NISTIR 6043

Network-Centric CAD: A Research Planning Workshop

3-4 December, 1996
National Institute of Standards and Technology
Gaithersburg, Maryland

Workshop Proceedings

Edited by:

William C. Regli and Simon Szykman
Manufacturing Systems Integration Division
National Institute of Standards and Technology

Stephen J.J. Smith
Department of Mathematics and Computer Science
Hood College

Peter F. Brown
Institute for Complex Engineered Systems
Carnegie Mellon University

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Edited by:

William C. Regli
Manufacturing Systems Integration Division
National Institute of Standards and Technology
Building 220, Room A127
Gaithersburg, MD 20899
regli@cme.nist.gov

Simon Szykman
Manufacturing Systems Integration Division
National Institute of Standards and Technology
Building 304, Room 12
Gaithersburg, MD 20899
szykman@cme.nist.gov

Stephen J.J. Smith
Department of Mathematics and Computer Science
Hood College
401 Rosemont Avenue
Frederick, MD 21701-8575
sjsmith@nimue.hood.edu

Peter F. Brown
Institute for Complex Engineered Systems
Carnegie Mellon University
Hamburg Hall 1203
Pittsburgh, PA 15213-3890
pbrown@cmu.edu

Workshop organized by:

William C. Regli, Simon Szykman and Peter F. Brown

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology
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Acknowledgment

These proceedings are a summary of *Network-Centric CAD: A Research Planning Workshop*, held on 3–4 December 1996 at the National Institute of Standards and Technology in Gaithersburg, Maryland. The workshop was sponsored by Carnegie Mellon University, NIST, DARPA's RaDEO program, the National Advanced Manufacturing Testbed, the US Navy Manufacturing Technology Program, the Army Research Office's Mathematics and Computer Science Directorate, and the Office of Naval Research.

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Opinions expressed in this report are those of the workshop participants and not necessarily those of the National Institute of Standards and Technology or its employees.

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Introduction

Workshop Mission Statement

There are a variety of visions for the next generation of engineering software tools for computer aided design and manufacturing (CAD/CAM) applications. Most of these visions include some form of distributed software, either across local networks, the World Wide Web or the Internet. To date, integration of engineering software has been done predominantly (though not exclusively) on the "desktop."

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. Present computing technology provides a number of opportunities untapped by the engineering software community. However, applications of these technologies in the engineering community are primarily still at the research stage and the area of integration of distributed software is still in its infancy.

The process of realizing this vision has generated new research and development issues that are only starting to be addressed in the engineering community. This workshop brought together parties from industry, government institutions and academia in order to map out directions for future research toward this end. The goals of the workshop were to:

- Create a dialogue between researchers and developers who have an interest in the next generation of integrated engineering software tools, and those in other communities who are performing cutting-edge research using relevant technologies;
- Develop one or more visions of these next-generation networked and distributed CAD/CAM software systems and tools;
- Identify the key technologies associated with the development of network-centric CAD/CAM tools and find gaps in currently available technology as well as key issues that have arisen in efforts to date;
- Identify approaches toward migrating existing software tools through the utilization of network-centric integration enabling technologies;
- Identify opportunities for corporate development, academic research, and potential collaborations among participants in the workshop as well as other members of the represented communities;
- Provide a roadmap that will aid in directing future funding, research, and development efforts in order to bring about rapid innovation and technology transfer.

Among the topics and issues that were discussed are:

- Implications of emerging technologies (e.g. Internet, Java, WWW, VRML, groupware, CORBA, OLE) for current and future software systems and engineering practices;
- Software modularity, application interfaces, and interoperability;
- Functional integration, message passing;
- Data sharing and representations;
- Role of existing standards and requirements for new standards, relating to both data and communications, for enabling interoperability of new distributed CAD/CAM environments.

Prevailing Themes of the Workshop

- Practical integration issues such as ease of use and compatibility with the underlying infrastructure;
- Discussion of the pros and cons of the CORBA standard;
- Discussion of the standards needs of the network-centric CAD community and how such standards as VRML are not sufficient;
- The increased necessity of outsourcing and the required changes in CAD;
- How to duplicate with three-dimensional CAD the successes of the (primarily two-dimensional) electrical CAD community;
- The need for STEP to become a more mature standard as soon as possible;
- How the next generation of CAD can still support legacy systems, as well as make use of information that exists only on paper, rather than in electronic form;
- Providing web technology inside existing applications;
- The capturing of design intent.

Note from the Editors

The text of the summaries that appear in this volume is based on the presentations made during the workshop. These summaries are not a verbatim transcript of the workshop. Rather, they contain a distillation of the significant points of each presentation and the discussions which followed. The reader should not attribute any direct quotations to any of the participants in the workshop on the basis of this text.

Agenda

Tuesday, December 3, 1996

7:30 am–8:00 am: **Registration, Coffee and Refreshments**

8:00 am–8:15 am: **Opening Remarks and Introductions**
Dr. Simon Szykman, NIST

8:15 am–8:30 am: **Welcome to NIST**
Dr. Richard H. F. Jackson, NIST
Director, Manufacturing Engineering Lab

8:30 am–9:00 am: **Overview of Workshop Goals**
Dr. William Regli, NIST

9:00 am–9:15 am: **Q&A**

9:15 am–10:00 am: **Keynote Speaker**
Mr. Dan Deitz, ASME
Associate Editor, ASME *Mechanical Engineering* Magazine
An Industry-Wide Perspective

10:00 am–10:15 am: **Break**

10:15 am–12:00 pm: **Panel Session #1 and Q&A:**
Defining the Common Ground and Issues
Dr. Al Klosterman, Vice President, SDRC
Support of Virtual Enterprise Computing by the Emerging Capabilities in MDA and PDM Systems
Dr. Ravi Ravindra, Senior Scientist, Computervision
Electronic Product Definitions and Internet Technology
Dr. Joe Erkes, Director, Design Integration, GE Corporate R&D Center
Supply Chain Integration and the WWW

12:00 pm–1:30 pm: **Lunch**

1:30 pm–2:00 pm: **Panel Session #1 (continued)**
Mr. Shaun Sewall, Development Manager, Bentley Systems
Internet Presentation

2:00 pm–3:45 pm: **Breakout Sessions: Technology Assessment**

3:45 pm–4:00 pm: **Break**

4:00 pm–4:30 pm: **Report Back Panel and Q&A**

4:30 pm–5:30 pm: **Technology Demonstration Session**
Beam Technologies
University of California, Berkeley
Stevens Institute of Technology, Design Manufacturing Institute

5:30 pm: **Conclude for the Day**

6:30 pm–8:00 pm: **Dinner at Gaithersburg Courtyard by Marriott**

Wednesday, December 4, 1996

8:00 am–8:45 am: **Coffee and Refreshments**

8:45 am–10:30 pm: **Panel Session #2 and Q&A:**
Research Issues and Directions

Dr. Rick Palmer, Senior Scientist, Beam Technology
Einstein Objects: An Open Standard for Web-Enabled Distributed Design and Simulation of Electro-Mechanical Products

Dr. Michael Terk, Rice University
Changing Priorities of Research on WWW-Based Engineering Services

Dr. John Mitchiner, Sandia National Laboratories
SmartWeld: An Expert-System Welding Advisor

10:30 am–10:40 am: **Break**

10:40 am–12:30 pm: **Panel Session #2 (continued)**

Dr. Don R. Brown, Associate Professor, University of Utah/PartNET, Inc.
PartNET

Dr. Clayton Teague, NIST
The National Advanced Manufacturing Testbed: Nanomanufacturing of Atom-based Dimensional Standards

Dr. Ranga Narayanaswami, University of Illinois, Urbana-Champaign, Machine Tool Agile Manufacturing Research Institute
Highly Interactive Network-Centric Tools for Collaborative and Distributed Manufacturing

Mr. Tony Blazej, National Industrial Information Infrastructure Protocols
National Industrial Information Infrastructure Protocols (NIIIP): Enabling the Virtual Enterprise

Dr. Edward Barkmeyer, NIST
The National Advanced Manufacturing Testbed Framework Project

12:30 pm–1:30 pm: **Lunch**

1:30 pm–2:30 pm: **Summary and Strategic Planning**

2:30 pm: **Workshop Close**

Glossary of Acronyms

- ACADIA: Association for Computer Aided Design in Architecture
- ACDS: Automated Configuration Design Service
- ACES: Automated Concurrent Engineering System
- ACORN: Adaptive, Collaborative, Open Research Network
- AEC: Architecture, Engineering, and Construction
- AMRI: Agile Manufacturing Research Institute
- AMRF: Automated Manufacturing Research Facility
- AP: Application Protocol
- API: Application Programming Interface
- ARPA: Advanced Research Projects Agency
- ASME: American Society of Mechanical Engineers
- ATM: Asynchronous Transfer Mode
- BC: Boundary Condition
- BIPM: *"Bureau International des Poids et Mesures,"* International Bureau of Weights and Measures
- CAD: Computer-Aided Design
- CAM: Computer-Aided Manufacturing
- CAPP: Computer-Aided Process Planning
- CFD: Computational Fluid Dynamics
- CGI: Common Gateway Interface
- CORBA: Common Object Request Broker Architecture
- DARPA: Defense Advanced Research Projects Agency
- DFSS: Design For Six Sigma
- EIT: Enterprise Integration Technologies
- EMSIM: EndMilling SIMulation
- FDATI: Fixture Design & Analysis Tool Interface
- FEA: Finite Element Analysis
- FITHIT: Find It Today, Have It Tomorrow
- GE: General Electric
- GIF: Graphic Interchange Format
- GM: General Motors
- GUI: Graphical User Interface
- HPC: High-Performance Computing
- HODE: Hyperbolic Ordinary Differential Equation
- HPDE: Hyperbolic Partial Differential Equation
- HTML: HyperText Markup Language
- HTTP: HyperText Transfer Protocol

- IBM: International Business Machines
- KET: Knowledge Engineering Team
- LAN: Local Area Network
- MADE: Manufacturing Automation and Design Engineering
- MBE: Molecular Beam Epitaxy
- MDA: Mechanical Design Automation
- MEL: Manufacturing Engineering Laboratory
- MES: Manufacturing Execution Systems
- MOSAIC-PM: Machine tool Open System Advanced Intelligent Controller for Precision Machining
- MPI: Message Passing Interface
- MSQL: Mini-SQL
- NAMT: National Advanced Manufacturing Testbed
- NETCAD: NETwork-centric CAD
- NFS: Network File System
- NII: National Information Infrastructure
- NIIIP: National Industrial Information Infrastructure Protocols
- NIST: National Institute of Standards and Technology
- NSF: National Science Foundation
- NURB: Non-Uniform Rational B-spline
- ODE: Ordinary Differential Equation
- OLE: Object Linking & Embedding
- ORB: Object Request Broker
- PartNET: the Parts information NETwork
- PC: Personal Computer
- PDE: Partial Differential Equation
- PDM: Product Data Management
- PETSc: Portable, Extensible Toolkit for Scientific computation
- R&D: Research and Development
- RaDEO: Rapid Design Exploration and Optimization
- RDD: Requirement Driven Development
- RDE: Requirements Driven Engineering
- RFQ: Request For Quote
- RPC: Remote Procedure Call
- RPM: Rotations Per Minute
- RSA encryption: Rivest-Shamir-Adelman encryption
- SCI: Supply Chain Integration
- SDRC: Structural Dynamics Research Corporation
- SLA: Stereo-Lithography Apparatus
- SP: Scaleable Parallel

- SQL: Structured Query Language
- STEP: Standard for the Exchange of Product model data
- STL: Standard Template Library
- STM: Scanning Tunneling Microscope
- TCP/IP: Transmission Control Protocol/Internet Protocol
- URL: Universal Resource Locator
- US: United States (of America)
- VRML: Virtual Reality Modeling Language
- VRweb: Virtual Reality web
- W3C: World wide web Consortium
- WWW: World wide web

Presentation and Demonstration Summaries

Opening Remarks and Introductions

Dr. Simon Szykman, NIST (szykman@cme.nist.gov)
(4 full-page slides start after page C-1)

Dr. Szykman thanked the attendees for coming to the workshop. He noted that he had met some attendees before, and only corresponded with others.

Dr. Szykman introduced himself, and acknowledged the sponsors of the workshop: Carnegie Mellon University, NIST, DARPA's RaDEO program, the National Advanced Manufacturing Testbed, the US Navy Manufacturing Technology Program, the Army Research Office's Mathematics and Computer Science Directorate, and the Office of Naval Research. Dr. Szykman acknowledged the contributions of Mr. Pete Brown of Carnegie Mellon University, the academic co-chair, who had not only aided in obtaining funding for the workshop but had contributed to the organization of the meeting as well. He also thanked Drs. Steve Ray and Ram Sriram of NIST for hosting and helping to sponsor the workshop. Dr. Szykman inferred from the good number of sponsors that there was a broad interest in the area of network-centric CAD, and expressed his hope that their investment in the workshop would pay off.

Dr. Szykman suggested that the participants could be categorized into two groups: those with expertise in "traditional" CAD (i.e., geometric modeling) and those working in the area of "nontraditional" CAD, which includes other areas of computer-aided design such as product data management, knowledge-based CAD, etc. He noted that some of the attendees were from domains outside of the engineering CAD field. He suggested that people might be interested in both what could be gained from current technology as well as what could be incorporated into the next-generation technology. He predicted that the CAD system of the next generation would not be monolithic, but rather a composition of tools optimized for specific applications.

Dr. Szykman discussed the final agenda for the conference. Dr. Jackson, director of the NIST Manufacturing Engineering Laboratory would introduce the activities of NIST in general and those of MEL in particular. Dr. Szykman made special note of Mr. Dan Deitz's keynote speech on the interests and activities of network-centric CAD to come. Dr. Szykman explained that the research centers listed under "Technology Demonstration Session" would be demonstrating software, perhaps software under development. He expressed his intention that the breakout sessions would set a research agenda, indeed, a road map for future research funding.

Welcome to NIST

Dr. Richard H. F. Jackson, Director, Manufacturing Engineering Laboratory, NIST (jackson@cme.nist.gov)
(20 full-page slides start after page C-7)

Dr. Regli introduced Dr. Jackson as the Director of NIST's Manufacturing Engineering Laboratory.

Dr. Jackson said he would talk about not just what the Manufacturing Engineering Laboratory was, but also what NIST was, to provide context. He emphasized that the workshop that the participants were about to engage in was extremely important to NIST, so that NIST could gain insight into their needs.

Dr. Jackson said that NIST was the only national research laboratory whose specific mission is to serve U.S. industry, and that that mission had been substantiated by legislation. NIST has served U.S. industry since 1901 as the National Bureau of Standards, and since 1988 as the National Institute of Standards and Technology. It was in 1988 that the government had added "assist industry in the development of technology and procedures" to NIST's mission. Guest researchers at NIST are one means of technology transfer to industry.

Dr. Jackson said that the NIST mission was: "To promote U.S. economic growth by working with industry—" and pointed out that "working with industry" was "right up front" in the mission, and that NIST is here to help industry.

NIST sponsors four main programs. The Advanced Technology Program is a cost-sharing program with industry; the Manufacturing Extension Partnership helps small and medium businesses adopt new technology; the Quality Program is far-reaching; the NIST Laboratory Program focuses on measurements and standards, including standard reference databases.

Recently, the reorganization of the Computer Systems Laboratory and the Computing and Applied Mathematics Laboratory has been approved at NIST, merging them into the Information Technology Laboratory. Manufacturing research occurs in all NIST laboratories.

The Manufacturing Engineering Laboratory (MEL) has four technical divisions, and also operates the Fabrication Technology Division, also known as "shops"—the people that make things for NIST. MEL serves especially the mechanical manufacturing industry — people who make discrete parts. Also, MEL addresses issues that cut across all manufacturing industries.

Among the basic units in the International System of Units (SI), there is only one remaining artifact standard, that is, a standard that is not derived from first principles. That standard is the kilogram in Paris at the International Bureau of Weights and Measures (*"Bureau International des Poids et Mesures"*, or BIPM). NIST has similar artifacts called K4 and K20, and provides calibration services for mass, length, acoustics, vibration and accelerometry.

MEL staff also works to provide information standards for interoperability. MEL considers how to develop and disseminate these standards, and how to provide calibration services and reports.

MEL is organized around four basis programmatic thrusts. Manufacturing Systems Integration is the thrust that sponsored the Network-Centric CAD Workshop. Manufacturing Metrology considers how to provide fast and reliable measurements, both in the laboratory and in the real world—on the shop floor. Manufacturing Processes and Equipment concerns high-precision manufacturing and machining. Intelligent Machines is the fourth thrust.

Manufacturing has changed throughout history. Through the Industrial Revolution, craft-based manufacturing became mass production. When industry faced the ability to integrate computers, machines, and robots, NIST asked itself what it would have to provide as mass production became automation. The answer then (ten to fifteen years ago) was that NIST would have to research flexible automation ("lights out" factories), which required a testbed. So NIST built the Automated Manufacturing Research Facility (AMRF) in order to pursue relevant research.

The AMRF had six workstations (now old hat, but exciting ten years ago) and a robot-guided cart. Through the AMRF, NIST considered in the AMRF what standards were needed but it is not meant to compete with industry.

Dr. Jackson described his "What's Next in Manufacturing?" slide as "lots of concepts and buzzwords." He summarized it by saying that in the future, there would be lean organizations, global in outlook, distributed in operation, and agile and flexible to adapt to customer needs. Information technology is changing what we do and how we operate.

It used to be that the primary inputs to a manufacturing process were capital, material, and labor. Now, the addition of information has become accepted. It is incumbent upon MEL to address issues of measurement and standards for information-based manufacturing. Thus, MEL built the National Advanced Manufactured Testbed (NAMT)—a showcase for the future of manufacturing, when people, computers, and software are networked.

NAMT was brought on-line on 24 September 1996. There are four NAMT start-up projects exploiting information technology; two of them—Manufacturing Framework and Nanomanufacturing of Atom-Based Standards—would be presented later at the conference. The other two are Characterization, Remote Access, and Simulation of Hexapod Machines; and Machine Tool Performance Model.

Nanoartifacts are the calibration standard of the future. They exist in a vacuum, so they must be used through teleoperation. But if one is to use teleoperation, one may as well do so remotely, from another room or even across the country.

The hexapod is the first new machine tool idea in a hundred years. NAMT focuses on its performance, its characteristics, and how to improve it.

The Machine Tool Performance Model project explores highly accurate simulation models of particular machine tools, and how to make those models more exact. The goal is to be able to "cut bits", before cutting air, before cutting metal.

Dr. Jackson thanked the participants for coming, and said that NIST believed that they could leverage their work on top of the work of NIST. One of NIST's goals is to identify barriers to that leverage, and how to eliminate those barriers.

Overview of Workshop Goals

Dr. William Regli, NIST (regli@cme.nist.gov)
(11 full-page slides start after page C-29)

Dr. Regli described the purposes, goals, and procedures of the workshop. The primary goal of the workshop was long-term research planning, in order to give feedback to government agencies who fund academia and industry.

Part of the workshop objectives were to determine which issues were research issues, and which were development issues, though this determination is a "moving target". The workshop was not meant to focus on proprietary solutions, but to identify long-term issues. Among the workshop attendees were many mechanical CAD researchers, as well as researchers from the AEC (Architecture, Engineering, and Construction) community.

The tools for NETCAD (NETwork-centric CAD) are important regardless of what domain they concern. "Information appliances" for NETCAD include PCs (Personal Computers). Tools will need to be tied into software applications and projects on a network, so that everyone from a small machine shop to General Electric can use them. The identification of new types of software services addresses the needs of customers, while interoperability is addressed by examining integration mechanisms.

Dr. Regli was pleased to introduce the keynote speaker, Mr. Dan Deitz, explaining that he had been covering Internet technology for about four years, and had talked to most of the companies that sent participants to the workshop.

Dr. Regli charged the workshop attendees and speakers to describe their successes, as well as their challenges—the latter not with a six-month horizon, but rather problems for years to come. Dr. Regli intended the participants to use the breakout sessions to propose other technical areas of study for the future, such as the next-generation Internet that would be a hundred times faster than the current Internet.

An Industry-Wide Perspective

Mr. Dan Deitz, Associate Editor, ASME *Mechanical Engineering* Magazine
(deitzd@asme.org)
(talk given without slides)

Dr. Regli introduced Mr. Dan Deitz as one of the associate editors of the primary publication of ASME (American Society of Mechanical Engineers), *Mechanical Engineering* magazine. Previously, Mr. Deitz had been editor-in-chief of *Computers and Mechanical Engineering*, and had spent ten years with ASME.

Dr. Regli said that he had been following Mr. Deitz's articles for three-to-four years, and had said to himself, "He's talking to the people I want to talk to!" Thus, Mr. Deitz was the ideal person to come and discuss issues: "where are the lines in the sand?"

Dr. Regli noted that he had warned Mr. Deitz that the audience would ask questions.

Mr. Deitz spoke from a typescript; a copy follows.

First, please let me say that it's a pleasure to be here to support the efforts of our sponsors, the speakers, and participants to investigate the opportunities and challenges posed by network-centric CAD. The distinguished speakers you'll hear later on will assess how the Internet as well as private networks will affect particular agents and activities of the product development process: agents such as the virtual enterprise and the enterprises composing a supply chain, for example, as well as activities such as product design, product definition, product data management, and supply chain management. Before they do, I'd like to give you a very broad introduction to network-centric CAD by addressing its central, if still emerging, role in the business strategies of enterprises of all sizes.

Since my affiliation with *Mechanical Engineering* magazine, I've had an opportunity to follow the development of the computer-aided design, engineering, and manufacturing industry from roughly about the time academics were showing off some of the first software programs for producing solid and surface models. Looking back, I'd say that the most remarkable and significant development since then is happening today, with the rise of the Internet occurring just as companies worldwide are embracing the single-database model for managing 3-D CAD data and just as they are beginning to recognize the value of managing product data throughout an enterprise, and sometimes throughout an entire supply chain.

I think it's safe to say that most or all of us recognize that the ability to manage product data on a meta level will have a profound impact on enterprises in the future. (Indeed, it is already today.) Enterprises are recognizing that the content produced or used by network-based CAD systems are key corporate assets, and many companies are putting in place programs for managing these assets as carefully and thoughtfully as physical assets and human resources are managed. In may cases, these assets are being made available far beyond the boundaries of engineering departments, in areas such as purchasing and sales, where web-enabled product-data-management (PDM), component-management, and other database-management systems equipped with browsers allow users to view and manipulate CAD data without knowing how to use CAD systems or work with CAD data.

Increasingly, these network-centric systems for managing engineering content will serve as decision-support tools for executives in various departments as they craft business strategies. For example, in addition to helping engineering managers keep projects on track, these systems will help executives identify key engineering benchmarks and track product- development milestones. They will also help executives communicate business goals more effectively to engineers and technical professionals. To mention just one possibility, companies that adopt Internet or intranet-based procurement-management

systems may help design engineers function more effectively as front-line soldiers in the battle to reduce the cost that end consumers ultimately must pay for a new product.

However, if enterprises want to leverage network-centric CAD systems' engineering content to the maximum, they must ensure that the systems are bi-directional. That means that the systems must enable engineers to have input in the formulation and evaluation of business goals and the strategies that underlie them. In a discussion of network-centric CAD, by necessity we'll have to focus on fostering the collaboration of engineers by making a richer, more intelligent set of product data available to whole product or platform teams and by facilitating the communication among and between these teams. However, we also need to keep in mind that network-centric CAD systems will have to be bi-directional not only between design and downstream applications, but also between engineering departments and corporate management.

In this regard, I'll venture to predict that, with the accelerating pace of technological change, the successful enterprises of tomorrow won't necessarily be technology-driven enterprises. Instead, they're likely to be engineering-driven enterprises. That means that they'll have in place a network-centric computing infrastructure and a CAD-content-management system that not only enables engineers and technical professionals to collaborate on the development of a product, but that also enables executives and technical professionals to evaluate the technological implications of a business strategy or goal. Ideally, these enterprises will establish a means of evaluating the technological implications of a business decision as meticulously and methodically as executives evaluate the tax impact of a business decision today. Network-centric CAD systems will play a major role in making this possible.

Developments in the business world clearly are driving companies to adopt a network-centric CAD and content-management model. New products are being introduced at an ever-faster rate and product life cycles are shrinking, making the cost of the product-development process itself more important as a cost driver than ever before. Traditional products are taking on new functions, as familiar devices such as cellular telephones are loaded with Java applets that extend their capabilities beyond those of voice communication. Scientists and engineers at universities and corporate research centers around the world are not just redesigning, but re-conceiving office equipment to take advantage of the compute power of next-generation CPUs. And as products continue to get smaller, whole new markets are emerging or appearing on the horizon for a wide variety of portable devices; the portable defibrillator is just one example. To successfully create these new products and markets, executives need more than ever to consider engineering and technology drivers along with traditional criteria, such as tax implications and return on investment, when making business decisions. In this environment, then, defining the goals of a network-centric CAD system and putting such a system in place are emerging as key elements of successful enterprises' business strategy of creating new products and inventing new markets.

Before I go any higher in the ether to give you this bird's eye view, I'd like to offer a concrete example of what I have in mind. As I was writing this speech, I was also researching an article for *Mechanical Engineering* magazine on the engineering uses of the Internet and private networks. In the process, I came across a company with a business plan that, it seemed to me, could only be executed successfully if a network-centric CAD model were in place. The company in this particular case is a joint venture of Bosch and Siemens in Europe that produces home appliances. The Bosch Siemens appliance division, a major force in the European appliance industry, is currently executing an ambitious plan to expand internationally. The company has started by announcing plans for opening a dishwasher-manufacturing plant to serve the North American market. According to Bosch Siemens' business plan, the company has identified a market niche of customers who want high-quality dishwashers that use less energy and less water like those already sold by Bosch Siemens in Europe. The company hopes to leverage its engineering expertise in general and its environmental engineering expertise in particular and will do so by

organizing existing engineering content current and legacy dishwasher design data so that it can be distributed to engineers at design and manufacturing sites around the world.

Many appliance manufacturers have learned the hard way that while "world products" appeal to accountants who love economies of scale, they don't always appeal to customers in the appliance stores in the real world. Thus, Bosch Siemens engineers will create dishwashers for local markets in part by re using existing component designs. Such customization efforts are in line with another goal of the company's business plan: to win new business by working with housing developers to deliver dishwashers that have been designed specifically to fit the various homes in a specific new housing development. In this context, design reuse is not just a critical goal of the engineering department; it's a key business goal of the company. As customer needs are identified, engineers designing dishwashers to be produced in the North American plant will do so by querying the network to find component designs with specific attributes: for example, those relating to water and energy use as well as geometry and field conditions. By reducing the need to manufacture custom components with low production runs and, conversely, by maximizing the lot sizes of purchased components or existing production runs, Bosch Siemens engineers potentially will be able to satisfy the desires of a narrow market niche while keeping costs more in line with those of mass-produced goods.

I'm sure you can see how having a network-centric CAD and content-management system in place could be the factor that makes or breaks such a strategy for any enterprise. With such a system, engineers could establish an infrastructure that enables the technical collaboration of design and manufacturing departments at sites around the world as they create appliances that cater to discrete market niches and as they create manufacturing processes and tools for producing these appliances. Moreover, the engineers could help executives evaluate business strategies and formulate business goals more effectively by providing data quickly on how much a customized product might cost.

If approached the right way, a network-centric CAD and content-management system could help provide the decision-support information most needed on the front lines of the sales and marketing organization. For example, such a system could deliver data that salespeople need to configure products, quote prices, or estimate delivery times. A network-centric CAD system could also help executives evaluate whether the current mix of customized products is being produced efficiently enough to justify current investment levels. And when research shows that the sales force has turned down business for a requested product configuration in the past due to internal limitations on the enterprise's ability to produce it, a network-centric CAD and content-management system could help to produce the information needed to justify an adjustment to current investment plans that could transform an overlooked opportunity into a revenue-producing reality. In this way, a network-centric CAD and content-management system can help enterprises make the leap from solving technological problems to determining how customer requirements can be met within given cost constraints.

I've mentioned this example not only because it illustrates the opportunities of network-centric CAD for the enterprise as a whole. I've mentioned it because it also helps us to focus on some of the technological limits of network-centric CAD. As many developers of Internet-based search-engine technologies will tell you, the type of network searches for identifying existing in-house designs or components from outside suppliers will be accepted by engineers only if they're fast, reliable, and easy to formulate. It goes without saying that engineers can't spend too much time investigating all the entries that might be excavated in a single search. Moreover, they won't have confidence in the results of a search unless they can be sure that relevant information hasn't been overlooked or omitted due to limits in their ability to formulate search criteria. On top of the way searches are conducted, we have to consider the limits of the computational infrastructure. For example, many computer scientists would agree that an ambitious network-centric CAD system for serving Bosch Siemens' needs ideally would be based on object-oriented software. However, it's highly likely that the legacy design data the linchpin of the

network-centric CAD system weren't created with object-oriented software. For the plan to succeed, it seems to me, theoretically all of the legacy design data must be available. The question is, then, just how much of the legacy data will it be feasible to capture, archive, and distribute using a network-centric CAD system?

The Bosch Siemens example gives us just a taste of the opportunities and challenges posed by network-centric CAD in terms of leveraging engineering expertise to identify and satisfy customer requirements. This example focused on the opportunities and benefits primarily in the design phase of the product life cycle. However, network-centric CAD and content-management systems will be just as important in the manufacturing arena, for many of the same reasons.

Now that many companies are putting in place a product-development process that is driven by customer needs, they're discovering that customer needs go beyond those associated with design specifications. For example, customers have expectations regarding delivery time that can only be fulfilled with the aid of engineering expertise. Network-centric CAD and content-management systems could help companies in the automotive industry address some of the problems associated with balancing production lines and managing mixed-model production lines. They could do so primarily by helping the enterprises to become more agile. Outside of the auto industry, other companies that are creating products targeted at ever-narrower market niches are also finding that the question of balancing production lines and lot sizes is more pressing than ever.

Although it's only anecdotal evidence, I've been astonished at how swiftly some manufacturers have adopted a network-centric approach for manufacturing applications. Internet-based servers seem to be natural repositories for all kinds of plant-floor data, and they seem to address some of the infrastructural issues surrounding on-line predictive maintenance of plant-floor equipment. They are also providing an infrastructure for quality-control schemes that link computer-based inspection of finished products for purposes of comparison with the original 3-D CAD models. As network-centric CAD and content-management systems are broadly adopted, their engineers will be able to take advantage of an infrastructure for embedding tool capabilities in CAD tools. As a result, such systems will help design engineers create parts and tools that can be produced by existing tools in the shop.

In researching my story on the role of the Internet and intranets at manufacturers, I also came across General Motors' plan to expand its presence in Far Eastern markets by leveraging its aggregate design and manufacturing expertise. Again, it occurred to me that such a business strategy basically presupposed a network-centric CAD and content-management approach. To execute the plan, GM's engineers are customizing automotive designs to meet customer requirements and to comply with the safety, environmental, and other regulations of local markets. Once again, customization is to be achieved through extensive design re-use to maximize economies of scale. In this case, however, much of the customization work will be done by engineers at GM's Opel Division in Rüsselsheim, Germany, for production in the "modular" manufacturing plants to be constructed initially in Thailand and then elsewhere in the Far East. The work of customizing manufacturing instructions and tooling to match the capabilities of local plants promises to be almost as engineering-intensive as the job of customizing the automotive products themselves. The rich and intensive bi-directional flow of information that network-centric CAD and content-management systems ideally will make possible is an essential ingredient in the success of such a venture.

The manufacturing opportunities of network-centric CAD are truly exciting. Network-centric CAD promises to revolutionize the communication of product attributes to those who produce it. Currently, design and manufacturing engineers must create a drawing or document to meet every foreseeable need for product information on the factory floor, not to mention the needs of all the other downstream processes. Creating and managing engineering documents, obviously, add considerable cost and time to the product-development process. In adopting a network-centric CAD model, some manufacturers

hope to create a whole new means of engineering communication that relies on low-cost personal computers and relatively easy-to-use web browsers, thereby mitigating the costs currently imposed by a strategy of making 3-D CAD models and 3-D CAD software available on the factory floor.

Using this new, emerging means of engineering communication, design engineers begin the design process much as they do today, by creating master product models that capture their design intent. After intelligent master product models have been created, engineers and other product or platform team members can use a browser to find that part of the model that they must work on, and they can create virtually on demand any documents that they need to do so. Ideally, a network-centric CAD and content-management system will help reduce the number of documents that must be generated for the next phases of work, and it should at least reduce, if not eliminate the need to create separate product databases for each step in the design and manufacturing process. Moreover, by the time the design and manufacturing set-up processes have concluded, workers on the factory floor when properly outfitted with and trained in the use of a browser ideally should be able to find any product data, generate any additional documents, or take any additional measurements needed to do their jobs or resolve problems that arise.

By the same token, enterprises can make videos of intended assembly sequences, written instructions, and equipment manuals available on-line using web home pages or other Internet connections. With the increasing availability of web publishing tools and of web-literate engineering graduates, enterprises are finding that delivering training videos or compiling a comprehensive on-line directory of all the equipment in a plant can be justified given the investment in cost and time, which can still be considerable. Indeed, with the increasing ubiquity of web-browser interfaces, it's becoming more realistic for companies to invest in custom-built displays or navigation menus created with standard tools. The widespread adoption of the web has also extended the reach of rapid-prototyping service bureaus, which can now obtain uncorrupted STL-file transmissions with ease over the Internet. Moreover, the availability of 3-D viewers enables engineers at a rapid-prototyping service bureau to resolve questions or address problems by exchanging 3-D e-mail with engineers at the customer site. Digital photographs of finished rapid prototypes are also being taken for transmission via the Internet to the customer, who then either approves the product or asks for modifications.

Why should these capabilities be crucial to executing a plan to design and manufacture partly customized products at design and manufacturing sites scattered all around the world? Perhaps the most compelling reason can be found in the changes already imposed by network-based CAD practices in the past. At the Chrysler Corporation, for example, the proper functioning of networks of engineers is crucial to developing new car, truck, and van models in an environment where product-development cycles continue to shrink. However, networks of engineers tend to become "hard wired" in other words, inflexible. Engineers who have worked together on one product-development cycle often stay together even during off periods until the next cycle begins.

In the past, this way of working was beneficial because there was nothing like the human brain or, to be more precise, networks of human brains organized on the principles of loyalty, friendship, professional esteem, and so on for keeping track of essential product information. This network of brain power, formally recognized in organizational charts, made it possible for organizations to remember why one change was made to a design while another wasn't. This institutional memory was and remains essential to the functioning of many manufacturing enterprises.

However, as engineers have taken advantage of new ways of incorporating design intent into intelligent master assembly models, and as they've taken advantage of new tools for managing and documenting work processes, it's become increasingly possible to transfer this institutional memory to memory chips. The more Chrysler engineers take advantage of these capabilities, the more flexibility the company's engineering managers have in using engineering talent. Today at Chrysler, as soon as one phase of a project has

been completed, engineers are assigned on an as-needed basis to other pressing projects. As a result, human-resources are being used more efficiently and more in accordance with the needs of product development, which is one of the reasons why Chrysler has made good progress in its goal of reducing the product development process overall.

Thus, by making vast product-definition databases or intelligent master product models available on the Internet or, more likely, on a private network, companies like GM and Chrysler are finding ways to preserve design intent so that anyone with the needed skills—and not just the requisite institutional memory—can contribute meaningfully to design and manufacturing projects. Moreover, the availability of such product definitions or master models, with all their attending documents, potentially makes it easier for engineers at manufacturing sites to gather the information needed to justify departures from a design strategy the use of a different material than the one specified, for example when local conditions warrant. Conversely, having such information available ideally should make it that much easier for engineers no matter where they are or what their role was in the design process to justify spending more to avoid repeating mistakes of the past.

The opportunities posed by network-centric CAD for enterprises with far-flung design and manufacturing centers, thus, are obvious. The pitfalls are obvious, too. Most CAD vendors will tell you that to use CAD systems to truly reduce product-development cycles, you typically need to re-engineer your product-development process as a whole. The problem is that our tools and technologies are changing so quickly it's hard to know where to allocate human resources. Much of the clerical work that engineers perform should be eliminated as more and more engineers use master assembly models and browsers to generate design and manufacturing documents on demand. On the other hand, additional work is being created in other areas. For example, there are new needs to make sure that engineering information on a project home page is up-to-date and accessible only to those who have a need to know. Unless organizations change the way individuals' job descriptions and departments' missions, network-centric CAD and content-management systems may provide only incremental benefits.

Many manufacturing enterprises have high expectations regarding network-centric CAD's ability to maximize engineers' efficiency and to leverage engineering talent in order to satisfy customers' desires. Network-centric CAD systems, then, will have to meet high expectations regarding the quality, integrity, and completeness of information to gain the confidence of users, which will determine to a great extent how successful installations will be. As a result, we're now seeing the transformation of engineering departments as they assume formal responsibilities for the archiving and management of engineering content. For example, materials departments at some companies are now establishing repositories of approved materials and their properties accessible on-line via the Internet or an intranet; some can be integrated for access with a CAD system, while others especially in installations where several CAD systems are used might be better accessed through a web browser.

As the boundaries between departments and work teams become more fluid, we're seeing a similar development in the relations of primary manufacturers and their suppliers in the supply chain. To some extent, they mirror changes in the relations between design and manufacturing. Since the shake-up in supplier relations at the largest manufacturers that was initiated by the adoption of just-in-time practices, suppliers have acted more and more as the "manufacturing departments" of their customers. This strategy allows primary manufacturers to focus on products and processes in which they have a particular advantage. As their customers have adopted network-based approaches to link internal design, analysis, and manufacturing activities, a corresponding need in many cases has arisen for suppliers to participate in the design and analysis phases. As internal design, analysis, and manufacturing departments have made progress in "getting designs right the first time," manufacturers are scrutinizing suppliers' performance more intensely than ever—a scrutiny made more intense yet again by the fact that suppliers are essentially

responsible for the last phase in the process, manufacturing, and thus by default are often seen as "bottlenecks."

Here again, network-centric CAD, inexpensive PCs, and easy-to-use browsers potentially offer suppliers a means of contributing earlier to design and analysis phases. However, some manufacturers have proceeded more cautiously in opening the lines of communication from their private internal networks to suppliers'. In the area of supply chain management, technical issues such as security and data exchange still tend to predominate, at least at the companies I visit.

From here on, this workshop will be devoted to exploring all of these areas the opportunities to realize the benefits of network-centric CAD and content management, as well as the technical questions. We'll hear some of the specifics regarding the agents of the product development process enterprises and supply chains and how they're using or could be using network-centric CAD tools to meet business goals, such as reducing product-development cycle times and costs and becoming more flexible. We'll also take a detailed look at how engineering tools are evolving in response to the rise of the Internet and private networks. These tools include design automation software and product-data-management systems. We'll also examine opportunities for using the web to manage the supply chain.

Before we go to the break, I'd like to offer one bit of anecdotal evidence that supports the importance of the efforts of the people in this room. The editors of *Mechanical Engineering* travel extensively to meet with engineers in all industries, and the most frequent request we've heard has to do with education. Small and mid-size companies including job shops are keenly interested in partnering with customers to help them solve business problems and achieve their business goals. Many of them are anxious to upgrade their hardware and software tools as well as the skill sets of their engineering; from our experience at the American Society of Mechanical Engineers, all-around engineers are in great demand. Requests for education by engineers at small and mid-size companies are echoed by engineers at primary manufacturers, who emphasize that educating their business partners is just as crucial to the success of network-centric business strategies as a network infrastructure itself.

Thus, wherever we go, we find growing interest in the 'Net and in network-centric approaches. Fortunately, I think this interest is going and will continue to go beyond being merely that, an interest, because, on paper at least, the 'Net itself and network-centric approaches make it fairly straightforward to realize even some of the most ambitious dreams. It looks like we're positioned for a fairly substantial transfer of technology to small and mid-size companies and for a continuing re-engineering of the development process for products of all kinds. Now, it's on to the details and to the many barriers that still remain.

A question-and-answer period followed Mr. Deitz's talk. Questioners are identified by number.

Q1: Regarding management of design content and design intent, what tools are available today, and what are the research issues? My CAD system can say "thickness-to-diameter for hole", but cannot capture design intent.

A: Problem: we don't have actual intent—that's in the research phase. There are stopgap measure such as "digital stickers" that designers can use to indicate why they made certain choices—but the stickers aren't searchable, so they're useless.

Q1: How about design process management?

A: The biggest companies are talking about it, but no one seems to be doing it. They're still evaluating tasks to see what takes the most amount of time.

Q2: Regarding the Bosch/Siemens integration, are they using off-the-shelf tools—the state of the art in customer systems—or in-house customization?

A: Customization with an in-house Unix system, that costs lots of money. But I think that a Windows-based system with PCs and browsers, Java, and the like could do the same thing more cheaply. They may have chosen Unix because of legacy data.

Q2: Do they use an added layer on top of their CAD systems?

A: They use CAD5, and Computervision, but customized.

Q3: Is there any movement to Product/Process Design Advisors to give advice across the Internet?

A: There's great interest, but it's a low research priority, because companies know that it will take a long time to get there. Like Environmental Management Advisors, they are research issues.

Q4: Are intranets or the Internet being used?

A: Engineers complain about the lack of timesharing resources—they use local resources, then distribute them.

Q5: Did you talk to small companies, of about 12-36 people, for example, design shops? Not just multinational companies?

A: Small companies are very important to us. Ten years ago, most ASME members were from large companies. Now, many more are from small or mid-sized companies. We find small and mid-sized companies very interested in the Internet as the great leveler, as it gives better access to information.

For example, we talked to a truck body manufacturing company, with an engineering design staff of eight people, under pressure to cut costs.

Q6: It seems that small companies are interested in herd-use downloadable design advisors, since they can't do large-scale customization like Siemens.

A: Exactly. We are aggressively covering that area in upcoming years. Lots of Java applets are being developed.

Also, virtual manufacturing process advising centers, such as one at the University of Nebraska, are coming into greater prominence. They are made virtual by the WWW, like education extension centers.

Q7: Do you find companies avoiding the Internet because of security issues? For example, one company I know of won't put their catalogs on the Internet because their lawyers fear it will bring down the company.

A: Yes. For example, I know of big rapid prototyping manufacturers who will not use the Internet at all, because they don't want their data to go out through firewalls. They are spending lots of money for in-house service bureaus instead.

Support of Virtual Enterprise Computing by the Emerging Capabilities in MDA and PDM Systems

Dr. Al Klosterman, Vice President, SDRC (al.klosterman@sdrc.com)
(24 slides on 12 pages start after page C-43)

Dr. Regli introduced Dr. Klosterman as having been at SDRC (Structural Dynamics Research Corporation) for almost 26 years, that is, since the beginning.

Dr. Klosterman said that he would talk about SDRC's traditional strengths in MDA (Mechanical Design Automation), new strengths in PDM (Product Data Management), and developing strengths in RDE (Requirements Driven Engineering). SDRC has 25,000 employees, 250 million dollars in sales, and is traditionally an MDA company. Ford and Siemens have standardized with SDRC's product.

Dr. Klosterman's focus is on how to computerize RDE to link people together and solve problems. He knew that he didn't need to belabor the network-centric CAD issue at a network-centric CAD workshop.

Regarding the assumptions involved with collaboration and user interaction, there are complex processes in building. Multidisciplinary electrical and mechanical computing takes place in a geographically distributed manner, as opposed to individual-centric systems. A system looking at integrated concurrent product engineering and PDM can deal with this entire enterprise process.

As product and process complexity grows, a system must manage complexity for the user. One important element is ease of use: a major inhibitor of technology to date. SDRC wants to automate the information equivalent of "housekeeping" in a better way.

A key element of the visual and direct interface is that if you are trying to build a product, it's important to be able the "virtually" bump this part against that part. Thus, the system must mimic physical reality.

The user interface metaphor involves thinking about full products, which are what design and modeling mean in this context—as opposed to generic part-modeling systems. To make systems easy to use, they must be customizable; an infrastructure is necessary in order to do this better. In the automotive world, they customize a standard CAD/CAM system to their specific needs. A task-specific user interface can be configured very quickly with visual tools.

The "ORB (Object Request Broker) Infrastructure Architecture" slide is SDRC's view of how this infrastructure would look, leveraging CORBA and other legacy technology. SDRC created an MDA system (I-DEAS) and a PDA system (Metaphase). SDRC is thinking about what PDE module is needed here.

SDRC intends to leverage agents to tie multiple disciplines together: the three disciplines are Design, Analysis, and Manufacturing. Variational (three-dimensional) geometry—not history information—is necessary to capture design intent. Because some users are in two-dimensional domains, and some are in three-dimensional domains, they must work together and propagate changes. Features are an important element in communicating a design across various disciplines.

Performance analysis is also important: while abstractions (such as finite elements) exist, they should be "under the covers". Additional physics are required, not just stress, but also fluids and electromagnetics.

In manufacturing automation, virtual machining must work in conjunction with design intent. Three-dimensional variational design can maintain design intent. In real time, the user should be able to interact with, sculpt, and bump surfaces. The associativity among views must be across abstractions, not independent data sets. Intelligent agents and advisors are necessary to communicate design intent.

In the PDM interface, because the problem at hand is a virtual enterprise, it is important that the systems work seamlessly together by automatically mapping the product structure. PDM systems don't provide this kind of control today.

The "PDM Interface & Integration Reqr.: Requirements" slide is SDRC's first effort to describe a PDM interface. PDM systems need to know which users created what parts with what information. There is also a need for transparent linkages to the other existing databases.

MetaWeb is an emerging Internet browser with a transparent linkage to external databases. MetaView is an application integration toolkit that reads the API (Application Programming Interface) of a database and of the PDM system and allows them to interoperate.

Design for variability must allow things to change under the right conditions. For example, using a different motor might require different support for the motor. The Requirements and Knowledge Assisted Product Development process involves getting requirements and representing them in a computer, so as to leverage corporate knowledge for future products. A "Requirements Engineering Advisor" illustrates the old way of doing things—by hand. The "Support for Virtual Enterprise Computing" slide summarizes the talk.

A question-and-answer period followed Dr. Klosterman's talk. Questioners are identified by number.

Q1: In your talk, you said that product complexity keeps growing. Did you mean mechanical complexity or integration complexity?

A: There are a lot more electrical components; for example, computers in cars. There are a lot more stringent requirements; for example, crash requirements in automobiles—but there's no crash simulator inside the computer. There's a lot more involvement from the marketplace.

Q2: Let's discuss your "ORB Infrastructure Architecture" slide. How much realized experience do you have with CORBA?

A: We feel CORBA is the right standard, and is better than Microsoft's expansion of OLE. CORBA doesn't have all the performance we want now, but we think it will over time. Our specific CORBA projects number in the dozens, not in the thousands.

Q3: Same slide. Are you using CORBA in an object brokering manner, or in a specific interfacing manner?

A: We're using legacy systems that were not built from an object-oriented point of view. CORBA supports both object-oriented systems and traditional systems. We use it more for traditional systems at this point, say about 80%.

Q4: You describe interesting large-company applications. How can they be passed to second-tier and third-tier suppliers with two-thousand-dollar to five-thousand-dollar CAD systems?

A: The National Industrial Information Infrastructure Program (NIIIP) is our context. They address both large and small companies. I'm one of the NIIIP technical advisors, so I'm making sure that small companies are part of NIIIP.

SDRC is focusing on large companies, but SDRC intends that others focus on small and medium companies. Small companies can download the information in our architecture.

NIIIP has been doing work for two years in the CORBA environment. We've done lots of work with CORBA and the Internet. Yes, there are breakages. But we're convinced that it's the right way to go. The CORBA engineers keep plugging holes.

Q5: Does CORBA keep up with other standards?
A: Yes. Press releases are easy—Microsoft's good at them.

Q6: In the "ORB Infrastructure Architecture" slide, it's very easy to say "look at manufacturability as design rules." What's your strategy for populating design rules through the environment for customers?
A: We provide an environment with an infrastructure and a CORBA interface. Customers provide rules in the context of that environment. They interview experts, collect data, and propagate rules.
Q6: Good idea. Follow-up question: How much input do knowledge engineers at, for example, Ford, have in these interfaces?
A: Lots of input, especially into the next release of the product. The interfaces are a "moving target" right now; we hope the moving target settles down.

Q7: Metaphase came from DARPA's RASP program. As part of that, RDD 100 came out, with its RDE focus, as did RDD 2000. How does RDD 100 fit into your RDE?
A: I was not aware of RDD 100 and will look into it. The original driver for Metaphase was from DMCS, a system from GE from the 70's and early 80's. I don't know what roots Metaphase has in government-sponsored programs.

Electronic Product Definitions and Internet Technology

Dr. Ravi Ravindra, Senior Scientist, Computervision
(rravindra@msgate.cv.com)
(talk given without slides)

Dr. Regli introduced Dr. Ravindra as having been at Computervision for nine and a half years. He said that Dr. Ravindra would give some anecdotal evidence for the state-of-the-practice.

Dr. Ravindra was happy to be at the workshop to describe his experience at Computervision and to draw from the participants' experience. Computervision is a high-end Electronic Product Definition solutions provider, and their next-generation architecture will include CORBA and the Internet. Computervision has a very robust Intranet within the company to solve major critical business problems.

Dr. Ravindra gave his view of why things are in the existing format, and where the industry is going. Computervision's product-and-process response to the customer needs to concurrently create, manage, share and reuse electronic product information in a collaborative environment, both throughout a product's life cycle and across a distributed value chain.

Computervision had slides similar to Dr. Klosterman's "ORB Infrastructure Architecture" slide describing what their products look like. Dr. Ravindra said that that was not his expertise; he looks at how the Internet and emerging technologies can solve problems.

Computervision has converted lots of documents to HTML for a lot of automotive and high-end airbus companies. Those companies don't want to be on the Internet to communicate with suppliers, so Computervision converts the documents to HTML and sends them to customers.

Computervision enhances products with Java and Javascript, bringing in end users, suppliers, and integrators to communicate about requirements.

Computervision is going through a lot of strategizing, producing a new mission statement. They believe that there exists a use for Internet technology and a way to work in collaborative environments.

As an example of enhancement, Dr. Ravindra described how difficult it is to educate people—especially management—on how to use technology. Computervision wanted to keep track of all commitments that management and others have made to customers from a central location. They started implementing a Lotus Notes solution, but without much success; it was limited to LANs (Local Area Networks), not a world network. So about two years ago they designed the system using WWW technology with Netscape to solve the problem.

Back then, there were no WWW-based interfaces to databases. Instead, they had to use CGI (Common Gateway Interface) under Unix. It worked! Computervision saved millions of dollars in administration and other costs by not using Lotus Notes. Computervision then took the interface, extended it to Java and Perl, put it in Sybase, and put in customer call-tracking information.

Computervision took the same concept and extended it to products for product information storage, and give restricted access to the information to people in the company. They used RSA (Rivest-Shamir-Adelman) encryption with a Netscape commerce server to maintain security. Even though the data was going over the Internet, it was secure because it was encrypted. This worked out well, so they enabled products inside the company to solve this particular problem.

