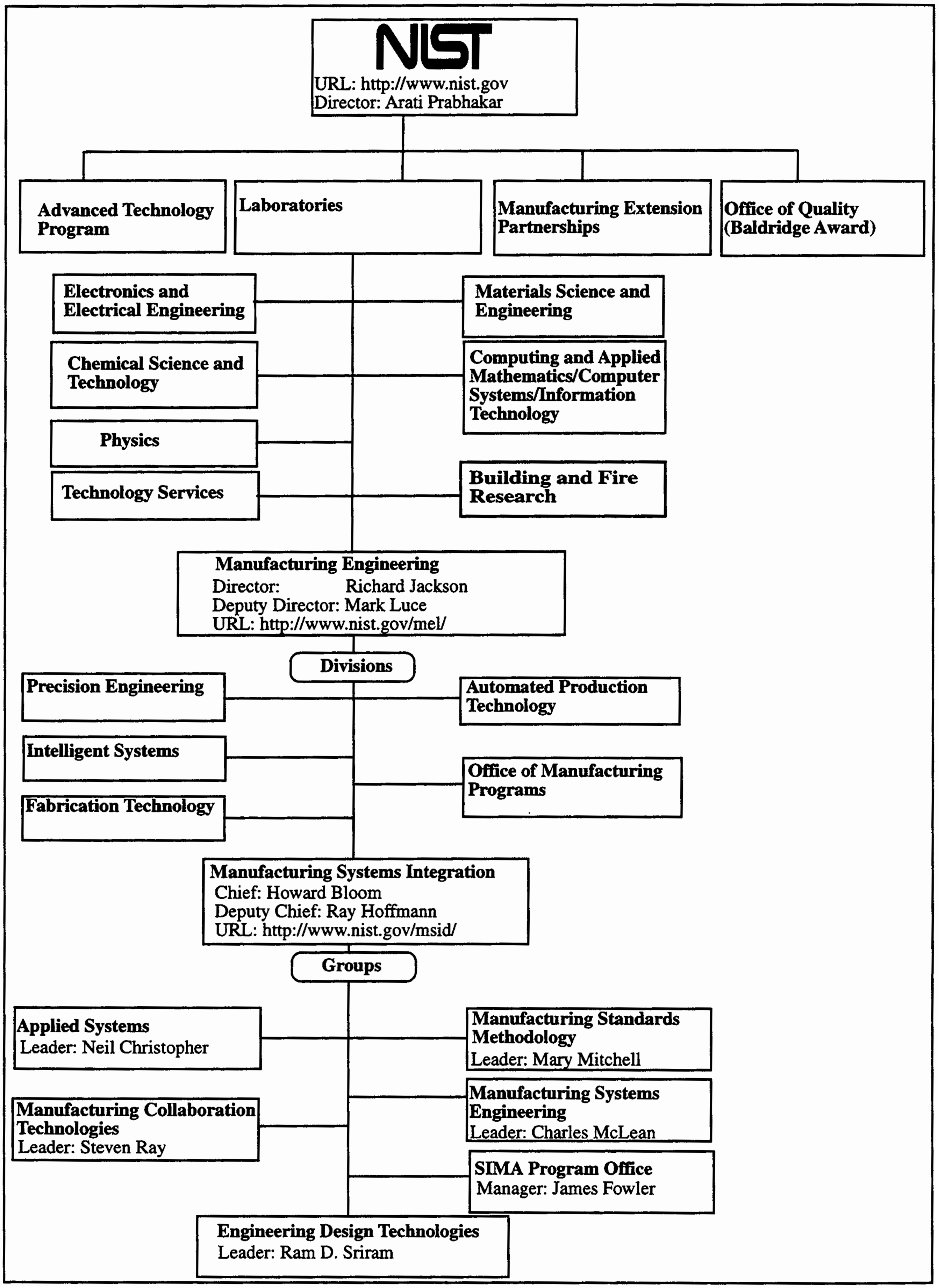
Augmented CAD to Assembly Planning: This task involves the development of exchange standards for data interchange between CAD systems (such as ProEngineer), augmented CAD systems (e.g., simulation-based design), and assembly process planning. The initial effort (coordinated with Washington State University) on augmented CAD systems will be on the creation of trajectory, component orientation information (process data), swept volumes, and assembly sequencing data that can be merged with the part representation. Various extensions to the STEP standard (AP 203) in the area of assembly planning will be explored.