One of British Aerospace's problems was adding a note to a product that can be accessed throughout the product development cycle. Computervision quickly developed a Java interface to do that.

Computervision is looking at the next generation of software development to take advantage of such technologies as Java, and Microsoft's OLE.

Dr. Ravindra asked why third-party companies are using proprietary interfaces. Brokerage companies are doing just fine with Java/CORBA interfaces. For example, some products from Enterprise Integration Technologies used a Java interface to a graphical development tool from CMU.

One important issue is how to integrate products without breaking infrastructure. One reason people are using proprietary interfaces is that there is no Java on some platforms, such as Windows NT and Windows 95.

Another of Dr. Ravindra's concerns was that Microsoft seems to be splitting the Java architecture to serve their own needs, that is, to be more profitable for them. When companies start splitting architecture, it starts to make it difficult to work globally.

If these companies have vested interest, what is NIST's role in standards? The W3C (World wide web Consortium) is implementing their own modifications for many vendors; very few people want to understand the whole technology.

Dr. Ravindra closed by saying that he is curious to know how other people feel so Computervision can make its products Internet-enabled.

A question-and-answer period followed Dr. Ravindra's talk. Questioners are identified by number.

Q1: You gave many examples of current technologies. What are your thoughts on getting beyond current technologies? What we have now are enabling technologies, not fundamental solutions to hard problems.

A: Lots of companies implementing these solutions are struggling with that. People in our own company are looking at this. For example, Java in Microsoft and Netscape.

Corel says there are inherent problems in using their Java Office system on Suns running Unix, but that it works on PCs running Microsoft products.

There are problems with massive data sharing on the Internet, both under existing bandwidth and making sure that it isn't tampered with.

People are willing to give out credit cards on the telephone, but reluctant to do so on the Internet with what I think is better, safer technology.

Q2: You mentioned bandwidth. Have you faced any slowness-of-HTTP problems?

A: Sun is pushing Web/NFS as a faster solution to these performance problems. NSF is looking at increasing bandwidth. People are looking at ATM technology to improve performance. DirecPC seemed to work efficiently at home—10 megabits per second. Switching networks is tough to implement overnight in big companies.

Q3: Did you do actual object brokering in CORBA?

A: Yes. We interface a family of product data over the Internet. I'm happy to put you in touch with those people (they're still in the research stage). Corel is doing something to implement Java, but alas, it's proprietary.

One idea is to have an interface as your desktop, so that you don't know what application you're actually using. VRML was an idea to handle CAD products, but Java seems to have overtaken it.

Supply Chain Integration and the WWW

Dr. Joe Erkes, Director, Design Integration, GE Corporate R&D Center
(erkes@crd.ge.com)
(12 full-page slides start after page C-57)

Dr. Regli introduced Dr. Erkes as having been heavily involved in DARPA projects for many years, especially the Agile Manufacturing Program.

Dr. Erkes said that the business realities of the 90's were tough, and getting tougher. Products were once roughly 80%-90% internally built, and 10%-20% outsourced. Now, they are roughly 10% internally built, and 90% outsourced. It's hard to be a good supplier across multi-tiered supply chains; to do so requires integrated product development.

Dr. Erkes related an anecdote about Willie Sutton, a famous bank robber from the 1930's. Sutton, asked why he robbed banks, replied, "That's where the money is."

Dr. Erkes is disheartened by products that don't talk to each other. The good news about supply chain integration is that there exists an extensive world-wide network; that the network is fast, despite complaints about its speed; and that important players use it. The bad news is that balkanization by companies such as Ford makes supply chain integration expensive for small companies that provide services, such as simulation houses, rapid prototyping suppliers, validation suppliers, and tooling suppliers.

Most U.S. manufacturing is at the three-sigma level: 66,807 flaws per million parts produced. This level costs 15% of sales (overall, counting more than just value of scrapped parts), which is 1.5 billion dollars for a company whose sales are 10 billion dollars. Those who start manufacturing at the six-sigma level early—3.4 flaws per million parts produced—will be a big threat to those who stay at three-sigma. Manufacturing at the six-sigma level requires design for six-sigma (DFSS).

To achieve process optimization, necessary for the four-sigma and five-sigma levels, a company must understand the processes that outside suppliers use to build products. To achieve six-sigma, a company must have a detailed understanding of their suppliers' manufacturing capability.

The DARPA agile manufacturing pilot program has the objective of reducing cycle time for sand-mold castings acquisitions. To achieve this objective, it must integrate a virtual castings enterprise across the National Information Infrastructure (NII)—that is, the World Wide Web; it must eliminate key technology barriers; it must streamline virtual business practices; and it must proliferate the solution across the supply chain.

Designers must co-design parts with the agile castings project team, to make the design stage much faster. This co-designing must occur over the web. Practices must be re-engineered to take advantage of emerging technology.

Dr. Erkes noted that he hadn't talked much about the migration path from legacy systems to all-CORBA systems. In this migration path, the end users must start "herding" vendors; such herding is now being done by companies like Microsoft for their own profit margins.

At present, a supply chain is a hierarchical process. A prime manufacturer doesn't communicate with a third-tier supplier. In the future, this process must be replaced with flat, parallel access.

Among the major project thrusts in supply chain integration (SCI) are: rapid communication—the web is the obvious solution, being cheap and widely available; exchange of rich information—that is, exchange concerned more with intent, not just with notes in margins; and new business practices—traditional hierarchical business processes must be eliminated.

Application opportunities for SCI include not just castings, but other items with long lead time. A solution to SCI could have high financial impact. A key idea in SCI is that the

first iteration cycle should be as good as if it were "in-house". One problem is that it is not only the prime suppliers who think that they have proprietary data, but the suppliers at other tiers have their own proprietary data as well. The issue of proprietary data goes beyond the issue of encryption, to the issue of how to use someone's data without making it public.

Dr. Erkes continued with some comments about the situation at GE. One change is cost-cutting, not just with travel, but also with computer hardware. Employees no longer have both a Unix workstation and a PC on their desks; they must choose one or the other. This leads to a more heterogeneous environment. The web provides a wonderful way to cut costs and live under these restrictions. As a solution, the web is good internally as well as externally. Dr. Erkes sees lightweight clients that communicate with machines that can handle heavy applications as one trend for the future.

A question-and-answer period followed Dr. Erkes's talk. Questioners are identified by number.

Q1: You could have said that real applications don't use CORBA as much.

A: CORBA is used widely in academia, not in industry. A similar situation exists with STEP.

Q1: How do you see CORBA being used with legacy systems?

A: We make money with legacy systems. We won't throw them away. We must move to CORBA by a migration path. Shell legacy systems could be available over the web, with CORBA gluing these systems together, even if they are not truly object-oriented systems.

Q2: If I could "Plug and Play" a supply chain, your other two national challenge problems are easy. Who does the "Plug and Play" supply chain interface?

A: The frustrating thing is, I don't know. If we start standardizing data, it would provide market pressure on vendors. Standardization by encapsulating legacy systems is the only way I see it happening.

Q3: One way to "herd" faster is by strategizing and lecturing like Jack Welch.

A: If Jack Welch were "herding", it would be done tomorrow. The problem is that upper-level managers have heard "spend now, earn later" before.

Q4: Naively, it sounds as if you are making everyone a first-tier supplier by a business model standpoint.

A: In the present, a first-tier supplier gives you a quote, you accept, and you don't know who's on the third tier. We need a negotiation process on the web where teams form to address lucrative projects. This would result in a multi-phase procurement: in phase I, design; in phase II, bids on the manufacture of the design.

Q5: Do you see VRML viewers as being used for three-dimensional drawing? You can't put design intent and constraints in VRML. Is VRML good enough? Can it answer queries?

A: Yes to all. VRML gives a quick and dirty method to look at three-dimensional parts. We glue together such things, so that we can have a phone conversation while simultaneously communicating about three-dimensional drawings.

Q5: Would GE push for precise VRML—NURBS (Non Uniform Rational B-Splines), not facets?

A: Honestly: maybe. The motivation is a fast design integration cycle; GE probably won't see NURBS as an important part of that.

Q5: But we still need GE to push on standards organizations.

A: Yes. There must be a better way than yelling at vendors. We need to get a critical mass of tools to start the process running.

Q6: We're investing so much in communication bandwidth. Does it make suppliers less independent? Why not just hire them all?

A: It's not going to happen. Outsourcing will continue, not reverse.

Q6: I absolutely agree. The reasons for outsourcing are that you can fire suppliers at will, and that suppliers can specialize to serve a larger audience. But if you make suppliers less independent, communication bandwidth becomes expensive, thus you don't want to fire suppliers at will, thus you lose an advantage.

A: Right. That's the problem with balkanization. Thus plug-and-play.

Q7: To achieve the three-sigma level, a disciplined approach is enough. To achieve the four-sigma and five-sigma levels, process optimization is necessary. What about process characterization in between?

A: Yes, it's in there, it just didn't fit in my three-minute summary.

Q8: One increasing important thing in supply chain plug-and-play: how do CAD systems, different between a first-tier supplier with a $40,000 CAD system, and a third-tier supplier with a $5,000 CAD system, talk to each other? STEP?

A: We can't wait around for STEP. In the short term, we'll go through a translation supplier, though STEP will kill translation suppliers in the long term.

Internet Presentation

Mr. Shaun Sewall, Development Manager, Bentley Systems
(shaun.sewall@bentley.com)
(slides unavailable)

Dr. Regli introduced Mr. Sewall as the person in charge of a web-enabled engineering tool. This tool has won awards, most recently from IndustryWeek. Mr. Sewall has been at Bentley for four years, and had previously been at Intergraph.

Mr. Sewall gave as background a description of MicroStation, a fifteen-platform family of CAD products. Mr. Sewall's plan is to bring the power of the Internet to an engineering CAD software seat. The Internet makes viewing strategies necessary.

Mr. Sewall demonstrated his web-enabled engineering tool in a sample Internet scenario. He began with a drawing of an office building in MicroStation. The browser is built inside MicroStation (the important thing being not that the browser is part of MicroStation, but that MicroStation and the browser are integrated and can interoperate). The browser helps with ease of use.

Mr. Sewall clicked on a bookmarked HTML page, which would be the chair that the office is authorized to purchase; the CAD view changed to a display of the product. Mr. Sewall supposed that the chairs are meant to be placed around a table in the office building; he simply "dragged and dropped" the chairs from the web page to the building.

Mr. Sewall noted that he was glossing over how such a web page is created in the first place. This creation is a two-part problem: convincing users to use the web page, and convincing manufacturers to create the web page.

The chair used in the demonstration is linked to an HTML page describing the product line, which is how the CAD system gets the specifications for the chair. Mr. Sewall emphasized that this had been only a demonstration of how to use Internet in the engineering seat.

Bentley feels that just graphics are not enough. Instead, built-in programs are necessary as well; for example a steel truss that automatically reinforces itself. Bentley calls this combination of graphics and a program a "modlet". Bentley sees component manufacturers making modlets available on a company website.

Mr. Sewall discussed possible viewing strategies. One strategy is a stand-alone viewer. This strategy has many disadvantages. First, this viewer would be a "fat" client; the application must have intelligence that understands the model built into it. Bentley's executables for CAD viewing-only are almost as large as full CAD executables. Second, if a file format is updated, all clients must be updated as well. Third, there are security problems; the CAD system must get an actual model.

A second strategy is a browser plug-in. This has the same disadvantages, plus a self-contained file format; that is, a file format with no external reference files and no external fonts.

Another strategy is standard formats. This strategy has the advantage of reduced complexity. One disadvantage is that whoever designs the standard format must know what people want to see ahead of time. Another disadvantage is that when a model changes, it must be republished in the standard format.

The best strategy is a Model Server Publisher, with all advantages and no disadvantages. The model resides on a web server. When a request comes in, the model is automatically published to the correct format. Now converted, that file is sent out in the correct format.

A conference participant interrupted Mr. Sewall to ask if many hits would cause a great deal of overhead and if the server would cache the conversion to save time. Mr. Sewall answered "yes" to both questions.

Bentley's web page (http://www.bentley.com/) demonstrates the Model Server Publisher in action. The Model Server Publisher can do client-side customization for simple viewing applications. On the server side, the Model Server Publisher can provide Internet capabilities without changing the accustomed environment. The Model Server is a relational database, not separate files. Since design data is stored in a design database, a designer can make changes, and then either throw away or commit to the changes.

In the future, Bentley will add methods to the models, because the graphics that define objects cannot be separated from the objects' behaviors.

A question-and-answer period followed Mr. Sewall's talk. Questioners are identified by number.

Q1: Why are you storing design data in a relational database, rather than using PDM?

A: To get away from thinking about engineering data as file-based, rather, putting it in a database that vendors can sell readers for.

Q1: Why did you use Oracle and not ObjectStore?

A: Oracle met our needs.

Q2: Why go through a browser to get the chair, rather than simply changing the Bentley interface?

A: We couldn't, in this case, because the product was already released. That's where we're going in the future, though.

Q3: Using modlets, how much data needs to be downloaded to run something? A parametric solid model? A whole solid model package?

A: Depends. Are you downloading the whole model? Pieces? Size is a concern.

Q4: You said that it could be an external browser—why did you make the design decision to use an internal browser?

A: Internal is better if you use it a lot—you don't have to do Alt-Tab. Also, six months ago, it wasn't as obvious everybody would have Netscape or Microsoft Internet Browser, as they do today.

Q4: Do you go from MicroStation into the browser, or vice versa?

A: Both. A browser can't do everything.

Q5: Regarding smart catalogs—have you talked with IndustryNet about getting suppliers to put catalogs up?

A: I haven't, but marketing is trying to build those relationships with suppliers.

Breakout Sessions: Technology Assessment

Directed by Dr. William Regli, NIST (regli@cme.nist.gov) and Dr. Simon Szykman, NIST (szykman@cme.nist.gov)
(breakout done without slides)

In the discussion that follows, Dr. Regli and Dr. Szykman, who are writing the charter for the breakout sessions on flip charts, are identified by name; other participants are identified by arbitrary numbers.

Dr. Szykman: We saw several things as issues. First, applications, such as product data management or supply chain management. In what ways is this technology being used? In what ways would we like to use it?

Second, technology: Java, CORBA, NIIIP, security, standards, and interoperability.

And possibly third (or possibly break up into just two groups), a meta-level: corporate issues? vision for next-generation CAD tools?

Q1: Standards could stand on its own under technology.

Dr. Regli: Standards recommendations would be very interesting to NIST: data standards, communications standards, interoperability standards.

Q2: These issues are too broad. Gives us a goal—say a list of things?

Dr. Szykman: Yes. We'll focus on what we want.

Q3: Tools should be under technology, for example, CAD browser tools.

Dr. Szykman: Okay.

Q4: A useful question: where is the line between what vendors supply and what it sits on top of?

Q5: An alternate way to do this: we need plug-and-play, how do we make it happen? The notion of legacy systems won't go away.

Q6: There are stakes pounded into the ground that we're not going to move.

Dr. Szykman: How about a list of larger efforts: what's necessary to speed them up? For example, plug-and-play.

Q7: I'm from a different background. I work from message-passing, for example, the Message Passing Interface (MPI). It started from a user interface, and they didn't worry about low-level problems—now it's useless, restricted to a single vendor.

Dr. Regli: What basic infrastructure—core communications standards—do you need? Put it up.

Q7: Basic is key.

Q8: I want a discussion of what users want. We usually miss it in R&D: "Here's something." "We don't want it."

Q9: But we don't have many end users here.

Q8: Yes, but for example, vendors, who we have here.

Dr. Szykman: At a previous workshop, users said vendors didn't care what they wanted.

Q10: Storage of information—on web server? That model's tough for small machine shops. Distributed storage?

Dr. Szykman: I'll use "business issues" for that.

Q11: We're in a rapidly changing world, but we're scaling from toy problems and prototypes to real problems.

Q12: Scalability in computational fluid dynamics is a key issue—they have whole conferences on it.

Q13: It's key here.

Q12: Agree, scalability is the most naively overlooked issue.

Dr. Regli: We want to focus on new research issues, and new generations of problems—figuring out what they are before they show up.

Q13: Business trends for the next five to ten years are interesting to write down—see if we agree on them.

Q14: When you make a system to enable goals of users, users can do new things, and so goals change. These "affordances" are often overlooked.

Q15: How do you go from a hierarchical organization to the flat model of GE?

Q16: Let's discuss as one group for a while, and decide whether to break up.

Dr. Szykman: Good idea. We want content, not just bullets. One important distinction: implementation (for example, if I hire one more person, what could I do?) versus research (for example, design rationale: some academic should come up with this, because I don't know how to do it).

Q17: I'm an academic who's been working on capturing design rationale for more than 20 years (and now I'm moving industry). There aren't enough guns to point at enough heads to make it happen. It's academic largely because it doesn't work. Network-centric CAD gives us lots of text and graphics that people use to communicate about designs that express rationale. How do we deal with it? It's not just academic anymore. Not recording design rationale will have grave consequences in the future.

Q18: Do you get this as a side effect? Really?

Q17: Well, if you get information about a design, you must save it.

Q18: Sure, but we did workshops at Cornell for a number of years. Indexing was always an issue. Scale was always an issue.

Q17: Task-based indexing wasn't discussed by Information Retrieval people. Something was done as part of a task, so—

Q18: Has it been demonstrated? Widely used?

Q17: We can beat the precision recall curve: "too broad, get garbage; too narrow, miss things." With task-based, we don't get garbage.

Q18: Has it been demonstrated?

Q17: I'll send you an article. Capture has been the killer for design rationale. People won't do extra work—but now with network-centric CAD you get capture with zero work.

Q19: But the information is too low-level: "I put a line here"—what does it mean?

Q20: Every time you do something, have the designer record something in a microphone.

Q17: That's one scenario. But, for example, I move a wall that you need. We discuss it. I've just done task-based indexing.

Q21: This is doomed to failure unless the criterion is: what's important is what industry will adopt, what they believe will help their profitability.

Q22: What will help their profitability is cutting the iteration cycle time, for example by design rational capturing.

Q23: We've been working on the product realization cycle. Not engineering time, but rather procurement time.

Q22: But mistakes are made in design, so that's where it matters.

Q23: If you look at defects, yes, it pushes to design.

Q22: Or pulls it kicking and screaming.

Dr. Regli: Shall we break into groups?

Q24: If we break into groups, we'll tackle the wrong problems.

Dr. Szykman: Well, we can tackle the wrong problems twice as fast in two groups.

Dr. Regli: Come back with some sort of technology assessment, research practices, and business practices.

Q25: Question I thought was interesting: what are natural trends? where do we want trends? how do we turn the first into the second?

Q26: Sure, for example, design rationale. How does it help?

Discussions: Group 1

(discussions done without slides)

Discussion summarized by Mr. Stephen Smith (sjsmith@nimue.hood.edu)
Participants:

Simon Szykman (szykman@cme.nist.gov)
Raymond McCall (mccall@phidias.colorado.edu)
Ranga Narayanaswami (narayana@staff.uiuc.edu)
Charles Smith (smythe@kingkong.me.berkeley.edu)
Tom Eidson (teidson@htc_tech.com)
Kathleen McKinney (mckinney@cive2.stanford.edu)
Rick Palmer (rick@beamtech.com)
Stephen Smith (sjsmith@nimue.hood.edu)

In the discussion that follows, participants are identified by arbitrary numbers.

Q1: What are the key business issues?

Q2: Why would Network-Centric CAD decrease integration cycle times? decrease cost? To what degree does how far in future we look affect these answers?

Q3: Good questions. There's a clear dividing line between vendors/technology/lots of business issues/transfer everything to the Internet on one hand, and the hearty issues of design integration on the other hand.

Q4: Vendors are beginning to see that. We've worked hard in the AEC community to get people to adopt computers.

Q5: People ask: "What can we do to be ahead of the competitor?"

Q6: CORBA isn't specific to this market—it's computer science. VRML is entertainment. Java is similar. What components do we use to connect things together?

Q7: What kind of breakthroughs—short-term horizon—can this technology give us?

Q8: I've seen lots of virtual reality engineering applications. In only one of them do they justify virtual, not just a big two-dimensional monitor. Similarly the Internet: here's a problem people can benefit from doing in a network-centric fashion?

Q9: For example, I'm starting a distributed programming environment project. But I'm only hiring people in my own office, because of communication problems.

Q10: Case study: meetings only every two weeks aren't adequate if design changes happen rapidly. The Internet solves this because we can share models and information. If people discuss why a wall moved, save the discussion. This is a big leap with a huge cost benefit.

Q11: Coordination, and going from one aspect of data representation to another—for example, architect to structural analysis—costs lots of money now, and it would be nice if it could be automated. The problem isn't automating disciplines, but automating different views: the questions you can ask of a database depend on how it represents things.

Q12: If you've got a big distributed system, what do you do with it? Sit in one spot, and it semi-automatically runs parameter studies when you change things.

Q13: I want to change something on my machine and have it change something on another machine. I want to have five different views of a building, all derivable from a common representation.

Q14: If something changes on another machine, there may be feedback. Must we include this interaction in a distributed system?

Q15: What are the criteria for going to the Internet? An interactive system is one of them—it's one way to capture intent. Mathematics can't describe intent.

Q16: The issue of design rationale is important, but it's not a reason to go to a network-centric CAD system.

Q17: But communication of design rationale is.

Q16: Sure, but communication is the key.

Q18: Distributed groups will "jump on" the Internet as a solution to their problems.

Q19: If you get information on the Internet, people won't just want to view it, they'll want to interact with it. "Every presentation is a provocation."

Q20: But even viewing helps, gets clients closer to design, closer to simulation.

Q19: True, but then, people say "I want to interact with it." Even annotation.

Q21: ACADIA (Association for Computer Aided Design in Architecture) is bad; it focuses on visualization, not interaction. Publishing downward and mouse-clicks upward is not the future of the Internet.

Q22: The Cave Project is a three-dimensional visualization distributed application, parts of which run on supercomputers across the country. But even that is mediocre. We want to interact with the data.

Q23: It's when you can't download the information that it gets industry.

Q24: "My design contains a component built by some company; I have a URL pointing to it." Once we have a representation, we can pull things in as necessary.

Q25: Does anybody look at our buzzwords: channels, broadcasting. That's software distribution technology. But it's also a way of updating any information, say for a collaborative network. You belong to some AEC design network. Parts you use are changed. You find out about it. This involves explicitly signing up.

Q26: People forget as designers that someone is actually building the thing—closer interaction would help.

Q27: Maintaining catalogs is a key problem. For example, in AEC, we need catalogs of paint, carpets, and gutters. The specification process in AEC—right before building, includes choice of vendors—is also a key problem.

Q28: In the manufacturing world, we use design requirements as specification. This precedes choice of vendors.

Q29: If I build motors, I have to give you performance characteristics, but won't tell you how I achieve them.

Q30: What are the technology barriers? Who's going to produce the underlying standard? What information do you need to know about an object—to annotate, to interact, to communicate design intent?

Q31: We address associating physical behavior with implementations. When you combine objects, what properties are maintained. Things like that require semantic binding: "what is this"? We need a semantic encoding, which is easy for modeling and simulation—you just use partial differential equations, which allow finite element analysis—but hard for other domains.

Q32: How do you map a data structure to objects? For example, for certain physical objects, use underlying ACIS/STEP/what-have-you geometry representation. Then associate annotations with them.

Q33: To have an advisor on some objects, I need to know what they are: "this is a door. This is a wall. Joe has to sit next to Sue. Joe's office must have a window facing east."

Q34: STEP provides one view of what a representation should be—geometry, mostly.

Q35: Who will provide commonality between Bentley, Autodesk, et cetera? History says: one will lionize the market, all will bow to them.

Q36: Most of the action is in domain-specific systems, not domain-independent.

Q37: Going back to plug-and-play: there must be a common domain-independent understanding. Right now, we just share graphic information. In the future, we'll share graphics plus what is attached to it.

Q38: We've covered necessary conditions for network-centric CAD: need representation, design rationale, etc. What we haven't covered is what Internet enabling technologies we have, and what we need? For example, STEP enables exchange of geometric information. For example, there are manufacturability software tools on the web.

I mean core technologies. For example, the Internet doesn't guarantee bandwidth. A teleoperating machine tool needs guaranteed bandwidth.

Q39: Hold your breath for five years, we'll have it.

Q38: No, we won't.

Q40: Idea: list requirements, not technology that fulfills it.

Q41: Is there money in high-performance Internet?

Q38: For example, five years ago, we needed the enabling technology of an interpreted language that worked across platforms. Now we have Java. Problem solved. I propose, for example, a standard for domain-specific applets.

Q42: To minimize bandwidth, have knowledge on both sides—minimize communication. If we had standardization for CAD communication, I could tell your machine "rotate cube" rather than sending a screen dump. Everything will be modular—I give you necessary tools for viewing, for example, not for the whole thing.

Q43: We need to start developing reusable Java components for CAD parts.

Q44: Autodesk likes the concept of modularity, but won't support standards.

Q45: Proprietary languages—like Autolisp—won't work.

Q46: VRML is a good example of companies grouping to set a common standard. But nobody's making money off it.

Q47: Creating a standard doesn't make money, but allows different ways of making money.

Q48: We have lots of components, but they have to work together. We need to develop interface standard for products, otherwise the same company has to sell you everything.

Q49: The set of standard must be layered, like the seven-layer TCP/IP model. This doesn't conflict with the user only knowing the top layer (such as ftp and telnet).

Report-Back Panel: Group 1

Presented by Ms. Kathleen McKinney (mckinney@cive2.stanford.edu)
(2 full-page slides start after page C-71)

Ms. McKinney presented the report from one of the breakout session groups. That group's key points of discussion were motivation and standards.

Motivation included examples of what that group thought network-centric CAD could do. For a business motivation, as always, work could be done faster, better, and cheaper. Because people are distributed, coordination is important. One example of coordination is communicating with a project engineer over the phone about a set of drawings. Without this coordination, if an architect moves a wall, somebody else finds out two weeks later, and then has to redo structural analysis.

Another motivation is interaction. The whole browser metaphor is *publication*, while the engineers want *interaction*. For example, people want to pause a VRML movie and give feedback.

The last motivation that group discussed was communicating design intent. Once design intent is captured, how do you communicate it and represent it?

One set of standards that that group found important was layered interface standards. We can't just have high-level and low-level interface standards; we need the entire spectrum. Interface standards do not just include data standards, but also multi-layer standards for code, such as an architecture on top of Java for building higher-level entities. But indeed, interface standards do include data standards: what is revealed?

Another important set of standards includes annotation standards, standards more advanced than redlining. There is ongoing research about annotation standards, but not for engineering domains. Query standards for querying databases and designs, and catalog standards to reuse designs and to store applications, also seemed important.

Finally, standards for views and abstractions are important. Every discipline has design-specific views: call them "multiple representations". For building, an architect thinks in walls and floors; an engineer thinks in pins and nodes; a contractor thinks about the layout; these views are all related by geometry.

Report-Back Panel: Group 2

Presented by Dr. John Mitchiner (jlmitch@sandia.gov)
(talk given without slides)

Dr. Mitchiner presented the report from the other breakout session group. He described that group as concerning themselves with issues and problems for network-centric CAD, and thus not having nearly as focused a set of recommendations as the other group.

It is no longer possible to put five million dollars per year into a project for five years. Now, we need incremental steps towards a long-term vision.

One strong vision is functionality. Yet, vision of an implementation could change overnight. For example, CORBA might be superseded by something else. Innovators can spend a great deal of money, but get few benefits.

That group then focused on specialization as its underlying theme for the rest of its breakout session. They asked themselves how they could create a world in which people do what they do best. This world must include open architectures and common interfaces. This world might include brokerage services, in which one vendor works with many CAD systems.

Standardization has made applications independent of tools, but STEP doesn't capture enough of the information which is important to users.

An ongoing problem is getting people to agree on boundary files. It takes five to ten years to reach agreement on a representation standard for parameters, and by that time, some other standard is needed.

Desiderata include common user interfaces to various CAD systems. Third parties could create these interfaces by leveraging stress analysis, tolerance analysis, and the like. These analysis tools could be auxiliary applets, downloadable from the Internet on demand.

Dr. Mitchiner noted that at this point in the group's discussion, Dr. Regli returned to the group and pointed the participants towards research issues. As research issues, the group selected Java standards; requirements-driven design (if a customer's requirements change, how do designs change?); an SQL (Structured Query Language) equivalent for CAD; and how to take a snapshot of a design and share it at low cost. Dr. Mitchiner pointed out that customer requirements were yet another set of data that presently exists on paper, rather than in any electronic form.

Technology Demonstration Session: Beam Technologies

Dr. Rick Palmer, Beam Technologies (rick@beamtech.com)
(demonstration given without slides)

Dr. Szykman introduced Dr. Palmer as a senior scientist at Beam Technologies, and still a research scientist at Carnegie-Mellon University, who had worked on the original DARPA Manufacturing Automation and Design Engineering (MADE) project.

Dr. Palmer has been working with web-based modeling and simulation, trying to extend web-based commodity viewers to show physical behavior. Dr. Palmer began his demonstration by loading a Java form to set parameters for configuration of a block and a pipe, represented in his system as "Einstein Objects".

Einstein Objects save lots of work by automatically computing joint boundary conditions. The objects are "smart"; when they come into contact, they know to couple the equations that define heat flow.

The system is extensible. It is possible to model objects with a CAD system, and then annotate them.

For example, suppose the top of the pipe has temperature 200, and the bottom of the block has temperature 0. All other surfaces are in contact with some other surface, or are insulated. The system recomputes the equations, and shows the steady-state heat flow.

The system takes data specified in Java and transfers it over the Internet. A C++ application takes that data, computes the equations, and sends back a VRML file with a different heat distribution.

Dr. Palmer noted that he was next demonstrating precomputed examples of three-dimensional elasticity. He showed that it was possible to take two objects, stick them together, put them in an environment, and get an answer. Thus, no one has to do analysis, and no one has to do programming; objects "know" all that they need to know.

A conference participant interrupted Dr. Palmer to ask if he was using VRweb as a plug-in. Dr. Palmer said that he was.

Finally, Dr. Palmer predicted that in the future, it will be possible to do an Internet search for components, and put them in the design.

A question-and-answer period followed Dr. Palmer's demonstration. Questioners are identified by number.

Q1: Are you doing primarily finite difference analysis, or finite element analysis?
A: In this demonstration, finite difference. In six months, finite element.
Q1: Is the meshing you showed us automatic?
A: The coarse mesh is part of the object. The meshing can be as fine as necessary to do the computation.

Technology Demonstration Session: University of California, Berkeley

Mr. Charles Smith, University of California, Berkeley
(smythe@kingkong.me.berkeley.edu)
(12 full-page slides start after page C-75)

Dr. Szykman introduced Mr. Smith as a graduate student at the University of California, Berkeley.

Mr. Smith began his demonstration by giving a presentation on his personal project, CyberCut, a system for distributed design and manufacturing over the Internet. The CyberCut approach is not a monolithic CAD system; rather, it is a dialogue between various engineering processes, or agents.

CyberCut has a simplified form of a CAD agent: a GUI (Graphical User Interface) that presents a user with design choices. For example, a design choice could be a list of features that the user can access directly. CyberCut's CAPP (Computer-Aided Process Planning) agent could negotiate feasibility with the designer. For instance, suppose the designer has chosen stereolithography for the design, and tries to design a hollow sphere. The CAPP agent should notify the designer that the design may cause problems by trapping fluid in the part as it is being manufactured. CyberCut's CAM agent generates the physical part using a milling machine, by stereolithography, or the like. For example, if using a milling machine, agent can increase the milling speed or slow down the feed.

So far, of the components necessary for the second phase of CyberCut, those that have been designed are CyberCut, the University of California at Berkeley planner, and the Machine tool Open System Advanced Intelligent Controller for Precision Machining (MOSAIC-PM).

Mr. Smith discussed three design consultants: a fabrication agent, a planning agent, and a design agent. A fabrication agent knows its own capabilities: the size of features it can make, the tolerances it can achieve, etc. A planning agent compares the process planning with the capabilities of the fabrication agent, and passes design options to the design agent. The design agent at its simplest is a user interface, but can be extended to include interactions with CAD tools. The design agent takes design options, puts them in a CAD system such as ProEngineer, allowing the user to use a familiar interface. The user's choices influence process planning, which is followed by manufacture of the part.

Mr. Smith followed by showing a video from the Integrated Manufacturing Laboratory at the University of California at Berkeley, which showed two Internet manufacturing environments, CyberCut and Reuleaux. Reuleaux allows the user to design and fabricate parts similar to a rotary component used in the Mazda RX-7. The designer watches a live video of the manufacture, and can obtain force data in real time. CyberCut expands on Reuleaux with a stand-alone CAD package allowing the design of parts.

A question-and-answer period followed Mr. Smith's presentation and video. Questioners are identified by number.

Q1: In the WWW demonstration, do you allow people on the web to say, "make this part"?

A: Because prototyping is expensive, in the WWW demonstration, users can drag features around, but the "make part" button does nothing.

Q2: Who uses the system?

A: Mostly people in the lab, for small design projects. My advisor jokes that we'll buy a warehouse, a computer, and a milling machine, and use the system commercially.

Technology Demonstration Session: Stevens Institute of Technology, Design Manufacturing Institute

Dr. George Mychaljuk and Dr. Kishore Pochiraju,
Stevens Institute of Technology, Design Manufacturing Institute
({george,kishore}@dmi.stevens-tech.edu)
(demonstration given without slides)

Dr. Szykman introduced Dr. Mychaljuk as a senior design engineer at the Stevens Institute of Technology Design Manufacturing Institute, and Dr. Pochiraju as a faculty in the Mechanical Engineering Department and research staff at the Design Manufacturing Institute.

Drs. Mychaljuk and Pochiraju demonstrated ACES (Automated Concurrent Engineering System), a feature-based design system. This object-oriented system takes the user through the design process from requirements to optimization.

The system has four components: ProEngineer, ACES's user interface, a kernel that includes communications objects and consists of 500,000 lines of C++ code, and a database and wraparound. ACES is object-oriented. Thus, the user feels comfortable in individual domains. The Design Manufacturing Institute is collaborating with Lucent Technologies on this project.

The process start with requirements. An object has an interface with attributes, such as a customer's requirements for a part. The designer starts with nothing, and then builds the geometry. ACES's paradigm for building the part is called "smart templates". Each template in ACES has two components: form and functions. ACES has knowledge to evaluate the design at two levels: a global level, such as the process design domain; and a feature level.

A conference participant interrupted to ask if the standard templates have invariant topologies, or if they can change size and thickness. Dr. Pochiraju answered that it was possible to create the topology in a CAD system, and then import the topology to ACES without difficulty.

In ACES, it is possible to highlight features for any of the parts in a design. The user clicks on geometric dimensions, and can see what ProEngineer is using to calculate the dimensions of the part. ACES has information about design rules (e.g., the range of allowable thickness is 0.5 to 0.25). ACES has the concept of feature-to-feature communication; for example, features can communicate about structure or about heat flow.

Another conference participant interrupted to ask if ACES assumes a standard representation scheme for the material properties database. Dr. Pochiraju replied that ACES can represent several materials in one part, and can represent what's physically possible, such as flow length for a thermoplastic resin. ACES puts material properties in a standard form that it likes. Changing materials in ACES is easy; the time for an update is one minute or less.

Design intent in ACES is constraint-based. Constraints can come from the feature level, or alternatively, from the global level. A conference participant interrupted to ask if ACES checks constraints automatically with each feature, or if the designer had to ask it to check constraints manually. Dr. Pochiraju replied that ACES checks constraints automatically by way of a dependency tree, comprising a subset of the dependent objects. ACES has a utility that shows the dependency tree, a good example of traceability.

ACES's economic analysis has a cost estimator, which considers material, mold, processing, assembly, and inserts. ACES also allows the designer to use a personal Excel spreadsheet if the designer prefers that over ACES's cost estimator.

The designer may wish to do tradeoff studies. Dr. Pochiraju demonstrated that by changing the size of a slot; ACES automatically updated the cost, and warned of a violated

stress constraint through its messaging system. Dr. Pochiraju went through the options necessary to repair the constraint violation.

ACES allows the designer to solve various constraints to allow optimization. There may be variables that can be changed, but that aren't described in ACES's domain. Once the optimization is done, the designer can press the Apply button to apply the optimization to system, or the designer can change a value and re-optimize.

A conference participant interrupted to ask why ACES was a concurrent engineering system—could it run on different machines? Dr. Pochiraju answered that yes, it could run on up to four machines. The questioner asked if people could work as a team; Dr. Pochiraju answered yes.

Another conference participant interrupted to ask what kind of database was being used. Dr. Pochiraju answered that it was in MSQL (Mini-SQL), a $600 relational database from Australia. The questioner asked whether MSQL has storage management; Dr. Pochiraju answered no, but MSQL has some kind of caching.

Dr. Pochiraju noted that he had demonstrated tradeoffs; what he hadn't demonstrated was content-building. The Design Manufacturing Institute uses ACES for injection molding; other people are using ACES to design electronic packaging.

A question-and-answer period followed the demonstration given by Dr. Mychaljuk and Dr. Pochiraju. Questioners are identified by number.

Q1: Are the function arguments real numbers?
A: ACES automatically detects real numbers, strings, lists, and so on. ACES has states called "cyclic" and "undefined".

Q2: Can you compile functions in the system?
A: No, all functions are interpreted in the kernel. The kernel does part of a compiler's job, though, in its dependency tree.

Q3: How is ACES linked to ProEngineer?
A: There's a special section for geometric dimensions in part attributes. Part attributes can be made using ProEngineer's feature creation facility.

Q4: Can two people touch the same object concurrently?
A: No.

Q5: How does ACES fit into Metaphase, for example?
A: In the web, we can separate the world into authors and readers. Readers can see the cost and the intent, but cannot change the design.

Q6: Do you classify the world solely into authors and readers, or also into "authoring privileges over certain parts"?
A: Solely into authors and readers—even that partition is somewhat hacked.
Q6: But if you have enough bandwidth, problems go away.
A: Well if you have enough bandwidth, you can just run Xclient.

Q8: How is ACES being used on the web now?
A: Not at all. We have plans for web readership.

Einstein Objects: An Open Standard for Web-Enabled Distributed Design and Simulation of Electro-Mechanical Products

Dr. Rick Palmer, Beam Technologies (rick@beamtech.com)
(20 full-page slides start after page C-89)

Dr. Regli re-introduced Dr. Palmer as a senior scientist at Beam Technologies.

Dr. Palmer noted that he had been working in this area for ten years, and that the work he was describing was done as part of MADE, now called Rapid Design Exploration and Optimization (RaDEO).

Dr. Palmer's goal is to create the Einstein Suite, an environment for composable, scalable, multi-level, multi-discipline product representation and have it be web-enabled. The Einstein Suite "does everything". Simulation allows one to cut costs and design time by an order of magnitude. Dr. Palmer supported VRML as a standard.

Working with Lockheed-Martin in Georgia, the Einstein Suite is redesigning a C-141 aileron actuator system. This is a real problem that has already been solved. Thus, it provides a good basis for comparison. Work is just getting started.

At present, there is no computer representation to support reasoning about products; this reasoning must include process planning, marketing, and so on. Einstein Objects are composable, scalable objects to represent the physical properties of electro-mechanical systems. Instead of physical models, designers can use the Einstein Suite to construct simulators. Composability would give simulation a breakthrough in cycle time. The web is truly integrated into Einstein Objects; the definition of Einstein Objects involves a URL (Universal Resource Locator) at each level.

In addition to Einstein Objects, the Einstein Suite includes other software. PDESolve is a C++ extension that allows the user to write a Partial Differential Equation (PDE) in C++-like syntax; PDESolve will then run and produce the correct answer. WebVis is an HTML-based visualization environment for engineering and scientific computing. PowerMath, a parallel High-Performance Computing (HPC) implementation of Einstein Objects and PDESolve, can run on a workstation, a network of workstations, or on an SP2 (Scalable Parallel 2) machine, the "world's fastest computer".

The Einstein Suite is being used to solve Computational Fluid Dynamics (CFD) problems, which can be more difficult than Finite Element Analysis (FEA) problems. For example, in CFD, one might have a model of a wing and a model of the air flowing over it. The shape of the wing affects the shape of the airflow, which in turn affects the shape of the wing.

The Einstein Suite uses reformulated CFD code to compute sensitivity of the answers. In the aileron design problem, reformulating the CFD code brought the number of answers from 600, which is impractically many, to 21, which is a number than can be dealt with.

Einstein Objects can make use of algorithms for solving a variety of equations and problems, including PDEs, Ordinary Differential Equations (ODEs), Differential-Algebraic Equations (DAEs), Discrete events (modeled by Hyperbolic ODEs (HODEs) and Hyperbolic PDEs (HPDEs)), and combinations of the above. These algorithms can model most engineering problems, and more specifically, most mechanical CAD problems such as modeling of fluids and solids.

Einstein Objects have geometry, state variables, and parameters, as well as behavior equations that model such properties as heat flow and elasticity. The physics meta-model encapsulates physical properties necessary for modeling. Geometry includes applying force at a point, computing the load along a surface, etc.

In the slides is a picture of a robot arm, and a graphical description of the robot arm. The graphical description includes the set of equations associated with a joint.

PDESolve is implemented as a C++ class library. One can write in one page of PDESolve what would take 600 pages of Fortran. PDESolve uses VRML for visualizations. In the PDESolve example in the slides, BC refers to a boundary condition. WhenContact specifies that the BC satisfies one condition when two objects contact, and another when they do not. The BC can therefore be computed at run-time.

The PowerMath implementation uses standard tools. PETSc (Portable, Extensible Toolkit for Scientific computation) is a numerical computing package from Argonne National Laboratory. PowerMath allows a programmer to use a supercomputer without programming for a supercomputer.

In an Einstein Suite design scenario, a thermal analysis and a rigid body analysis can be done from the same representation. One can make the design available on the web for others to use. A script allows the user to see the steps taken in performing the analysis.

There is a need for a product representation language to support design, assembly, maintenance, manufacturing, analysis & simulation, management, and marketing. For example, a maintenance object can be augmented with URLs to pop out pages describing how to maintain the object.

The need for composable objects is an important one. Without them, when there is a need to combine multiple objects, a great deal of work needs to be repeated. There is also a need for scalable objects. After a motor is modeled, a scaled version of that model should be able to be inserted in the model of a car and still be usable.

To get industry buy-in, the fundamental issue is the financial bottom line. Legacy systems need to be brought into the future and to be made available as technology changes. To get an open standard, one may try an informal approach instead of a formal group. Or, as a slightly less desirable model, we can look to the way Java developed.

A question-and-answer period followed Dr. Palmer's talk. Questioners are identified by number.

Q1: Your solver is nonlinear as well as linear. Do you use the same methods for both?
A: We do a symbolic linearization of nonlinear problems to produce linear problems.

Q2: What's your schedule of availability?
A: Within six months I'll show a full demonstration.
Q2: Is the Einstein Suite written in Java?
A: No. We use Java. Java is a general-purpose network-computing programming language, but it isn't enough for higher-level communication of network-centric CAD data. We use Java and VRML for what their strengths are: general-purpose programming. If we have a Babel of programming languages, we're not focused on the right problems.

Q3: How does an end-user create primitives?
A: Using an existing CAD system, such as AutoCAD, and annotating the primitive as necessary for material properties.
Q3: What standard are you using for geometry input?
A: We want to be geometry-input-neutral. We have requirements on representation, for example, shape.
Q3: How do you handle legacy code?
A: The architecture allows a plug-in at the solving-equation level. But legacy code becomes just one big object.
Q3: Here's a migration path idea: first, use existing simulation tools; second, create geometry in an easy way without having to annotate it.

Q4: What were the technical challenges in linking these applications?

A: We have this C++ library. We could write a C++ program to do things. Instead, we write an Einstein Suite interpreter that passes the object over the Internet to a C++ compiler. But URLs can exist at any level, so the compiler might have to go to the Internet to get pieces of the object.

Changing Priorities of Research on WWW-Based Engineering Services

Dr. Michael Terk, Rice University (terk@rice.edu)
(17 full-page slides start after page C-111)

Dr. Regli introduced Dr. Terk as a professor in the Department of Civil Engineering at Rice University, formerly of Carnegie Mellon University, who worked on the DARPA ACORN (Adaptive, Collaborative, Open Research Network) project.

Dr. Terk said that the ACORN project had been doing web-based services for about three and a half years. The goal of ACORN was to build a community of design and manufacturing services that use the Internet; This project was led jointly by the Engineering Design Research Center (EDRC) at Carnegie Mellon University and Enterprise Integration Technologies (EIT). EIT was responsible for developing low-level infrastructure to support ACORN, while CMU was involved in building engineering services as a proof-of-concept. ACORN's objective was to create as many services as possible and to use demonstration of these services in real product development scenarios to excite the manufacturing community.

ACORN's overall vision was to target small product development teams that rely on a lot of external services. ACORN targeted the WWW as the basis for its infrastructure because it allows wide access to external resources.

One of ACORN's important considerations was providing support and demonstrations for a wide range of engineering services and a wide range of interactions with those services. In the first phase of this effort, ACORN selected four services to be built: the SLA (Stereo Lithography) prototyping service which is a web interface to an existing stereolithography shop; the ACDS (Automated Configuration Design Service), a design service developed at University of Michigan which used information catalogs on the web to perform configuration design of electronic components; a Shape Acquisition service, developed at University of Pennsylvania, to do reverse engineering; and an Assembly Analysis service which, based on the assembly sent to them by the user, provides alternative disassembly plans to the user who can then evaluate them.

The SLA and ACDS services can be classified as batch services, since they use well established formats for their input and require minimum user interaction once the input has been submitted to the service.

In the SLA service, a part geometry (as STL (Standard Template Library) files, or as a ProEngineer files converted internally), and additional information such as type of resin and a delivery destination is submitted as part of a RFQ (Request For Quote). A quote is then returned to the user. Upon submitting an order, the part can be tracked through CAD verification, scheduling, in-machine and out-of-machine. The finished part is then delivered by Federal Express. This WWW interface is currently being used by ALCOA SLA service to support interaction with their internal customers.

The web encapsulation of batch services provides significant benefits to the clients of the service. Customers who are involved in product development and are operating under short product development cycles tend to use a small sub-set of entrusted service providers, in many cases forgoing cost savings that may be had by using a new provider. The main reason for this is that any delays in filling an order have a significant ripple effect on all activities of the product development process. This becomes increasingly critical as the duration of the development cycle decreases. Thus, the ability to track service activities and to monitor what is happening to an order is critical to ensure that the order is being filled on time. The SLA service interface showed how the WWW interface can be used to provide clients with the ability to track service activities 24 hours a day and from any location on the Internet.

WWW interfaces to batch services also benefit service providers. Two main benefits are the ability to provide detailed service description at low cost and the ability to operate the service remotely. The WWW provides an efficient mechanism for offering a detailed, multi-media description of service capabilities. Since this information is stored with the service provider, it can be easily updated as the service capabilities change. As the result, providers can just give clients a business card with a URL, rather than a big packet of printed information that may become quickly outdated. In addition, the WWW interface can be used to allow the service provider to operate the service remotely. In the case of the SLA service, the WWW interface allowed the authorized service provider to access the list of RFQs and orders, assign them to various technicians, track their status and generate responses. It can be further expanded to allow the service provider to execute computer tools that verify the CAD models submitted to the service.

Because of the success of the web interfaces to the SLA and ACDS batch services, the second phase of ACORN funded the creation of six additional Internet-based services. Soligen is a solid casting service. IndustryNet is a catalog of manufacturing information. Engineering Geometry Systems does rapid prototyping. STEP Tools translates CAD files from proprietary formats to STEP. The Virtual Market Square at CMU provides education for potential service providers. Concurrent Technologies implements a material database. (Several of these, such as IndustryNet and STEP Tools, have since evolved beyond these original services.)

Shape Acquisition Service from University of Pennsylvania can be considered an example of a Pre- and Post-Processing services. The goal of this service is to produce a CAD model by scanning an existing part. This service uses the automated positioning and scan integration software to produces a low-fidelity model of the part. The WWW interface can then be used to present the user with the current model and allow user to define which areas would require additional scanning to improve the quality of the model. This allows the user to reduce the number of scans performed (and the cost of the service) by communicating the domain specific information once the initial scan is performed. This is an example of a "conversation with customer" that can be supported by the to define a problem in more detail or to refine the solution generated by the service. This class of services provides increased amount of interaction between the service customer and service provider but this interaction occurs at strictly defined points in the service operations

Initially, the Shape Acquisition Service developed an user interface based on WWW forms and image maps. Because of the interactive nature of service, the WWW image maps made the interaction with the service difficult. JavaScript language provides an improved the solution. Using a JavaScript, the service interface can be extended to receive a scan position from the customer, acquire data from a scan, integrate it with an existing model, and then ask for a new scan position. The result of the service can be produced in VRML. ACORN is investigating having the user control the scanner through Java .

Finally, ACORN has explored the development of interactive services. In this class of services, the user interactively defines the problem. There are no industry-wide standards for the input. As an example of this type of services, EDRC has developed a fixture analysis service that utilizes FDATI (Fixture Design & Analysis Tool Interface) interface to fixture analysis tools. This interface allows the user to interactively manipulate a 3D model of an assembly of part, define a set of possible fixture points, submit this information through FDATI for stability analysis, receive results and interactively changes the fixture points. The interface to this service is implemented as a Java applet that support display of 3D objects and interactive definition of fixture points.

From the ACORN project, several lessons were learned. First, web-based services improve customer satisfaction with increased communication bandwidth. Second, the wide availability of WWW and the ease of its interface is helping to move the ideas of distributed engineering systems to the mainstream. Third, the major features of WWW software (such as security and access speed) are driven by the entertainment world and the business world, not by the manufacturing world. Features that are needed by manufacturing but to a lesser

degree by the drivers (entertainment and business) such as integrating file uploaded into a web browser, are still absent.

Finally, the emergence of a broad community of engineering services that are available through the Internet requires a clear understanding of the legal and societal aspects of interaction with remote services through an electronic medium. This understanding will enable companies to take full advantage of the Internet to support a community of engineering and manufacturing companies.

A question-and-answer period followed Dr. Terk's talk. Questioners are identified by number.

Q1: Our experiences are similar. The right methodology is to provide web technology inside existing applications.

A: Agreed. For example, a CAD application.

Q1: I think that there's a profound message here: end users have expertise in the context of their favorite tools.

A: Yes. It would be different if browsers were good CAD front-ends, but they're not.

Q1: Also important: developing workflow across the web.

A: Yes. Customers say, "We always do things in the same order—why do, save, do, save, et cetera?"

Q2: Did ACORN interact with the Manufacturing Extension Partnership?

A: Yes. We used the Cleveland Advanced Manufacturing Testbed.

SmartWeld

Dr. John Mitchiner, Sandia National Laboratories (jlmitch@sandia.gov)
(21 full-page slides start after page C-131)

Dr. Regli introduced Dr. Mitchiner as the Knowledge Engineering Team Leader at Sandia National Laboratories.

Dr. Mitchiner began by calling Sandia the design-engineering-for-nuclear-weapons laboratory. At Sandia, engineers have to build parts with 40% of the money they had several years ago. Sandia is about 40 years old (built in 1952), so people there tend to work 40 years and then retire—which means that their expertise is lost. Expertise is also lost through downsizing.

One current objective is to be able to design and manufacture products with this greatly reduced capability. This has to be done in a shorter amount of time, at lower cost, and with higher quality (Design For Six Sigma). Sandia has the same concerns as industry for the same reasons. This is a six to ten year project within Sandia, with an investment of tens of millions of dollars.

This project has an Enterprise Integration team, whose charge is to exploit high-speed networks and CORBA support, as well as a Manufacturing Process Technologies team. One concern that had come up was that processes that ran perfectly for six months would fail for two months, and then work again. Was the failure because of temperature? humidity? chemical changes in the incoming materials? Nobody knew.

Dr. Mitchiner works with the Knowledge Engineering Team (KET) on Virtual Manufacturing. The KET takes knowledge in heuristic form from engineers and attempts to codify this knowledge as a mathematical model. The advantages of a mathematical model are that it is completely reproducible, that it is improvable, and that it is available twenty-four hours a day, in contrast to an expert who might take three weeks to give somebody fifteen minutes of his time. Another problem that was faced is integration and interaction of experts. This problem is critical, but often overlooked.

KET has three active projects, as well as one project in the quasi-development stage. SmartWeld is a three-year project at five million to six million per year. SmartWeld takes welding from art to science by means of many welding tests and models, and then puts the science in a CAD tool where people can use it. SmartWeld is a concurrent model-driven environment. At present, it uses a Netscape interface on Sandia's intranet; KET will try to go through the process to make it available on the Internet, outside of Sandia.

SmartWeld includes a Welding Advisor, the focus of the first part of this talk. It also includes a Welding Scheduler, which determines how fast the welding beam should be moved, and in what arc. A welder had initially told KET researchers that the speed and arc of the beam are dependent on five variables, but after modeling, they ended up with 300 to 400 variables.

With the Welding Advisor, at the time that a part is defined, so a basic problem area (e.g., housing welds). The user answers questions, and the advisor generates physically realizable processes and designs. Green colors indicate designs in which everything is okay; yellow colors indicate designs in which all defined (hard) constraints are okay, but desirables (properties which are not hard constraints) are violated; red colors indicate designs in which a defined constraint is violated. If you click on a yellow- or red-colored design, the Welding Advisor has an explanation facility to describe the problem—something that is very useful to a welder.

The Near Net Shape Process Selection Advisor, which will be operational by the end of the year, is concerned with the problem of casting. In casting, it takes six to nine months to get an initial part, but this length of time has been evolving down to three to four weeks, mostly as a result of rapid prototyping.

The Machinability Advisor is a "spellchecker for features". It needs information on functionality—for example, a slip-fit hole.

Most of the tools developed by the KET reside on different computers on Sandia's California/New Mexico network, but since the information is passed seamlessly, customers didn't know about the distributed nature of the system.

A conference participant interrupted Dr. Mitchiner to ask how the KET tied together the tools. Dr. Mitchiner replied that KET used Remote Procedure Calls (RPCs) to tie together the tools. This was pre-CORBA. The computers were fairly homogeneous: mostly Suns, with a few Crays.

KET proposes the KET Project Integration shown in the slides. This also involves the System-Level Integration shown in the slides. As part of System-Level Integration, the part/whole viewpoint starts to map into a processing viewpoint.

A question-and-answer period followed Dr. Mitchiner's talk. Questioners are identified by number.

Q1: How successful have you been in general?

A: Depends on your definition of success. SmartWeld has designed a part that was ready to be manufactured. A domain expert used the system, and the system told the weld expert about something that he had forgotten. Thus, SmartWeld was extremely successful.

How much has it been used? Based on that definition, SmartWeld has been moderately successful. We're not really satisfied as yet. We're developing a formal process of wrapping uses in as a board of advisors.

Q2: Do you find demand from internal customers?

A: Yes, but we have a wide range of people. Some won't touch computers to save their souls.

Q3: Has your machinability advisor looked at the characteristic of tolerance?

A: Right now, our machinability advisor operates in a one-dimensional mode: information passes to, not from, the manufacturing floor. That's a future direction.

PartNET: the Parts Information Network

Dr. Don R. Brown, Associate Professor, University of Utah/PartNET, Inc.
(don.brown@part.net)
(6 full-page slides start after page C-155)

Dr. Szykman introduced Dr. Brown as having done work at Stanford on NextCut, and now being at the University of Utah and PartNET, Inc. (the Parts information NETwork).

Dr. Brown began by describing PartNET as a parts catalog scheme on the Internet, started at the University of Utah and commercialized by twelve people in a research park adjacent to the University. PartNET is funded by DARPA and the U.S. Navy.

Informal studies show that 85% of design flow time is spent on parts research and acquisition. On the one hand, design flow time is not engineering time, so this is not as expensive as it might sound. On the other hand, design flow time has, for example, F-16's sitting on the ground waiting for parts so there are costs involved.

FITHIT (Find It Today, Have It Tomorrow) is hot topic within the military. A 90- to 100-day delivery cycle is undesirable, but it is not unusual.

The PartNET architecture is distributed. On one side of the architecture are databases—be they relational databases or object-oriented databases—that describe what parts a company can provide. On the other side of the architecture are two types of clients, Windows clients (both Windows NT and Windows 95) and WWW clients.

The Network Information Broker is a directory to help users find parts on the system. Consider the following scenario: a client proposes a query, say a search for one- to three-inch diameter ball bearings. The Network Information Broker processes the query, sends it to vendors, receives and collates responses, and sends them back to the client. Because the architecture is distributed, it is maintained by suppliers. Importantly, the responsibility of maintaining the databases is theirs. The system uses public-key encryption.

Searches can be done on part characteristics, national stock number, manufacturer, distributor, or part number. Searches can produce pricing information, part characteristics, and data sheets. Searches can also produce availability information: one vendor tells you how many parts they have on the shelf, which helps with planning and scheduling. Finally, searches can produce CAD models; one vendor has more than 65,000 models of parts. There are currently one million parts on the system, half mechanical, half electric.

A question-and-answer period came between Dr. Brown's talk and his demonstration. Questioners are identified by number.

Q1: Is there any problem on the pricing issue because of vendors being concerned about putting prices out there?
A: Some vendors will, some won't. Some won't even tell their own salespeople.

Q2: How detailed are CAD models?
A: CAD models are as detailed as the vendor wants. Some vendors feel the models are proprietary, and others fear reverse engineering. PartNET actually has been used for reverse engineering, but that vendor said it's worth it to have the parts available out there.

Q3: What format does PartNET use for CAD models?
A: PartNET uses AutoCAD ".dwg" format.

Q4: For what parts is it easiest to get CAD models?
A: I don't have enough experience to answer the question. I'm sure it varies across industries.

Dr. Brown continued with a quick mock-up demonstration. There is a web interface at http://www.part.net/, but it's under construction; it will be enhanced and sped up greatly.

The demonstration was done using the actual Windows interface used by Department of Defense customers. Parts can be searched for by keyword or by browsing a hierarchy. Dr. Brown demonstrated the hierarchy, going from parts, to mechanical parts, to English gears, to helical gears. A query window came up with units (it can do conversions on the fly). Dr. Brown asked for gears with 60 teeth between 1.5 and 3 inches.

The search then goes out and queries vendor databases to retrieve the desired information. In the mock-up, the search is instant; in reality, it takes 20-30 seconds. One company came up as having four parts that matched the specifications. The user can view more detailed part descriptions, CAD models, images, or jump to the company's home page.

Dr. Brown demonstrated the purchasing interface. He entered the keyword "resistor", selected carbon composition, and asked for resistance of 16 megaohms, tolerance less than 10%, and vendors with at least 300 resistors in their inventory (which eliminates vendors that don't make inventory information available). PartNET then created a shopping cart. (For vendors that give quantity discounts, if the quantity in the shopping cart changes, the price changes). At this point, PartNET is ready for the user to give an address and have the part shipped (though the user does have to have an account set up with the vendor in advance).

A question-and-answer period followed Dr. Brown's demonstration. Questioners are identified by number.

Q5: Do any of your vendors ask you for statistics about what queries lead to sales?
A: Yes. We give information about what parts clients are buying, what parts clients are finding, and what parts clients are not finding.

Q6: What about optical components?
A: We don't cover them yet, but we want to.

Q7: What about graphical searches?
A: We'd love to do those as well, but haven't done so yet. We'd work with a willing graphical search partner.

Q8: The parts database exists at the vendors, and you have pointers?
A: Usually, yes. We also have a hosting service, but if they have it at their site, they can maintain it.

Q9: Are there client-slide requests for automatic links?
A: Nothing formal. There are some experiments in hooking up applications—similar to design optimization.

Q10: How much do I have to pay you to have my parts come up first?
A: All you have to do is buy your own fast server and your own fast connection.

Q11: Any interest in fitting PartNET into a CAD model? into a containment box?
A: Sure. Boeing's interested. This is a good area for research. People sometimes don't know the name for what they want. People also ask, "can you set up PartNET inside our company?" But they have custom parts, which are even harder to categorize.

The National Advanced Manufacturing Testbed: Nanomanufacturing of Atom-Based Dimensional Standards

Dr. Clayton Teague, NIST (clayton.teague@nist.gov)
(slides unavailable)

Dr. Szykman introduced Dr. Teague as a researcher from NIST who was working on one of the four main projects for the NIST National Advanced Manufacturing Testbed.

Dr. Teague further identified himself as a scientist in the Precision Engineering Division of NIST. He expressed his regret that he could not have attended more of the workshop. Nanomanufacturing is one-quarter of the National Advanced Manufacturing Testbed. At present, electronic connections in microchip circuits are 350 nm (nanometers) wide. This width impacts the speed of the processor, the chip memory, and other desiderata. An industry goal is to reduce this width to 180 nm, and then to 120 nm.

The "Moore Rule" says that the size of memory drops by a factor of two every 4-5 years. But there are limits on how long this can go on. There are imperfections and irregularities in the edges of circuit lines that are tolerable at 350 to 500 nm, but which are not acceptable if the circuits are as narrow as 180 or 120 nm.

In reality, circuit lines are neither perfectly vertical, nor perfectly straight, nor perfectly parallel. Artifact tolerances are about 50 nm at present. High-performance STMs (scanning tunneling microscopes) can measure to 0.1 nanometer tolerance with repeatability. The ideal goal is to make artifacts as perfect as nature allows: atomically straight and vertical. If you count the number of atoms across a circuit line, 180 nm to 200 nm is only about 1500 atoms. There is a need for infrastructure to allow measurement and manufacture of ultra-high-accuracy artifacts.

To see the vision of future distributed nanomanufacturing, consider current fabrication techniques for X-ray lithography. The supplier fabricates the mask and ships it to the customer, the customer inspects it for imperfections and ships it back to the supplier, the supplier fixes the imperfections and ships it back to the customer, the customer performs the X-ray lithography.

The cleanliness of this process is astounding. Class N cleanliness means that there are no more than N contaminating parts, each restricted to less than 1 micrometer in size, per cubic meter. Class 100 and Class 10 cleanliness exist; Class 1 is coming. In the next generation, transportation of these masks will be done in a highly controlled environment: an ultra-high vacuum system.

The typical crystal is highly granular. The industry wants a mean roughness standard of one-tenth of an atomic diameter. Because the mean roughness is averaged over a big area, this standard is sensical. To achieve this, processes must overcome the roughness and randomness in naturally-formed features.

Using the traditional nanomanufacturing processes of Molecular Beam Epitaxy (MBE) and probe transport (pick up individual atoms and transport them), artifacts can be created that show (in STM images) near-perfect right angles and squares. Industry needs this near-perfection.

There are limitations in transport: there is a need for a vacuum system that is transportable. We would like to have a standard for moving artifacts from one vacuum system to another. Standards such as those for mechanical design, Finite Element Analysis, are helping to understand how to do this. Toward this end, the Precision Engineering Division is working with divisions that are more used to capabilities in the mechanical engineering area.

A question-and-answer period followed Dr. Teague's talk. Questioners are identified by number.

Q1: What issues are involved in coordinating remote control of highly specialized machines?

A: There are three components of the project: making artifacts, developing solid models of transport systems, and telerobotic operation and telepresence of fabricating and testing devices.

We have an MBE system in one building, and an STM in another building. Both are two million to three million dollar machines. The MBE operators wanted the STM to be attached to their machine; the STM operators wanted the MBE to be attached to their machine. We want one way to operate both.

We're designing a vacuum suitcase by people distributed around NIST using available collaborative tools. These tools are audio/video only, and they run on Unix, not PCs and Macs, which is what we need. We have hope from the Bentley demonstration.

Q2: Why telerobotic operation?

A: There is an expensive system with expertise located in one place. Telepresence allows scientists to "watch over' an operator's shoulder. Someday, we hope for telerobotic operation to give scientists remote control.

Highly Interactive Network-Centric Tools for Collaborative and Distributed Manufacturing

Dr. Ranga Narayanaswami, University of Illinois, Urbana-Champaign, Machine Tool Agile Manufacturing Research Institute (narayana@staff.uiuc.edu)

(22 full-page slides start after page C-163)

Dr. Szykman introduced Dr. Narayanaswami as having been at the University of Illinois, Urbana-Champaign, since April.

The objective of Dr. Narayanaswami's work is to allow an engineer to machine a part at a variety of plant sites, or outsource the part. His method of doing this is design for manufacturing by accessing machining tools at various areas.

EMSIM (EndMilling SIMulation) was under development for a couple of years without the web in mind but has recently been web-enabled with CGI (Common Gateway Interface). Engineers improve accuracy by automatically calling EMSIM from an open architecture machining tool, such as the one that is part of CyberCut at the University of California at Berkeley.

EMSIM leads the user through a simulation, where the user configures EMSIM through its input parameters, such as radial depth, axial depth, RPM, feed speed, and runout data. In the simulation, the spindle axis can be tilted, leading to eccentricity and the Y-Force changes with runout. The tooth passing frequency is the key frequency; if runout occurs, one should use another frequency.

For a common CAD interface, researchers had to decide between ProEngineer and a neutral file structure, each having its advantages and disadvantages. A neutral file structure, STEP, was chosen. With the CAD interface, one can rotate a part, click on a particular surface, or generate different views of the surface. Having generated different views of the surface, one can export them to fixture analysis software located at Penn State.

The Kodak case study part shown in the slides comes from the film-making industry. Some the operations used to make the part are end-milling operations. Views of this part are used as input to position fixtures. The three dots shown on the part in the Netscape slide are fixture locations.

Edge quality relates to the question: is there an edge defect, or not? If there is an edge defect, it is usually a burr. In burr simulation, the user can see whether there is a high percentage of burrs. Process parameters can be adjusted to try to obtain smaller burrs. This allows the designer and process planner to modify the plan based on design criteria. In process monitoring for fault diagnosis, tool signals are matched to find out if we can predict process errors. If parameters for one machine don't work on another machine, then the need for integration of machining models arises.

Suppose that there is a specialized tool that one wishes to use from a remote site. One could then use VideoMosaic to handle incoming information, archive it in the workstation, and later do data mining (for example). The specialized tool could be accessed by a remote user in this manner.

A question-and-answer period followed Dr. Narayanaswami's talk. Questioners are identified by number.

Q1: Is all this accessible by a network?
A: That's in the development stage.

Q2: How many industrial participants in AMRI (the Agile Manufacturing Research Institute) use your tools?

A: GM, Ford, Kodak, and Caterpillar.

Q3: What telepresence are you trying to achieve?

A: We're not trying the robotic kind of movements. Rather, we want to remotely move spindles, et cetera.

Q3: What about interfaces to the network?

A: They are also under development.

National Industrial Information Infrastructure Protocols (NIIIP)

Mr. Tony Blazej, National Industrial Information Infrastructure Protocols (blazej@vnet.ibm.com)

(23 full-page slides start after page C-187)

Dr. Szykman introduced Mr. Blazej as affiliated with NIIIP, a consortium headed by IBM to develop protocols for an information infrastructure.

Mr. Blazej began by telling the attendees that they should be aware of the existence of NIIIP and the work NIIIP is doing. NIIIP started in 1993 and their grand challenge is to enable virtual enterprises. Phase One of NIIIP's challenge is to show that virtual enterprises are feasible; Phase Two is to get people to use virtual enterprises. NIIIP will publish the Protocols to enable virtual enterprise.

Why NIIIP? A great deal of money has been spent on single-plant solutions, but there are not many open solutions yet. NIIIP has formed a consortium around roughly 18 participants, and has had reasonably good success.

The philosophy behind NIIIP is that minimal invention of new technology is required to enable virtual enterprises. Instead, this is a systems engineering problem. The consortium will publish protocols open to everyone. The large number of legacy systems that remain in existence cannot be ignored.

On NIIIP's web site a perusable reference architecture is available (but it's 1000 pages long, so it's not easy to use—something NIIIP is trying to address). End users propose a challenge problem, and NIIIP tries to solve it. NIIIP works on a nine-month cycle. The question of how virtual enterprises do useful work is addressed in the first and second cycles. NIIIP is currently in the third nine-month cycle, in which the questions of how a virtual enterprise is created and ended a virtual enterprise, and how people join and leave are addressed.

Manufacturing is not like running bank sales. Both domains use transaction-driven systems, but bank sales are transactions that take seconds or minutes, whereas in manufacturing transactions take months or years. Product management, driving work, and vendor schedules must all be addressed. Each integrated area forms its own community; before NIIIP, nobody attempted to impose interoperability.

The NIIIP reference architecture concerns the methods of accessing and managing data repositories. After some debate, it was decided to use a web browser as an interface to the system, which proved very useful. The architecture is similar to the one described by Dr. Narayanaswami. One characteristic of this architecture is that it addresses interoperability between tools, but also enables corporate plug-and-play. In NIIIP's plug-and-play model, members join and leave as business requires.

The test scenario involves providing services as part of the consortium architecture across geographically distributed locations. Workflow services all run at IBM Boca Raton, Florida; STEP tools all run in Troy, New York; Internet services all run at EIT in Palo Alto, California; and the integration center is in Cincinnati, Ohio. In the demonstration process flow, tools run wherever they reside. The demonstration runs over the course of the day and as the speed of Internet traffic changes, fluctuations must be dealt with. For example, when Chicago goes to lunch, there are lots of stock queries, and the network in that region slows down.

NIIIP has demonstrated the use of CORBA over the Internet. This demonstration is immature, but usable and stable. People with many different skills can relate to a web browser. NIIIP set out not to be a standards body, but to use existing standards, not to invent technology but to harvest it.

NIIIP has real cash customers with real problems. They are not tied to any vendor, and have therefore been able to engineer an open solution. The technical advisory board meets three times a year to comment on what is being done. This keeps NIIIP current, relevant, and broadens out research.

NIIIP's technical approach is permissive. A complete solution is not required to get started. Rather, technology is phased in gradually. API's have been the traditional way to open systems up for interoperability; NIIIP adds rules.

A question-and-answer period followed Mr. Blazej's talk. Questioners are identified by number.

Q1: In what stages of deployment are your different programs?

A: We are four months into deploying into a shipyard environment. We are four months into a three-years NIST-funded integration into the shop floor. NIIIP Lite involves parts of NIIIP for a small supplier. NIIIP Lite has its first demo in January 1997.

This time next year, we'll give a final report on Phase One. We've been encouraged by DARPA to bid on similar projects. We have three proposals in process. NIIIP Phase Two will probably be a number of separately funded projects.

If there is an interest, you are welcome to work with our project office in Stamford, Connecticut. We have about 15 corporate participants and about 20-25 laboratory sites.

The National Advanced Manufacturing Testbed: NAMT Framework for Discrete Parts Manufacturing

Dr. Edward Barkmeyer, NIST (edbark@nist.gov)
(presentation on behalf of Mr. Neil Christopher, NIST (neilc@nist.gov)
(5 full-page slides start after page C-213)

Dr. Szykman introduced Dr. Barkmeyer as giving a presentation on behalf of Mr. Neil Christopher, who was ill.

Dr. Barkmeyer began by describing the focus of the project: production floor interface protocols (not engineering phase). The goal here is not to develop standards, but to test them out (thus the word "testbed" as part of the project name). There are many Manufacturing Execution Systems (MES) consortia with quasi-standards. There are good ideas coming from various places. The purpose of developing a testbed is to answer questions such as "What works? What doesn't? How do we improve what doesn't work?"

The first STEP testbed element was an inspection. One thing that quickly became apparent was that there was no specification for organizing information to be presented to or from inspection stations. A defunct STEP effort, STEP AP (Application Protocol) 219 was consequently restarted. AP 219 is concerned with an inspection plan, a sequence of inspection operations, and possibly with resulting data. Researchers are looking at how specifications can fit together to form a cohesive whole.

The second year of the framework component system project began in October 1996. The activity set is shown on the Framework Component System Diagram slide. It indicates the scope of the project. The project's focus is interfaces to and from a workcell controller and a shop controller. The project includes an inspection workcell controller but no real cells. Instead the cells are simulated; they are forced to err, or to be late, to see what the consequences are.

The project's view of the shop floor interface with engineering systems is a Product Data Manager (PDM). The PDM takes part designs, control programs, and plans, and translates them to the system of interest: process and inspection planning. The PDM is a repository of specifications, not a database.

One additional important thing to note: one of the project researchers had come across a comment on the Internet that said something to the effect of: "Web for the Internet, CORBA for an intranet." This project uses CORBA in its intranet and that's all. The next step is to select what standards, nominal standards, and proposed standard to implement. Testing will begin in September 1997.

A question-and-answer period followed Dr. Barkmeyer's talk. Questioners are identified by number.

Q1: An observation that concerned me: you're dropping the information and measurement repository.

A: No, we aren't dropping it, though we might delay it beyond 1997.

Q1: That's where the tie to design comes from.

A: Exactly.

Summary and Strategic Planning

Dr. William Regli, NIST (regli@cme.nist.gov)
(talk given without slides)

Dr. Regli closed the conference with a few minutes of summary. In the discussion that follows, Dr. Regli and Dr. Szykman are identified by name; other participants are identified by arbitrary numbers.

Dr. Regli: We hope two things have happened here: one, information exchange; two, that you met colleagues working in related topics. We'd like to take suggestions on "what NIST can do"—what topics to keep dialog going on.

Dr. Szykman: Dr. Erkes made interesting points about where the financial payback is, that is, in business opportunity

Q1: I'm walking out of here feeling good about two-dimensional investment, but disappointed about the addressing of network-centric CAD. We've discussed a lot of infrastructure, but not how CAD might evolve in a network-centric world. CAD is compute-intensive and monolithic. In the last three years, there has been a tremendous increase in compute power at low price: a top-of-the-line Pentium costs $2000. 28.8K modems are bad for moving data around, but in three years they'll be better. How do we change the monolithic approach into something different? What are the migration paths to really network-centric CAD?

Q2: An appropriate role for NIST is to sponsor discussions on certain issues. A network is good for access to anything anytime anywhere—data, applications, et cetera—and to people, too. This group should expand to include collaborative design.

Q3: We are getting a flavor of the demands and requirements on CAD data and applications. This should be of interest to vendors and research as a business driver for network-centric CAD. What can researchers do that industry can't and vice-versa? Industry isn't happy with research: technology transfer isn't that easy.

Q4: To CAD vendors: would a session on what CAD might look like five years down the road be useful? NIIIP sponsored? [Small chorus of "Yes".]

Q5: I'd prefer if we could have some NIIIP-sponsored input to what's going on in HTML, VRML et cetera.

Q6: How far can we make entertainment people listen to a CAD-suitable product? VRML is for display, not for engineering.

Q7: But people like Java3D, Cosmos3D want our input. We should have some consensus on what our interests are. Sun and Silicon Graphics sell a lot to Ford and GM.

Q8: And they don't want to lose you to PCs.

Q6: Yes, but the needs of display are different from the needs of engineering.

Q9: Anything sponsored should include users as well, not just vendors saying what we think users want.

Q10: Users say, "you guys have to push NURBS into the VRML community." Like all CAD vendors, we spend lots of time listening to users.

Dr. Regli: CAD vendors should ask users: what technologies should we consume? what are your business drivers?

Q11: What is NIST doing to use the Internet to build consensus in the community? Very seldom at ARPA did anybody say, "This is how I'm going to apply this process to myself".

Q12: One of NIIIP's commitments to DARPA was, "We're going to eat our own dog food." Two years later, we're still struggling. Many tools are not ready for prime time.

Q11: At ARPA, we were having trouble using our own stuff. Design capture tools were too intrusive. We ended up sending email with text and GIF files.

Q12: How can NIST get major customers in a room to put pressure on vendors?

Q11: We have voluntary standards in this country. We really need pressure from end users. NIST can facilitate, but can't do more.

Q12: NIST can have workshops of national scope, with big publicity, like Sun pushed Java. NIST can disseminate information of interest.

Dr. Regli: We can bring CAD vendors in by having meetings at NIST-Boulder.

Dr. Szykman: As described, it will be hard for vendors to justify the time spent to come to NIST.

Q13: One problem: small-shop end users won't come here.

Dr. Szykman: Yes, they'll go to a trade show or some such.

Q14: I'm very specific-goal-oriented. This needs to be "put to bed": measure a meaningful dimension and tolerance of a VRML object, and update a VRML object when a part updates.

Q15: Make lists off-line about what we need to talk about, prioritize them, then come to the workshop.

Q16: CORBA is another standard we need input to. We've had lots of experience with it.

Dr. Szykman: Issue about next versions of HTML, VRML: those who care put in their time going to meetings, et cetera.

Q17: Unix vendors who drive HTML and VRML want to listen to us. But we need to make meaningful input.

Dr. Regli: We have an exploder on network-centric CAD, and a periodic newsletter.

Dr. Szykman: The mailing list ended up with marketing information, calls for papers, and the like.

Q18: I'm so frustrated with email. Do a newsgroup.

Q19: I prefer email.

Q20: I also prefer email.

Q21: It would be a lot more proactive if there were an active web site with pointers to NIIIP, et cetera.

Q22: We can't have that web site at NIST, because of our slow approval process. There will be a web site set up outside of NIST for the email list.

Q23: Let's have another meeting of the same size.

Dr. Regli: How often?

Q23: Six months. Late spring.

Q24: Have specific topic meetings—segment the groups of attendees.

Q25: Try to create a CAD vendor voice.

Presentation Slides

Opening Remarks and Introductions

Dr. Simon Szykman, NIST (szykman@cme.nist.gov)

The summary for this presentation can be found on page 13
4 full-page slides follow

Network-Centric CAD
A Research Planning Workshop

3-4 December, 1996
National Institute of Standards and Technology
Gaithersburg, MD

Organized by
William C. Regli and Simon Szykman

NIST

Sponsors

- Carnegie Mellon University (Peter F. Brown)
- NIST (Steve Ray, Ram Sriram)
- DARPA, RaDEO Program (Kevin Lyons)
- National Advanced Manufacturing Testbed (David Stieren)
- US Navy Manufacturing Technology Program (ManTech)
- Army Research Office, Mathematics and Computer Science Directorate (Ming Lin)
- Office of Naval Research (Ralph Watcher)

Network-Centric CAD: A Research Planning Workshop

December 3-4, 1996
National Institute of Standards and Technology

Preliminary Agenda

Tuesday, December 3, 1996
NIST Lecture Rooms A-B

7:30 am - 8:00 am:	**Registration, Coffee, etc.**
8:00 am - 8:15 am:	**Opening Remarks and Introductions** Dr. Simon Szykman, NIST
8:15 am - 8:30 am:	**Welcome to NIST** Dr. Ric Jackson, NIST Director, Manufacturing Engineering Lab
8:30 am - 9:00 am:	**Overview of Workshop Goals** Dr. William Regli, NIST
9:00 am - 9:15 am:	**Q&A**
9:15 am - 10:00 am:	**Keynote Speaker** Dan Deitz Associate Editor, ASME Mechanical Engineering Magazine "An industry-wide perspective"
10:00 am - 10:15 am:	**Break**
10:15 am - 12:00 pm:	**Panel Session #1 and Q&A: Defining the Common Ground and Issues** Dr. Al Klosterman, Vice President, SDRC "Support of Virtual Enterprise Computing by the Emerging Capabilities in MDA and PDM Systems" Dr. Ravi Ravindra, Senior Scientist, ComputerVision "Electronic Product Definitions and Internet Technology" Dr. Joe Erkes, Director, Design Integration, GE Corporate R&D Center "Supply Chain Integration and the WWW"
12:00 pm - 1:30 pm:	**Lunch**
1:30 pm - 2:00 pm:	Mr. Shaun Sewall, Bentley Systems TITLE TO BE ANNOUNCED
2:00 pm - 3:45 pm:	**Breakout Session #1: Technology Assessment**
3:45 pm - 4:00 pm:	**Break**
4:00 pm - 4:30 pm:	**Report Back Panel and Q&A**
4:30 pm - 5:30 pm:	**Technology Demonstration Session** Beam Technologies University of California, Berkeley Stephens Institute of Technology, Design Manufacturing Institute
5:30 pm:	**Conclude for the Day**
6:30 pm - 8:00 pm:	**Dinner at Gaithersburg Courtyard by Marriott**

Wednesday, December 4, 1996
NIST Lecture Rooms A-B

8:00 am - 8:45 am: **Coffee, etc.**

8:45 am - 10:30 pm: **Panel Session #2 and Q&A: Research Issues and Directions**

Dr. Rick Palmer, Senior Scientist, Beam Technology
"Einstein Objects: An Open Standard for Web-Enabled Distributed Design and Simulation of Electro-Mechanical Products"

Dr. Mike Terk, Rice University
"Changing Priorities of Research on WWW-Based Engineering Services"

Dr. John Mitchiner, Sandia National Laboratories
TITLE TO BE ANNOUNCED

10:30 am - 10:40 am: **Break**

10:40 am - 12:30 pm: **Panel Session #2 (continued)**

Dr. Don Brown, PartNET/University of Utah
"PartNET"

Mr. Edward Barkmeyer, NIST
"The National Advanced Manufacturing Testbed: Framework Project"

Dr. Clayton Teague, NIST
"The National Advanced Manufacturing Testbed: Nanomanufacturing of Atom-based Dimensional Standards"

Dr. Ranga Narayanaswami, University of Illinois, Urbana-Champaign, Machine Tool Agile Manufacturing Research Institute
"Highly Interactive Network-Centric Tools for Collaborative and Distributed Manufacturing"

Mr. Tony Blazej, National Industrial Information Infrastructure Protocols
TITLE TO BE ANNOUNCED

12:30 pm - 1:30 pm: **Lunch**

1:30 pm - 2:30 pm: **Summary and Strategic Planning**

2:30 pm: **Workshop Close**

Welcome to NIST

Dr. Richard H. F. Jackson, NIST (jackson@cme.nist.gov)

The summary for this presentation can be found on page 14
20 full-page slides follow

Manufactuirng Engineering at the National Institute of Standards and Technology

Richard H.F. Jackson, Director
Manufacturing Engineering Laboratory
National Institute of Standards and Technology
http://www.nist.gov/mel/

MEL NIST

NIST Functions

- **Assist industry in the development of technology and procedures needed to**
  - improve quality
  - modernize manufacturing processes,
  - ensure product reliability, manufacturability, functionality, and cost-effectiveness, and
  - facilitate the more rapid commercialization...of products based on new scientific discoveries.
- **Develop, maintain national standards of measurement.**
- **Assure international compatibility of national measurement standards.**
- **Advise industry and government on scientific and technical problems.**
- **...**

NIST Resources

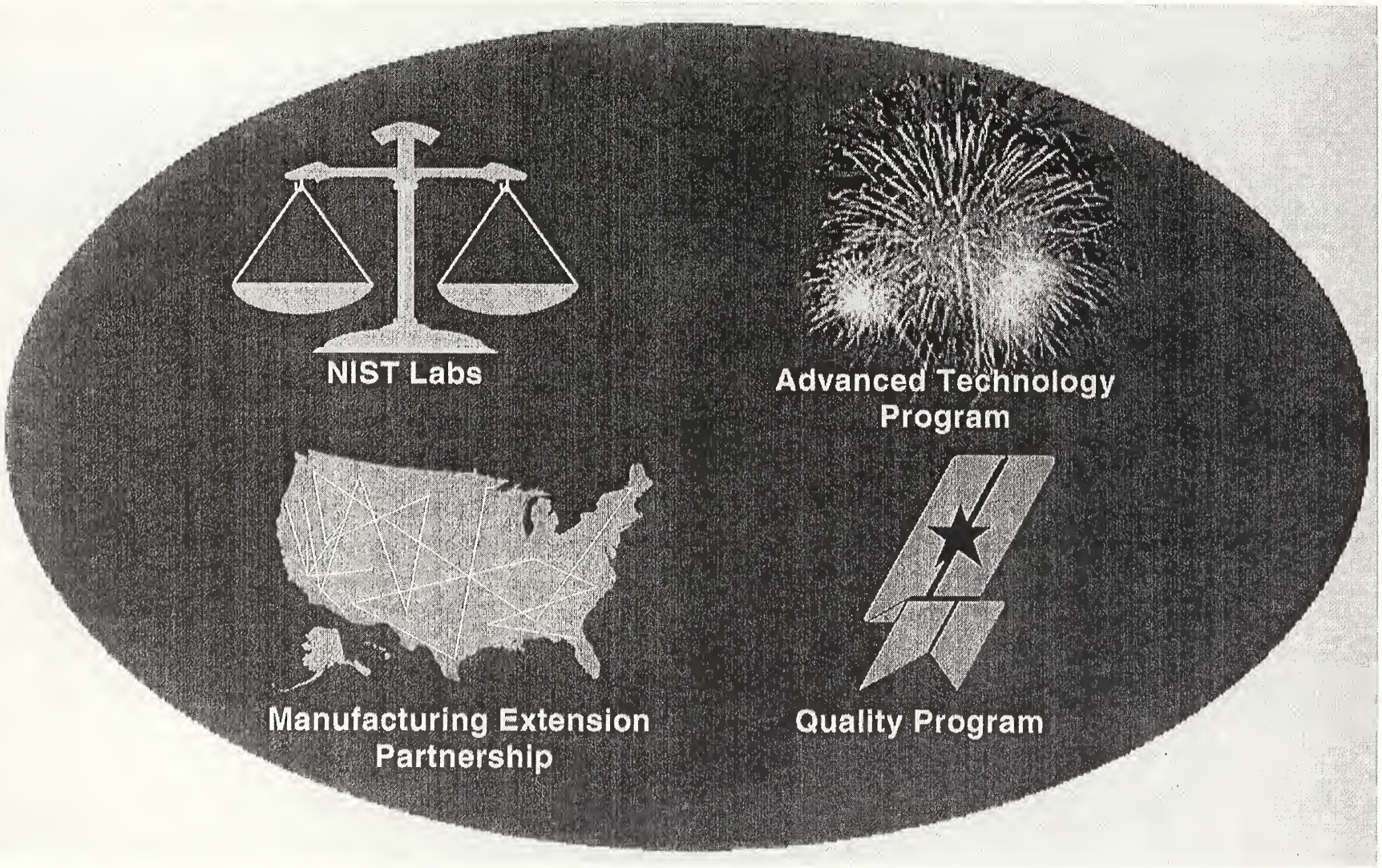
Fiscal Year 1996

- 3320 Employees
- About 1250 Guest Researchers
- $259M Appropriated Laboratory Funding
- $739M Operating Budget
- $60M for Construction of Research Facilities

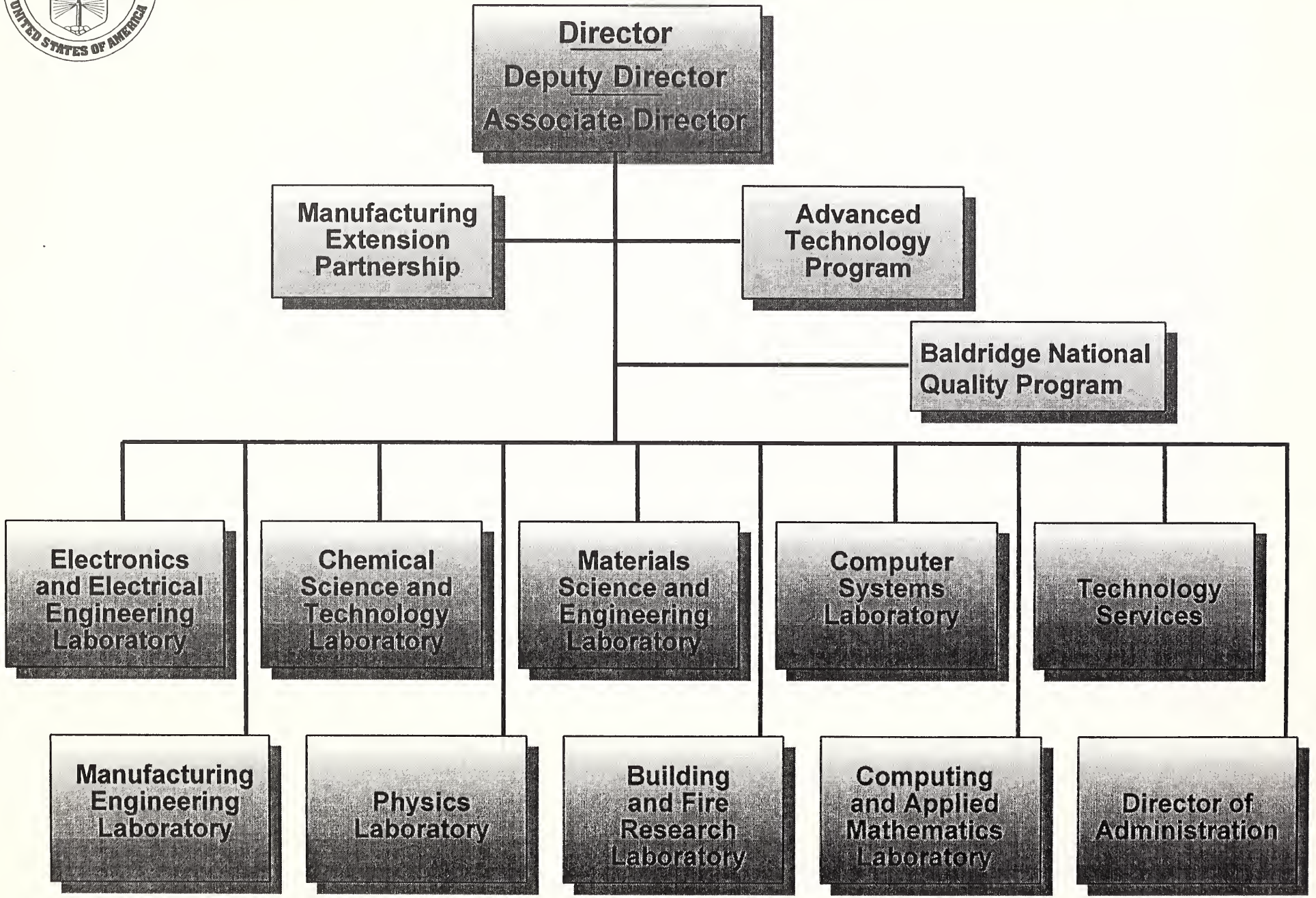
NIST Mission

To promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards.

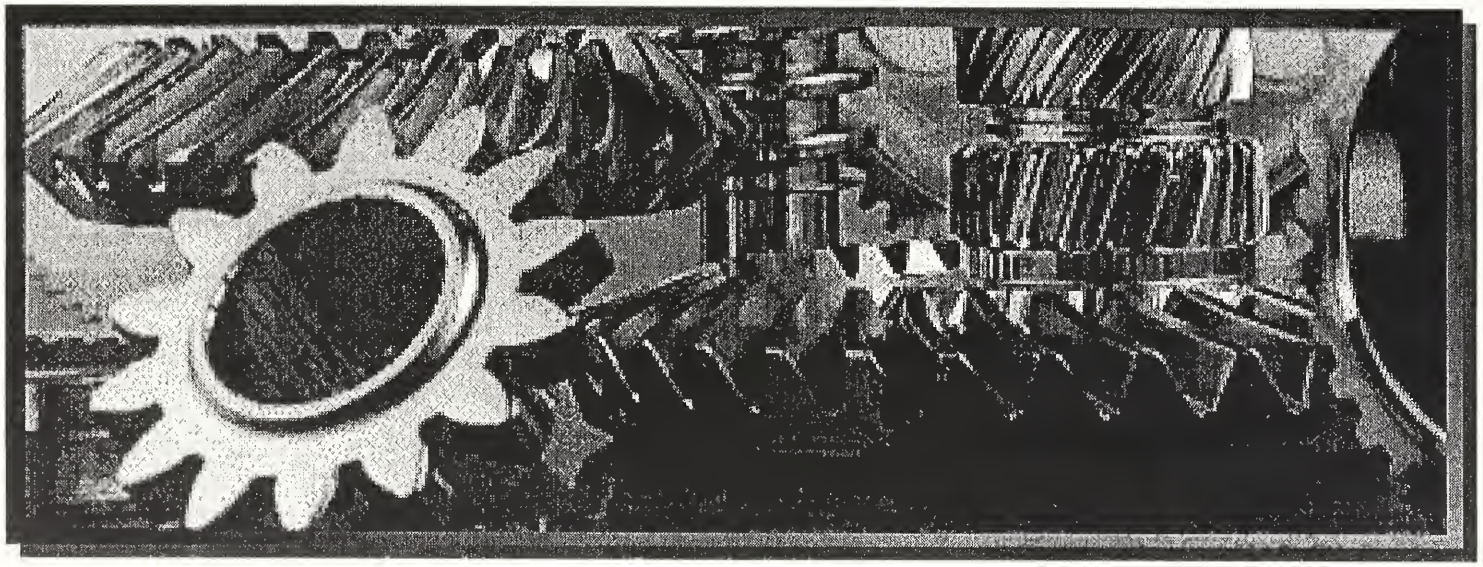
National Institute of Standards and Technology



National Institute of Standards and Technology

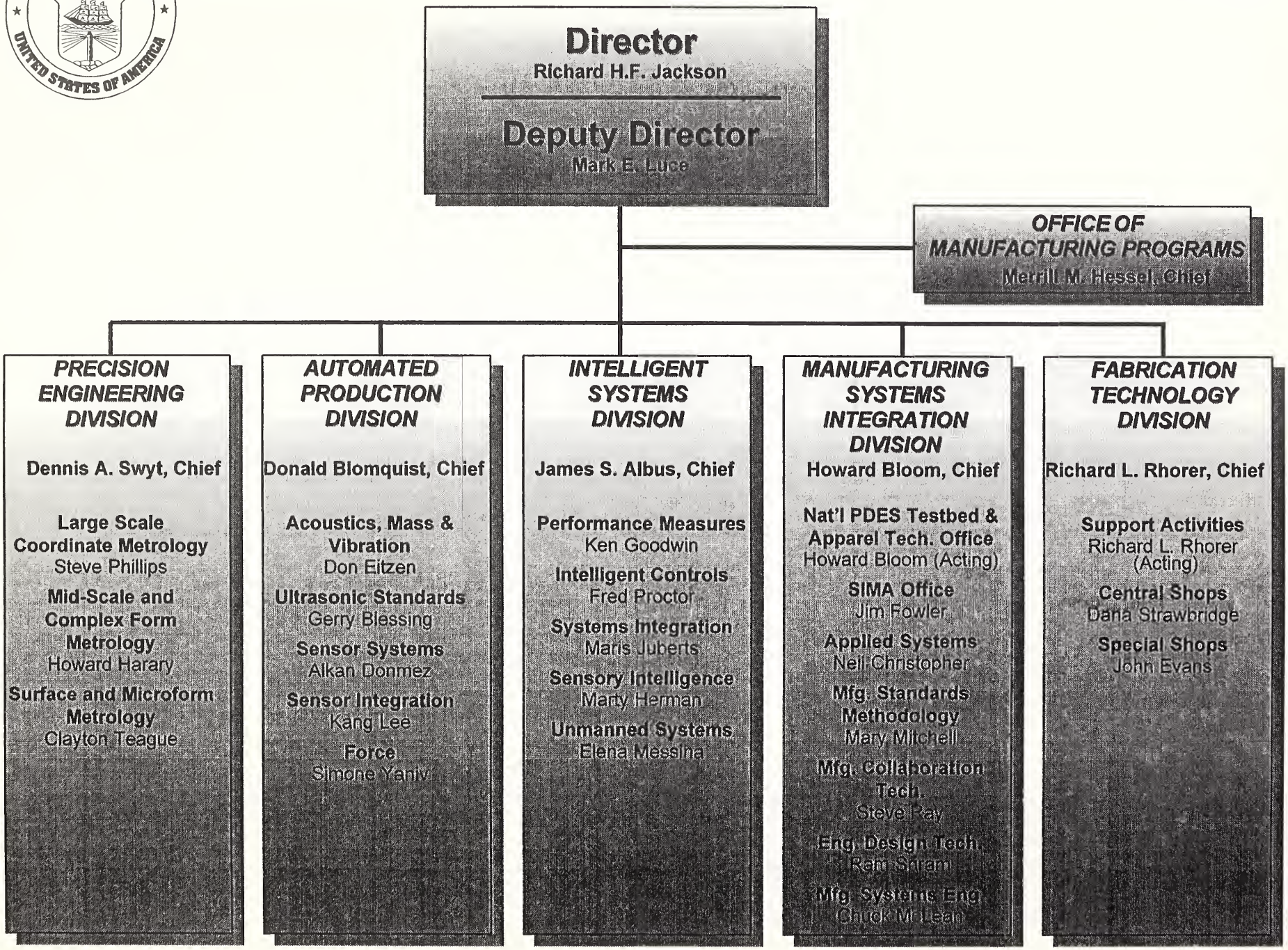


Manufacturing Engineering



Laboratory

Manufacturing Engineering Laboratory



MEL Role

Serve the ***whole*** manufacturing enterprise, ***each*** of the manufacturing sectors, and the **range** of manufacturing technologies, with special focus on the mechanical manufacturing industry.

Provide ***physical*** and ***informational*** standards.

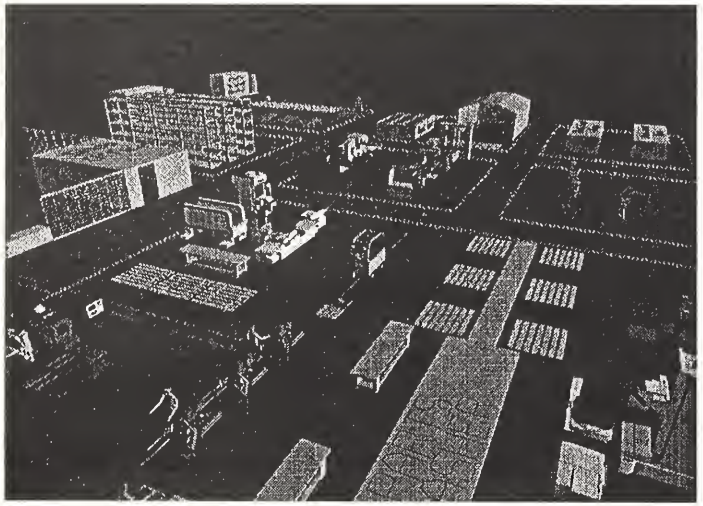
Disseminate the dimensional and mechanical standards of length mass, vibration, force, acoustics, and ultrasonics.

Realize the SI units of length and mass.

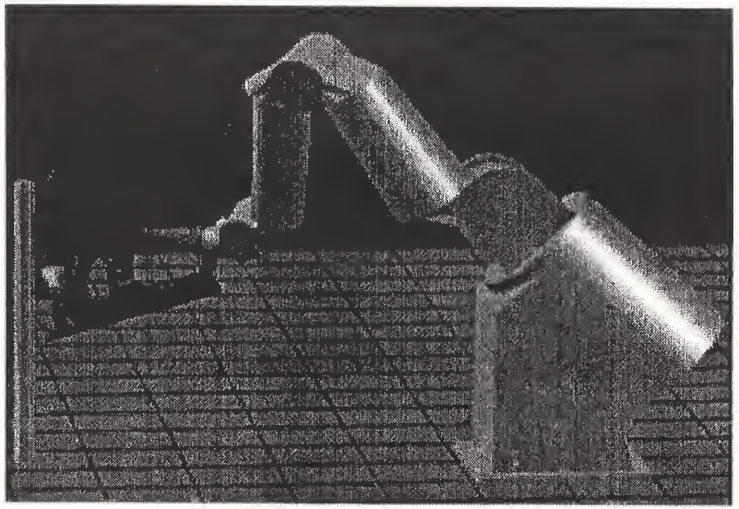
Provide ***fabrication*** services to NIST.

Programmatic Thrusts

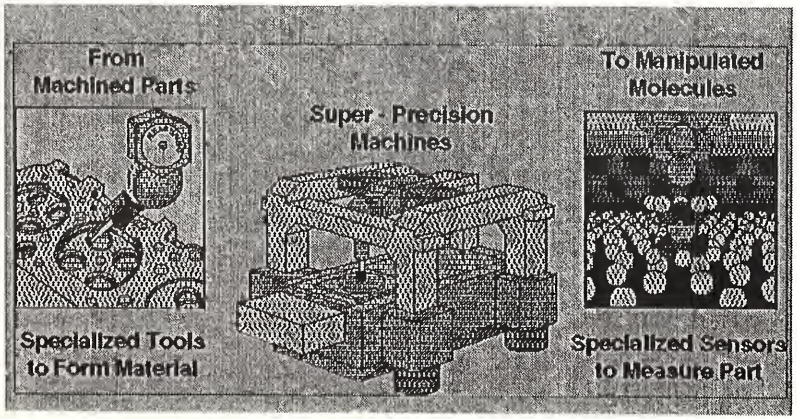
Manufacturing Systems Integration



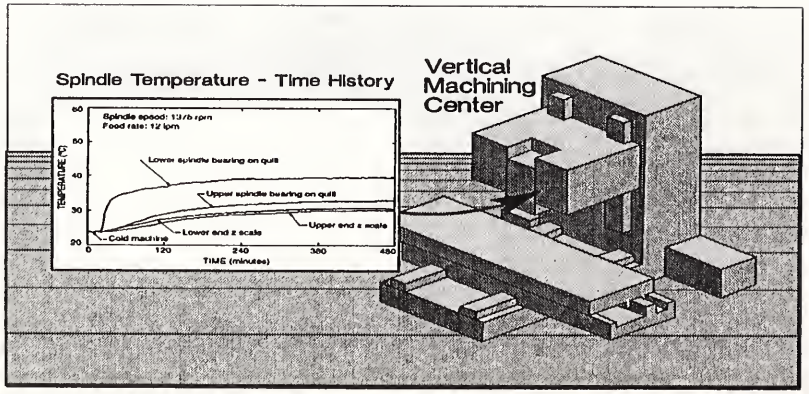
Intelligent Machines



Manufacturing Metrology



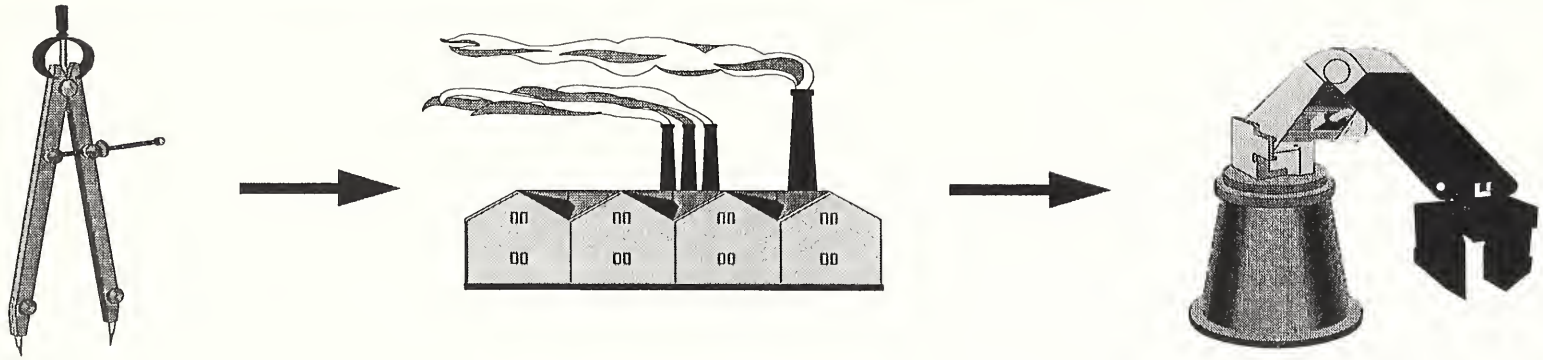
Manufacturing Processes & Equipment



MEL NIST

Trends in Manufacturing

Craft → *Mass Production* → *Automation*



Process improvements driven by a desire to increase marketshare by improving *quality*, reducing *cost* and decreasing *time* to market.