Solid Interchange Format: This task involves the use of STEP's generic resources for the development of a standard for the exchange of CAD data with Rapid Prototyping systems, which have been developed for producing physical structures in layers (e.g., 3D Printing).

Engineering Ontologies: This task will explore the development of engineering ontologies in EXPRESS or an extended version of EXPRESS. These ontologies will aid in knowledge level communication.

Collaborators
Potential collaborations are being pursued with Black & Decker, Caterpillar Inc., PACCAR Inc., Boeing Corp., Lockheed Martin, and Thar Designs.

Relevant Standards
STEP AP203, AP 224, AP 209, and their extensions.


NIST
URL: http://www.nist.gov
Director: Arati Prabhakar
Advanced Technology Program
Laboratories
Manufacturing Extension Partnerships
Office of Quality (Baldridge Award)
Electronics and Electrical Engineering
Materials Science and Engineering
Chemical Science and Technology
Computing and Applied Mathematics/Computer Systems/Information Technology
Physics
Technology Services
Building and Fire Research
Manufacturing Engineering
Director: Richard Jackson
Deputy Director: Mark Luce
URL: http://www.nist.gov/mel/
Divisions
Precision Engineering
Automated Production Technology
Intelligent Systems
Office of Manufacturing Programs
Fabrication Technology
Manufacturing Systems Integration
Chief: Howard Bloom
Deputy Chief: Ray Hoffmann
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Groups
Applied Systems
Leader: Neil Christopher
Manufacturing Standards Methodology
Leader: Mary Mitchell
Manufacturing Systems Engineering
Leader: Charles McLean
Manufacturing Collaboration Technologies
Leader: Steven Ray
SIMA Program Office
Manager: James Fowler
Engineering Design Technologies
Leader: Ram D. Sriram