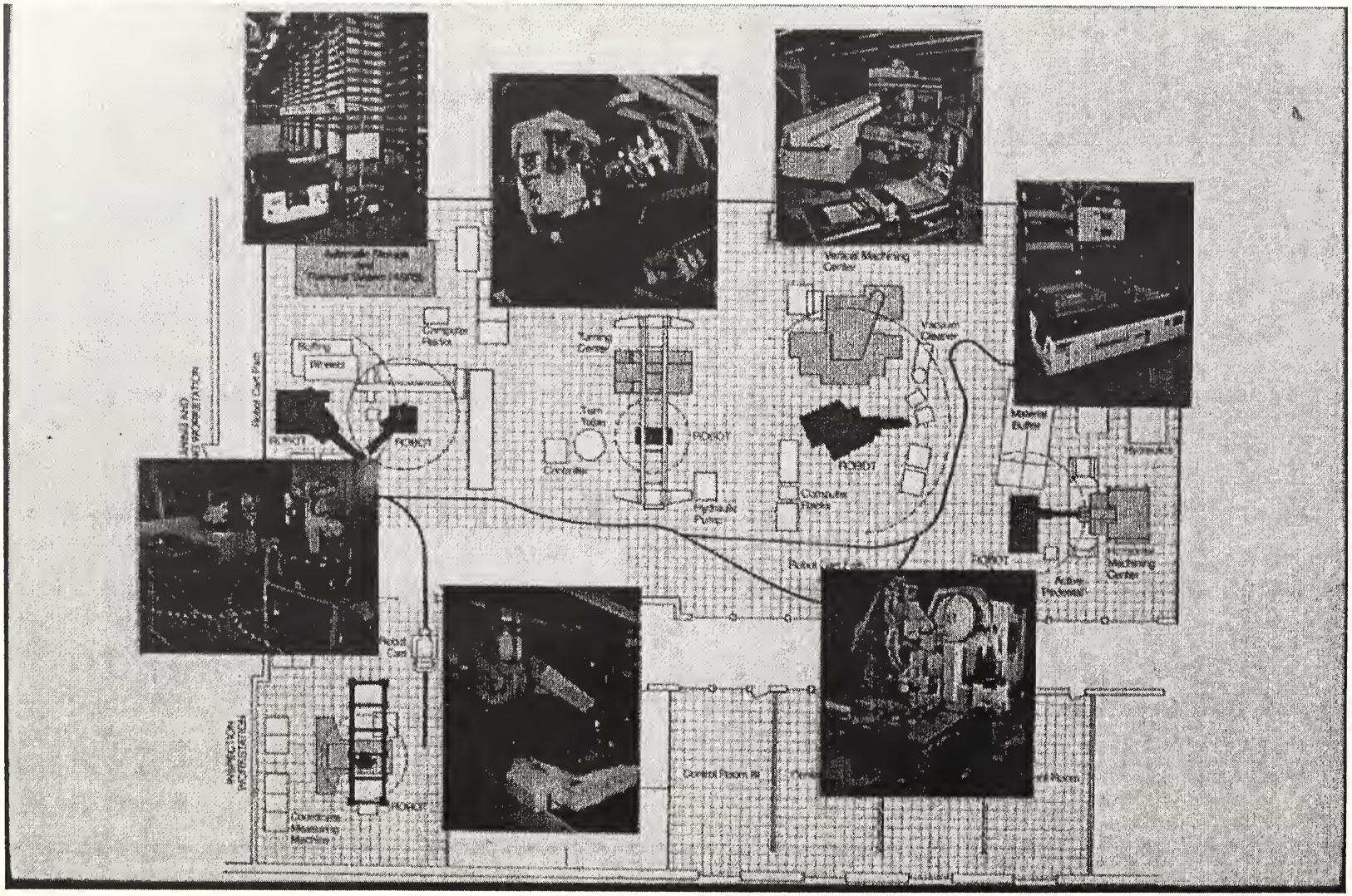
The Automated Manufacturing Research Facility

- A research test bed for the factory of the future
- A U.S. Navy Center of Excellence

AMRF Project

- Build a test bed flexible manufacturing system
- Support manufacturing systems research by NIST, Academia, Industry, and other agencies
- Conduct continuing studies of interface standards
- Conduct continuing studies of advanced metrology
- Transfer technology to American Industry

AMRF Floorplan

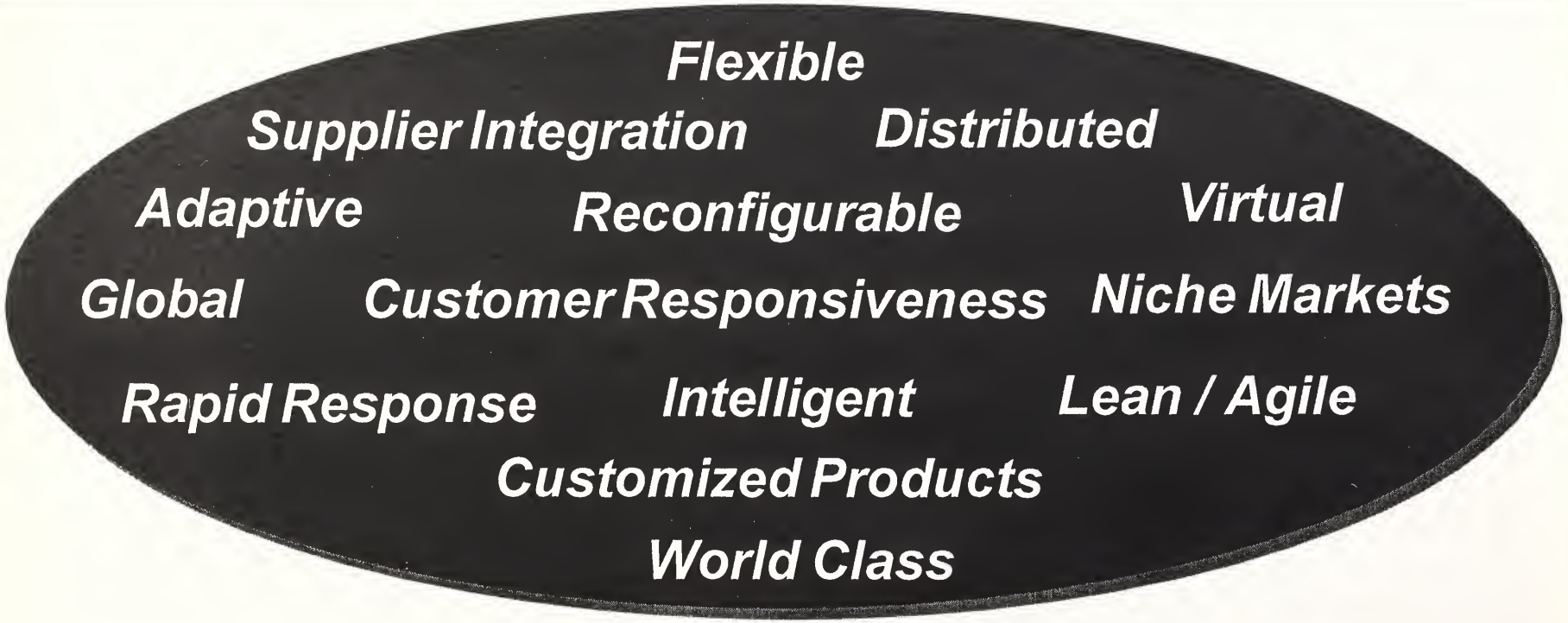


MEL NIST

AMRF Accomplishments

- 21 Standards
- 14 Products
- 17 Patents
- 11 Subsystems
- 80 Research associates from 50 firms
- 15 Theses from 40 academic connections
- 9 OA projects totaling more than $10M
- Donations totaling more than $20M

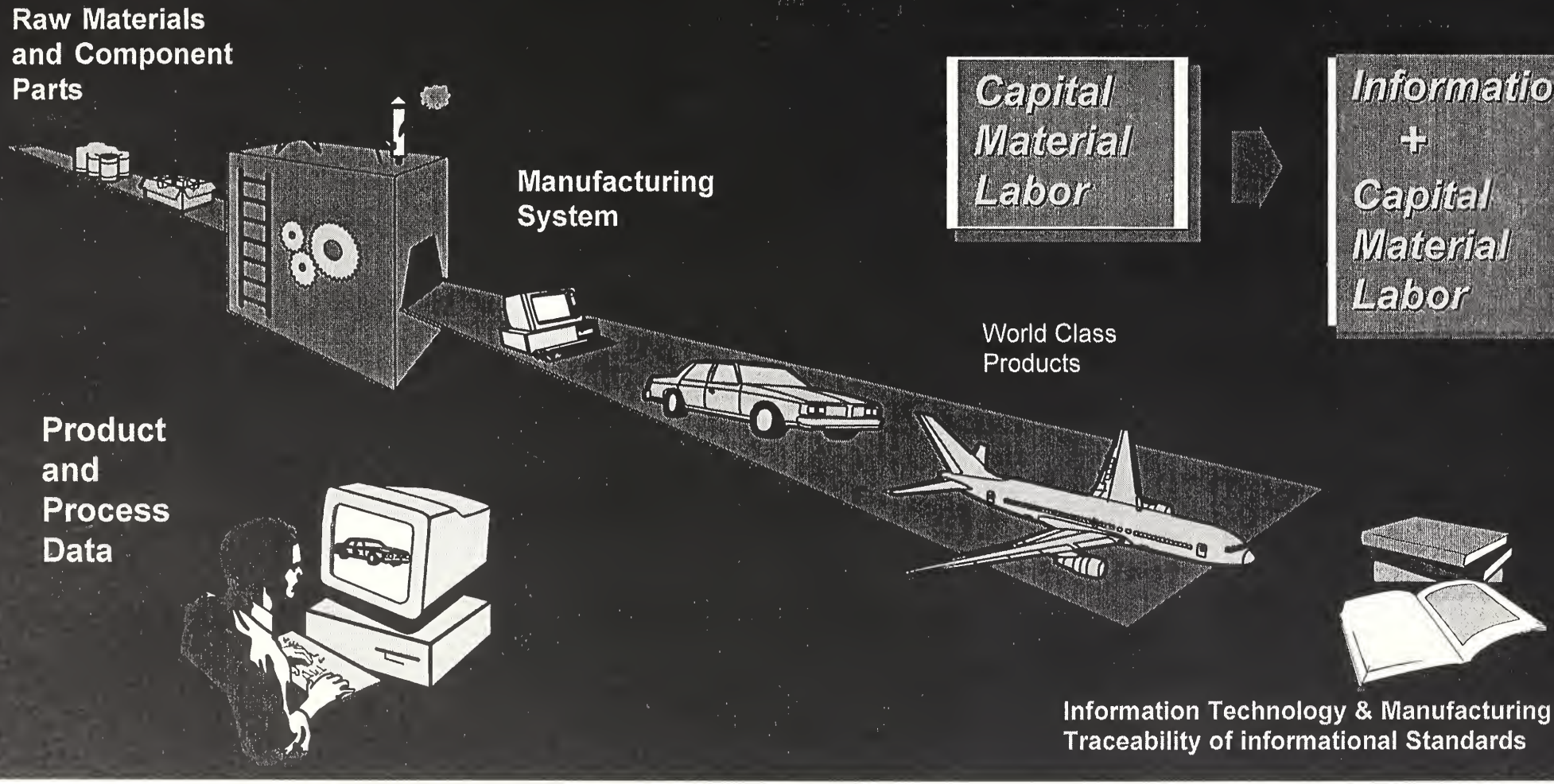
What's Next in Manufacturing ?



"Information Technology is the Key Enabler"

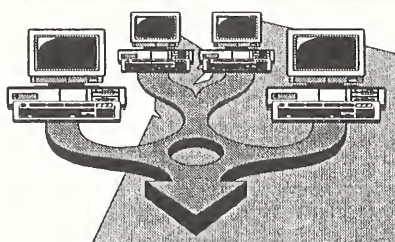
...information-based manufacturing...

...manufacturing that relies upon and exploits the capabilities available to systems & processes through the application of information technology as a value-added resource...

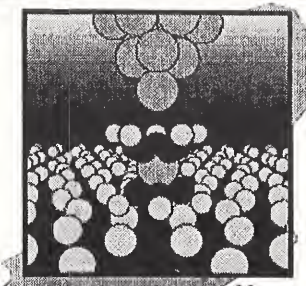


Information Technology & Manufacturing
Traceability of informational Standards

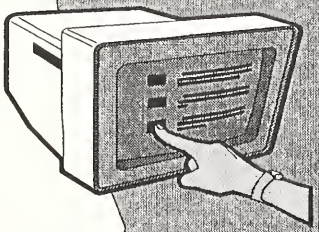
Measurements & Standards for Information-Based Manufacturing



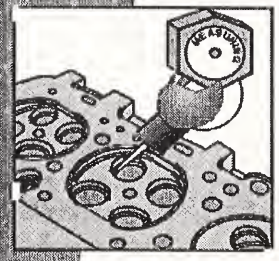
Integration Framework



Advanced Metrology



NAMT

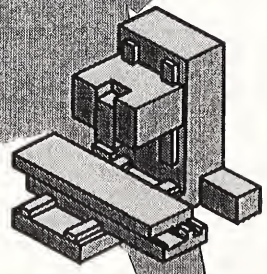


Interface Standards for Virtual Manufacturing

Measurement Standards

Computing & Communications Infrastructure

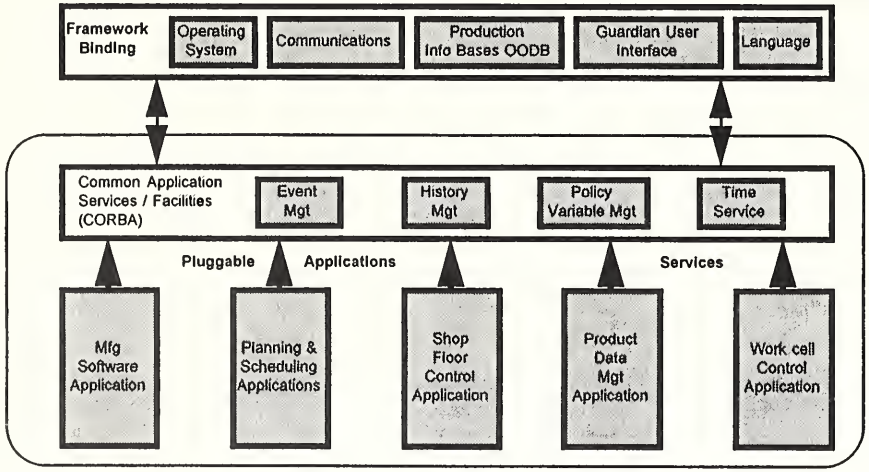
Simulation Testing



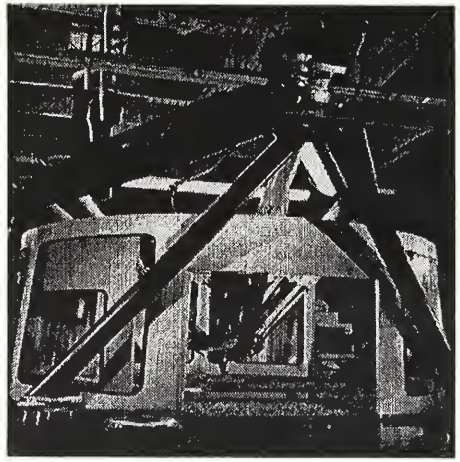
Machine Tool Modeling

NAMT Projects

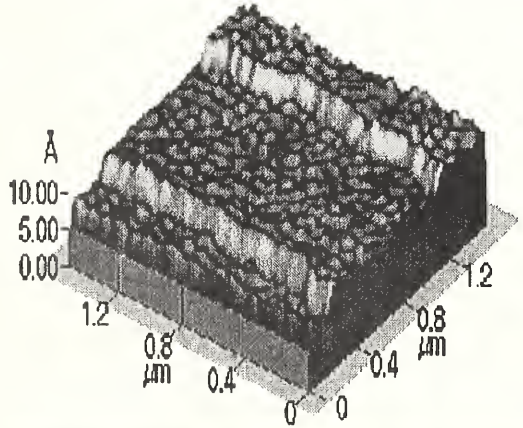
Manufacturing Framework



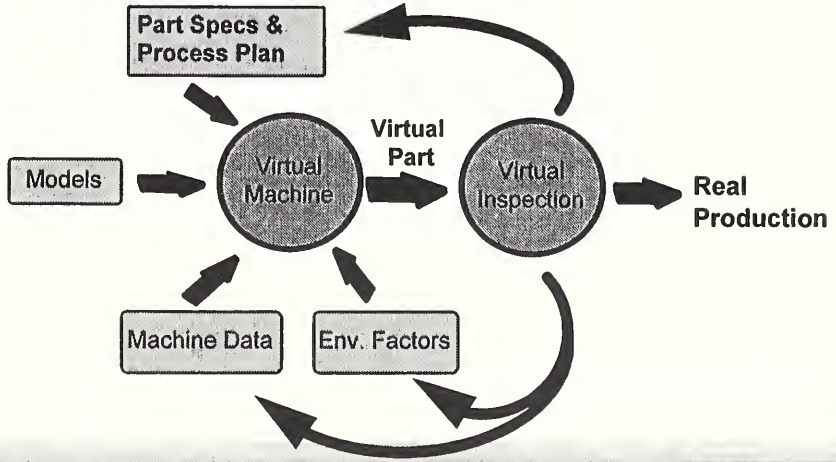
Characterization, Remote Access, & Simulation of Hexapod Machines



NanoManufacturing of Atom-Based Standards



Machine Tool Performance Model



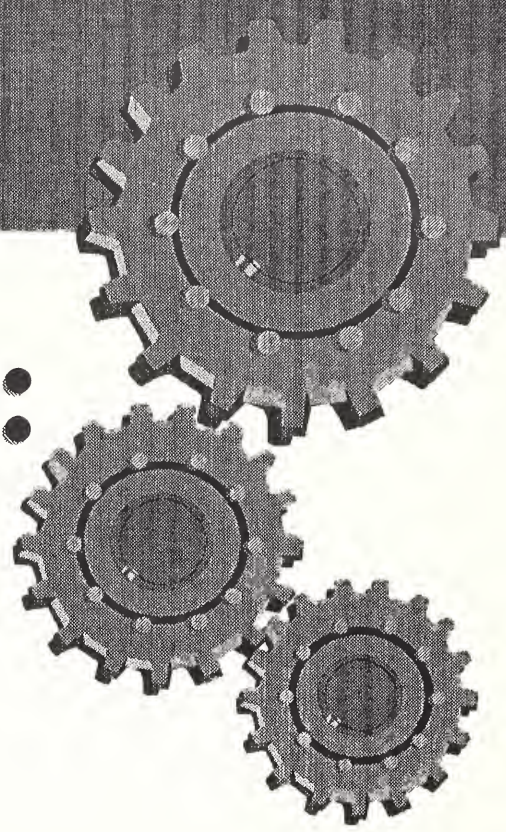
Conclusion

- Four programs of support for industry
- Cooperative planning and research
- Solid support for overcoming barriers

Overview of Workshop Goals

Dr. William Regli, NIST (regli@cme.nist.gov)

The summary for this presentation can be found on page 16
11 full-page slides follow



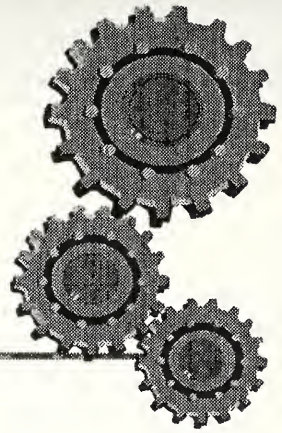
Network-Centric CAD: Research Planning Workshop

William C. Regli
Manufacturing Engineering Laboratory

NIST

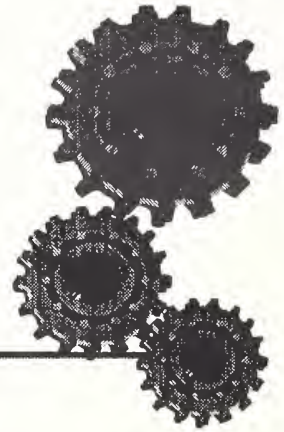
The National Institute of Standards and Technology
United States Department of Commerce

Meeting Objectives



- Identify future R&D issues and directions
- Determine critical points
- Enable technical interchange with colleagues and collaborators **across perspectives**
  - attendees include those doing CAD R&D in mechanical and AEC domains
- Collect opinions and find common needs
- Status report and roadmap for funding agencies

Makeup of Attendees

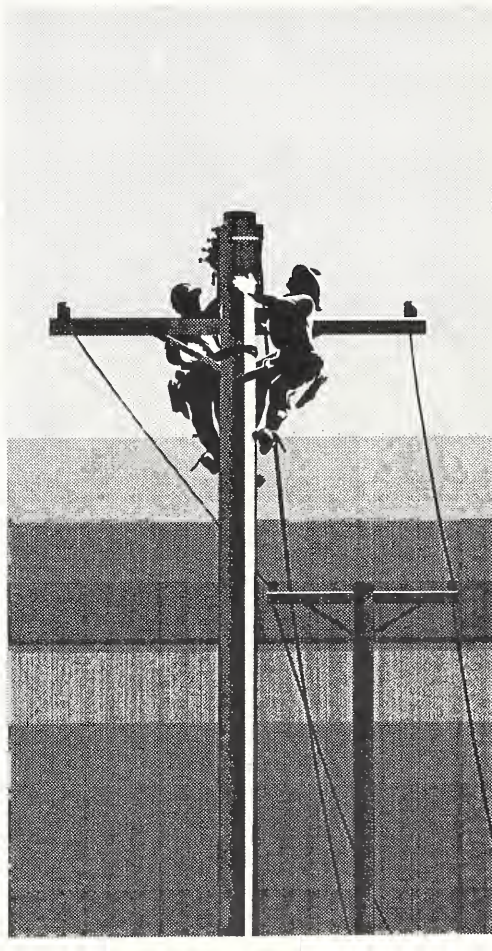


- Mix across businesses and disciplines
  - Academia/Research 20%
  - Industrial end-users 40%
  - Industry, software vendors 40%
- Interests
  - Developers building next-generation Internet-aware CAD tools
  - R&D agencies and startups companies

NETCAD Vision

A networked suite of integrated engineering software tools accessible by "information appliances" via the telecommunications infrastructure (e.g. The Internet).

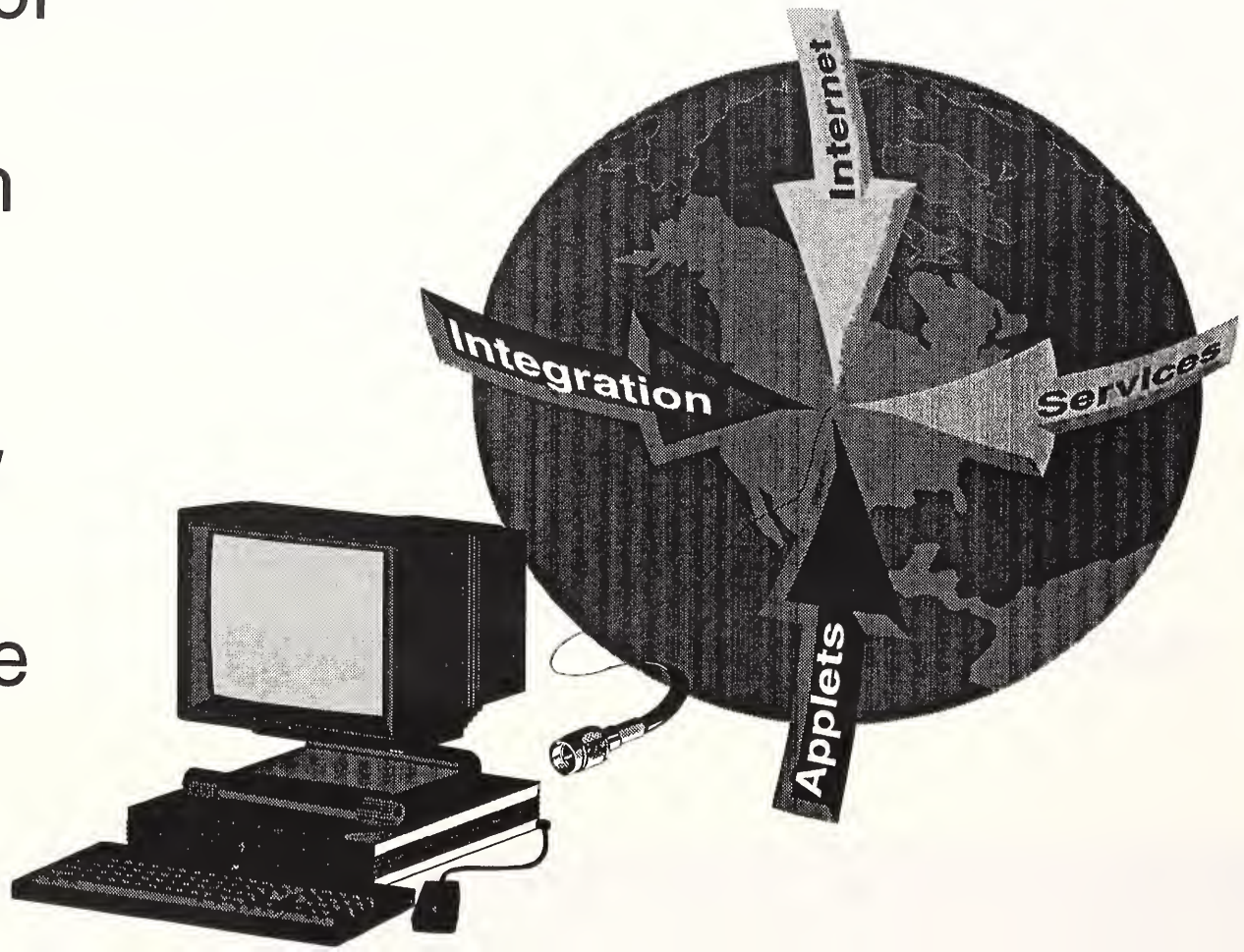
- Includes the latest sophisticated engineering software
- Availability of smart catalogs, libraries, and repositories
- Highly inter-networked distributed software and hardware
- Seamless integration
- Access to advanced manufacturing services



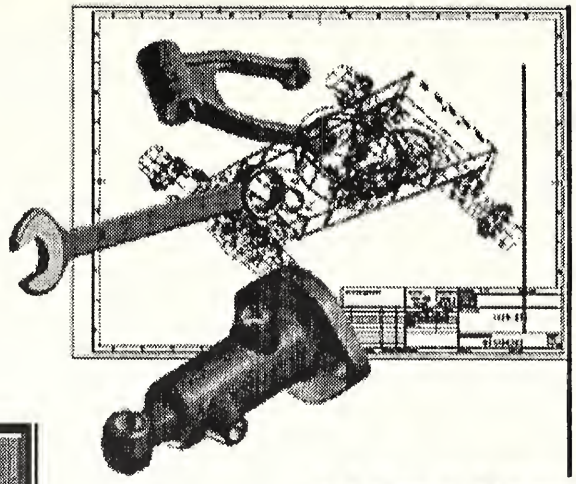
Network-Centric CAD

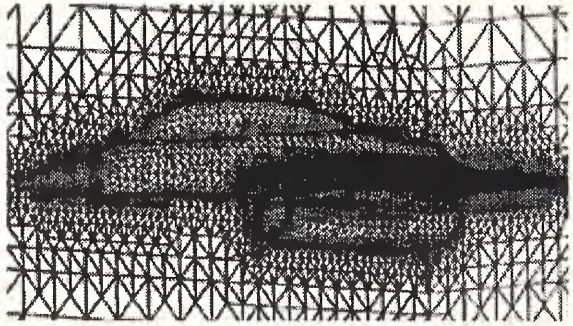
Building network-enabled tools for CAD-centered computer-aided engineering....

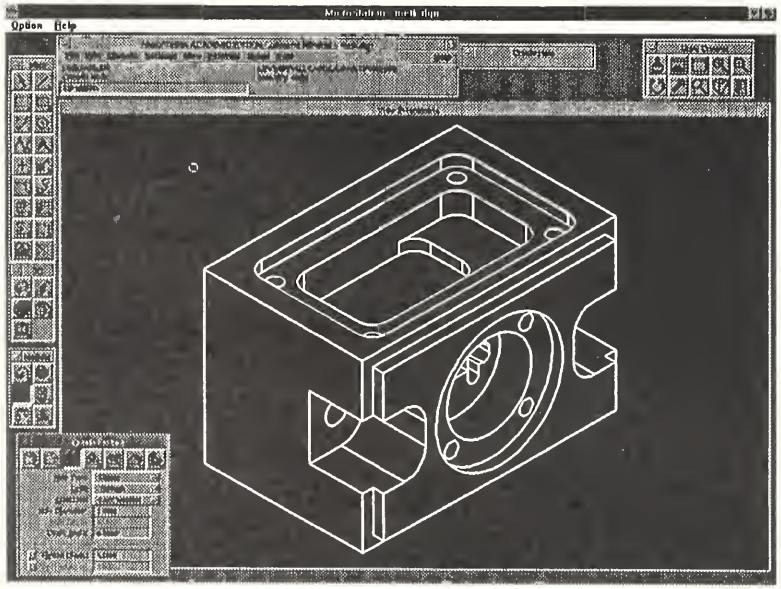
- Identify new types of software services
- Develop integration mechanisms
- Migrate existing applications to new paradigm
- Deliver and execute over the Internet

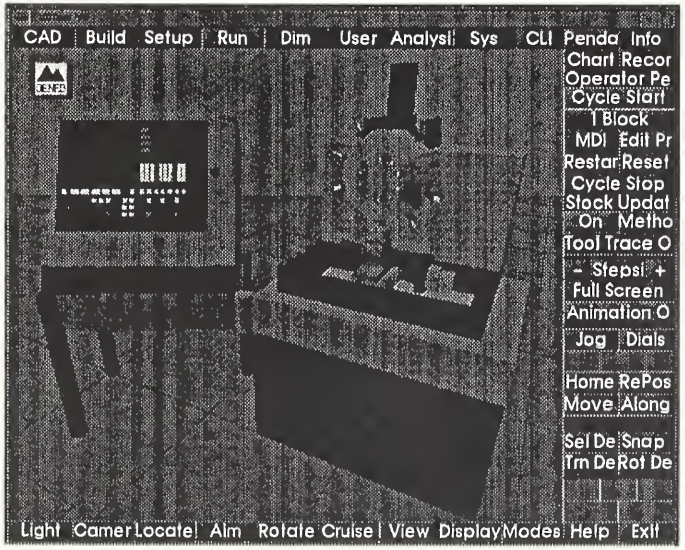


A Networked Software Suite

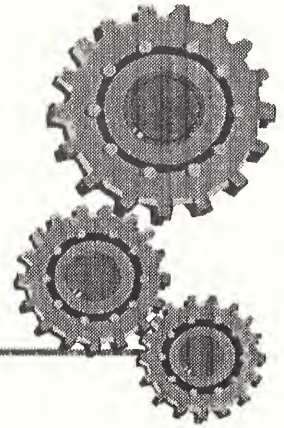






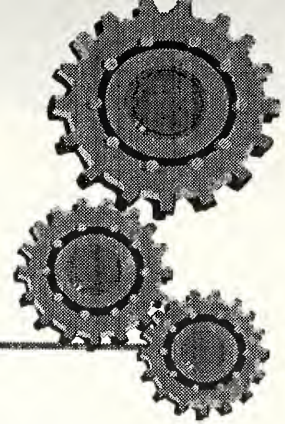


Objectives



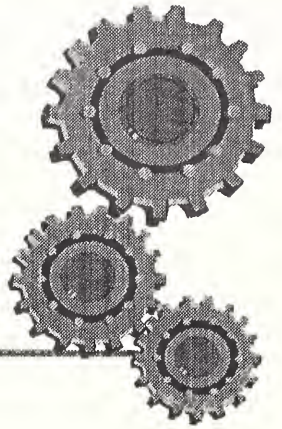
- Generate a degree of consensus on technical issues
- Status report and R&D mandates
- Feedback back to funding agencies
- Proceedings and working notes to be distributed to attendees and others

To Achieve Objectives....



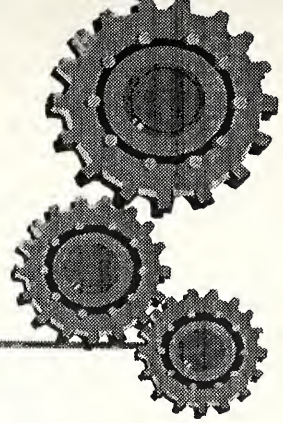
- Keynote Speakers
  - Dan Deitz, Assoc. Editor, ASME Mechanical Engineering Magazine
  - Dr. Nino Vidovic, AT&T Western Technology Center
- Speakers/Presentations
  - Today: Industrial participants delivering systems
  - Tomorrow: R&D participants developing prototypes for next generation tools
- Focused roundtable discussion is encouraged
- Proceedings Editor: Dr. Stephen Smith

Breakout Sessions



- Two Breakout discussion sessions
  - Breakout #1, this afternoon
    - Technology Assessment
    - What are the easy problems?
    - Where are the difficult problems?
  - Breakout #2, tomorrow afternoon
    - Research Planning
    - On what issues should R&D be invested?
    - Ex: NSF Program for High-Performance Internet

Related NIST Activities



- National Advanced Manufacturing Testbed (NAMT)
- Systems Integration for Manufacturing Applications (SIMA) Program
- Advanced Systems and Networking Testbed (AMSANT)
- Advanced Technology Program (ATP), Technologies for Integration of Manufacturing Applications (TIMA)
- Engineering Design Technologies Project
- Manufacturing Collaboration Technologies Project
- National Process Planning Testbed
- CAME Project

Sponsors

- Carnegie Mellon University (Peter F. Brown)
- NIST (Steve Ray, Ram Sriram)
- DARPA, RaDEO Program (Kevin Lyons)
- National Advanced Manufacturing Testbed (David Stieren)
- US Navy Manufacturing Technology Program (ManTech)
- Army Research Office, Mathematics and Computer Science Directorate (Ming Lin)
- Office of Naval Research (Ralph Watcher)

Support of Virtual Enterprise Computing by the Emerging Capabilities in MDA and PDM Systems

Dr. Al Klosterman, Vice President, SDRC (al.klosterman@sdrc.com)

The summary for this presentation can be found on page 25
24 half-page slides follow on 12 pages

MDA, PDM & Reqr. Engr. in a Virtual Enterprise

Support of Virtual Enterprise Computing via the emerging capabilities in:

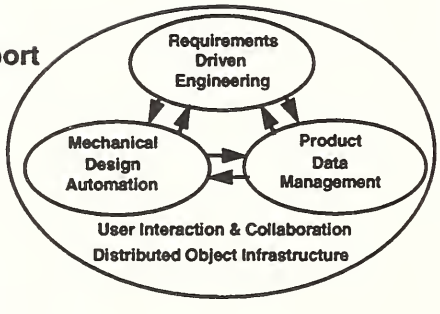
- Mechanical Design Automation (MDA)
- Product Data Management (PDM)
- Requirements Driven Engineering (RDE)

by
Albert L Klosterman, Ph.D.
V.P. & Chief Scientist
SDRC

MDA, PDM & Reqr. Engr. in a Virtual Enterprise

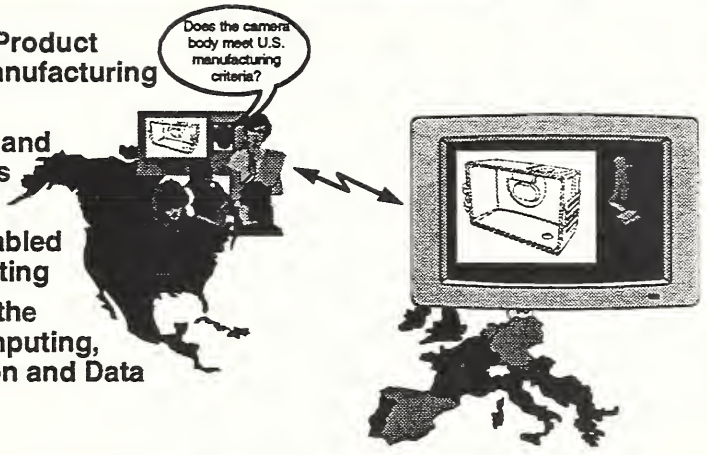
Outline

- Virtual Enterprise Computing
- Infrastructure to support MDA, PDM and RDE in a Virtual Enterprise
  - User Interaction & Collaboration
  - Distributed Object Infrastructure
- Emerging MDA Capabilities in support of Virtual Enterprise
  - Variational Design
  - Performance Analysis
  - Manufacturing Automation
- PDM Interface & Integration requirements
- Requirements Driven Engineering
  - Requirements and Knowledge Assisted Product Development Process



Virtual Enterprise Computing

- Collaborative Product Design and Manufacturing
- Distributed Organizations and Heterogeneous Platforms
- Enterprise Enabled Global Computing
- Supported by the Emerging Computing, Communication and Data Standards



Facilitate distributed team collaboration by leveraging emerging capabilities for MDA, PDM and RDE

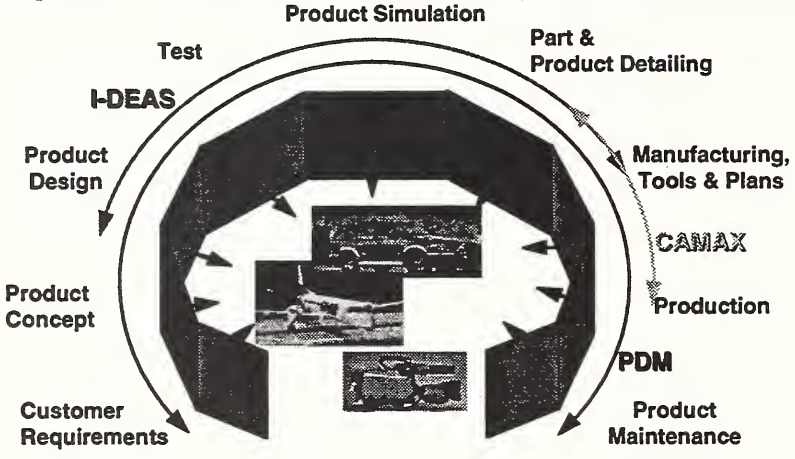
Collaboration & User Interaction

Assumptions

- Mechanical engineering problems will become increasingly more complex
  - Complex products
  - High "engineering content"
  - Complex processes
  - Increased concurrency in the development process
- At many companies Mechanical Product Development is an inherently collaborative activity
  - Large teams
  - Multiple disciplines
  - Multiple organizations
    - dispersed organizations
    - suppliers and independent contractors
- Future MDA/PDM/RDE systems will need to comprehend a larger portion of the Product Development Process

Collaboration & User Interaction

Integrated Concurrent Product Engineering and PDM

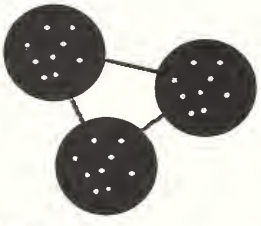


SDRC 5

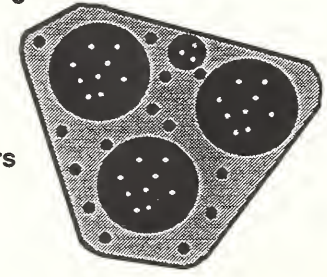
Collaboration & User Interaction

Collaboration

- Elements of collaboration
  - data sharing and control
  - coordination
  - communication of design intent
- Technology
  - multimedia conferencing
  - shared whiteboards
  - multimedia annotation
  - Web Browsers/HTML/ VRML/Java
  - Object Request Brokers (ORB)/CORBA
  - Data Standards/STEP



Today
Small, tightly knit teams within a single organization and computer installation with weak links between installations.



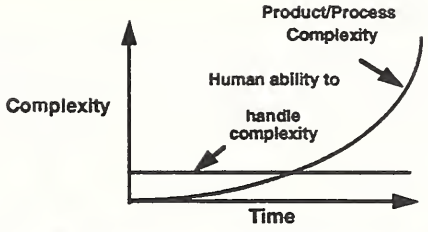
Future
Large, geographically dispersed teams with fluid organizational boundaries and a project-wide installation.

SDRC 6

Collaboration & User Interaction

Requirements

- Simple to Use
  - manage complexity
  - focus on the task at hand
  - levels of scope
- Scaleable
  - team size
  - problem size
  - organization size
  - user expertise
- Enterprise-Wide Integration
  - virtual enterprise
- Inherently Collaborative
  - global teams (space)
  - span product lifecycle (time)



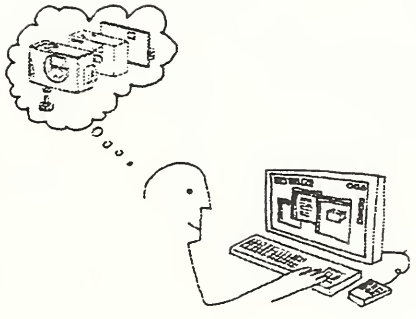
The fundamental problem we need to solve is that of allowing a user to be productive at a particular task while not losing sight of the entire product and process...

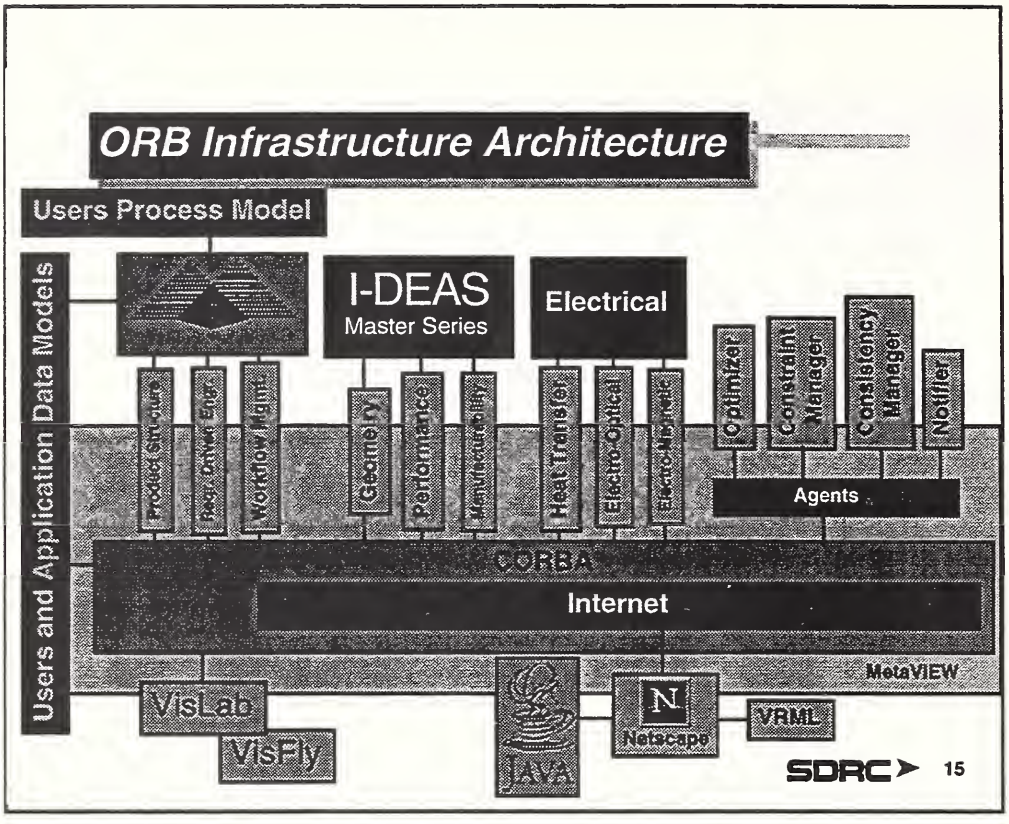
...this is inherently a problem of managing compexity.

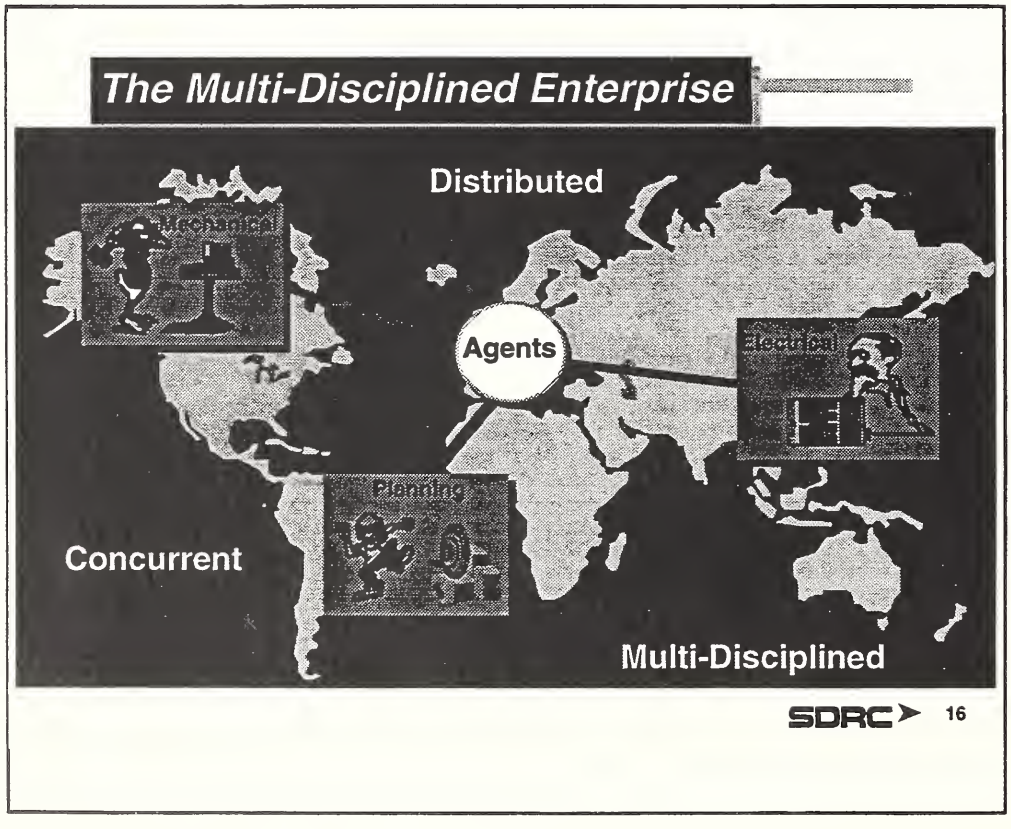
Collaboration & User Interaction

Task Centered

- Focus on user task, not application or computing mechanics
  - focus on data, not applications
  - tools and user interface should use concepts and terminology familiar to user
- Automate "housekeeping" tasks
  - management of data and files
  - analysis
  - execution of processes
  - tracking data and results




ORB Infrastructure Architecture
Users Process Model
Users and Application Data Models
I-DEAS
Master Series
Electrical
Optimizer
Constraint Manager
Consistency Manager
Notifier
Workflow Agent
Geometry
Performance
Heat Transfer
Electro-Optical
Agents
CORBA
Internet
MetaVIEW
VisLab
VisFly
JAVA
Netscape
VRML
SDRC 15

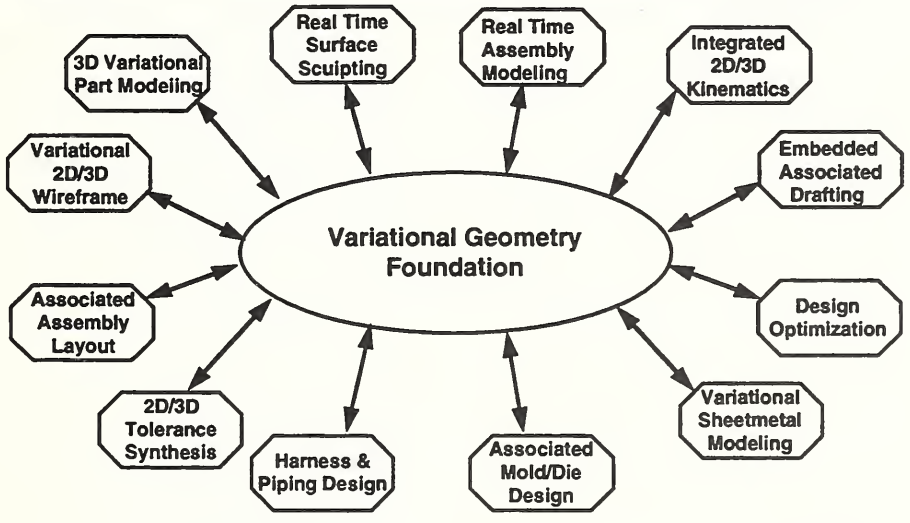

The Multi-Disciplined Enterprise
Distributed
Agents
Concurrent
Multi-Disciplined
SDRC 16

Directions in Mechanical Design Automation

- **Variational Design**
  - Integrated Variational Geometry (VG) Driven Applications
  - Drag and Drop Real Time Product Design versus Part Modeling
  - Real Time Physically Based Modeling, Surface Sculpting & Assembly
  - Fully Integrated 2D/3D Product Centric versus Part Centric Design
  - Multimedia Capture of Engineering and Geometric Design Intent
  - Leverage Feature Creation, Recognition, Mapping and Reasoning
  - Use of Intelligent Agents and Advisors
- **Embedded Transparent Performance Analysis**
  - Minimal User Interaction with Physical Analysis Abstractions
  - Additional Physics, Perspectives & Applications (physical, function,..)
  - Embedded Material Selection Guidance
- **Manufacturing Automation**
  - Automated Generative & Virtual Machining
  - Assembly/Disassembly analysis & planning
  - Leverage of DFMA, Cost Estimation, MRP & Quality Mgmt. systems
  - Network and PDM access to Suppliers, Catalogues and Process Data

3D Variational Design

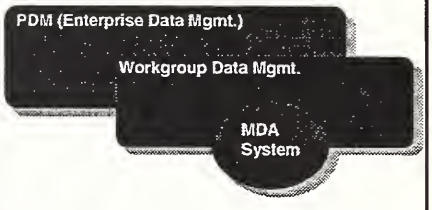
Integrated Variational Geometry Driven Applications



PDM Interface & Integration Reqr.