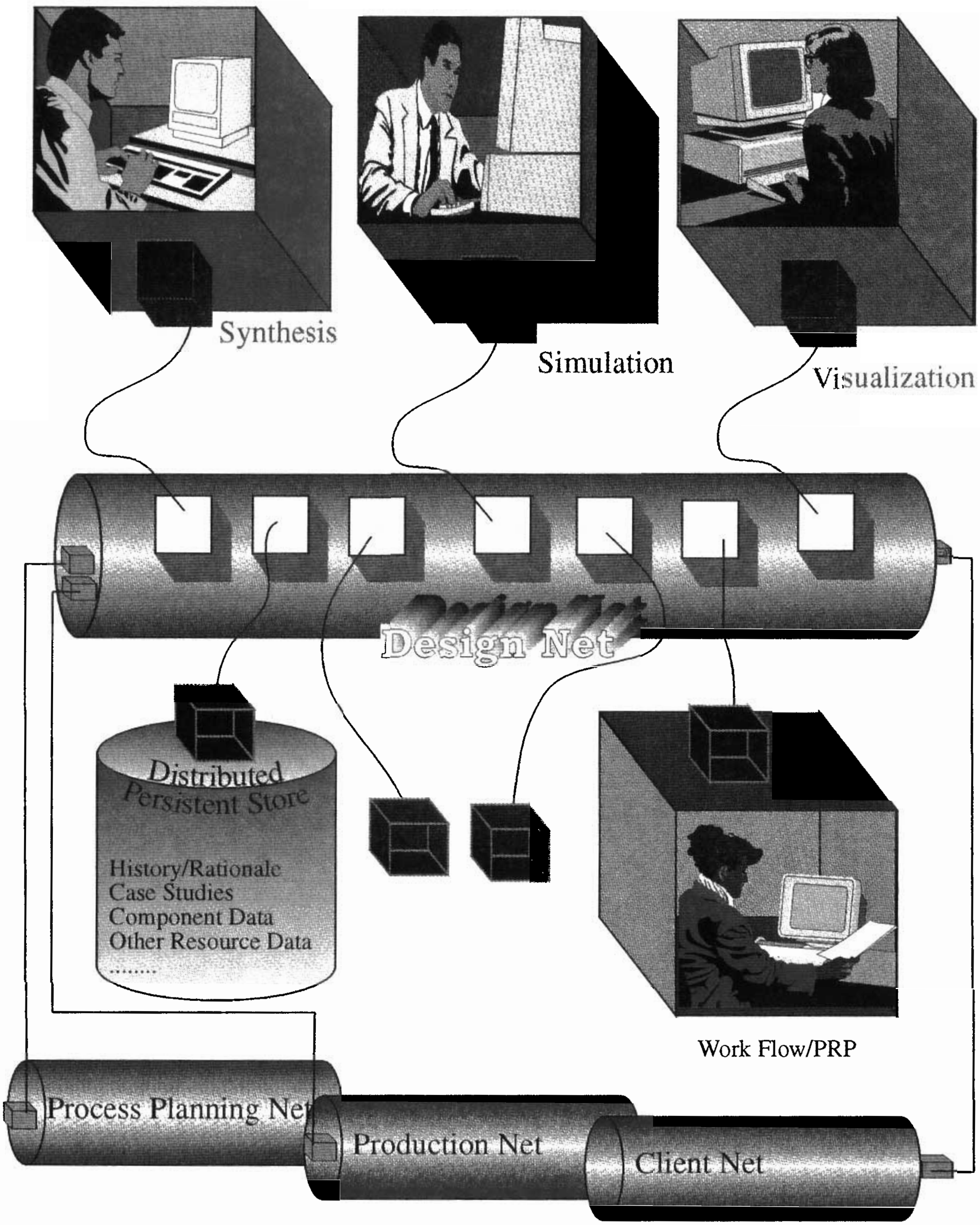

Figure 1: A Collaborative Design Framework

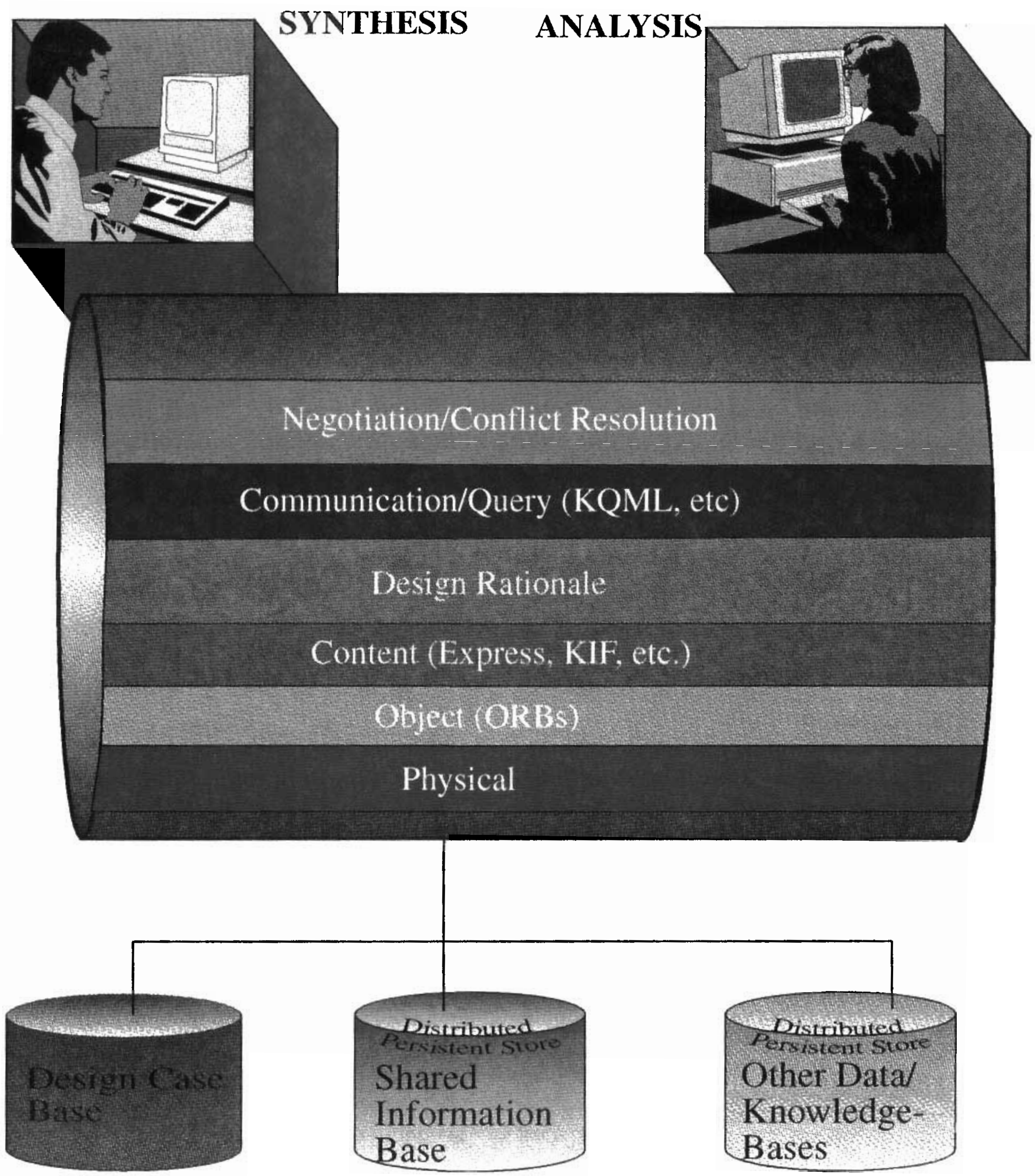

Figure 2: Communication Framework for Engineering Information Web

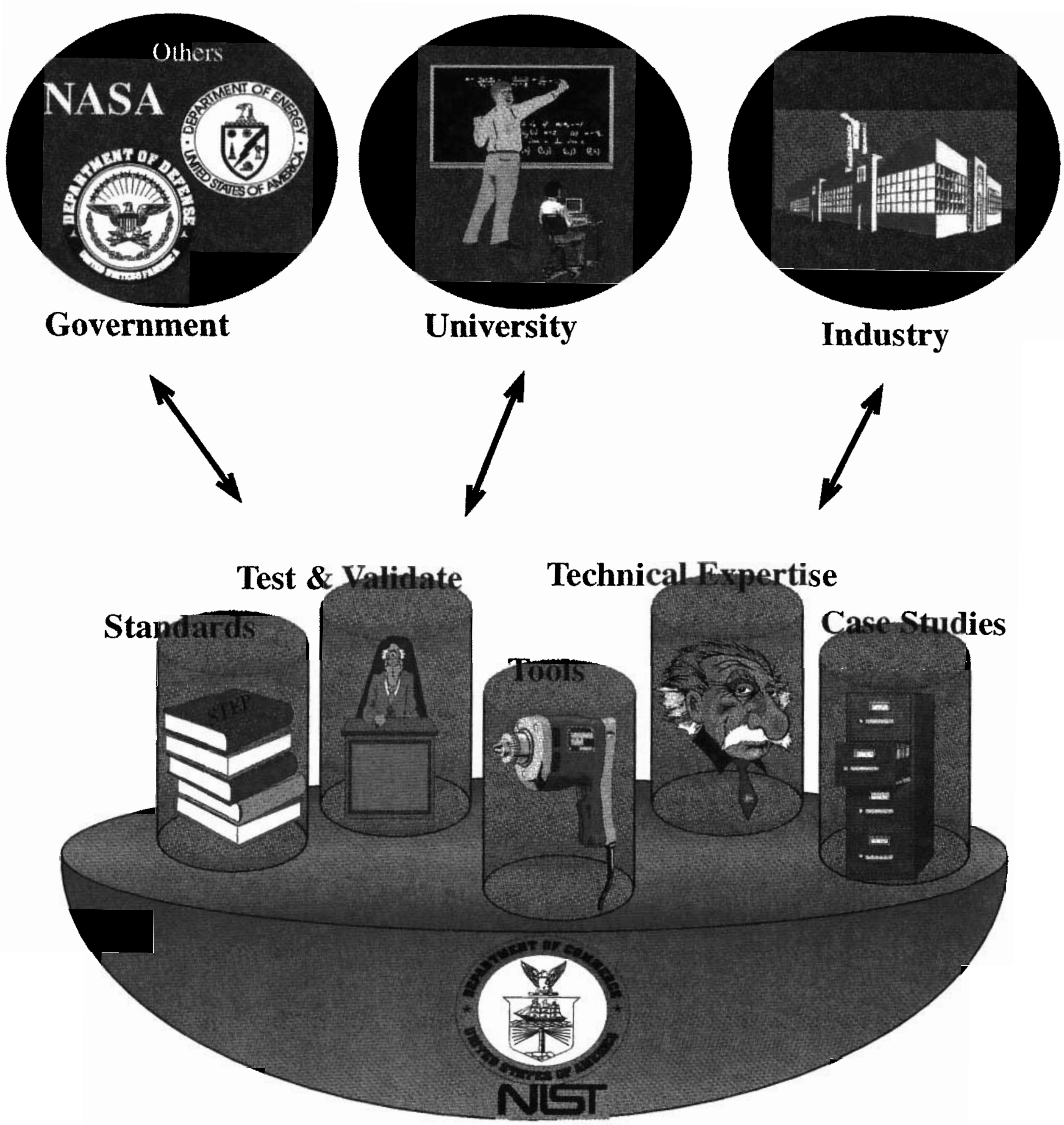