Requirements

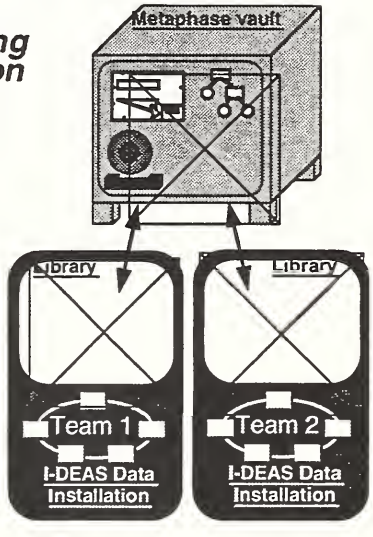
- Workgroup and PDM (Enterprise Data Mgmt.) systems need to work seamlessly together
  - product structure representation mappings
  - minimize discontinutities between Workgroup and Enterprise
  - overlapping capabilities should be minimized
- PDM systems need to provide control and access to enough data granularity to address requirements across the Virtual Enterprise
- PDM & Workgroup systems need closer integration to support the needs of the Virtual Enterprise from Product Requirements through Maintenance



PDM Interface & Integration Reqr.

The I-DEAS / MetaPhase Interface is an example of the emerging MDA & PDM integration

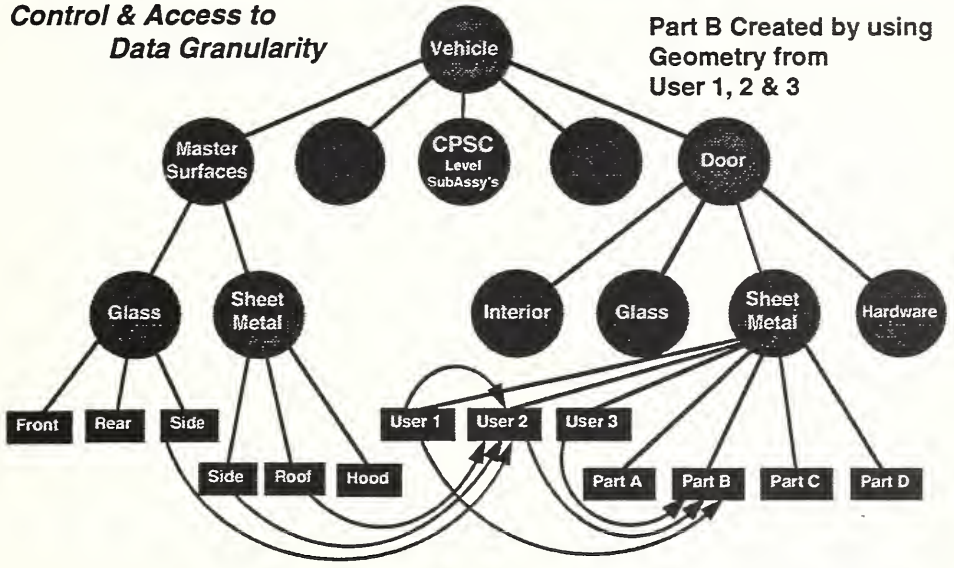
- I-DEAS library parts, assemblies, and drawings can be checked into Metaphase vaults
  - They appear as I-DEAS specfic data objects
- I-DEAS specfic data objects in Metaphase can be copied or checked out to selected I-DEAS libraries within an I-DEAS data installation
  - Facilitates sharing of I-DEAS data between installations
- The Metaphase concept of control is honored
- Once copied or checked out to an I-DEAS library, ownership rules remain enforced
  - If an object is copied from Metaphase into I-DEAS, I-DEAS will not allow modification of that data; in the case of check-out, I-DEAS will allow modification



PDM Interface & Integration Reqr.

Control & Access to Data Granularity

Part B Created by using Geometry from User 1, 2 & 3



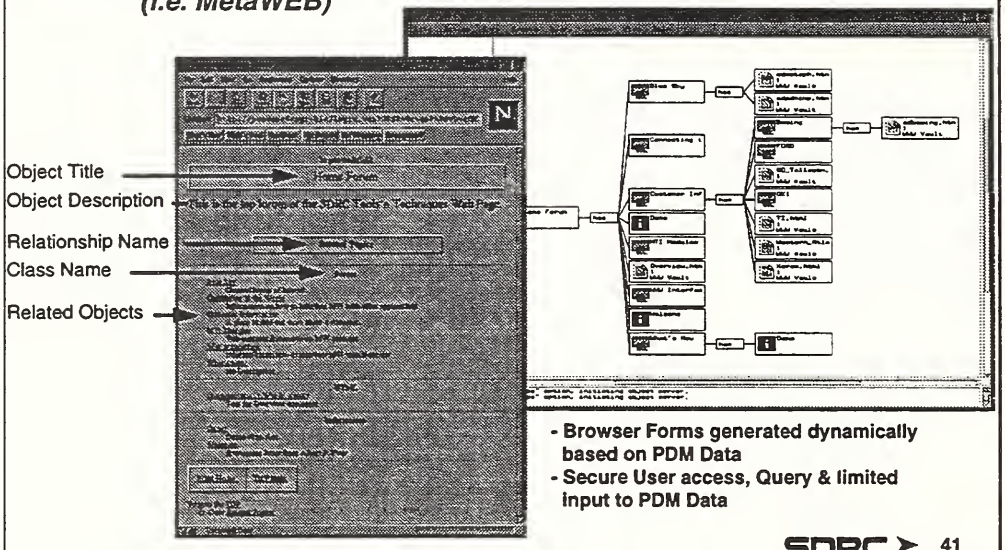
PDM Interface & Integration Reqr.

Requirements

- ➤ Support for the Virtual Enterprise product design process
  - enterprise-wide browser access to product data
  - simplify management of data and eliminate redundancies
  - transparent linkages to other business application data
    - marketing/business acquisition
    - manufacturing/production
    - support
  - workflow and life cycle management support
- ➤ Design for Variability
  - Mass Customization
  - Generic Part/Product definition
- ➤ Flexible Release Models
  - release at any stage
  - allow for ambiguity

PDM Interface & Integration Reqr.

Example of an emerging Internet Browser interface to PDM Data (i.e. MetaWEB)

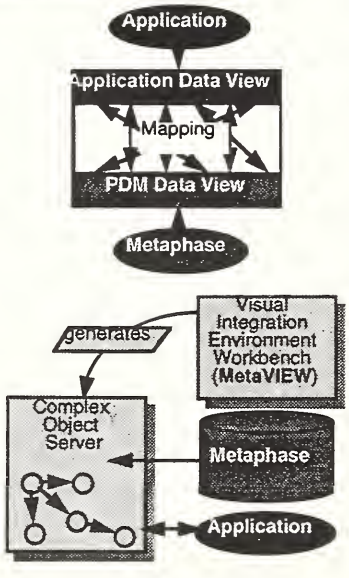


- **Browser Forms generated dynamically based on PDM Data**
- **Secure User access, Query & limited input to PDM Data**

PDM Interface & Integration Reqr.

MetaVIEW is an example of the emerging Application Integration Toolkits

- Integrates applications and their proprietary data storage mechanisms to external data storage systems like PDM that provide data control and versioning
  - Encapsulates the mapping of an application's view of the data to the PDM's view of the dta in an intermediate layer
  - Generates an "object server" for the application to use at runtime
- Assists applications in using data from multiple sources
  - Models "complex objects" which encapsulate the interfaces to the applications owning the objects present in the model
- Insulates applications from direct dependence on vendor specific API's for data access



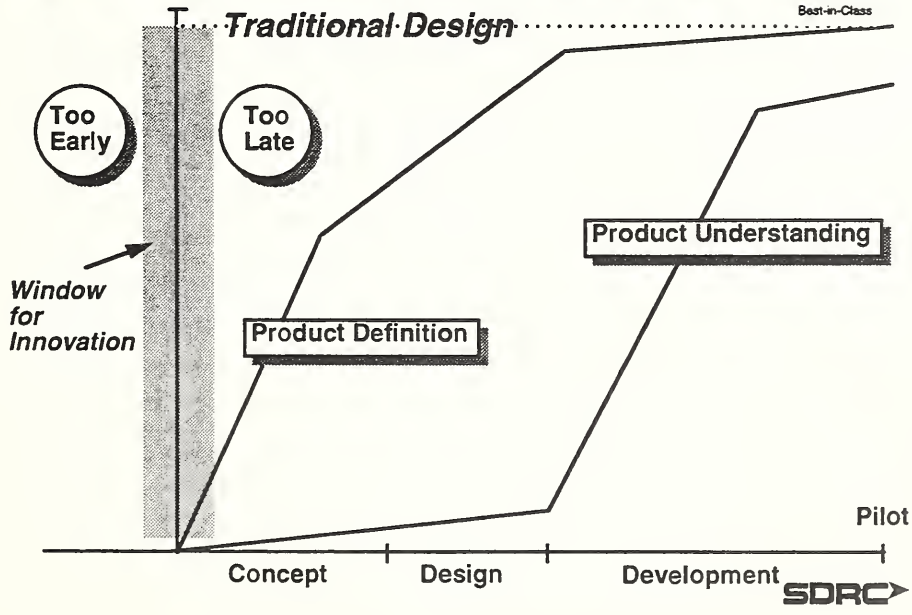
Requirements Driven Engineering

Requirements and Knowledge Assisted Product Development process

- **Structured processing of Voice of Customer (VoC) Requirements**
- **Early definition of Product Characteristics & Alteratives leveraged throughout the Product Life Cycle**
- **Tools for Decision Support Framework**
  - QFD, House of Quality & DOE Diagrams & Evaluators
  - Graphical view of Relationships & Specification Tracing
  - Relationship Manager for multiple trade-offs, knowledge capture, etc.
  - Structure, Layout, Function and Alternatives Diagrams & Tables
- **Specification Evaluators**
- **PDM Integration to track decisions, approval process & access data**
- **Process Knowledge leveraged for timely Change Propagation**
- **Simulation, test and field experience automatically leveraged in Corporate Memory/Knowledge Base for future products**

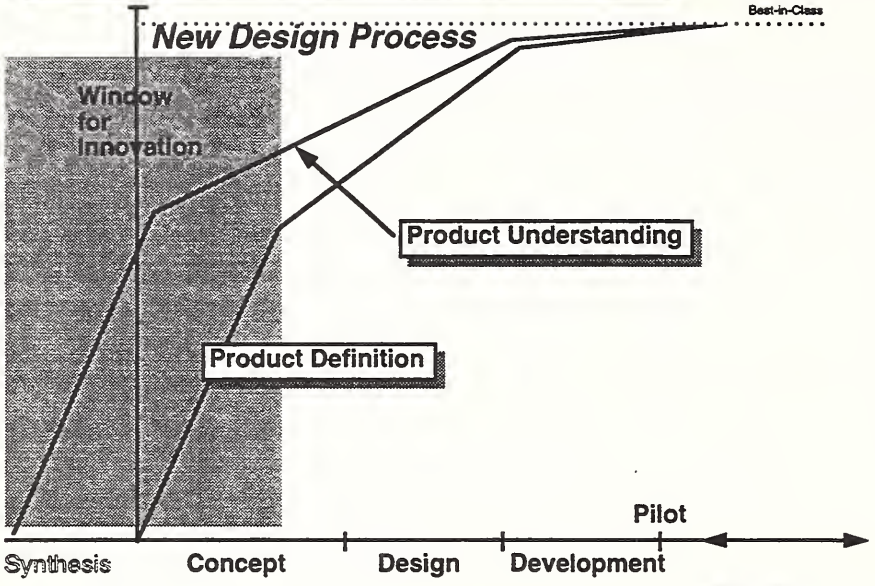
SDRC 47

Requirements Driven Engineering



SDRC 48

Requirements Driven Engineering



SDRC ➤ 49

Requirements Driven Engineering

Foundation of Requirements Driven Engineering is based on QFD Concepts

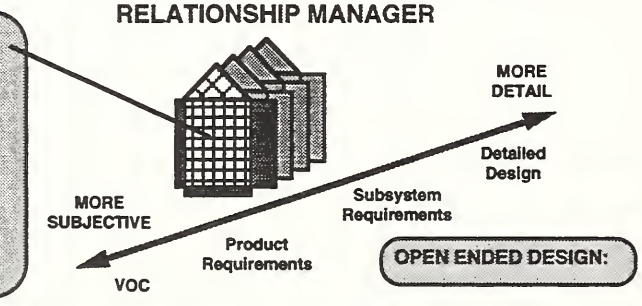
STRENGTHS:

INTERROGATE Relationships

- Deal With Multiple Issues
- Focus on Most Important Influences

Key Additional Information

- Competitors
- Objectives, Targets



OPEN ENDED DESIGN:

ENHANCEMENTS:

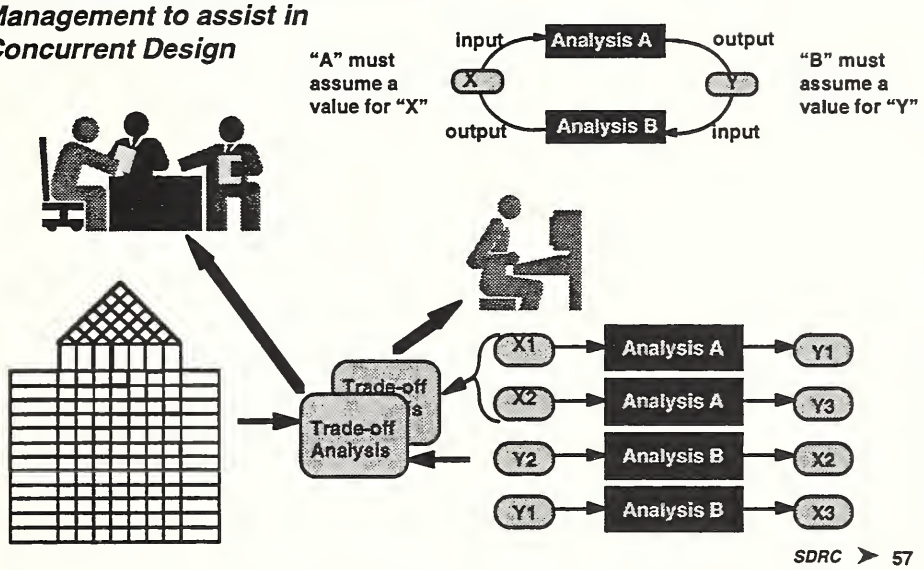
Practical Use Across Multiple Levels of QFD

- Uses Graphical Views of Relationships
- Allows Easy Navigation Through Various Levels

SDRC ➤ 50

Requirements Driven Engineering

Use of Agents and Workflow Management to assist in Concurrent Design



MDA, PDM & Reqr. Engr. in a Virtual Enterprise

Support for Virtual Enterprise Computing

- ➤ To support the Virtual Enterprise, User Interaction and Collaboration techniques in MDA, PDM & RDE systems will need to become more direct and intuitive and address a broader scope of interaction with People, Places, Products and Processes
- ➤ Industry standard Internets, Intranets and Object Request Brokers will allow vendors, third parties and multiple disciplines to work more harmoniously together to share resources and knowledge
- ➤ Variational Geometry will significantly enhance the ability to capture the Design Intent necessary to support the Virtual Enterprise
- ➤ Design Intent will be highly leveraged to enhance and help automate the highly structured portions of the Product Development Process
- ➤ PDM Systems will closely interface with RDE, MDA and Manufacturing systems to provide finer grained data, enhanced Design for Variability, Flexible Release Cyles and global Product Life Cycle access and support
- ➤ Requirements Driven Engineering will be computerized to leverage the Voice Of Customer requirements and Corporate Intellectual Capital across the Virtual Enterprise

Supply Chain Integration and the WWW

Dr. Joe Erkes, Director, Design Integration, GE Corporate R&D Center
(erkes@crd.ge.com)

The summary for this presentation can be found on page 30
12 full-page slides follow

Challenges for 21st Century Manufacturing Enterprises

January 9, 1997

Joe Erkes
GE Corporate R & D
(518) 387-5195
erkes@crd.ge.com

Business Realities of the '90s

The Challenge

Fierce, global competition

Accelerating pace of change

- Cost: *only the low cost manufacturers will survive*
- Speed to market: *must continuously cut product introduction time*
- Quality: *increasing expectations; significant impact on yields, energy, and cost*
- Shorter product cycles, smaller runs, many product variations: *must decouple historic cost-volume relationships*

Industry's Solution

Downsizing, partnering and expanded sourcing

The Problem

Now need to integrate design and mfg <u>across distributed enterprises</u> ("virtual companies")

Three "National Challenge" Problems...

Supply Chain Integration across the WWW

Because manufacturing is increasingly being outsourced

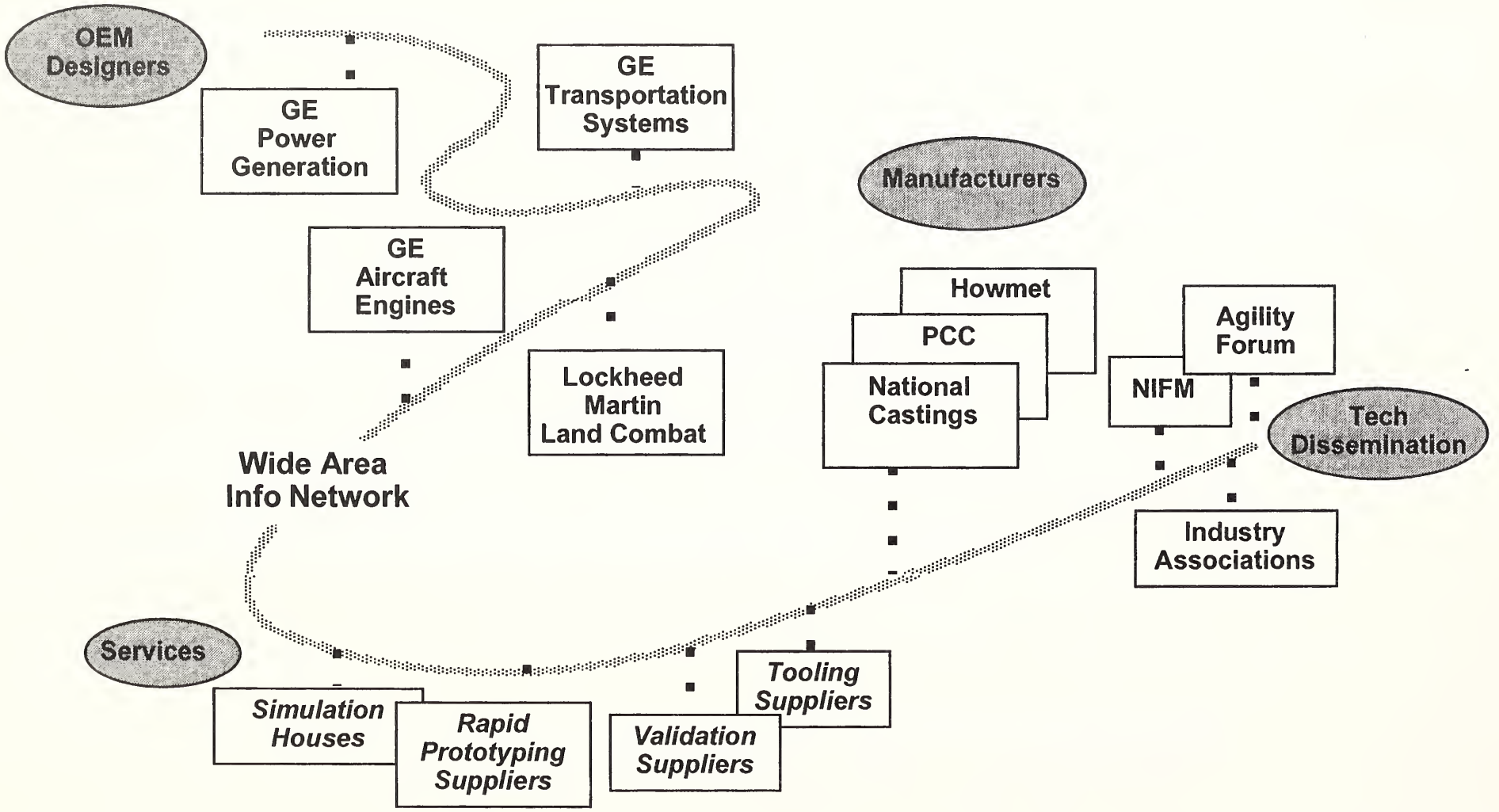
DFSS across multi-tier supply chains

Because there are large financial incentives

"Plug and Play" Supply Chain Infrastructure

Because the alternatives are too slow and costly

Supply Chain Integration across the WWW



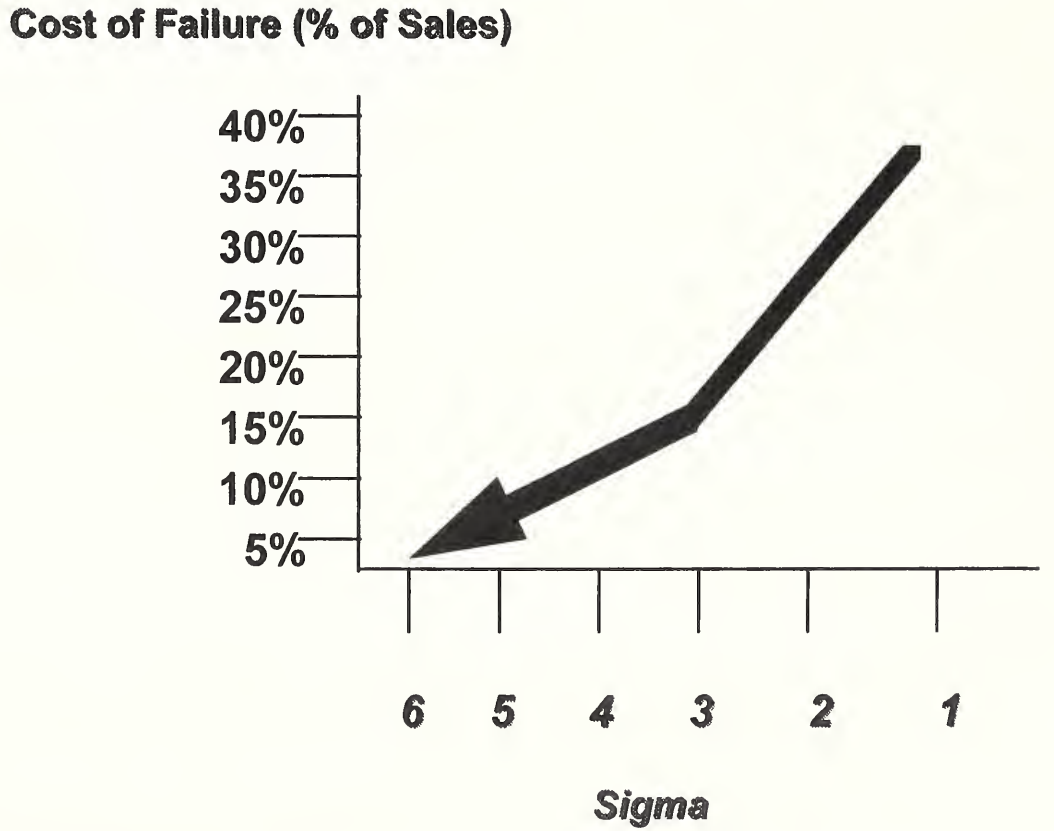
DFSS across multi-tier supply chains

Jack Welch's Challenge:

"GE will be a Six Sigma company by 2001"

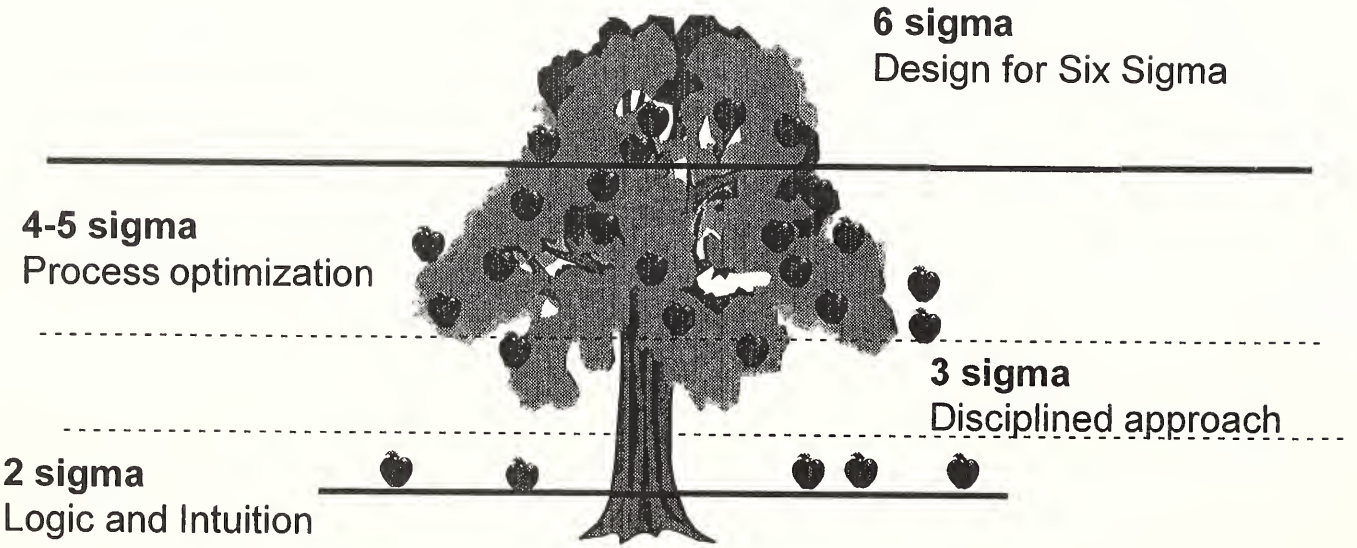
σ	PPM
6	3.4
5	233
4	6,210
3	66,807
2	308,537

Process Capability — Defects per Million Opportunities



The Quality Tree

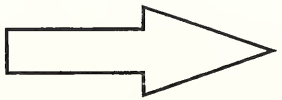
Discipline, process characterization and optimization will get you to 5 sigma.... to get to 6 sigma you need design for manufacturability.



Plug and Play Supply Chain Infrastructure

Today's environment:

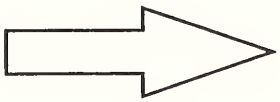
- "captive" supply chains
- proprietary exchange standards
- costly to set up
- dominated by the first tier suppliers
- hard to change suppliers



"balkanized supply chains"

Tomorrow's environment

- agile creation or dissolution
- cheap and easy infrastructure
- participation by the entire multi-tier chain



"agile web-based teaming"

DARPA Agile Manufacturing Pilot: "Agile Development of Castings"

Objective: *"Leverage NII integration technologies to streamline and demonstrate amongst a multi-tier supplier chain a dramatically improved sand-mold castings acquisition process for both military and commercial applications"*.

Goals:

- –Integrate a virtual castings enterprise across the NII
- –Eliminate key technology barriers
- –Streamline virtual business practices
- –Proliferate the solution across the supplier chain

Bottom-line Metrics:

- – Cut castings acquisition cycle from 26 weeks to 2-4 weeks
- – Respond to a design change in one week

DARPA

Major Project Thrusts

Rapid Communication

Networked (internal and external electronic networks including the internet)

Accessible (PC, Workstations, Office, on the road, global)

Easy (Icons. Buttons, Forms, Hyper Text, Tranparent functions, help)

"SCI -in-a-box"

Exchange of Rich Information

Isolate design intent

Define what is producible and what is not

Prepare well and early for manufacturing

Validate against design intent

New Business Practices

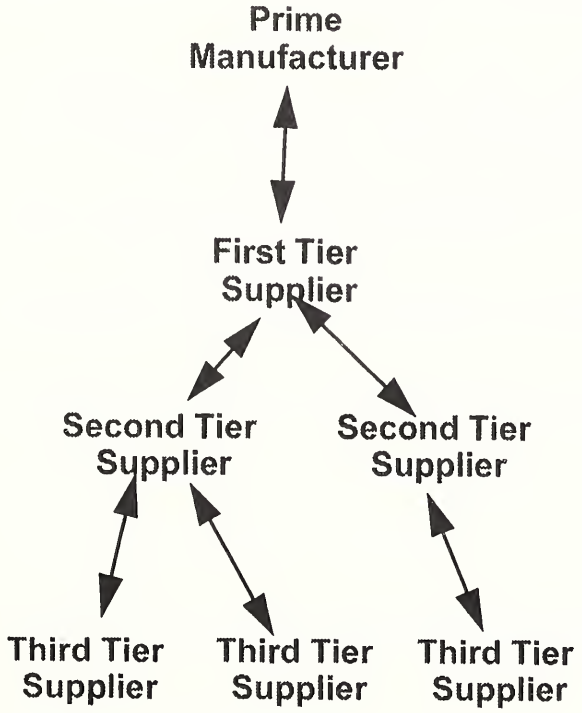
Robust process that is repeatable even if suppliers change

Supplier chain integration with information flow to deepest tier

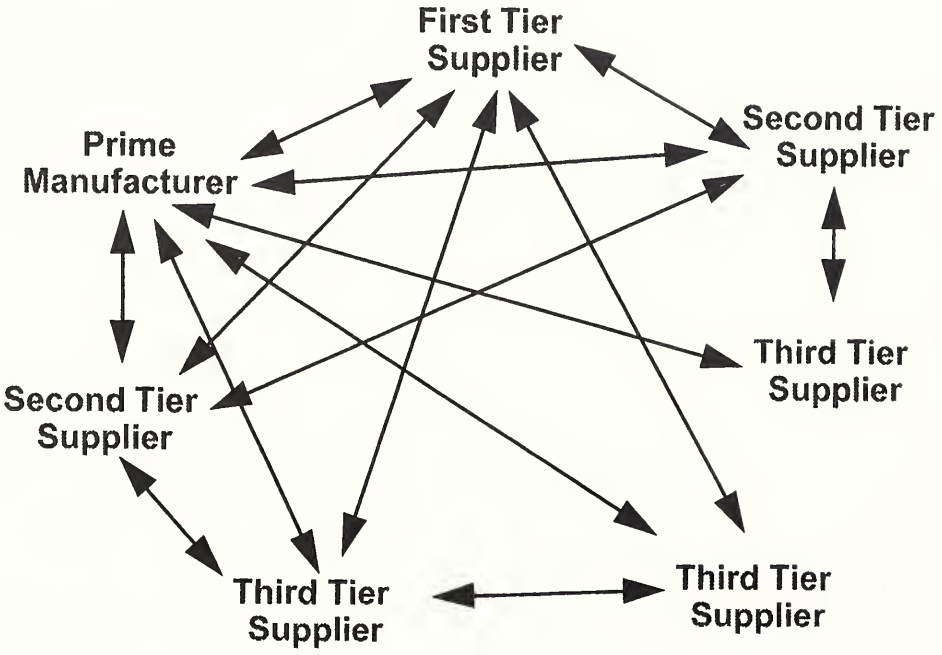
Distributed work among suppliers

Integrated product and process development (simultaneous development of detailed product design and manufacturing instructions

Integrated Multi-Tier Global Supplier Chain



hierarchical team
limited communication
"up the chain"



flat team
parallel access

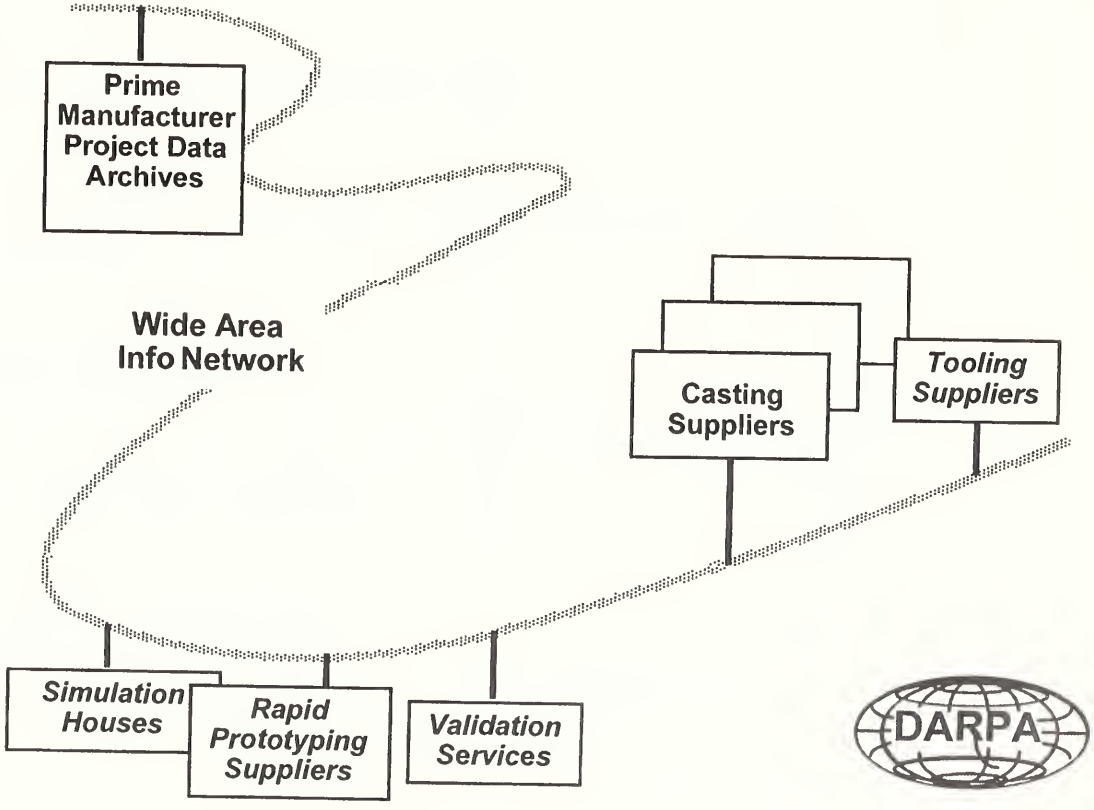
Up to 80% cycle time reduction due to:

- Electronic communications
- Exchange of "rich" information
- Applying new business practices

DARPA

Central Project Archive

- Shared model and document archive
- Easy access to remote partners via Net Browser
- Push-button downloads
- Configuration control and security
- Automatic notification for ECOs
- Shared viewing of models
- Network access to relevant tools



Three "National Challenge" Problems ... Key Issues

- Supply Chain Integration across the WWW
  - Design iteration cycles comparable with "in-house", which are...
  - Low cost, easy to use, ubiquitous
- DFSS across multi-tier supply chains
  - Faithfully flow back producibility and life-cycle issues, data and constraints...
  - In the context and language of the participants...
  - While protecting proprietary data
- "Plug and Play" Supply Chain Infrastructure
  - "New " suppliers up and running overnight, using...
  - Common approaches, tools, exchange standards, data formats, etc.

Report-Back Panel: Group 1

Presented by Ms. Kathleen McKinney (mckinney@cive2.stanford.edu)

The summary for this presentation can be found on page 40
2 full-page slides* follow

* Original slides were handwritten and have been retyped.

Motivation

- Business - faster, better, cheaper
- People are distributed
- Coordination
- Interaction
  - Feedback
- Communicate design intent

Standards

- Layered interface standards
  - Communication
  - Data
- Annotation standards
- Query standards
- Catalog standards
- Views/abstractions
- Multiple representations

Technology Demonstration Session: University of California, Berkeley

Mr. Charles Smith, University of California, Berkeley
(smythe@kingkong.me.berkeley.edu)

The summary for this presentation can be found on page 43
12 full-page slides follow

CyberCut:

Distributed Design & Manufacturing on the Internet

Present to the

Network-Centric CAD Workshop

by

Chuck Smith

http://kingkong.me.berkeley.edu/cybercut/

U.C. Berkeley Integrated Manufacturing Lab

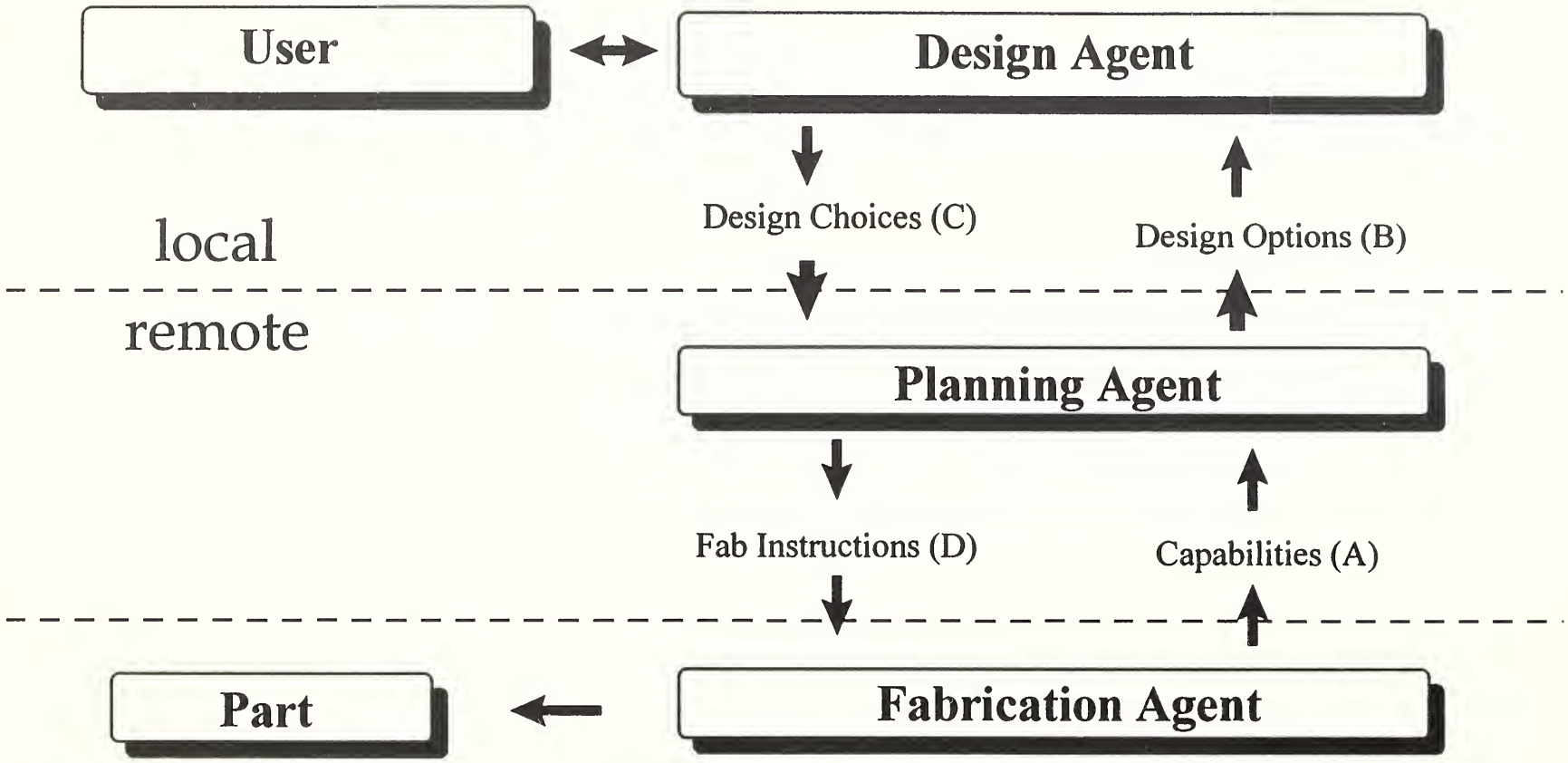
The Cybercut Approach

- Divide part creation in three parts
  - CAD, CAPP, CAM
- Create separate agents addressing each facet
- Make software readily available
  - WWW for distribution
  - Java for cross platform / interactivity

Agent Specs

- CAD Agent
  - GUI that presents user with design options, and displays the choices made so far.
- CAPP Agent
  - Accept raw part geometry and generate fabrication instructions. Possibly negotiate the feasibility with the designer.
- CAM Agent
  - Follow instruction set to generate a physical part. Possibly archive data or adapt fabrication instructions.

Architecture



Benefits / Drawbacks

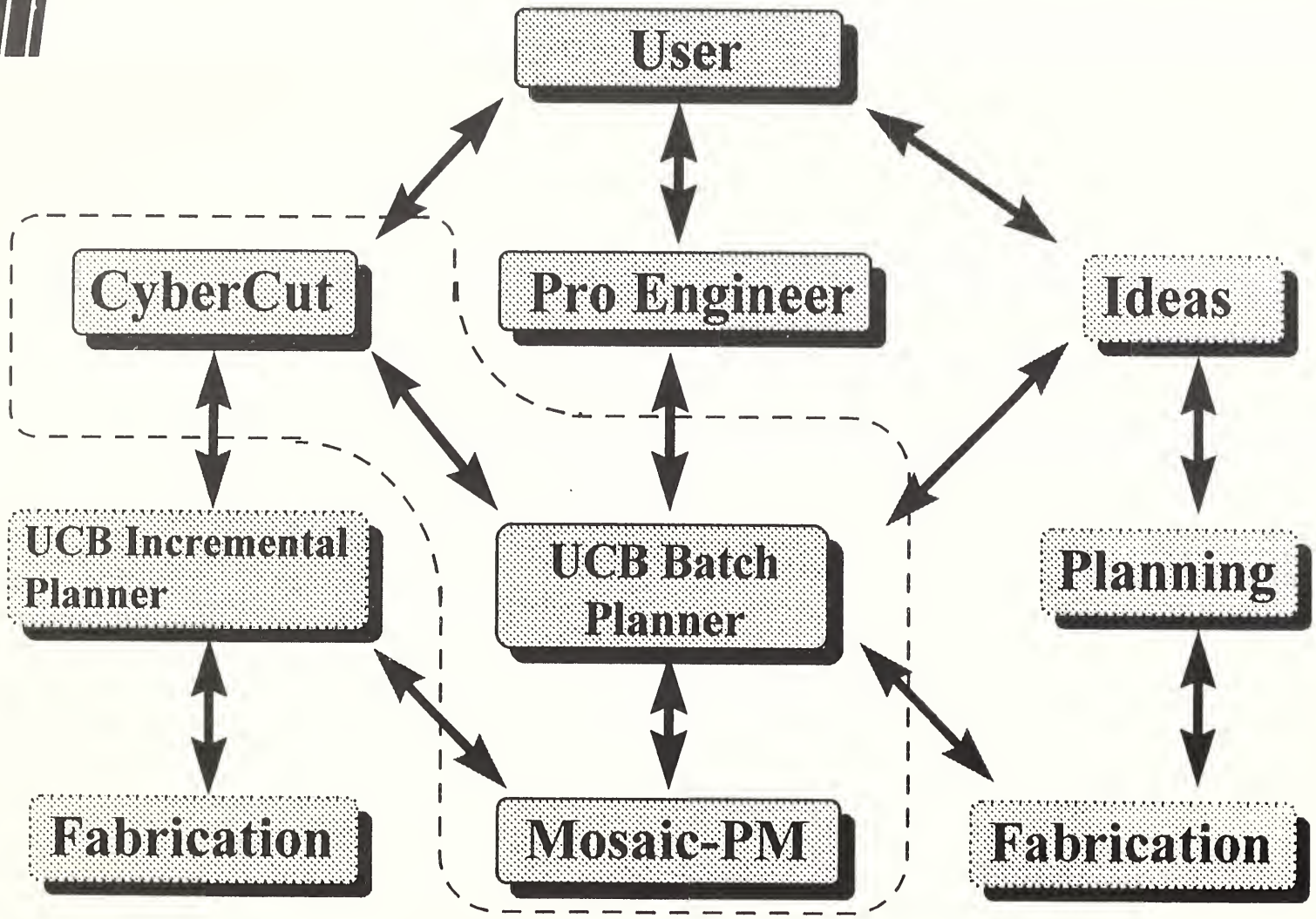
- Benefits
  - Still reduce cycle times
  - Hardware & software simplified
  - Cross platform
  - Easy access
- Drawbacks
  - Legacy (oops)

The Network Solution

- Multiple agents at each level of the design to fabrication process
- "Pick and choose"
- Open Infrastructure
  - Java Agent Template
  - KQML

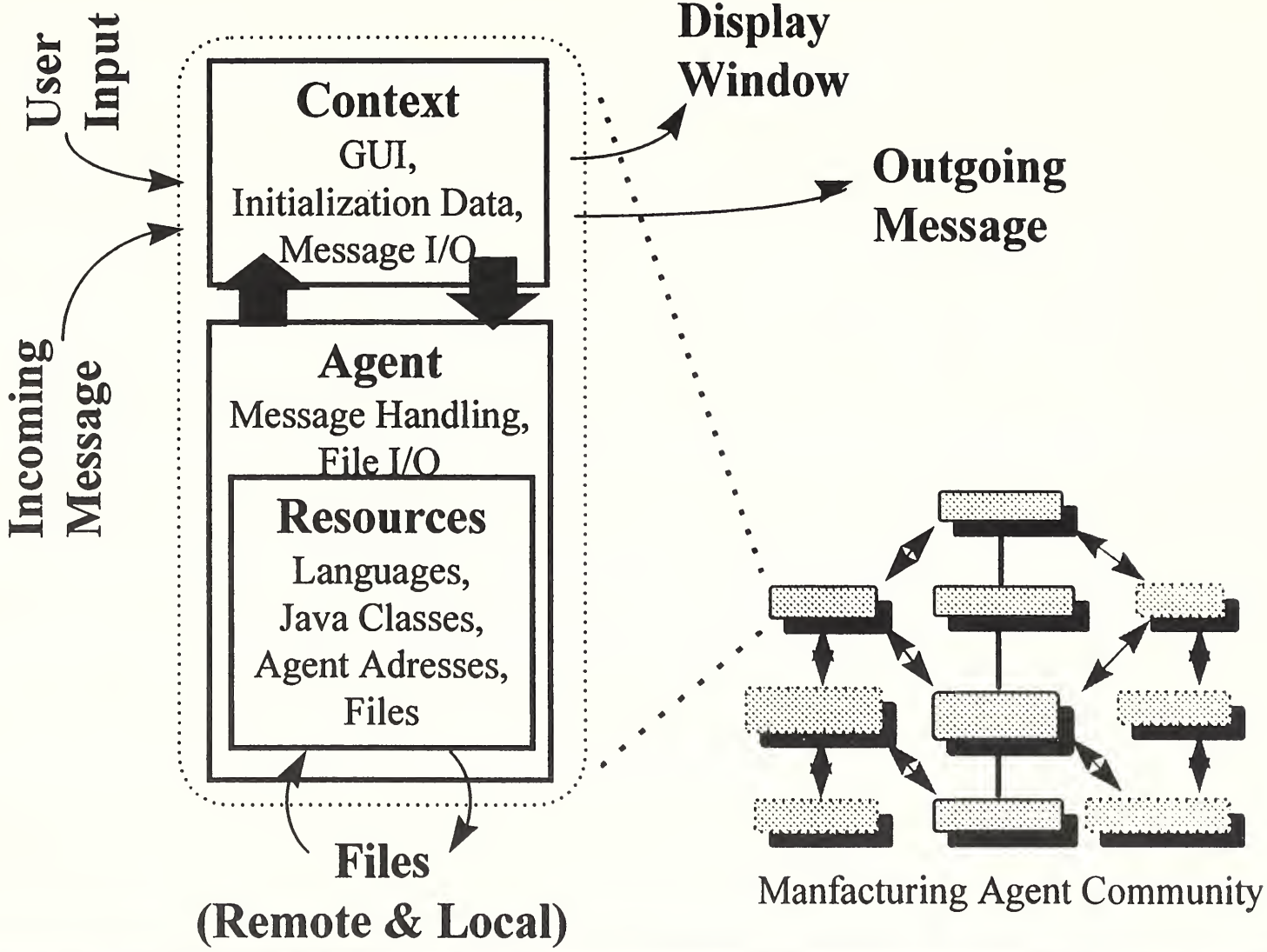
Interoperable Network Agents

- Design
  - Choose from a variety of interfaces
  - WebCAD Java based, configurable UI
  - Commercial CAD add-ons
- Process Planning
  - Multiple processes
  - Various planning methods (incremental, batch)
- Fabrication
  - Multiple methods (STL, CNC Milling)
  - Different sites



Manufacturing Agent Community

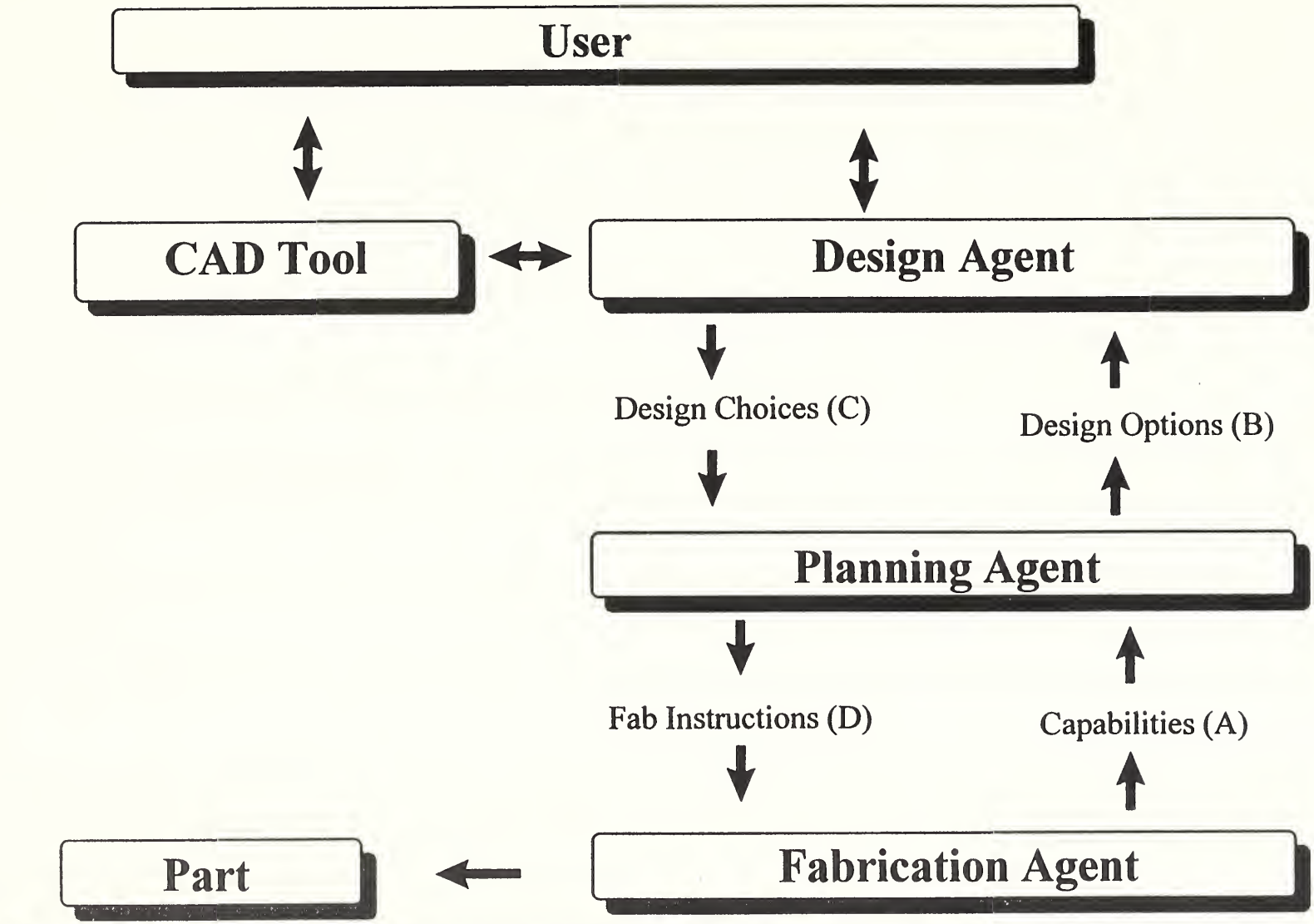
JAT Structure



Design Consultants

- Attack the legacy problem
- An agent running parallel to commercial CAD (ProE, AutoCAD)
- Depends on use of developer's software (ProDevelop, ARX)

Design Consultants



The Future

- Strategic alliance for design consultants
  - AutoDesk / Parametric Design /SDRC
  - Provide added benefit of CAD > CAM
  - Get one, the others will follow
  - Bring in outside expertise

Einstein Objects: An Open Standard for Web-Enabled Distributed Design and Simulation of Electro-Mechanical Products

Dr. Rick Palmer, Beam Technologies (rick@beamtech.com)

The summary for this presentation can be found on page 46
20 full-page slides follow

Einstein Objects: An Open Standard for Web-Enabled Distributed Design and Simulation of Electro-Mechanical Products

Rick Palmer
Vice President, Software R&D
Beam Technologies, Inc.

Outline

- The *Einstein Suite*: A web-enabled engineering environment for composable, scalable, multi-level, multi-discipline product representation language and environment that supports "**simulation on demand"**
  - Overview of *Einstein Suite* software components
  - Description of *Einstein Suite* concepts
- Advancing Net-centric CAD
  - Criteria for success
  - The *Einstein Objects* representation language as an open standard

Beam Technologies' *Einstein Suite* Project

- Part of DARPA **RaDEO** (formerly MADE) program
  - Kevin Lyons, Program Director
  - Richard Palmer, PI
  - Beam is teamed with Lockheed-Martin
- Contract includes *Einstein Suite* redesign of C-141 Aileron actuator system -- real-world electro-mechanical-hydraulic system -- representative of many DoD upgrade programs
  - Redesign already completed using traditional methods -- will provide effectiveness metric
- Work described and demonstrated today has been performed in first 6 months of three year contract

DARPA

Technology Gaps Addressed

- Currently no unified computer representation for electro-mechanical products that
  - represents geometry, materials, physics, design process , and analysis
  - enables:
    - Assembly of electro-mechanical component models
    - No-additional-cost construction of simulation and analysis tools for predicting behavior
- Currently no design capture language/system
- Currently no Web-based software architecture using above technology

Opportunity -- achieving the potential of automated simulation

- Simulation can reduce product design and development cycle time by at least 10-100 times by:
  - Reducing the need to construct physical models
  - Allowing designs to be evaluated and refined or discarded more quickly
  - Providing a base for automated optimization of geometry and other design parameters
- Currently simulation is too costly and time consuming
  - too much manual reformatting
  - models not *composable* -- current simulation models can not be "clicked together" to create simulation models of assemblies

The *Einstein Suite*: a WWW-based engineering environment

- ***Einstein Objects*** -- Composable, scalable objects to represent electro-mechanical systems
  - Automatic generation of analysis and simulation from ***Einstein Objects*** with minimal additional time or cost. (***Einstein Objects*** contain multi-level, multi-discipline math models that represent their behavior)
  - Distributed collaboration via communication of design components via Internet (WWW)
- Impact: Order of magnitude improvement in ***cost, time and quality*** of designing electro-mechanical systems
  - Integrate engineering models into system level simulation (e.g., battlefield simulation)

The Einstein Suite

- ***Einstein Objects*** -- Composable encapsulation of mathematically described objects (e.g., physical properties of electro-mechanical products) -- simulators ***automatically constructed on demand***
- ***PDESolve*** -- Software environment for rapid construction of Partial Differential Equation simulators
- ***HybridSolve*** -- Large scale distributed simulation of hybrid ODE/DAE systems (e.g., battlefield scenarios, rigid bodies, active controllers)
- ***WebVis*** -- Web-based visualization environment for engineering and scientific computing
- ***PowerMath*** -- Parallel HPC implementation of Einstein Objects and PDESolve computational substrate

Einstein Suite Applications Driver: C141 Electro Mechanical Aileron Actuator

- Replace existing hydraulic system for aileron actuation with an electro-mechanical system.
- Increase reliability, reduce maintenance, increase performance.
- Lockheed is a subcontractor to Beam as part of this contract.
- Design of the C141 electro mechanical aileron actuation system will be carried out in the Einstein Suite environment.
- This is a real world program which Lockheed is performing for the Air Force.
- Representative of **many upgrade requirements** the DoD is faced with.

Einstein Objects

- An ***Einstein Object*** is a "syntactic form" that characterizes a electro-mechanical product -- can be saved and communicated via Internet.
  - Geometry, assembly structure, materials, control algorithms, physics models
- Simulation and analysis modules defined by coupled math and engineering models:
  - Partial Differential Equations (PDEs)
  - Ordinary Differential Equations (ODEs)
  - Differential-Algebraic Equations (DAEs)
  - Discrete events (HODEs, HPDEs)
  - Combinations of above

Einstein Objects Concepts

- ***Primitive*** -- an ***Einstein Object*** that is a basic building block in a design -- typically contains shape, material properties, interaction ports
- ***Assembly*** -- An ***Einstein Object*** assembled from other Einstein Objects
- ***Port*** -- "publishes" an Einstein Object's state variables for use in interactions
- ***Interaction*** -- an object that represents interaction between ***Interaction Ports*** defined on two ***Einstein Objects***, e.g., contact, hinges
- ***Physics meta-model*** -- contains equations and rules for constructing a simulator for an ***Einstein Object*** Examples: Heat transfer, elasticity, kinematics

Einstein Objects Concepts

Physics Meta-model

Heat

Elasticity

Geometry

Solid

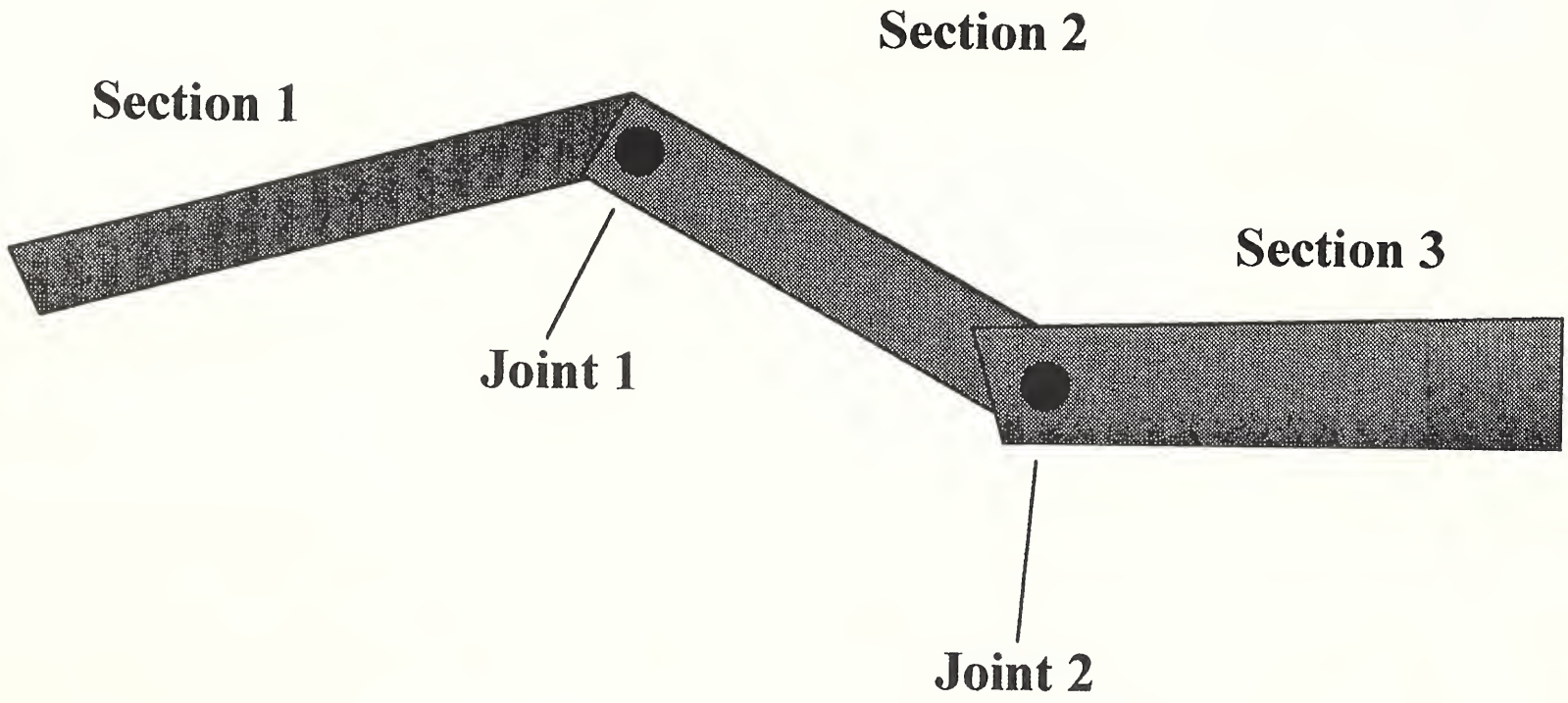
Math Models

Finite Difference
Linearization
ODE Integration
DAE Integration
Finite Elements
Spectral Methods
Control Models

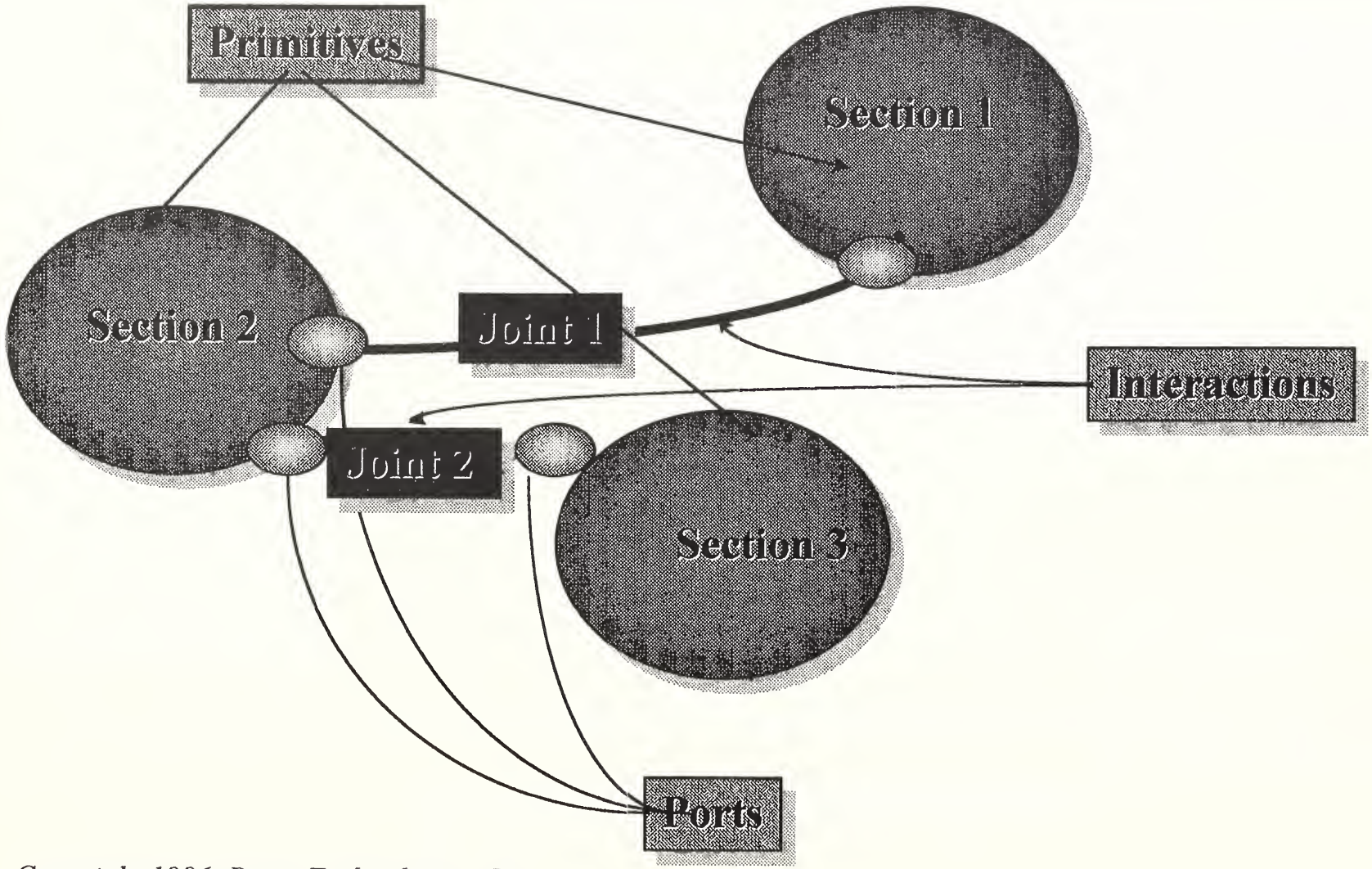
Material Models

- Meta-models
- Models
- Ports
- Math Methods

Example: Robot Arm



Example: Robot Arm



PDESolve

- A C++ Class library
- Simulators specified directly in terms of Partial Differential Equations
  - PDESolve apps easy to create, debug, modify and understand
  - resulting cost and time savings
  - PDESolve simulators typically 1/100th the size of equivalent FORTRAN or C++
- Finite Difference (Soon: FEM, Spectral)
- VRML, Java, Matlab interfaces

PDESolve Example

```
Domain domain0 = Domain(0, bx1)* Domain(0, by1)* Domain(0, bz1);
Domain domain1 = Domain(bl2x, bx2+bl2x) * Domain(bl2y, by2+bl2y)
  * Domain(bl2z, bz2+bl2z);
Grid grid0(domain0, FDGrid(int(grid1x))
                * FDGrid(int(grid1x))
                * FDGrid(int(grid1x)));
Grid grid1(domain1, FDGrid(int(grid2x))
                * FDGrid(int(grid2x))
                * FDGrid(int(grid2x)));
Function u0(2);
Function u1(2);
BC bc0 =
  BC(dx*u0, dx*u0) *
  BC(2*dy*u0, 2*dy*u0) *
  BC(1000*u0, WhenContact(100*dz*u0 && 1000*u0, 3*dz*u0));
BC bc1 =
  BC(dx*u1, dx*u1) *
  BC(2*dy*u1, 2*dy*u1)  *
  BC(WhenContact(dz*u1 && u1, 3*dz*u1), u1-100);
```

WebVis

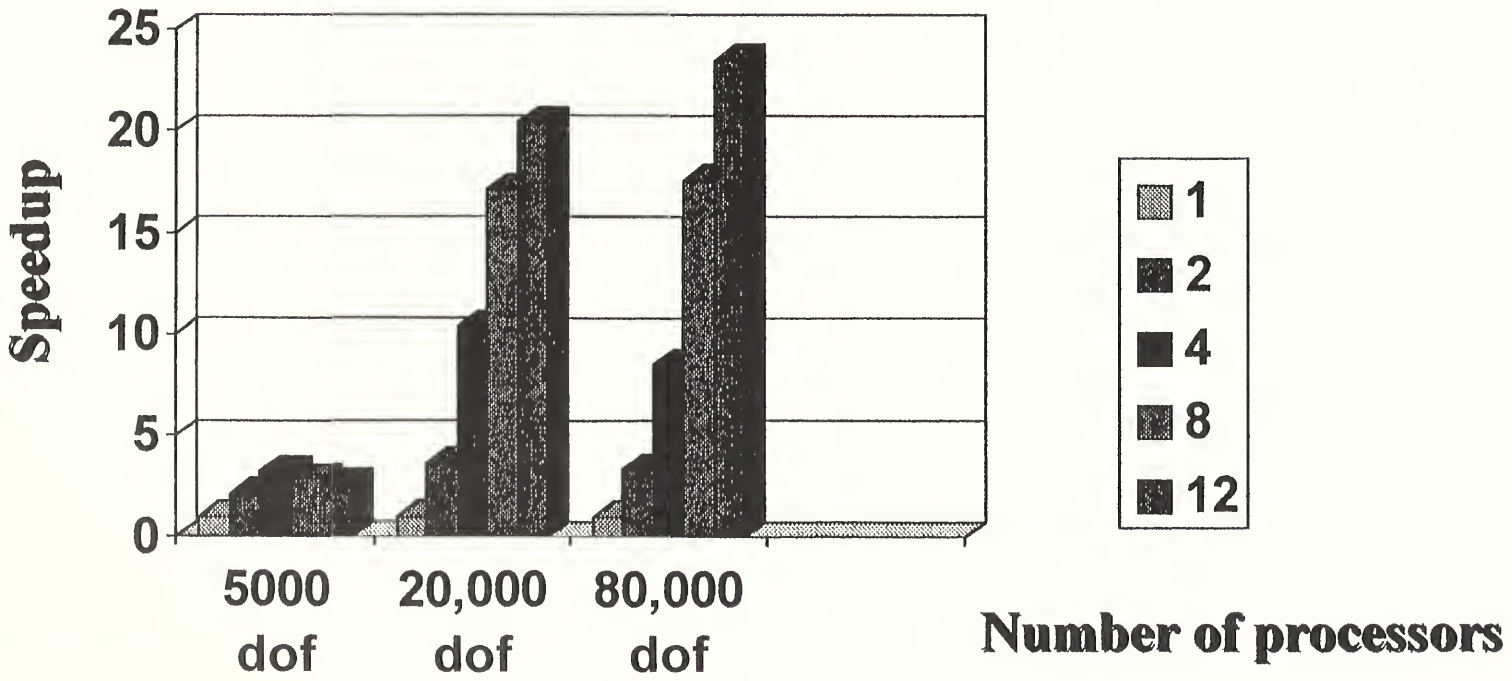
- VRML/Java/C++ based visualization tool
- Visualize using standard Web tools, e.g., Cosmo Viewer, Netscape, etc.
- Interactively define, visualize, solve, and explore solutions to Einstein Objects designs
- Import/Export standard formats, e.g., draw3D

PowerMath

- HPC Compute Engine for PDESolve, ***Einstein Objects***
- PDESolve programs and Einstein Objects ***execute unchanged*** on SP2, NoW (Network of Workstations), etc.
- Standards-based implementation: MPI, PETSc -- maximizes portability, performance
- Provides top end of a suite of computation solutions for ***Einstein Objects*** -- PC for early design, Workstations for intermediate analysis (e.g., structural) , and HPC for highly compute-intensive (e.g., coupled 3D fluids/structures)

PowerMath Timing Results

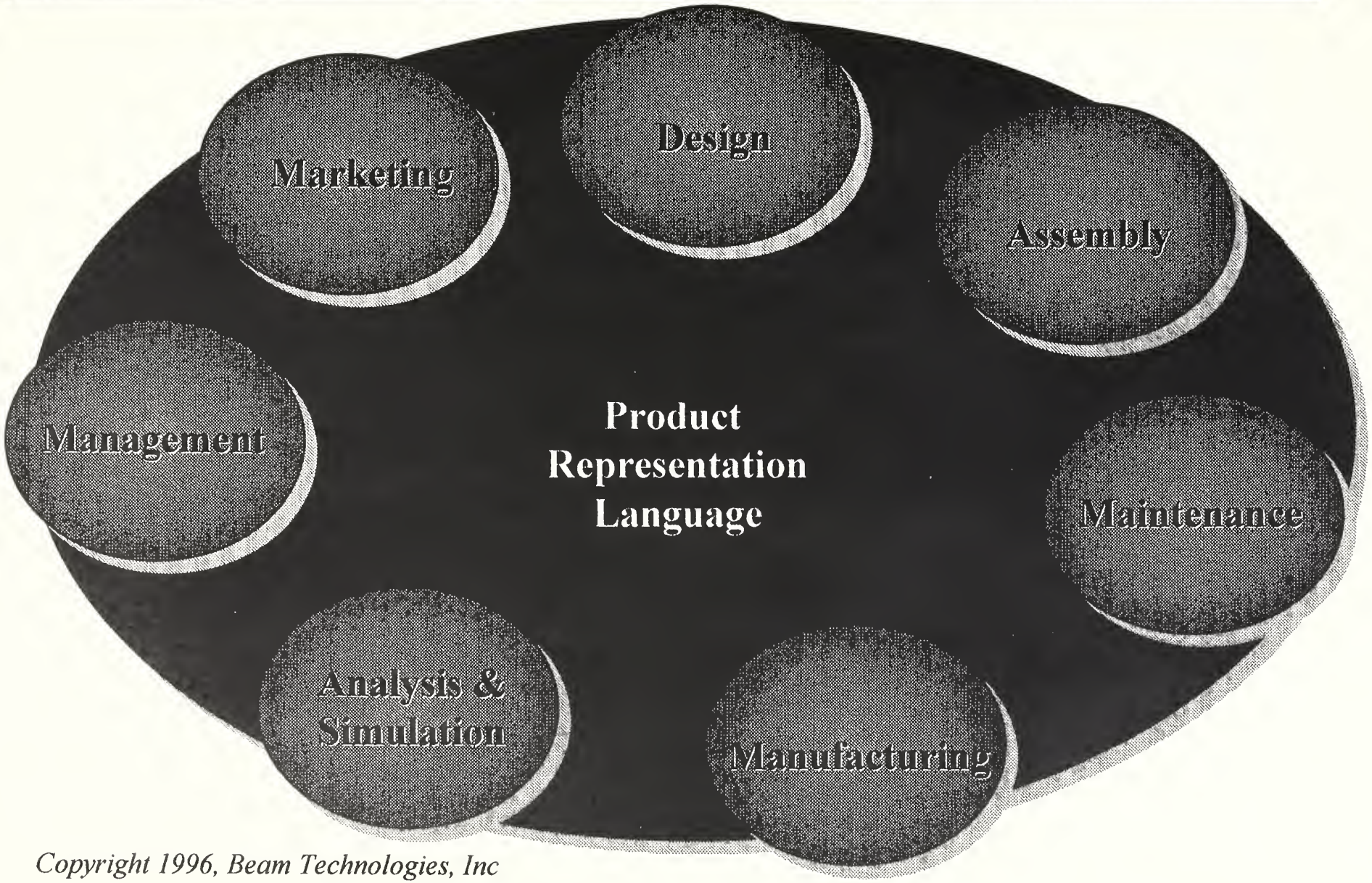
- IBM SP2 (CTC)
- 3D Elliptic Partial Differential Equation
- Speed up (wall clock time, averaged)



Outline

- **Advancing Net-centric CAD**
  - **Criteria for success**
  - **The *Einstein Objects* representation language as an open standard**

Product Representation Users



Changing Priorities of Research on WWW-Based Engineering Services

Dr. Michael Terk, Rice University (terk@rice.edu)

The summary for this presentation can be found on page 49
17 full-page slides follow

Changing Priorities of Research on WWW-Based Engineering Services

by
Michael Terk
Department of Civil Engineering
Rice University and
Engineering Design Research Center
Carnegie Mellon University

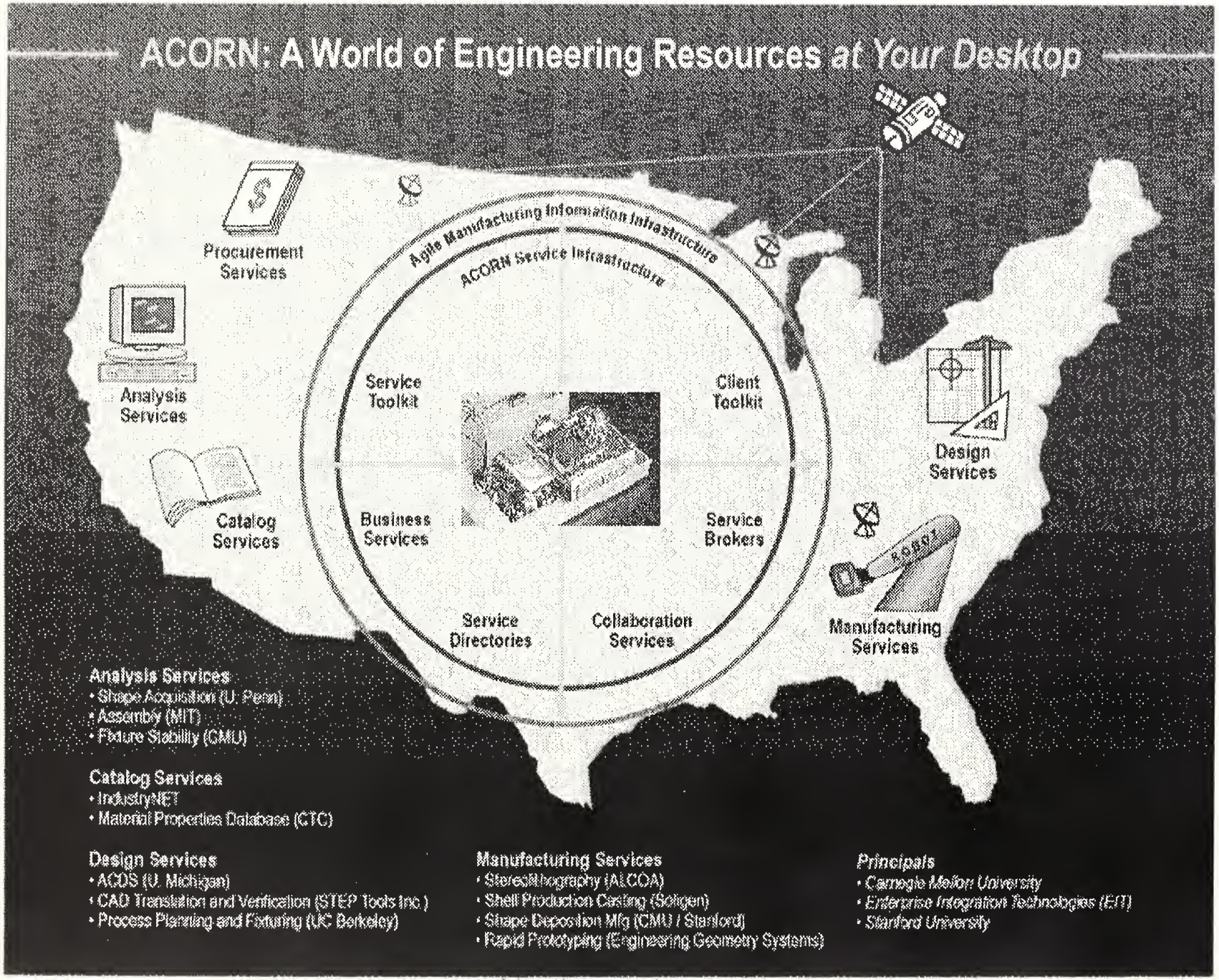
ACORN Phase I

- Started in 1993
- Sponsored by DARPA as part of the AMII
- Lead
  - CMU and EIT
- Activities
  - Build services designed to take advantage of the Internet
  - Evaluate service performance in product development scenarios
  - Identify technology gaps and build tools to fill them (when appropriate)

http://acorn.eit.com

ACORN Goals

- Develop a Critical Mass of University and Commercial Services
- Conduct Research on Network-Based Collaborative Design and Manufacturing
- Develop Scenario-Based Prototypes and Demonstrations
- Encourage Design and Manufacturing Community



http://acorn.eit.com

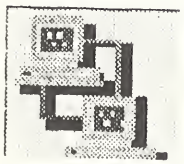
Service Development

- Cover a Range of Service Types
  - Design, Analysis, Manufacturing & Purchasing
- Cover a Range of Interaction Types
  - Batch, Pre- and Post-Processing, Interactive

SLA service (CMU & ALCOA)

Electronic Design Service (U. Michigan)

Shape Acquisition (UPenn)



Assembly Analysis (MIT)

http://acorn.eit.com

Batch Service Development

- Batch Service
  - Small amount of information required
  - Standard representation
- ALCOA SLA Service
  - Encapsulates a commercial operation
  - Provides a mechanism for RFQ and orders
  - Ability to track activities remotely

File Edit View Go Bookmarks Options Directory Window Help

ALCOA

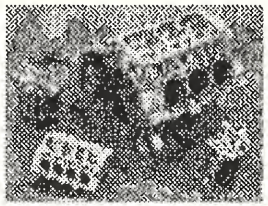
SLA Service Forms

Request an estimate
View an estimate
Order a part

Rapid Prototyping and Rapid Tooling

ALCOA Technical Center

Stereolithography



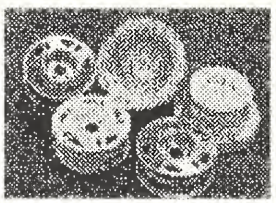
Concept Models for

- Marketing
- Design Review
- Manufacturing Review
- Request for Quotes

Patterns for Silicone Rubber Tools and Casting Core Boxes
'Lost' Parts for Investment Casting
Direct Tooling - low volume, fast turn-around, tooling

More infomation on stereolithography...

Sprayed Metal Deposition



Rapid Manufacture of Tooling and Tooling Inserts

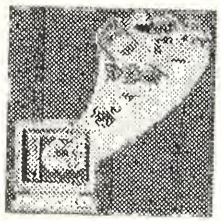
- zinc and kirksite tooling
- copper tooling
- steel tooling

Batch Services Over the WWW

- Client Benefits
  - Better access to the service
  - Improved ability to track activities
- Provider Benefits
  - Wide service availability
  - Ability to provide detailed description of the service
  - Reduce order processing time

ACORN Phase II

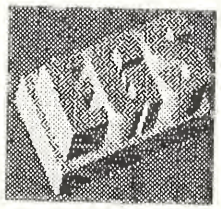
- Started in 1995



Soligen

IndustryNet

IndustryNet

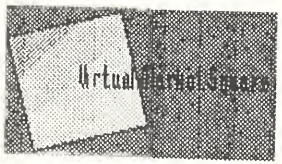


Engineering Geometry Systems

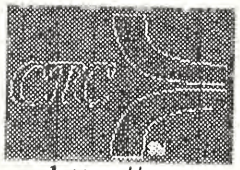
CYBER CUT

UC Berkeley

STEP Tools



CMU

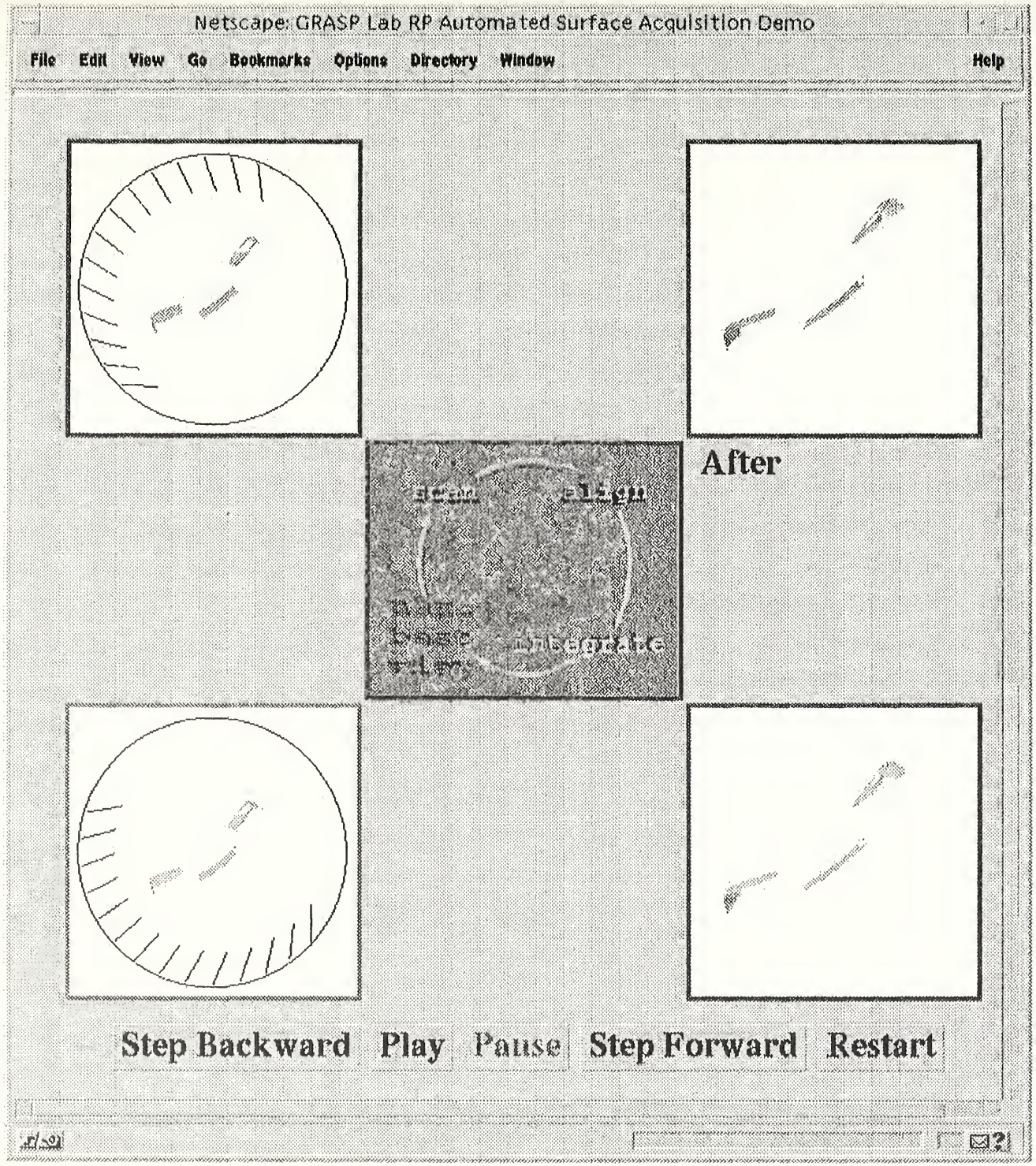


Concurrent Technologies Corp

http://acorn.eit.com

Pre- and Post- Processing Services

- Pre- and Post-Processing Services
  - Not all information can be communicated
  - Some level of feedback
- Shape Acquisition Service (U.Penn)
  - Ability to interactively refine the problem statement
- Benefits
  - Reduced communication problems
  - Reduced cost


Netscape: GRASP Lab RP Automated Surface Acquisition Demo
File Edit View Go Bookmarks Options Directory Window Help
After
Step Backward
Play
Pause
Step Forward
Restart

Interactive Service Development

- Interactive Services
  - No standards for the input
  - Dynamic problem definition and exploration
- Fixture Analysis Service (EIT and CMU)
  - Ability to interactively define the problem statement
- Benefits
  - Wider customer base
  - Lower cost
  - Improved quality of communications

File Edit View Go Bookmarks Options Directory Window

Loaded Models: cubes, concave, convex

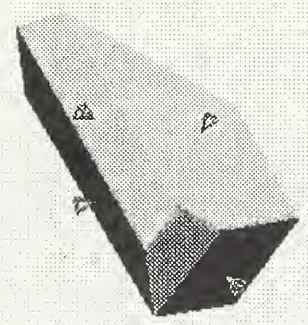
Display Model | Delete Model

Model Name:

Model URL:

Model: convex

Zoom Out | Zoom In



Shift-click to add fixels. | -X | +X

Analysis Options | Display Options | Submit | Quit

Unsigned Java Applet Window

File Edit View Go Bookmarks Options Directory Window Help

Summary of Submission

You submitted the following fixture elements:

1. (-0.612, -0.265, -1.000) along direction 0.000i+ 0.000j+ 1.000k
2. (-0.045, 2.000, -0.410) along direction 0.000i+-1.000j+ 0.000k
3. (0.421, 1.241, 0.759) along direction 0.000i+-0.707j+-0.707k
4. (0.318, -0.846, 1.000) along direction 0.000i+ 0.000j+-1.000k
5. (-4.000, -0.104, 0.614) along direction 1.000i+ 0.000j+ 0.000k
6. (2.290, -0.710, 0.215) along direction -0.707i+ 0.707j+ 0.000k

You wanted a full 3-D analysis

You wanted form closure

Some information about your fixture design

You've applied 6 fixture elements. The theoretical minimum number of fixture elements for your needs is 7.

n = 6, m = 6

Results

The fixture plan IS NOT stable.

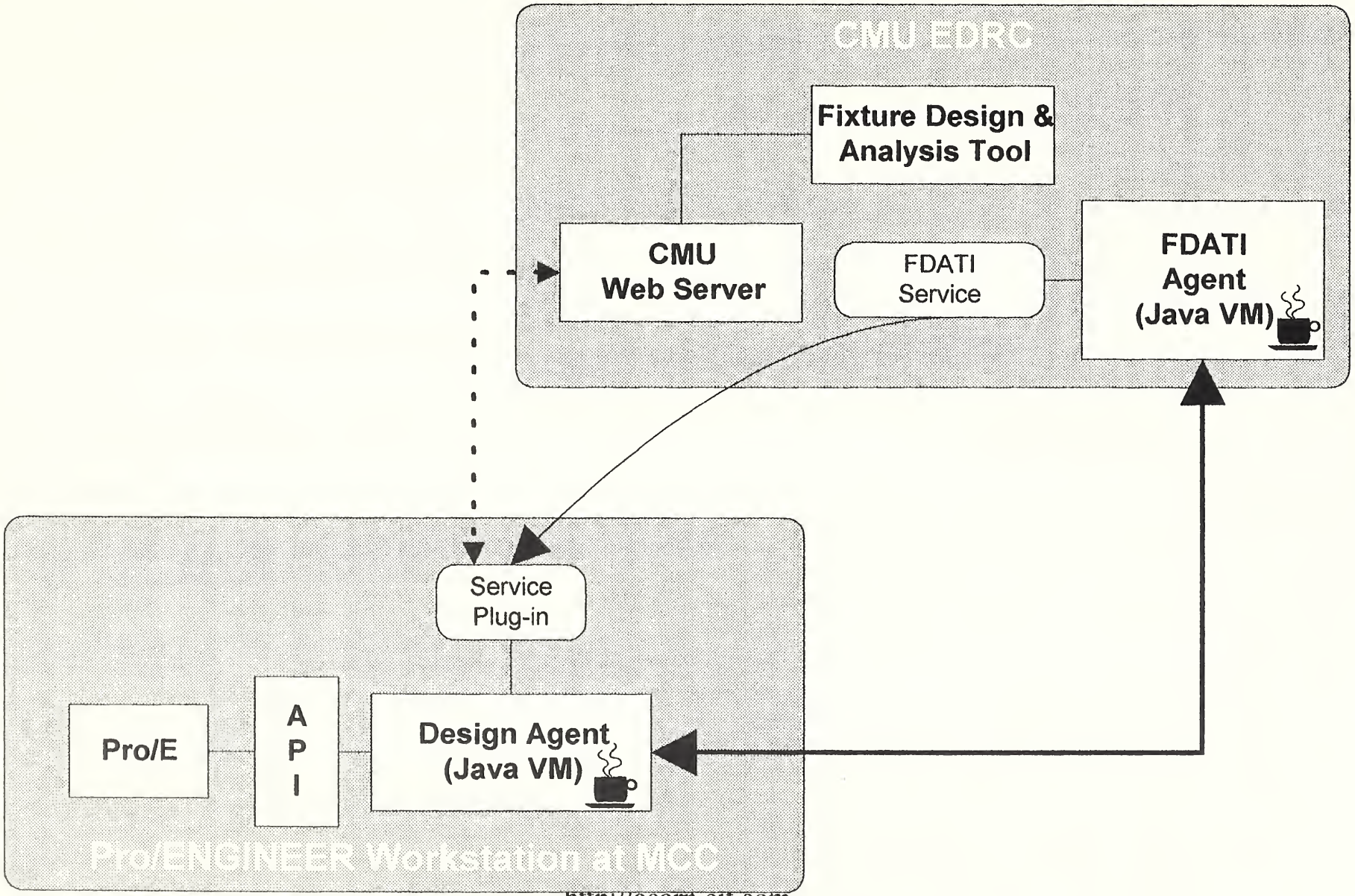
Please press the Back button to return to Fixture Applet Page is you want to perform additional analysis

Back

Linking Applications to the WWW

- CAD tool service front-end
  - Connecting to a WWW-based service from ProE
  - Improved versions of the analysis services
- Client Support
  - Connecting information modeling software to the WWW
  - Service interaction capture and re-use

FDATI-ProE Interaction



Lessons Learned

- WWW-Based Services
  - Increased customer satisfaction
  - Rapid access to distributed resources
  - WWW made it acceptable to talk about distributed systems
  - Technical issues are being addressed but our community is not in control
  - Legal and business issues need closer attention

Future Topics

- Finding the "right" service
- "Right information" and the "right time" in the "right form"
- Keeping and using histories of service interactions
- Moving from single-service interaction to multi-service collaboration

SmartWeld

Dr. John Mitchiner, Sandia National Laboratories (jlmitch@sandia.gov)

The summary for this presentation can be found on page 52
21 full-page slides follow

Knowledge Engineering Team System Design

John Mitchiner
Knowledge Engineering Team Leader

CCT Managers: Kim Mahin – SmartProcesses
Margaret Olson –Virtual Manufacturing

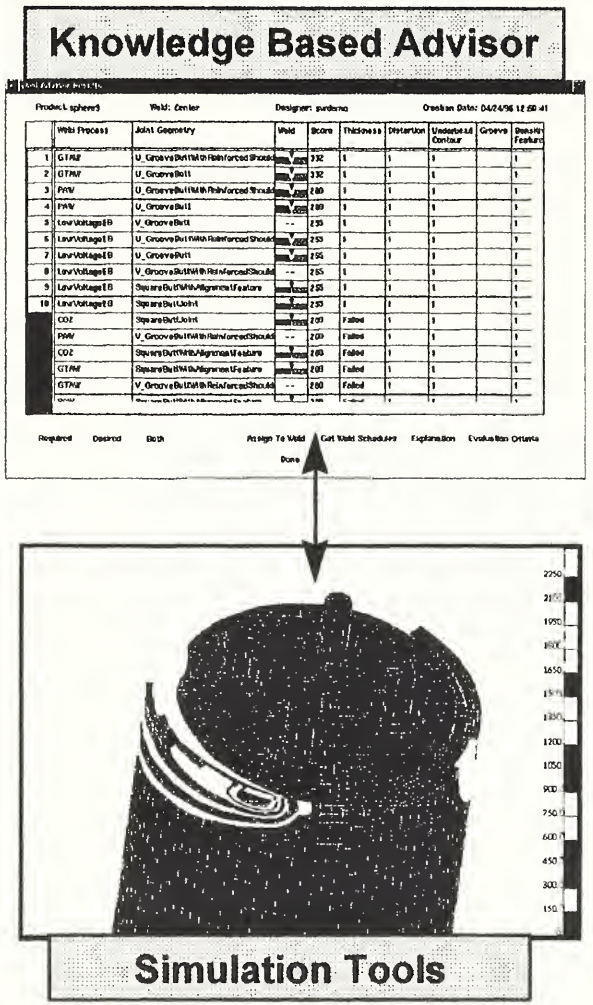
Team members: Steve Kleban, Bill Stubblefield, Jill Rivera, and Robert Lafarge

KET Projects

- SmartWeld
- Near Net Shape Process Selection
- Design for Machinability
- Material and Process Selection

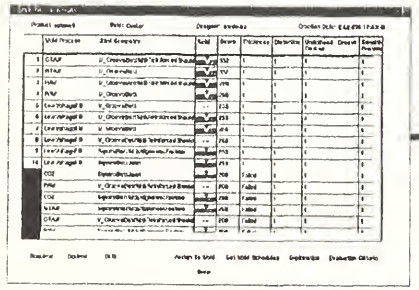
SmartWeld System

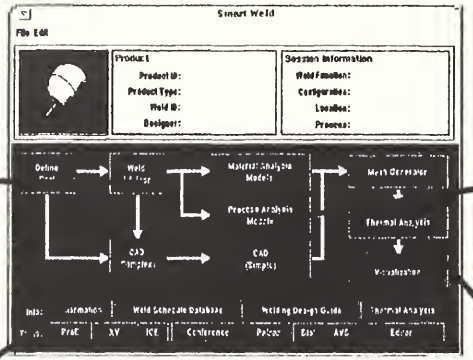
- **Description:** SmartWeld is a concurrent engineering system for design & manufacturing of welded assemblies.
- **Objective:** To reduce product realization times and costs by optimizing designs off-line using intelligent advisors & science-based models.
- **Impact:** Iteration times for redesigns are reduced to hours rather than weeks.
- **Customers:** FY97 focus will be on DP customers SWPP and Neutron Generators. Key industry & institute links are being negotiated.