Figure 3: Engineering Design Testbed

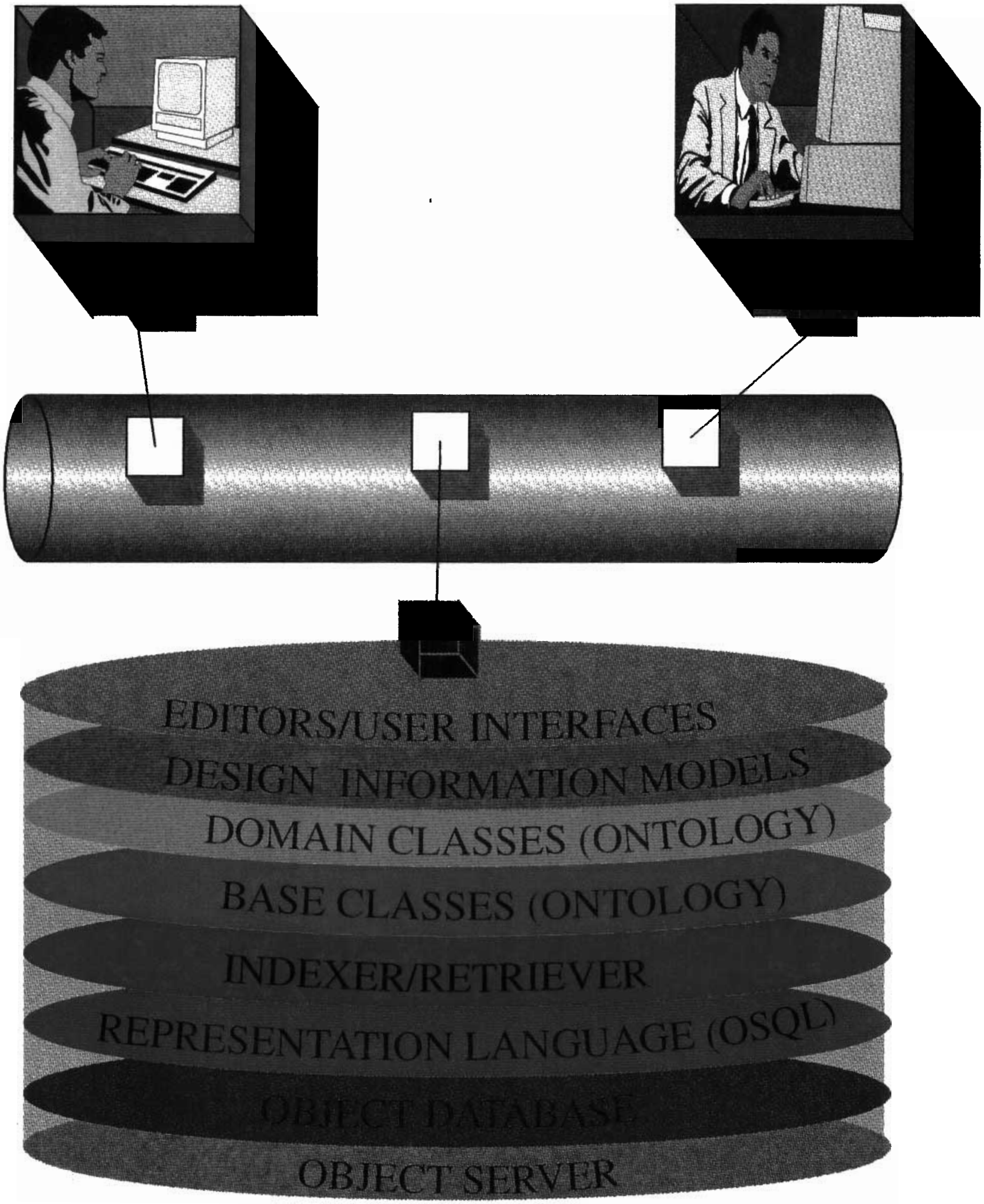

Figure 4: Schematic