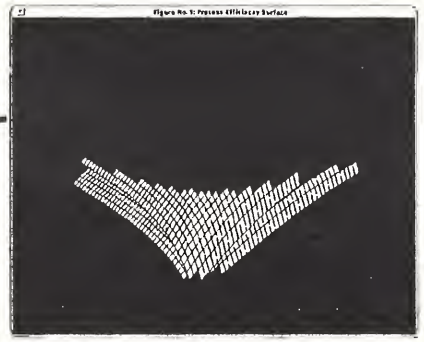
The SmartProcess / SmartWeld environment links the user to the right information and tools

Knowledge Bases / Databases



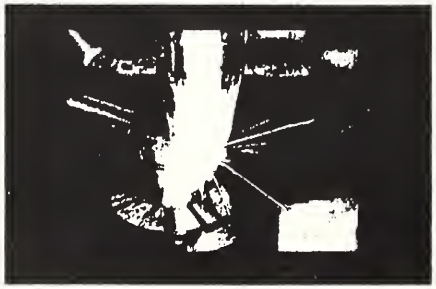


Optimization Models



Rapid Prototyping

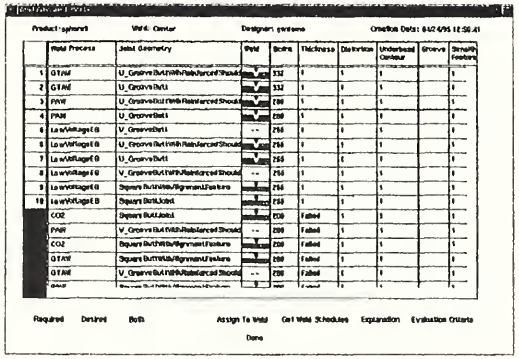
Product Realization



Process Simulations

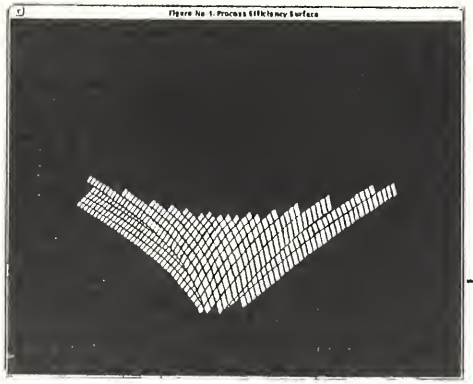
The SmartWeld system is reducing iteration times for redesigns of welded parts from weeks to hours

Knowledge Base / Databases



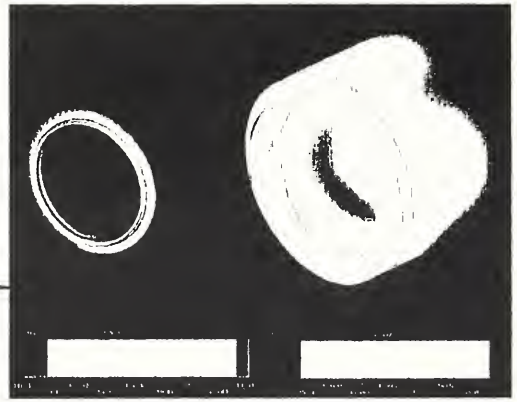
Rapid process and schedule selection based on design / performance req'ts

Optimization models



Identification of most robust operating regimes

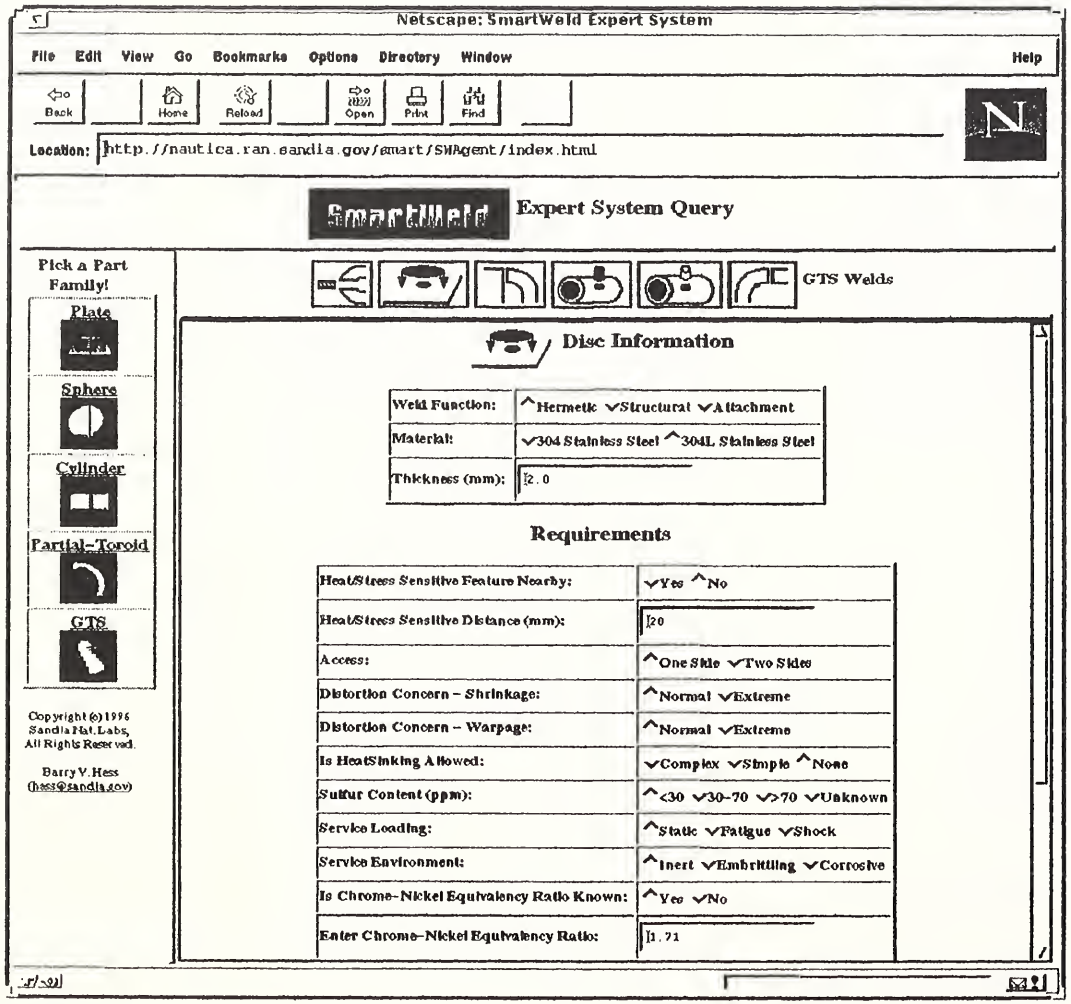
3D Simulations



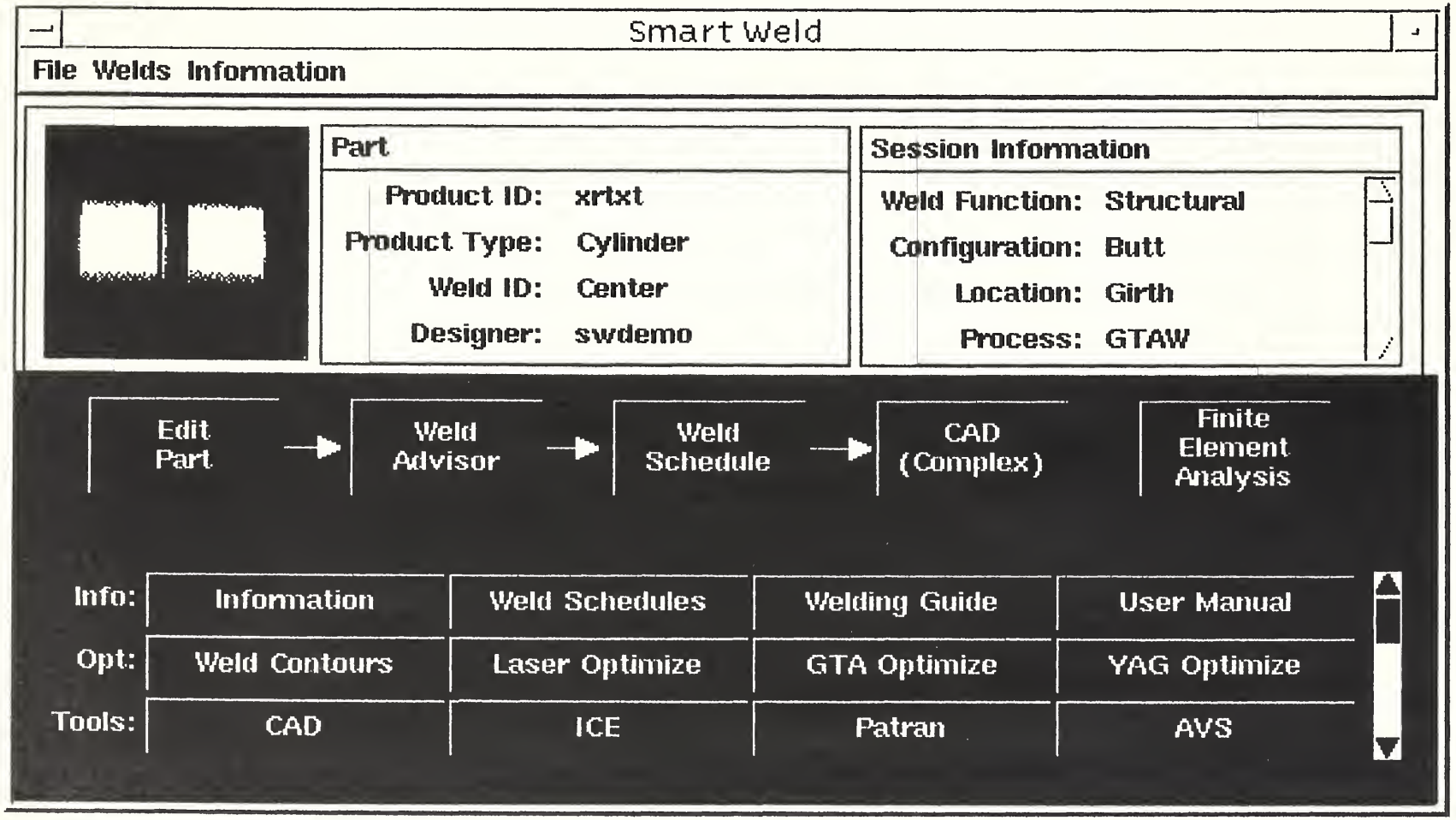
Evaluation of weld-induced temperatures and stresses.

"What If" Iteration Cycle

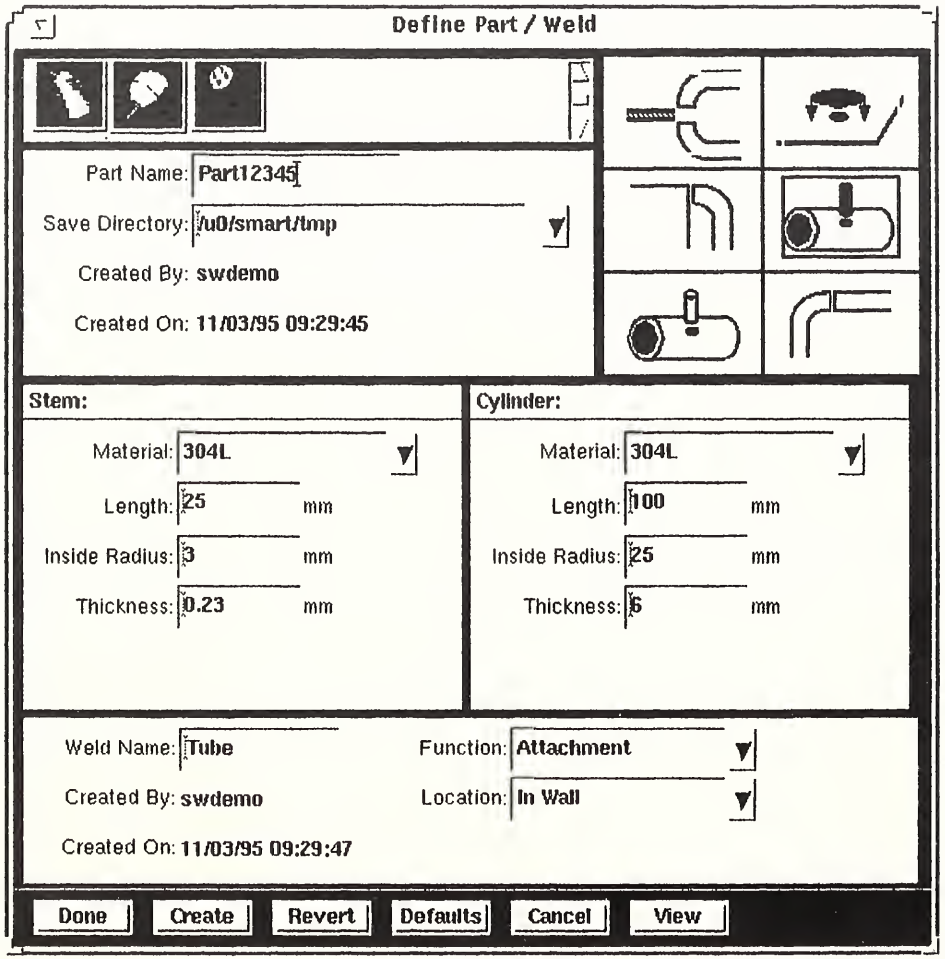
The SmartWeld Expert System can now be accessed and run through Netscape



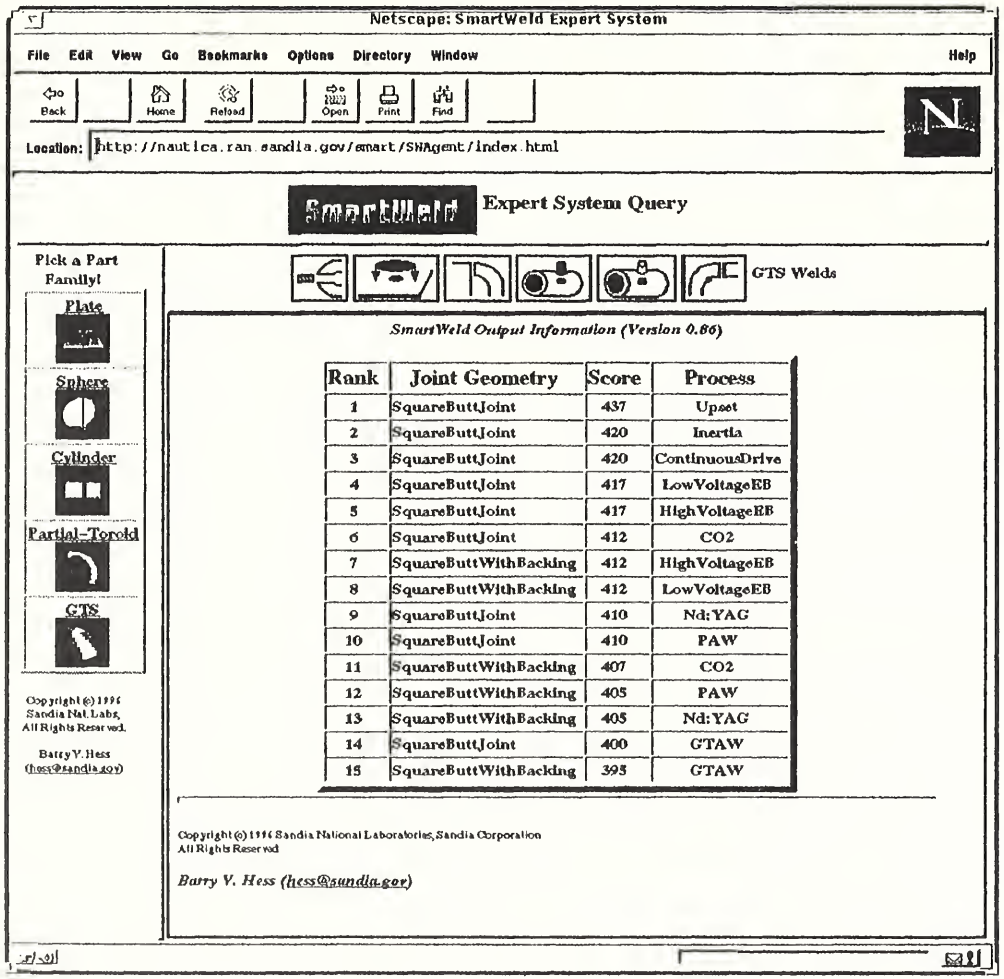
The new SmartWeld interface provides a simpler workflow for guidance through the system



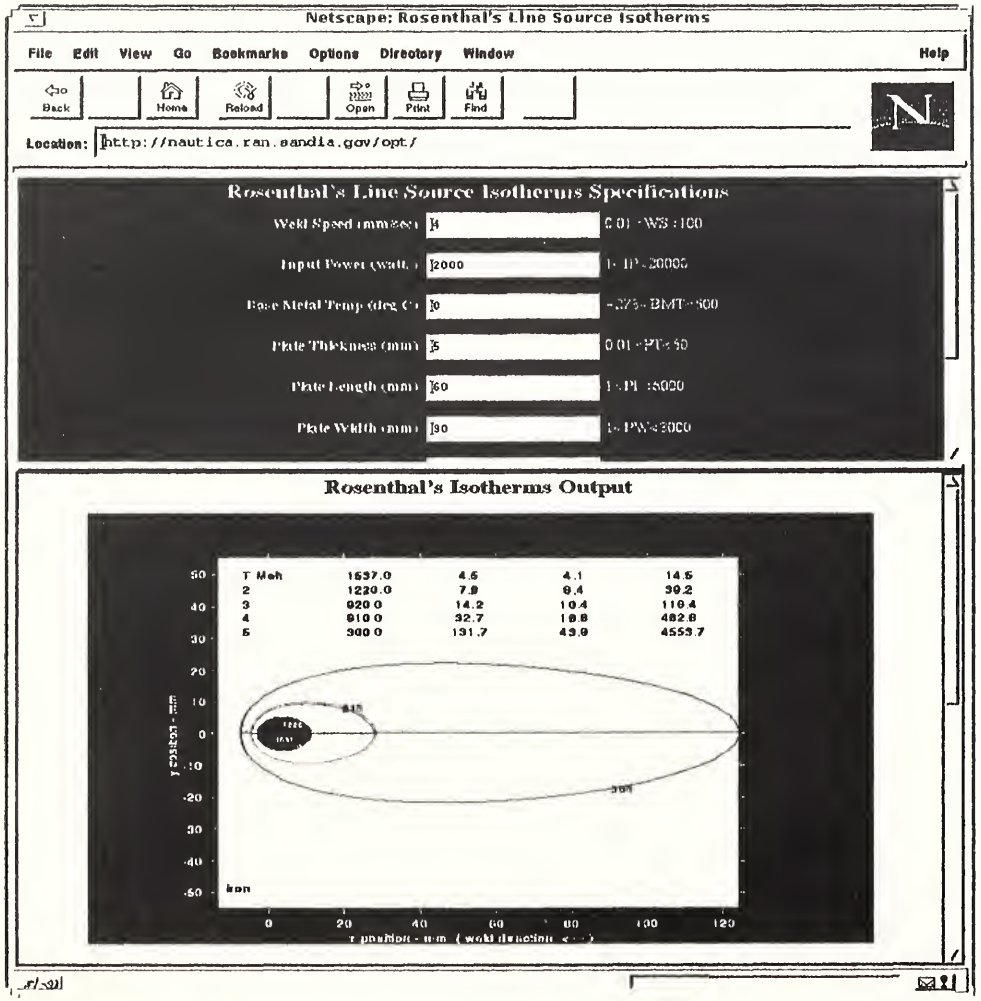
SmartWeld saves time and minimizes error by importing the design requirements and identifying approved weld joint locations and process options



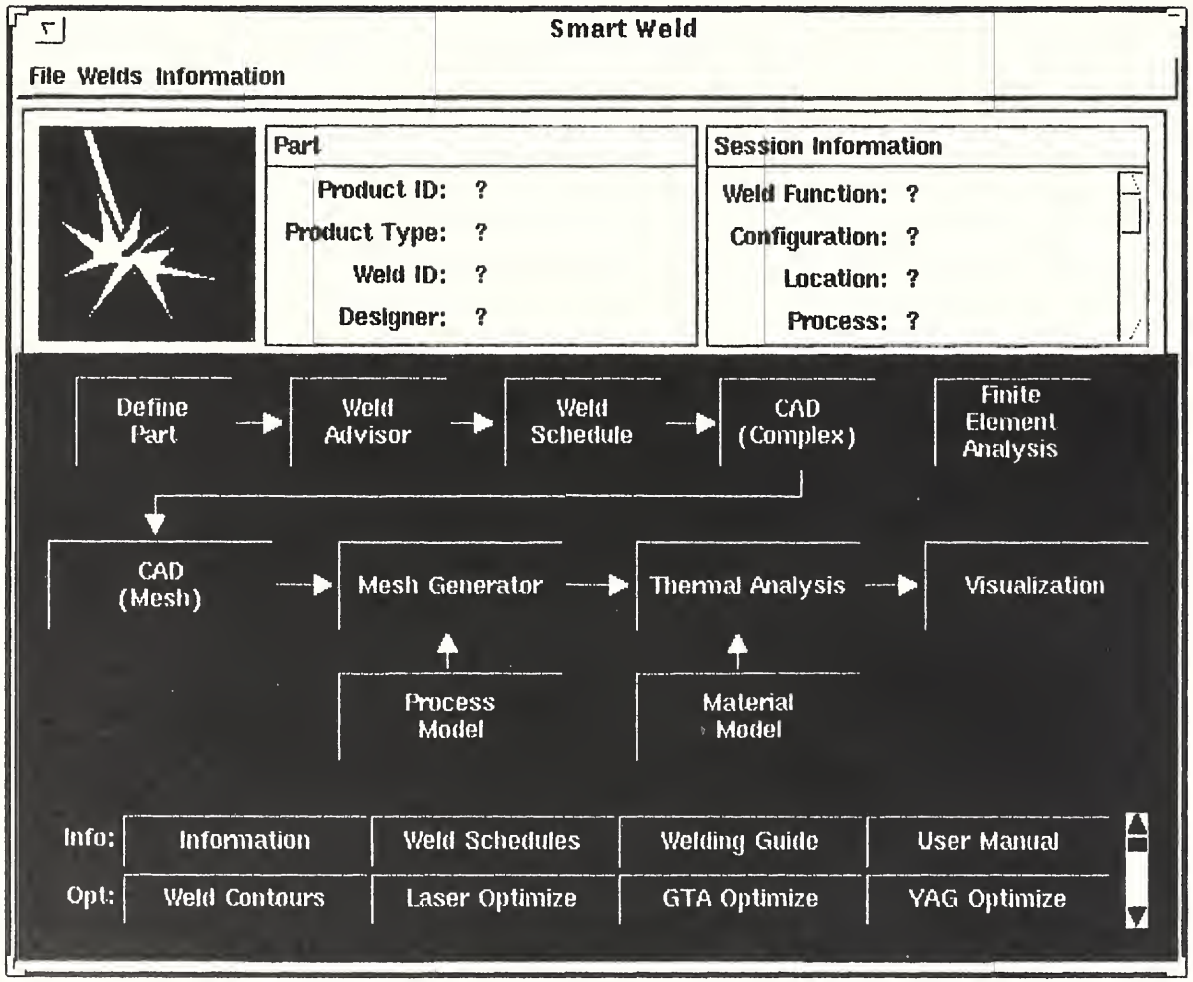
The Welding Advisor provides process and joint design recomendations for a variety of welded assemblies via the Net



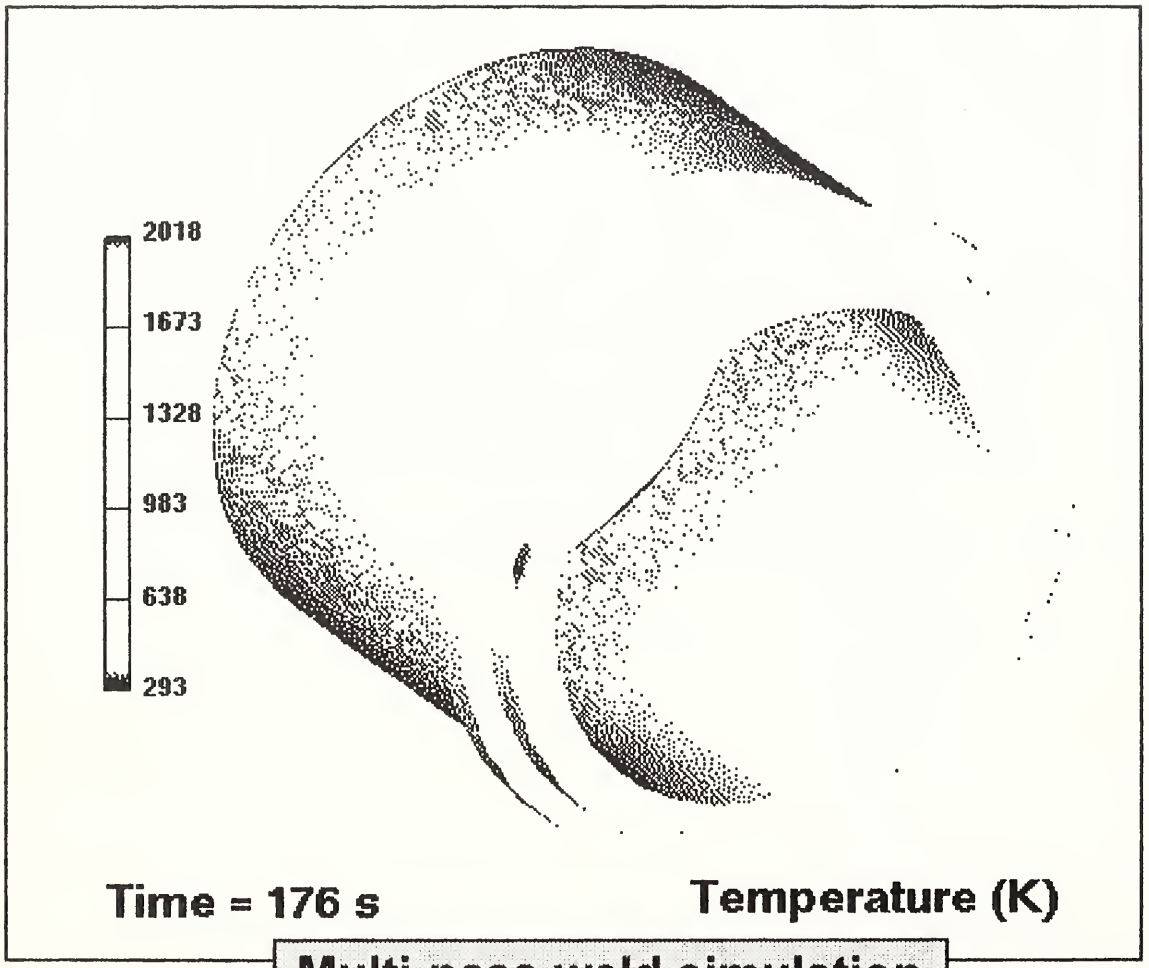
Designers and Process Engineers can get quick estimates on thermal distributions using the Rosenthal option in the Optimization Model



Access to predictive process simulation tools is captured in a workflow diagram, which allows the user to select different material and heat flux models



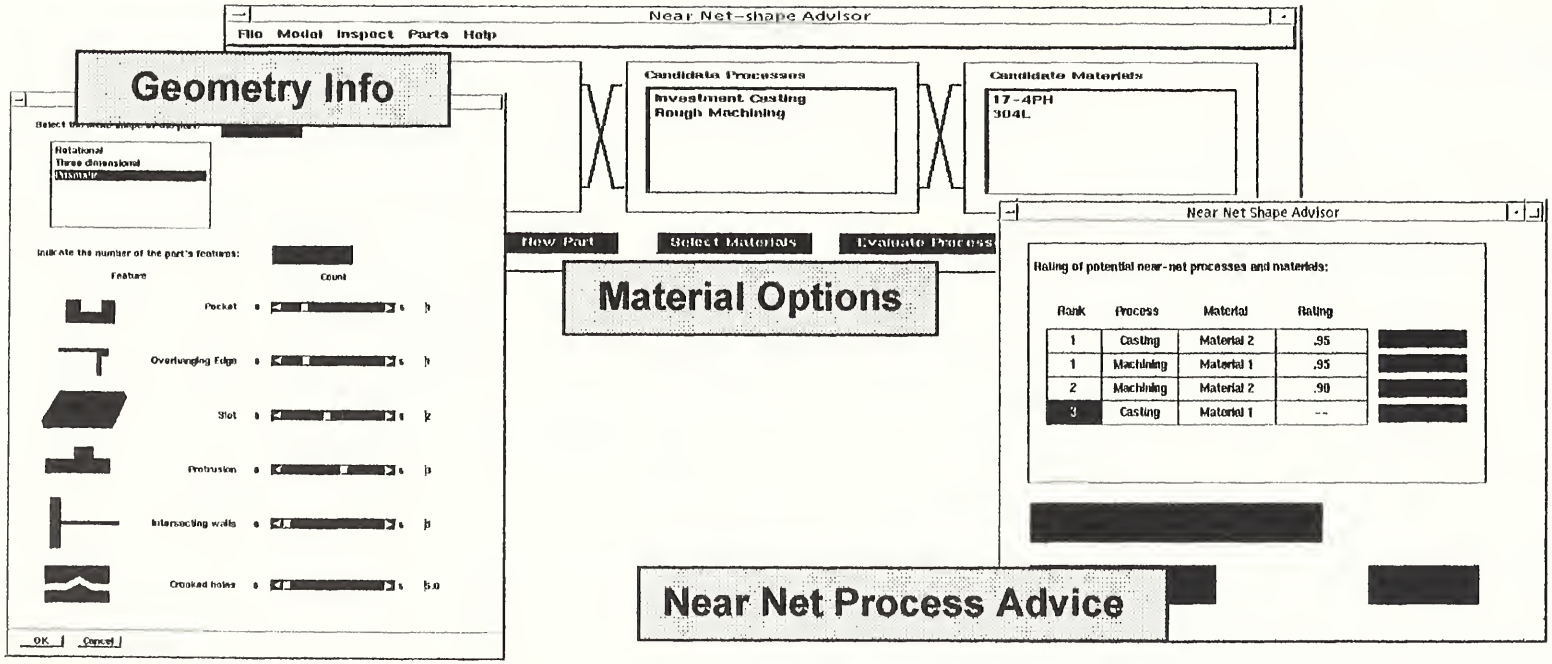
Numerical models of process effects and material behavior provide quantitative information on part quality, performance, and reliability



Multi-pass weld simulation

Near Net Shape Process Selection Advisor

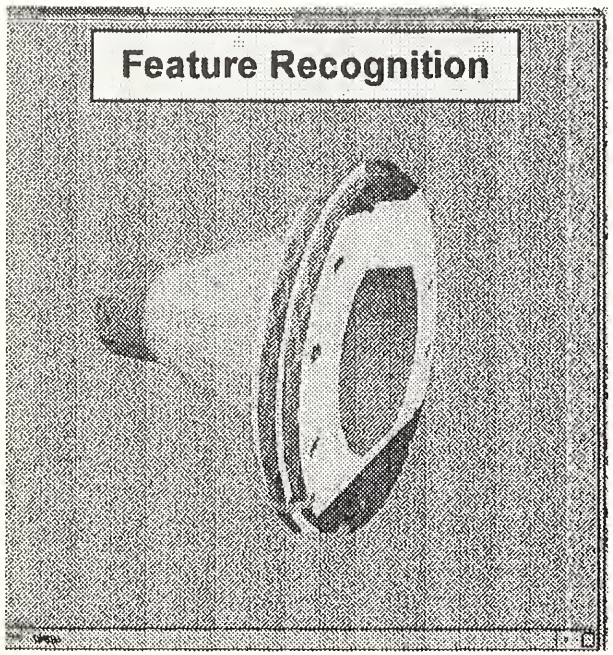
Technology Capability: Knowledge-based Advisor which integrates information on geometry, material, and design requirements to evaluate machining vs. casting options.

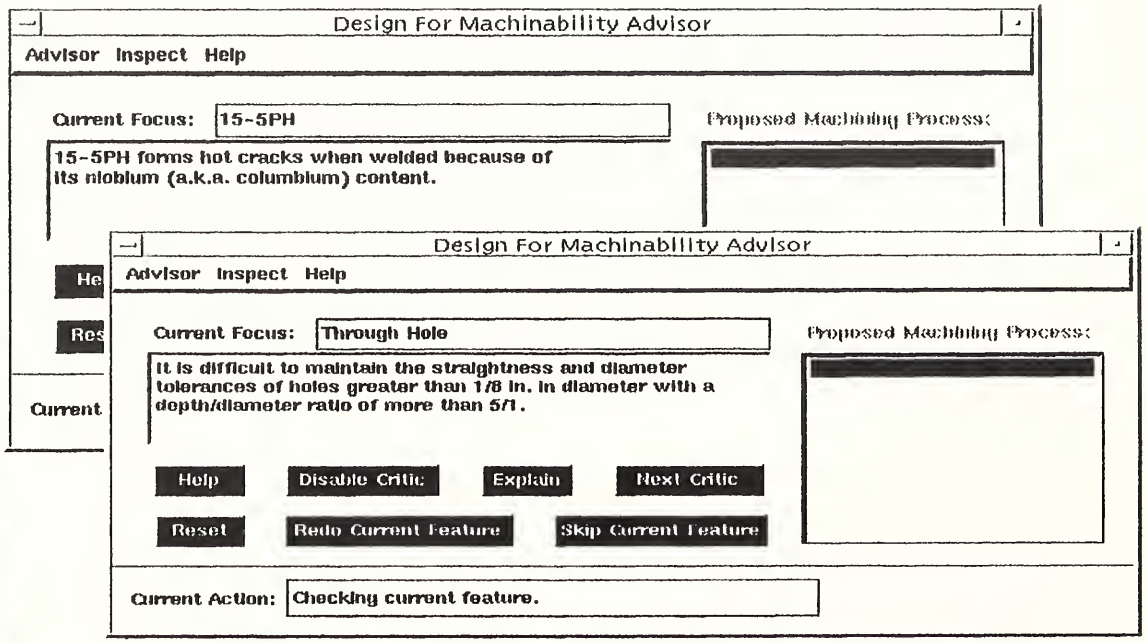


Impact: Objective evaluation of design and manufacturing constraints. Improved manufacturability, faster production, and lower cost.

Machinability Advisor

Technology Capability: Geometry-based design critic that "spell checks" CAD models for difficult to manufacture features and materials.



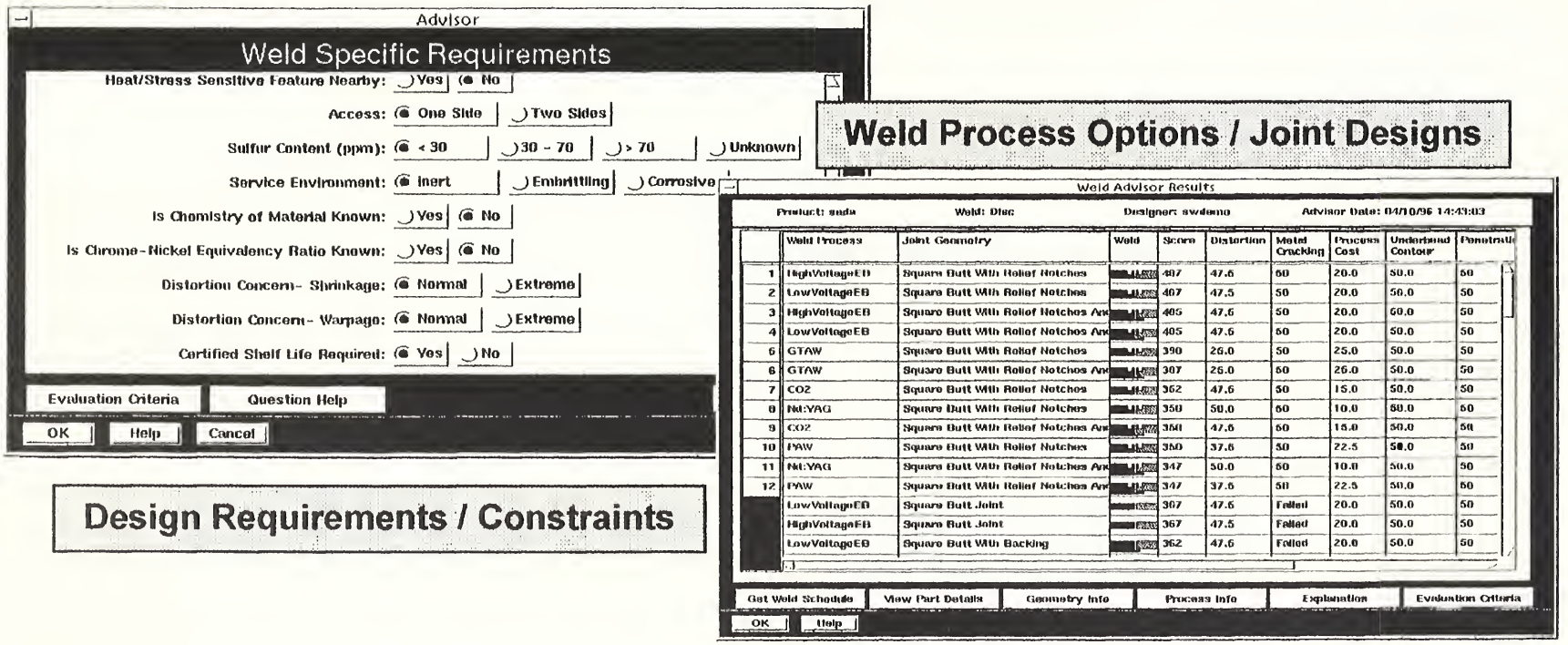


Material and Feature Critics

Impact: More cost-effective, manufacturable designs.
Reduced product realization cycle times; reduced costs.

Welding Advisor

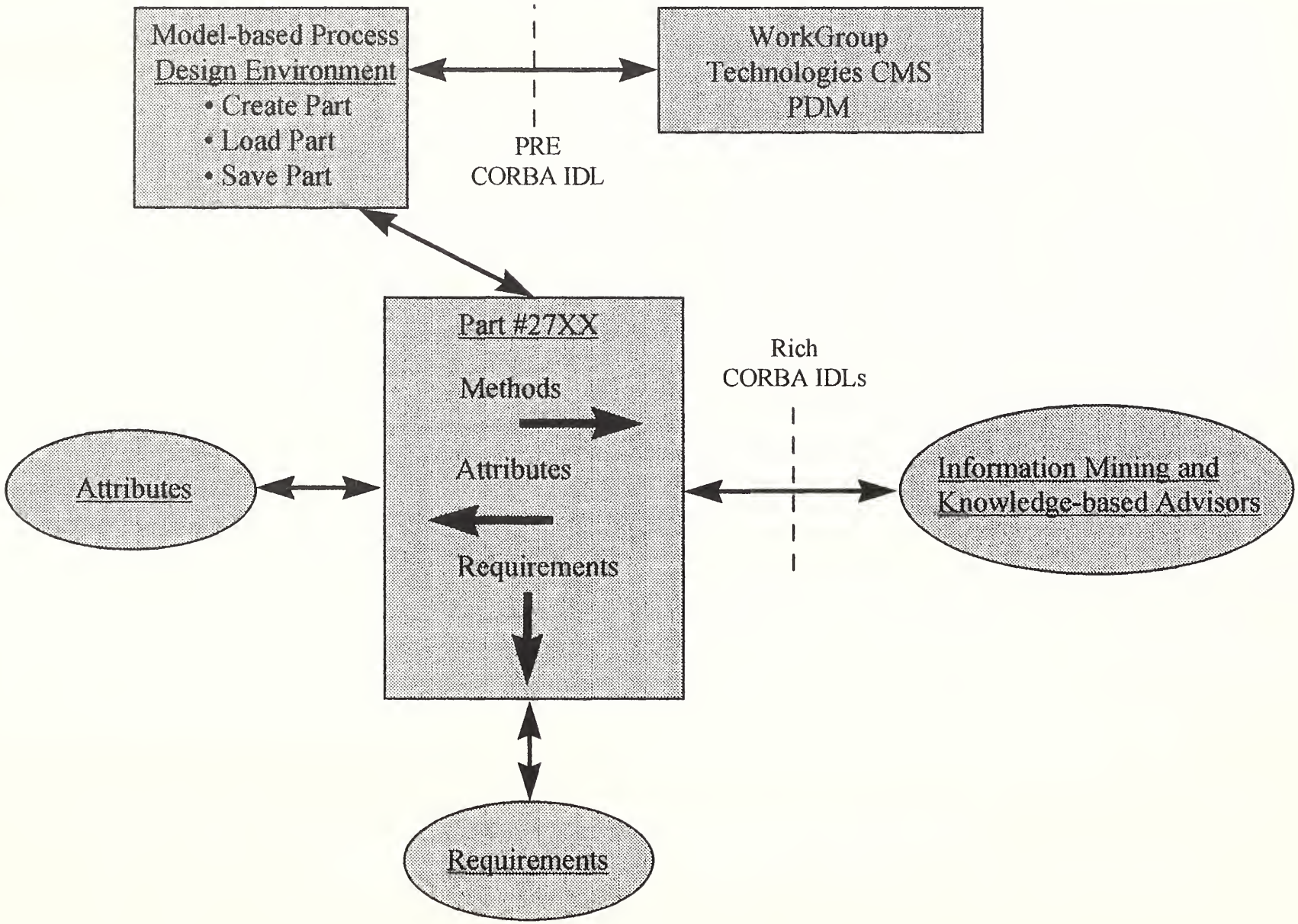
Technology Capability: Knowledge-based Advisor which recommends most appropriate weld process and geometry combinations based on design requirements / evaluation criteria (s.a. cost, schedule,qualification).



	Weld Process	Joint Geometry	Weld	Score	Distortion	Weld Cracking	Process Cost	Undercut Contour	Penetrati
1	HighVoltageEB	Square Butt With Relief Notches		407	47.6	50	20.0	50.0	50
2	LowVoltageEB	Square Butt With Relief Notches		407	47.5	50	20.0	50.0	50
3	HighVoltageEB	Square Butt With Relief Notches Ar		405	47.6	50	20.0	50.0	50
4	LowVoltageEB	Square Butt With Relief Notches Ar		405	47.6	50	20.0	50.0	50
5	GTAW	Square Butt With Relief Notches		390	26.0	50	25.0	50.0	50
6	GTAW	Square Butt With Relief Notches Ar		307	26.0	50	26.0	50.0	50
7	CO2	Square Butt With Relief Notches		362	47.6	50	15.0	50.0	50
8	Nd:YAG	Square Butt With Relief Notches		350	50.0	50	10.0	50.0	50
9	CO2	Square Butt With Relief Notches Ar		350	47.6	50	15.0	50.0	50
10	PAW	Square Butt With Relief Notches		350	37.6	50	22.5	50.0	50
11	Nd:YAG	Square Butt With Relief Notches Ar		347	50.0	50	10.0	50.0	50
12	PAW	Square Butt With Relief Notches Ar		347	37.6	50	22.5	50.0	50
	LowVoltageEB	Square Butt Joint		307	47.6	Failed	20.0	50.0	50
	HighVoltageEB	Square Butt Joint		367	47.5	Failed	20.0	50.0	50
	LowVoltageEB	Square Butt With Backing		362	47.6	Failed	20.0	50.0	50

Impact: Exploration of *all* logical welding alternatives; decreased scrap. Increased productivity for designers and welding engineers.

KET Project Integration



CORBA Methods

- Current PRE IDLs are context free
  - Execute
  - Launch
  - Convert
  - Query
  - GetData
  - PutData
- Need semantically rich IDLs for Product Realization
  - FindMaterials Part#27XX
  - FindSubstituteMaterials Part#27XX
  - GetApplicableMaterials Part#27XX SelectedProcess
  - GetApplicableProcesses Part#27XX SelectedMaterial

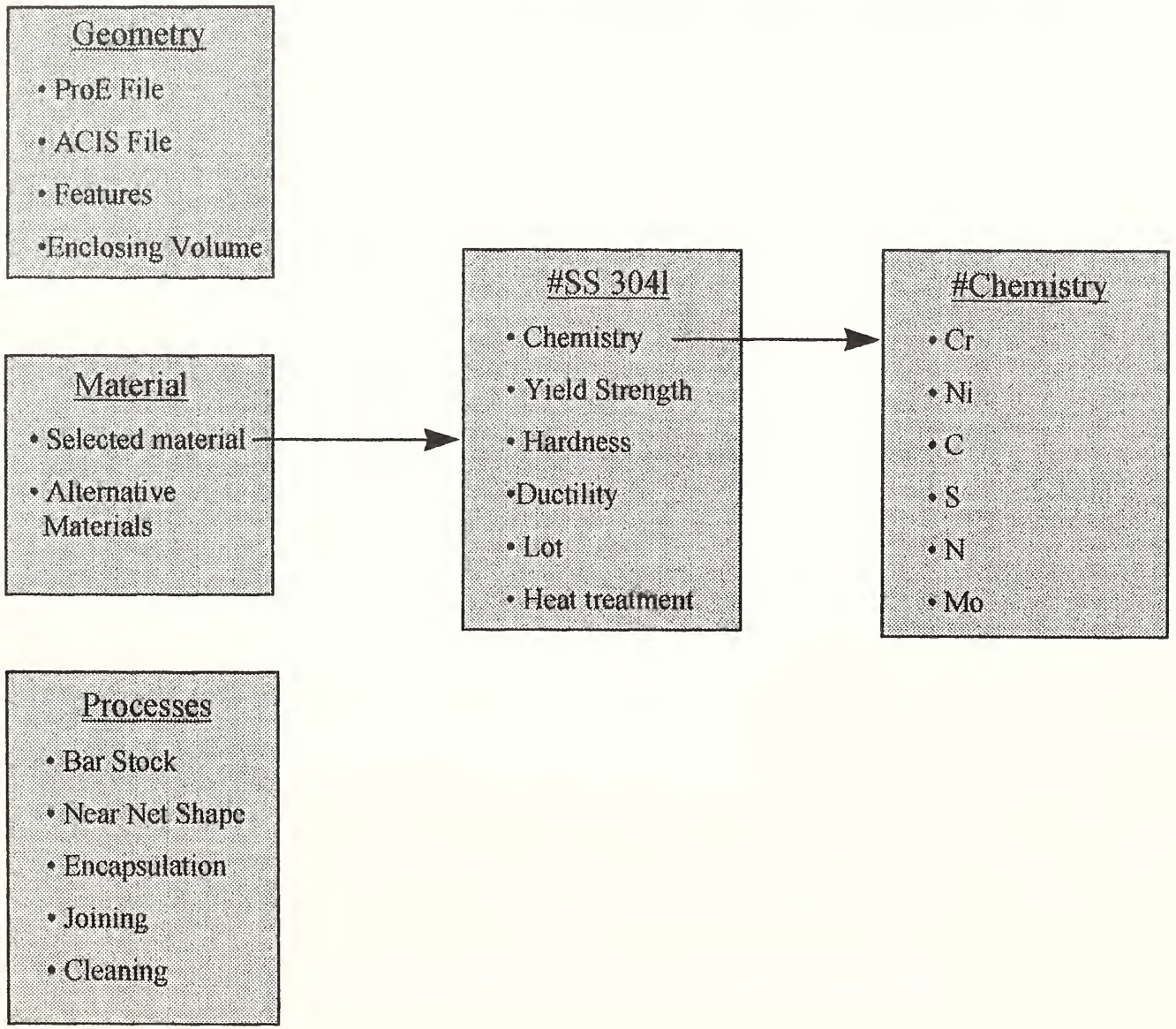
Information Mining and Knowledge-based Advisors

- Geometric Feature Extraction
- Near Net Shape Process Selection
- Material and Process Selection
- SmartWeld
- Design for Machinability
- Design for Environment

Part Requirements

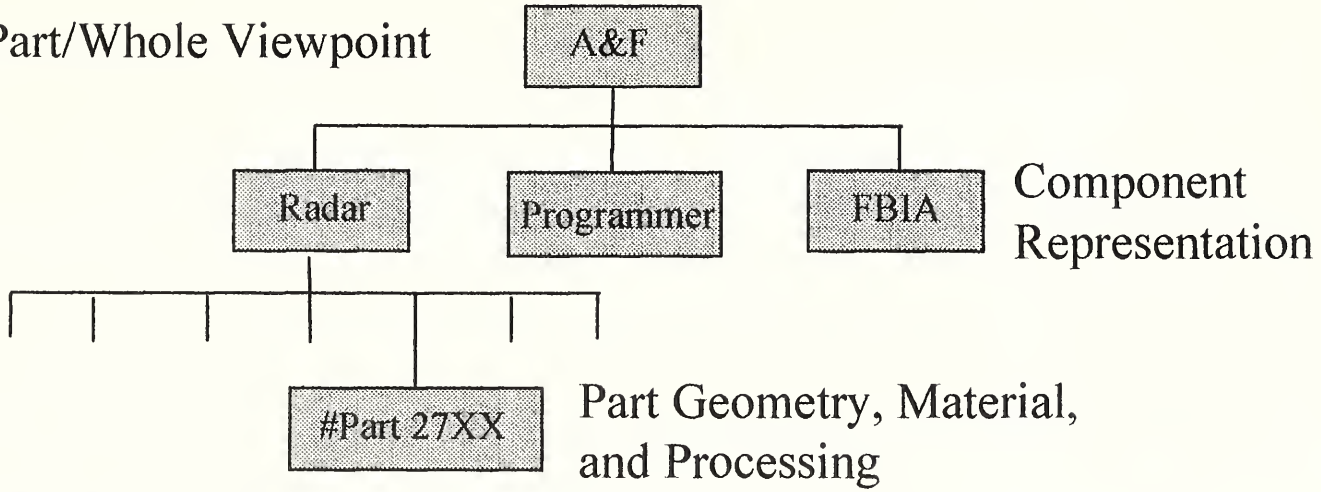
- Material Requirements
- Functional Product Requirements
- Manufacturing Requirements
  - Schedule
  - Lot size
  - Location

Hierarchical Attribute Representation

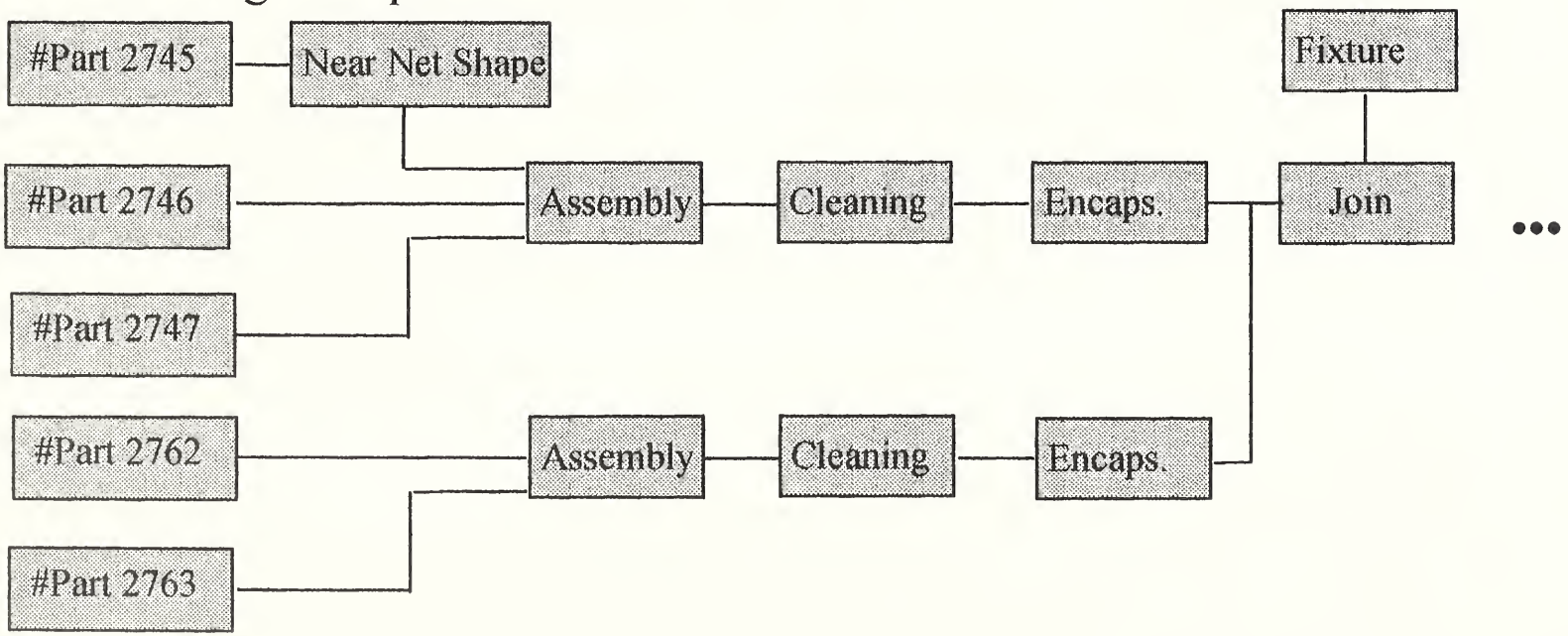


System Level Integration

- Functional Viewpoint
- Part/Whole Viewpoint



- Processing Viewpoint



PartNET: the Parts Information Network

Dr. Don R. Brown, Associate Professor, University of Utah/PartNET, Inc.
(don.brown@part.net)

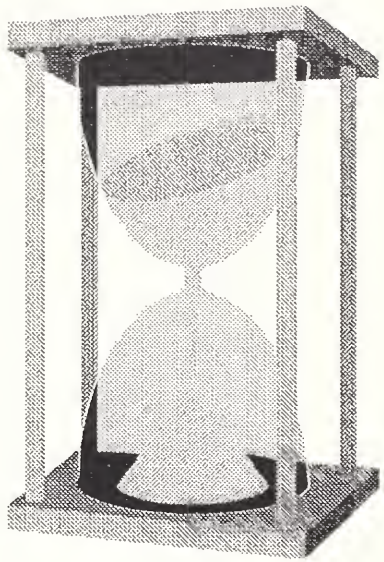
The summary for this presentation can be found on page 54
6 full-page slides follow

PartNET

the parts information network

Don Brown
Net-Centric CAD Workshop
NIST
December 4, 1996

http://www.part.net



Parts Research and Acquisition Delays Development

85% of design flow time is in parts research and acquisition

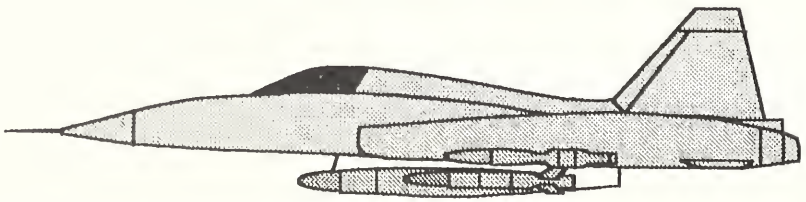
Source: Sacramento Air Logistics Center

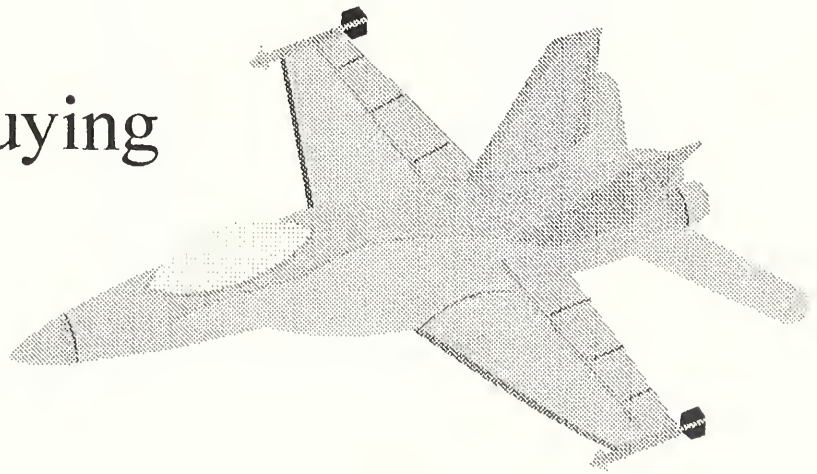
PartNET Mission

FITHIT: Find It Today. Have It Tomorrow.