View of Design Storage Framework

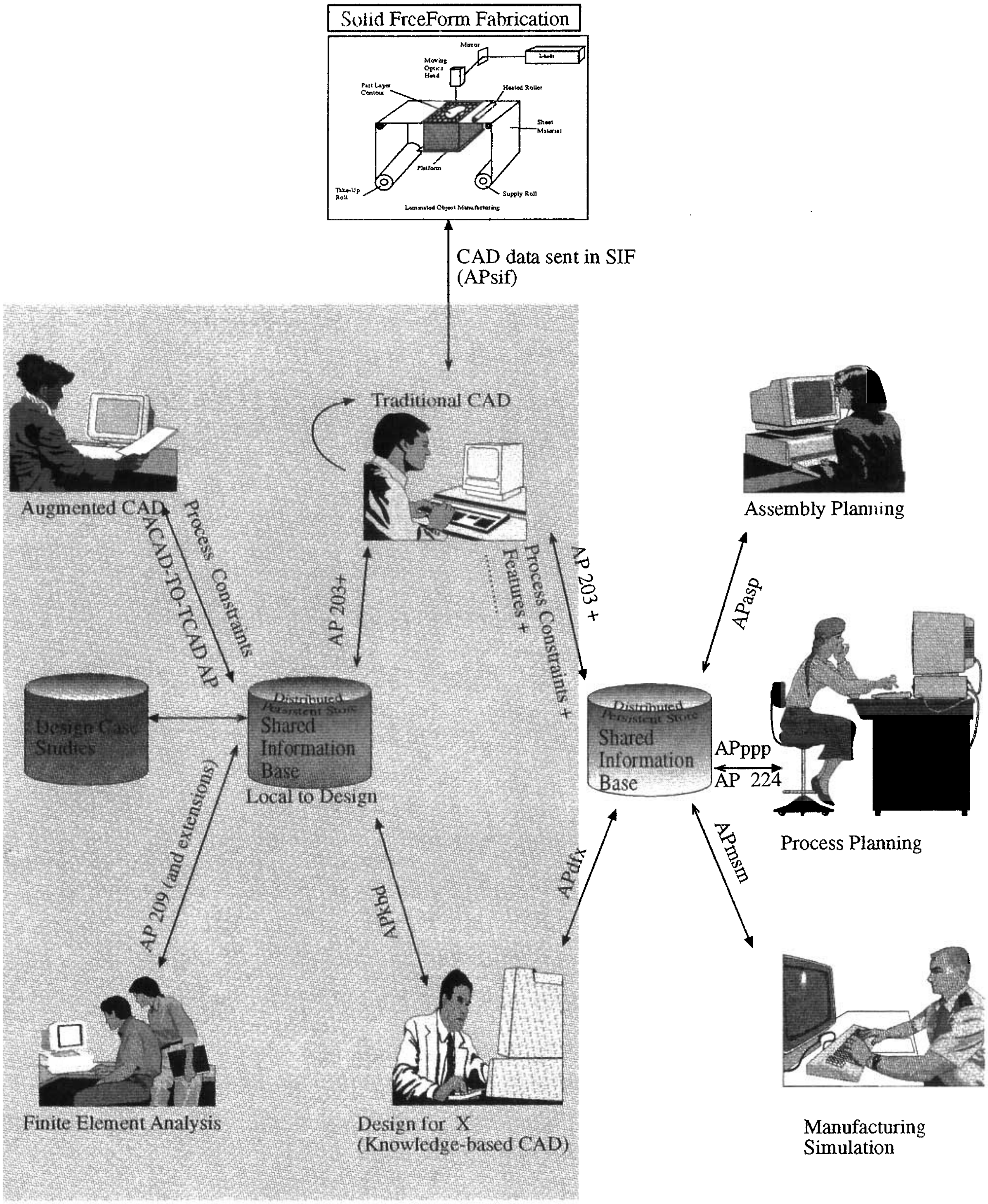

Figure 5: Design to X Integration