Through:

- Distributed Cross-Vendor Search over the Internet
- Secure Online Buying

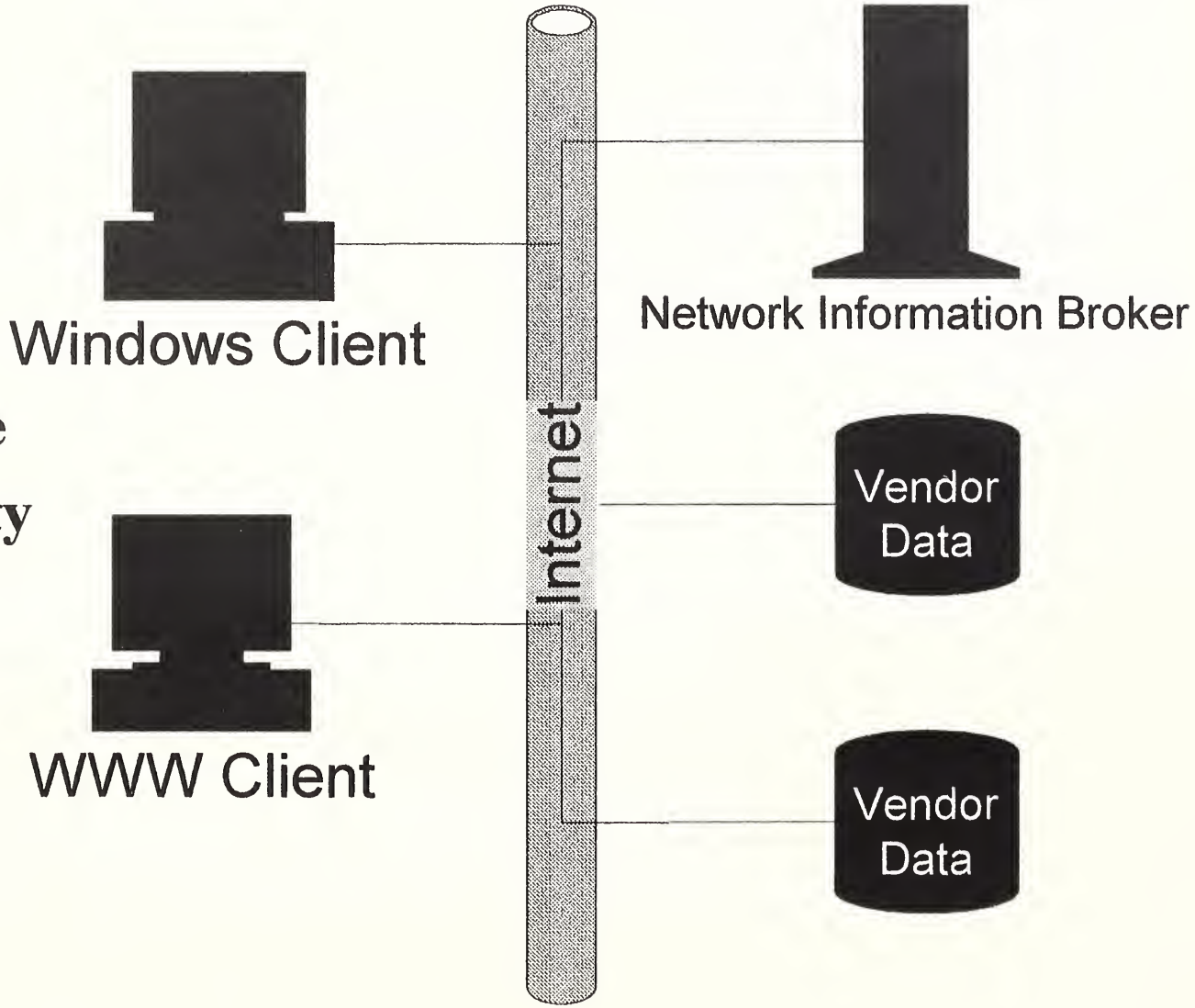




PartNET Architecture

Distributed

- **–Scaleable**
- **–Supplier Maintained**
- **–Current/Accurate**
- **–Unlimited capacity**
- **–Fault Tolerant**



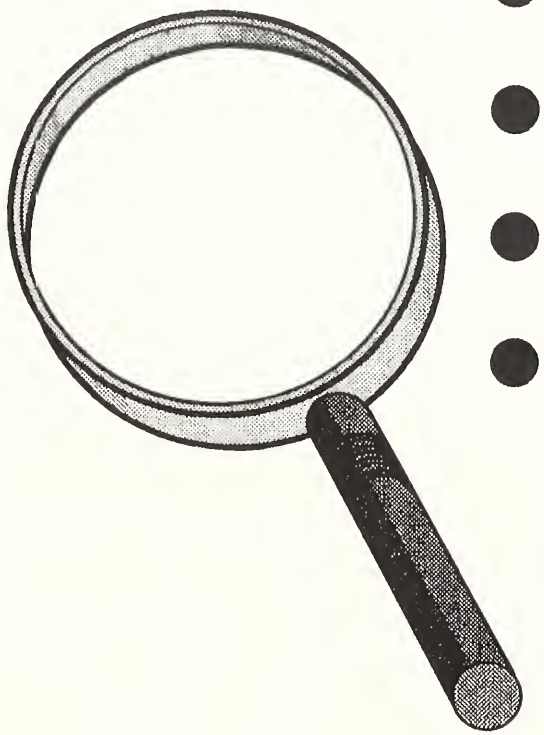
Secure!

University of Utah/PartNet

Types of Searches

- Part Characteristics
- National Stock Number
- Manufacturer
- Distributor
- Part Number

Types of Information Available



- Pricing
- Availability
- Part Characteristics
- CAD Models
- Data Sheets

Highly Interactive Network-Centric Tools for Collaborative and Distributed Manufacturing

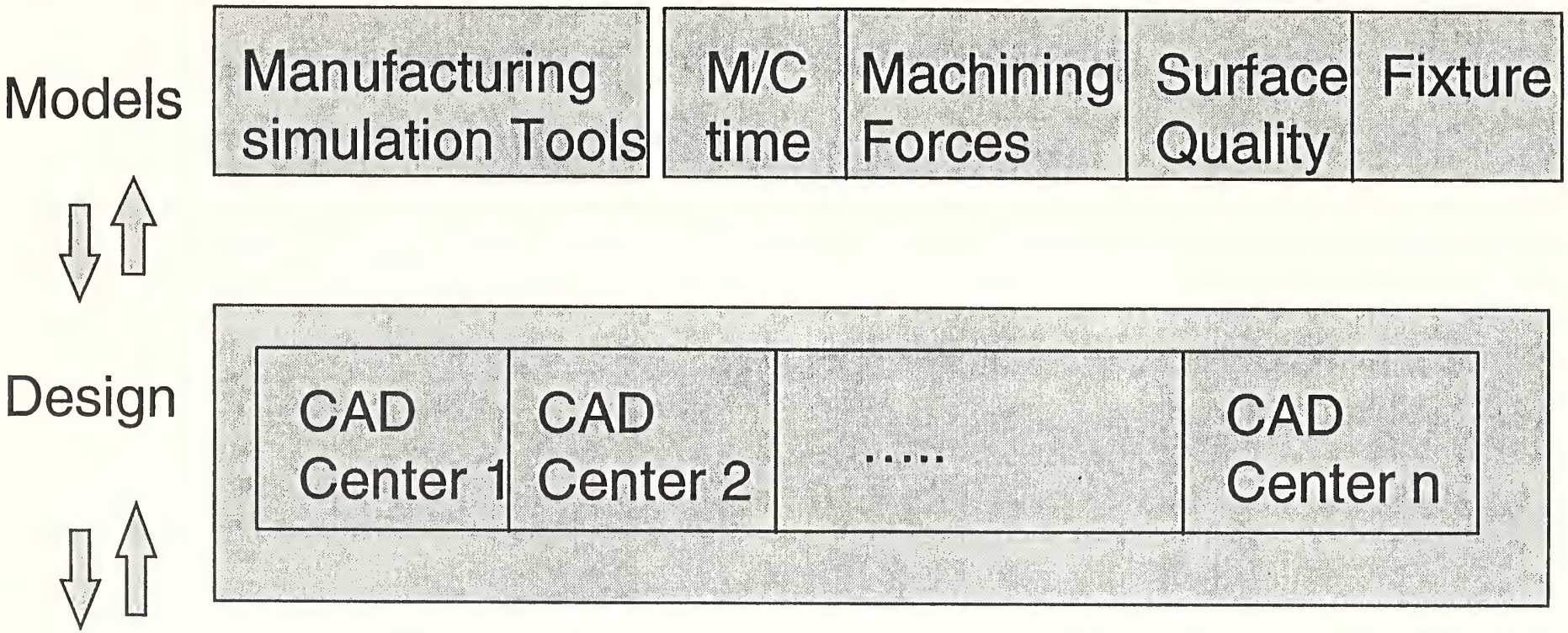
Dr. Ranga Narayanaswami, University of Illinois, Urbana-Champaign, Machine Tool Agile Manufacturing Research Institute (narayana@staff.uiuc.edu)

The summary for this presentation can be found on page 58
22 full-page slides follow

Highly Interactive Network Centric Tools for Collaborative and Distributed Manufacturing

Ranga Narayanaswami
University of Illinois at Urbana-Champaign

Representation



What it Requires?

- Machining Models
- Machining Planner
- Design Data Exchange
- Integration of machining models
- Remote Process Observation
- Plant /Vendor Characterization

EMSIM:Endmilling Simulation

- Web enabled with cgi
- DTM server enabled
- Used as a force calculation

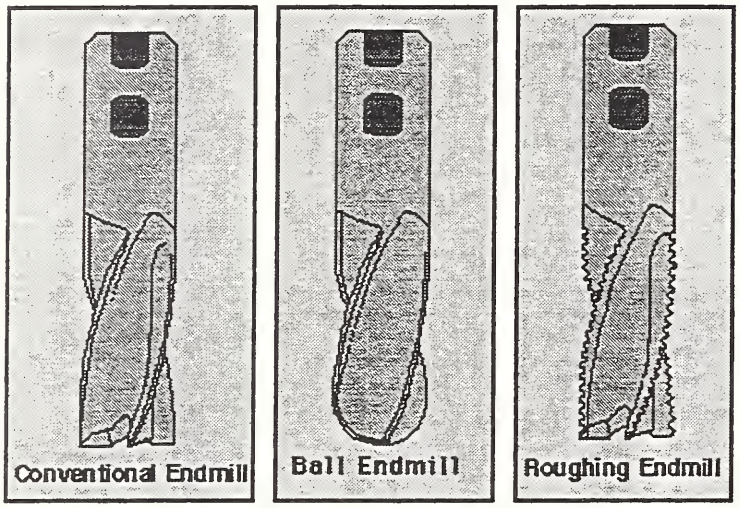
and surface accuracy prediction tool

- Used in course projects
  - Georgia Tech.
  - Northwesterrn University

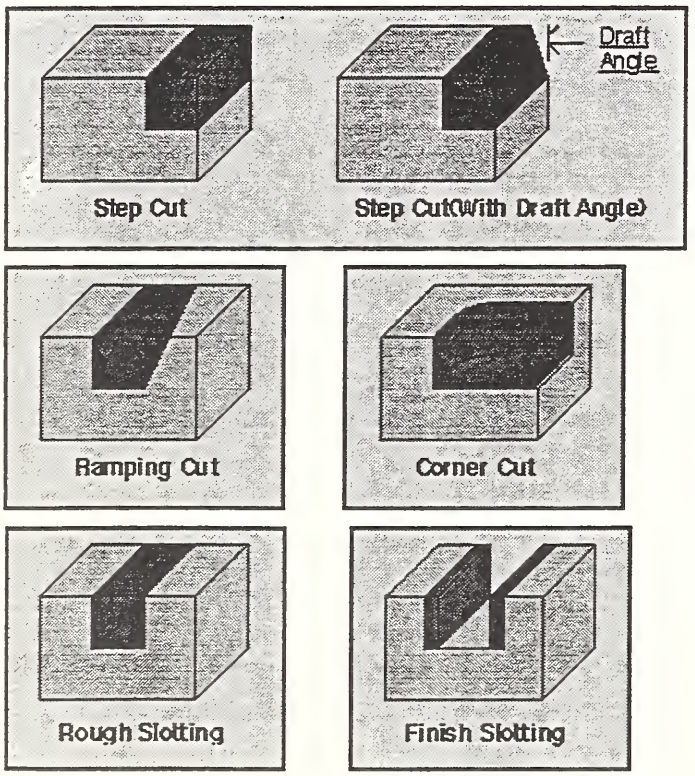
Choose the type of cutter and the type of cut :

You can choose the cutter by clicking on the button next to the picture of the cutter you want. Then click on the picture of one of the cuts to simulate that cut.

Cutter types



Cut types



Menu Page for Step Cut with Straight endmill

There are several input parameters that you can specify for the Step Cut. These have been separated into the five different categories shown below :

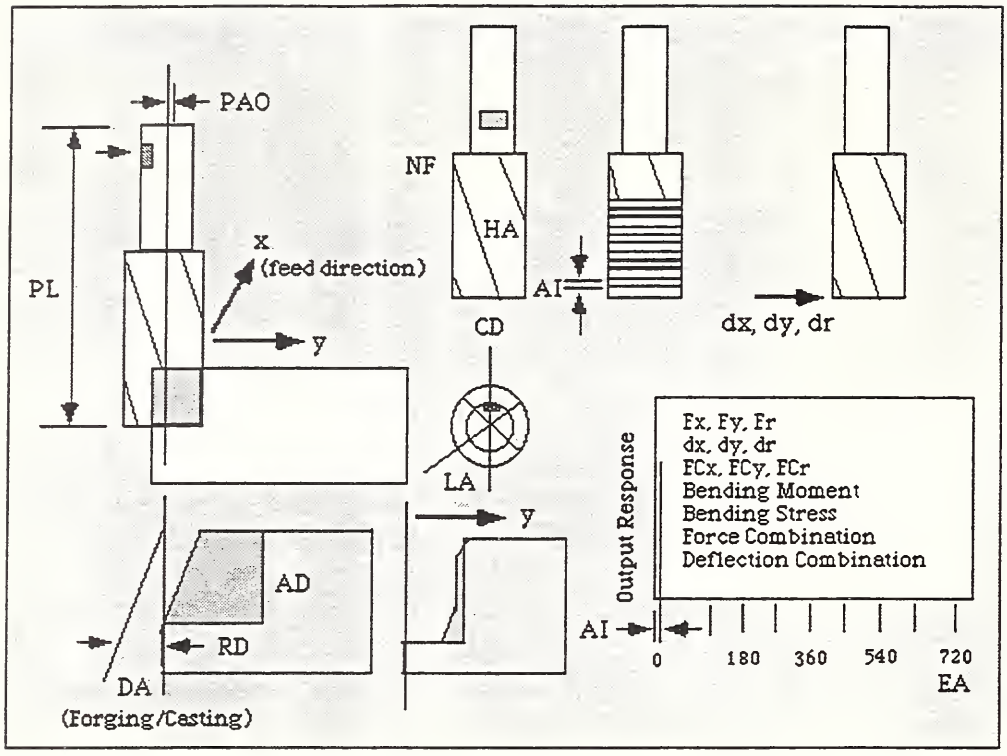
- Workpiece data
- Cutter data
- Cutting conditions
- Process Faults data
  - Runout data
  - Flute deviation data
  - Flute breakage data
- Simulation parameters

Each line above is a link to a page where you can modify the parameters of the corresponding category. Please follow the link to the page which contains the parameters you want to modify. From there you can go on to the summary page (explained below) or come back to this page and then go on to another page.

When you are done selecting parameters in all the six categories, you can go on to the **summary page** by clicking on the link below. The summary page shows all input parameters you have chosen. You can then start the simulation from there.

- Summary page

Summary of input parameters



General data

- Units = English
- Model = Static

Workpiece data

- Workpiece material = Gray Cast Iron (150-220 BHN)
- Workpiece draft angle = DA = 0 degrees

Cutter data

- Tool material = Uncoated Carbide
- Helix = Right handed
- End mill diameter = 0.75 inches
- Projection length = PL = 3.625 inches
- Number of flutes = NF = 4
- Helix angle = HA = 30 degrees
- Radial rake angle = 10 degrees

Cutting conditions

- Milling convention = Down/Climb Milling
- Axial depth of cut = AD = 0.5 inches
- Radial depth of cut = RD = 0.15 inches
- Feed per tooth = 0.004 inches
- Spindle speed = 500 rpm

Runout data

- Parallel axis offset runout = RO = 0 inches
- Locating angle for offset runout = 0 degrees
- Runout tilt angle = 0 degrees
- Locating angle for runout tilt = 0 degrees

Flute deviation data

- There is no flute deviation

Flute breakage data

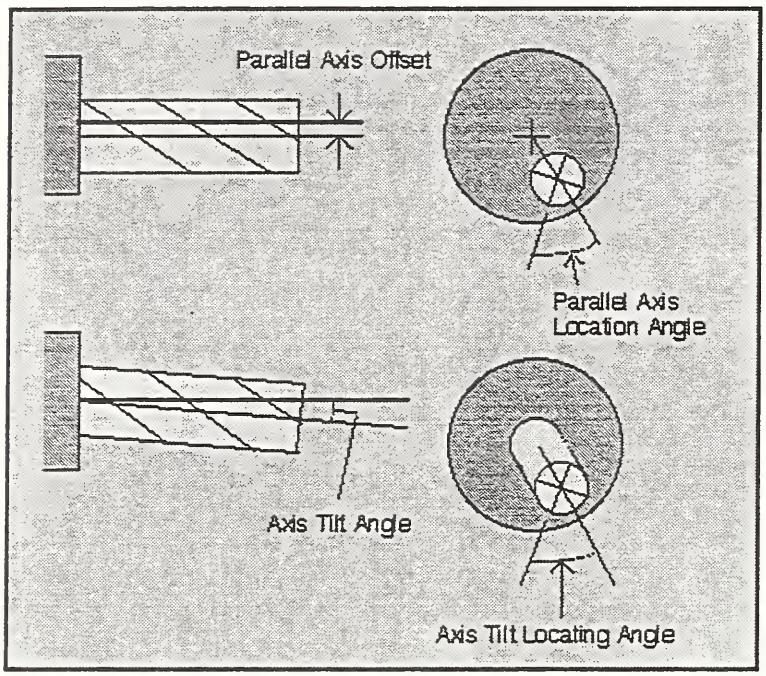
- There is no flute breakage

Simulation parameters

- Surface roughness is being simulated
- Axial increment = AI = 0.02 inches
- Angular increment = 5 degrees
- Total angle of simulation = EA = 360 degrees

End Milling Simulation Inputs

Runout data

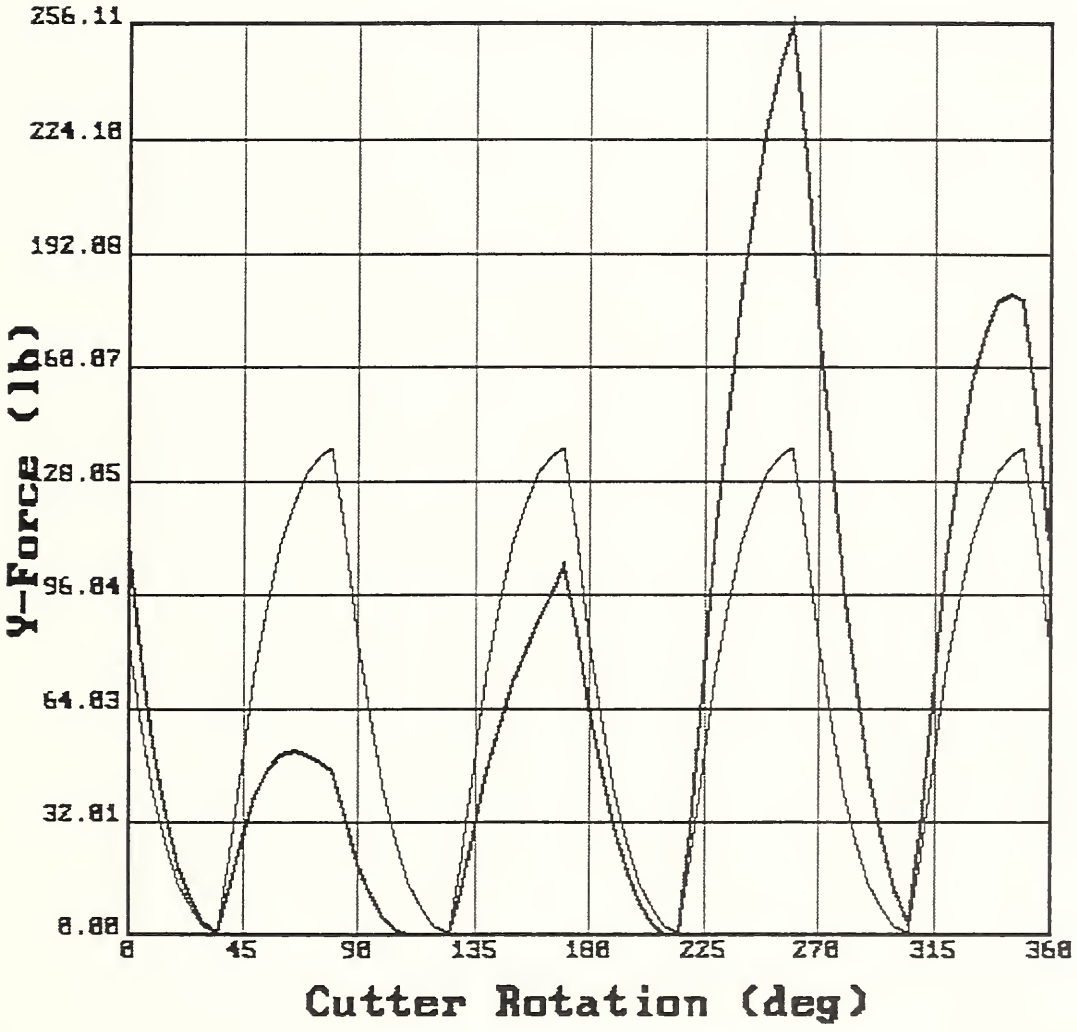


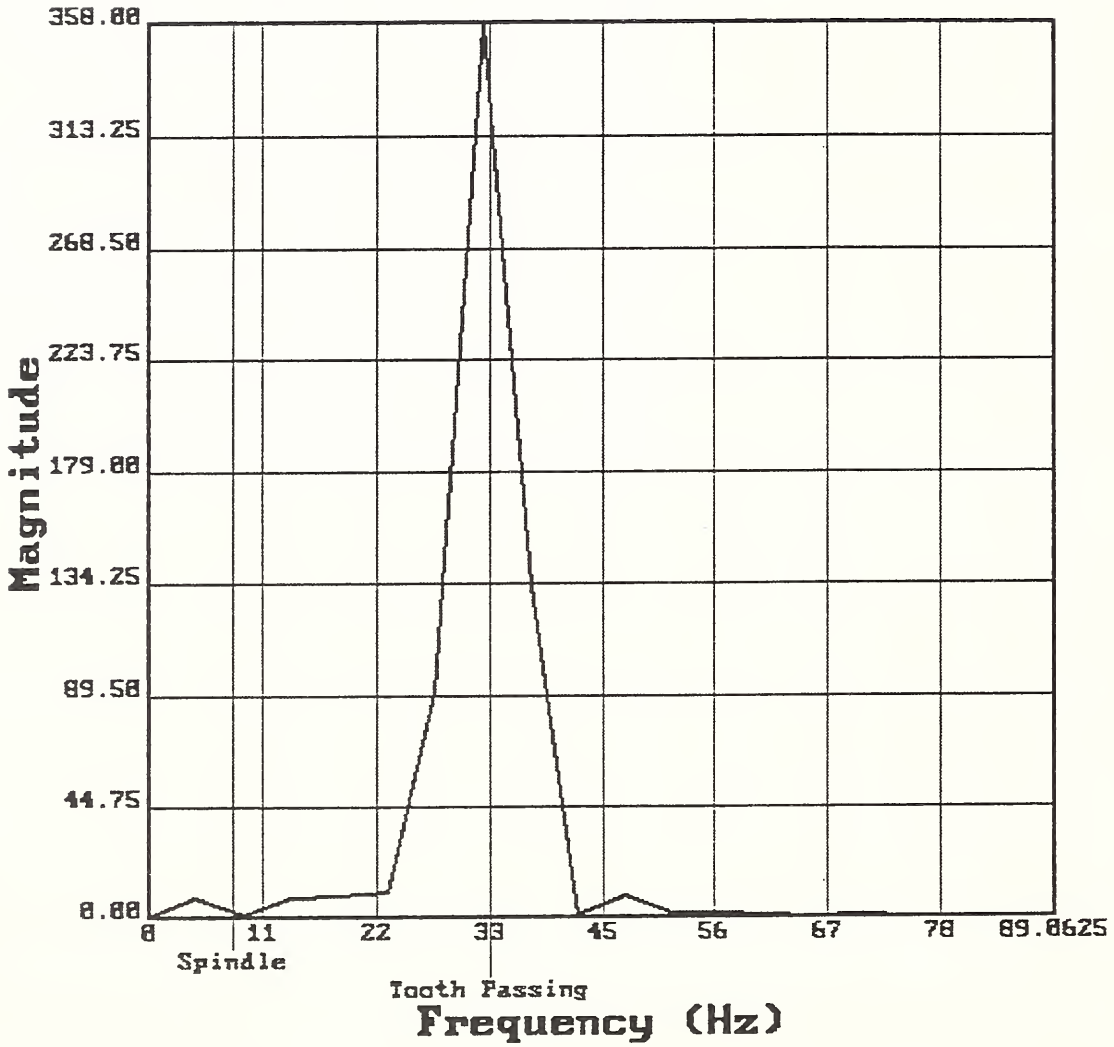

```
     Parallel axis offset runout :  inches
Locating angle for offset runout :  degrees
               Runout tilt angle :  degrees
  Locating angle for runout tilt :  degrees
```

Menu page Summary Page

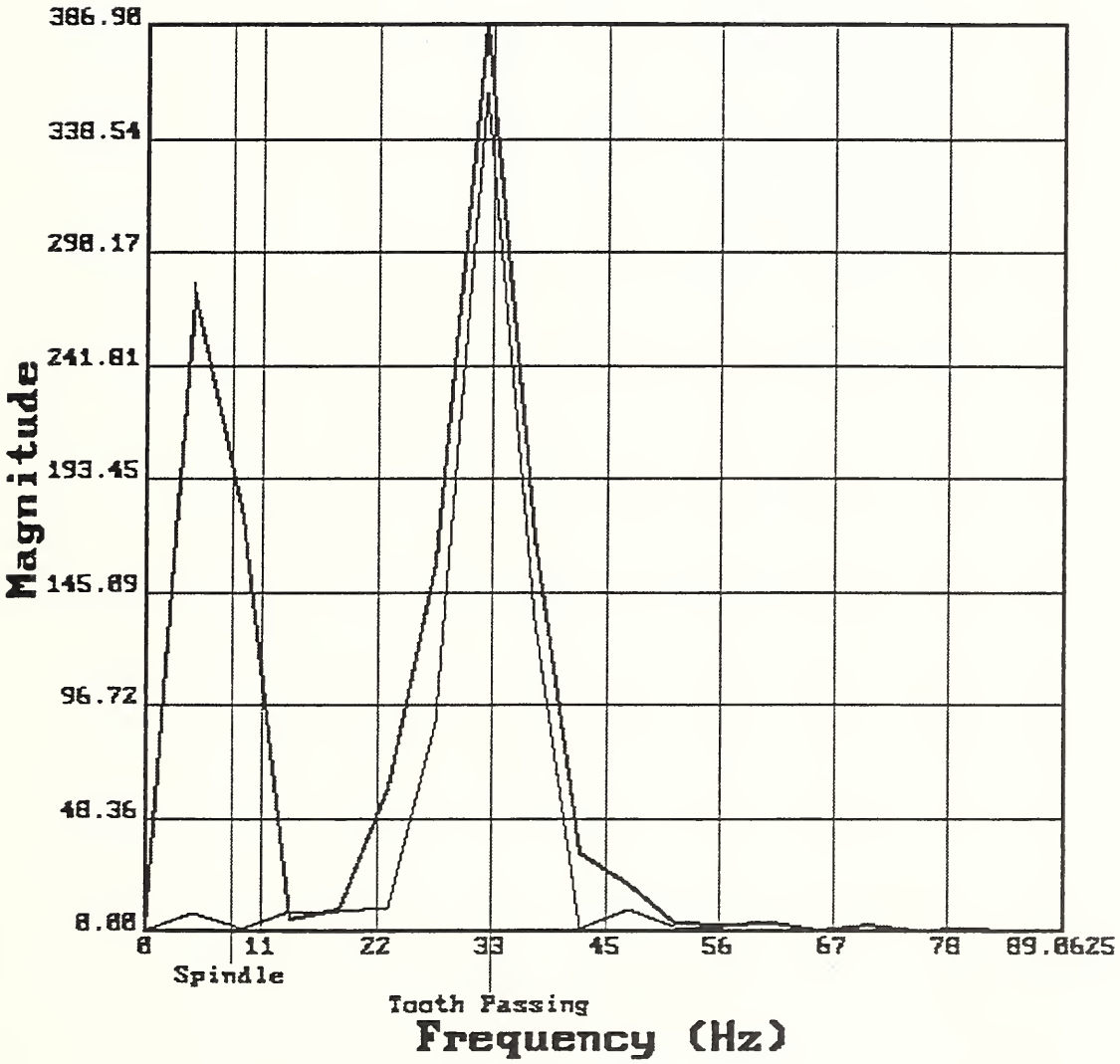
Warning : The values you entered will be updated only if you choose Update

Y-Force vs Cutter Rotation Angle

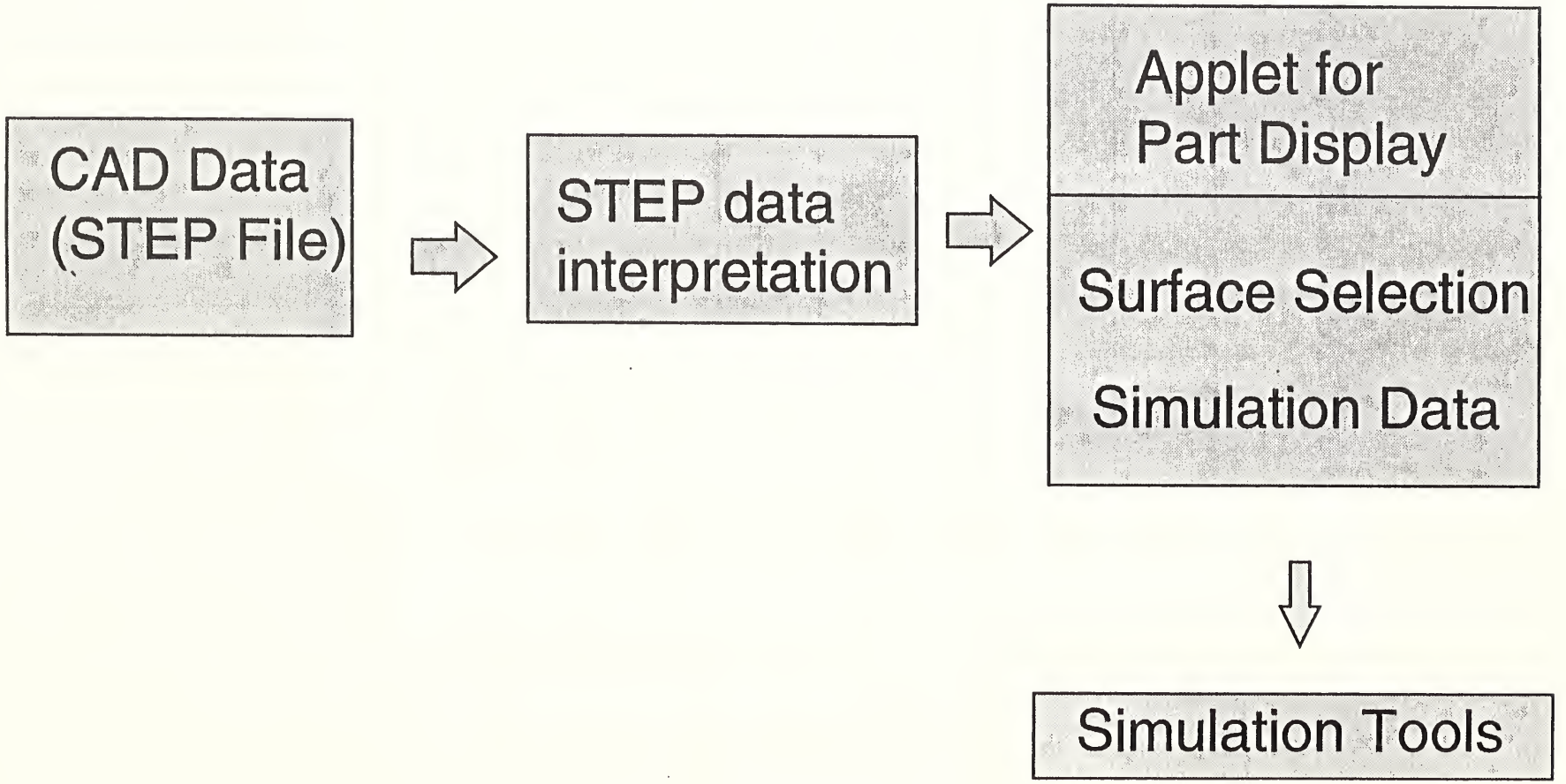



Power Spectrum of Y-Force
358.00
313.25
268.50
223.75
179.00
134.25
89.50
44.75
0.00
Magnitude
0
11
22
33
45
56
67
78
89.0625
Spindle
Tooth Passing
Frequency (Hz)

Power Spectrum of Y-Force



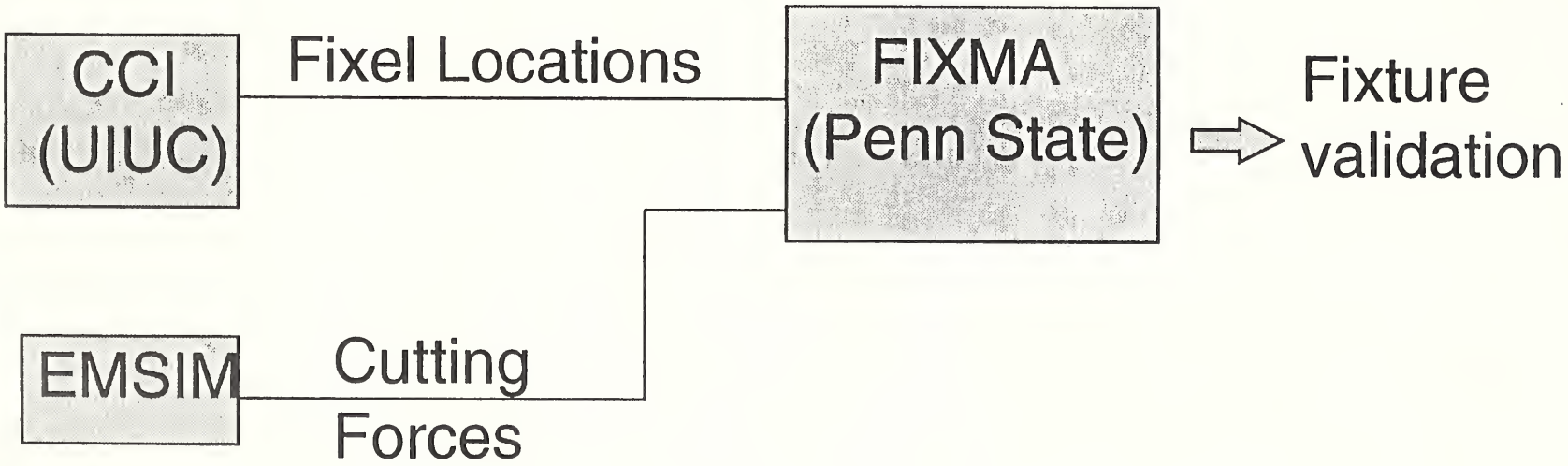
Common CAD Interface



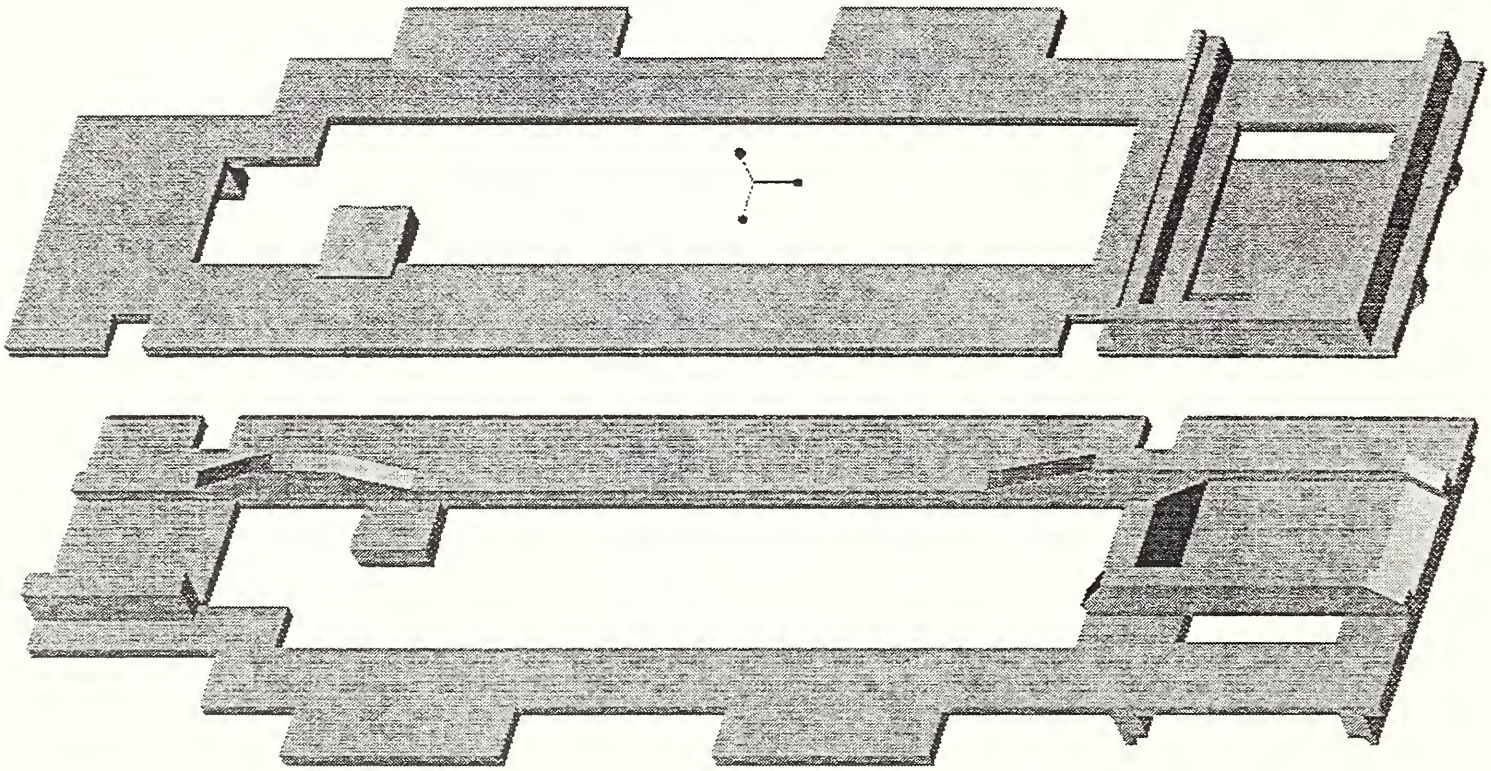
Part Fixturing

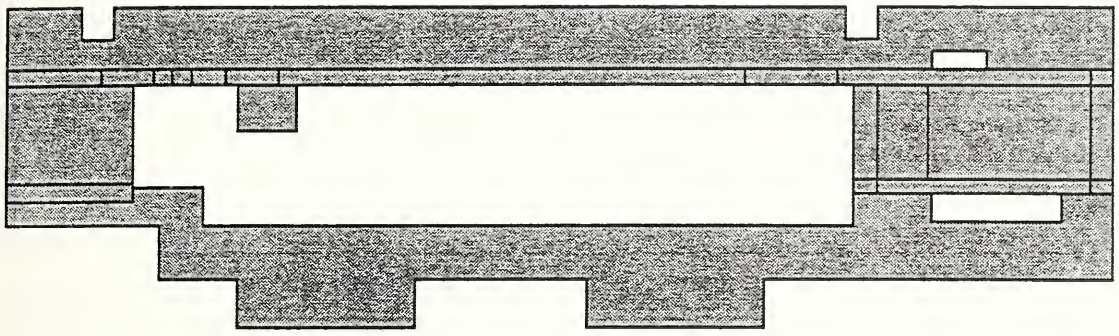
Fixturing:

- Kinematic Restraint
- Total Restraint
- Actuator Intensity

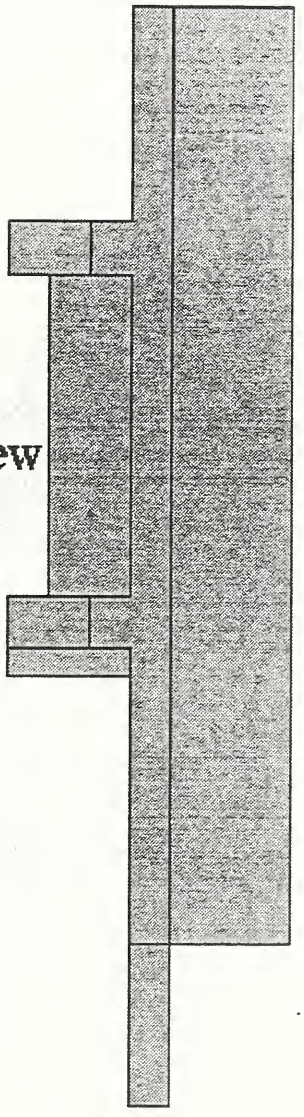


Kodak Case Study Part in Pro/Engineer



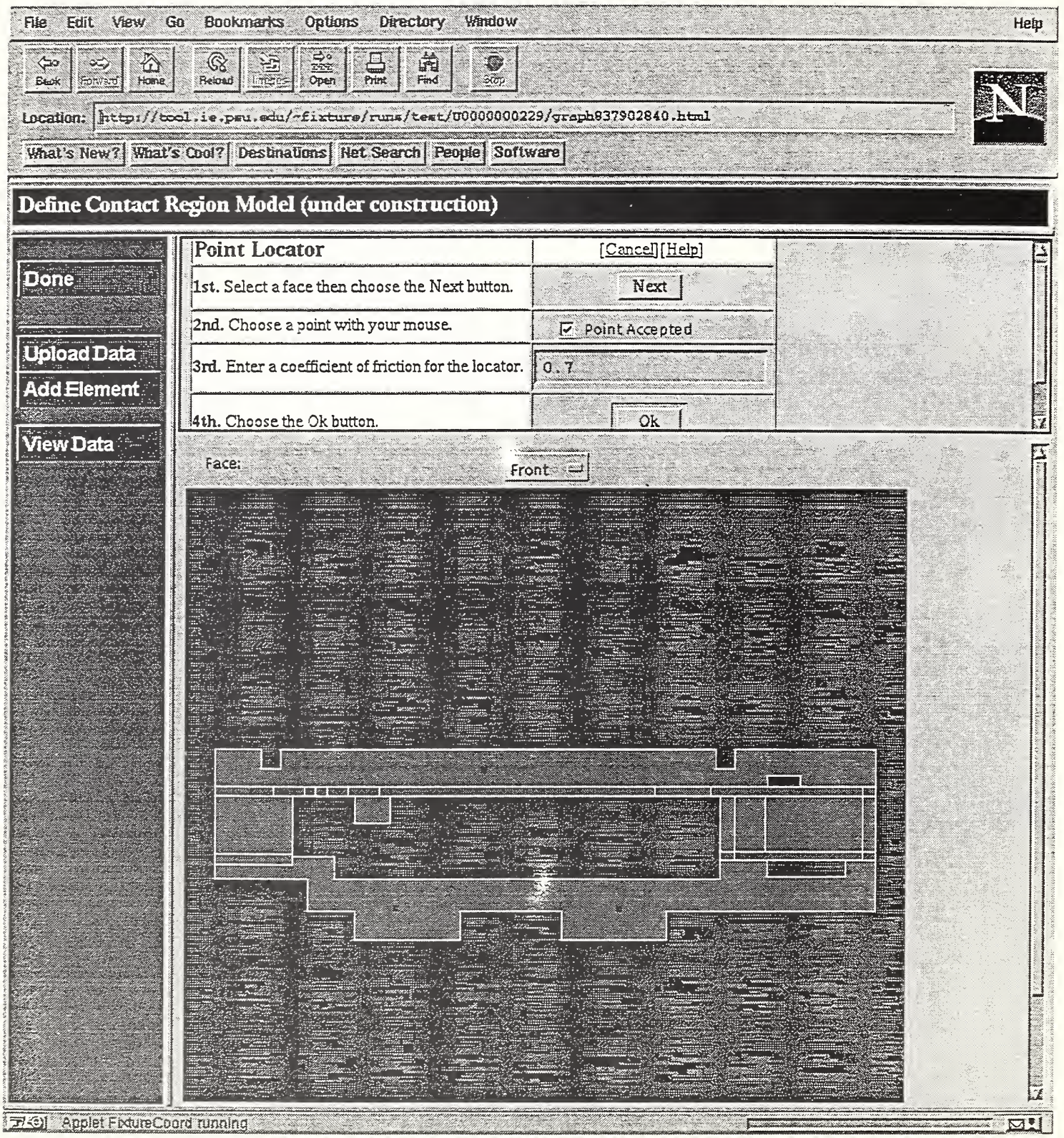


Bottom View

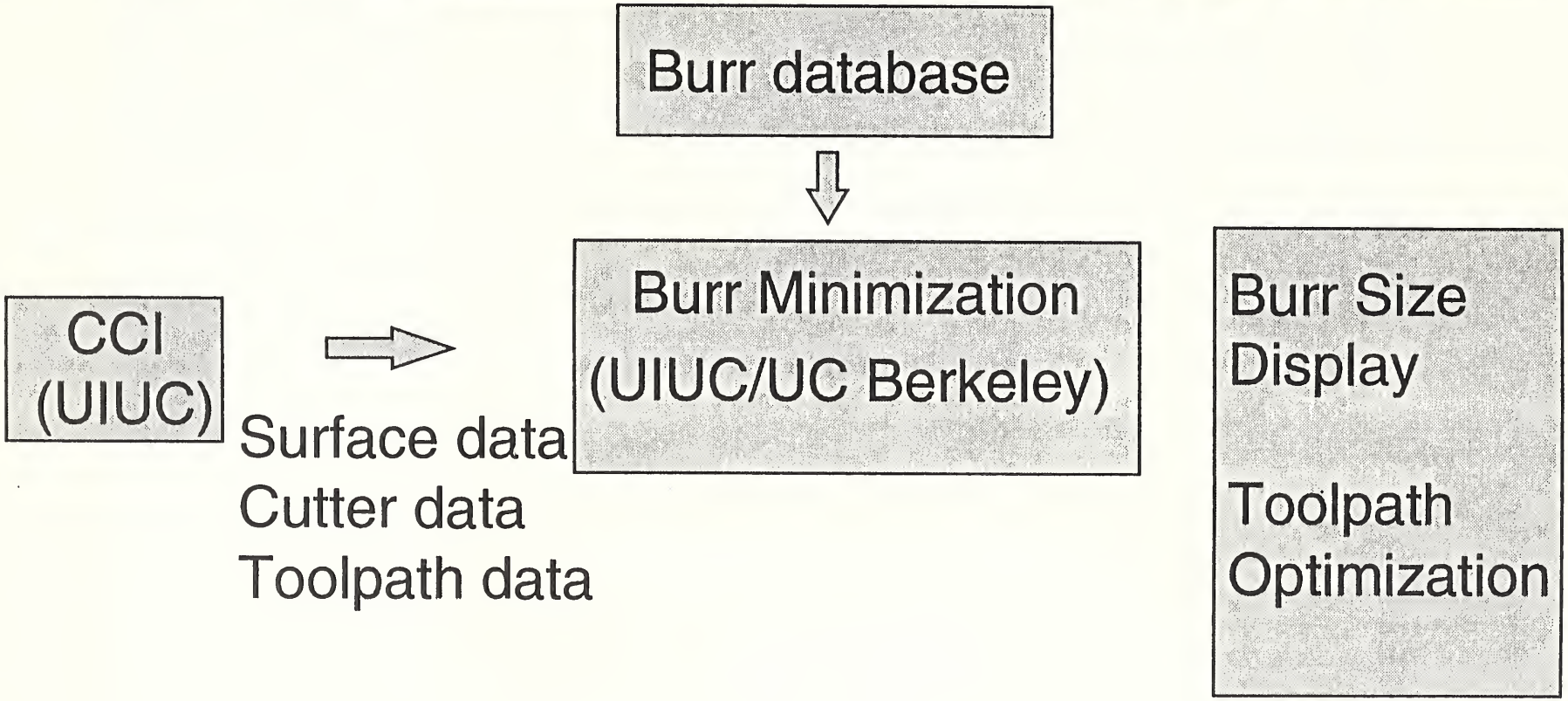


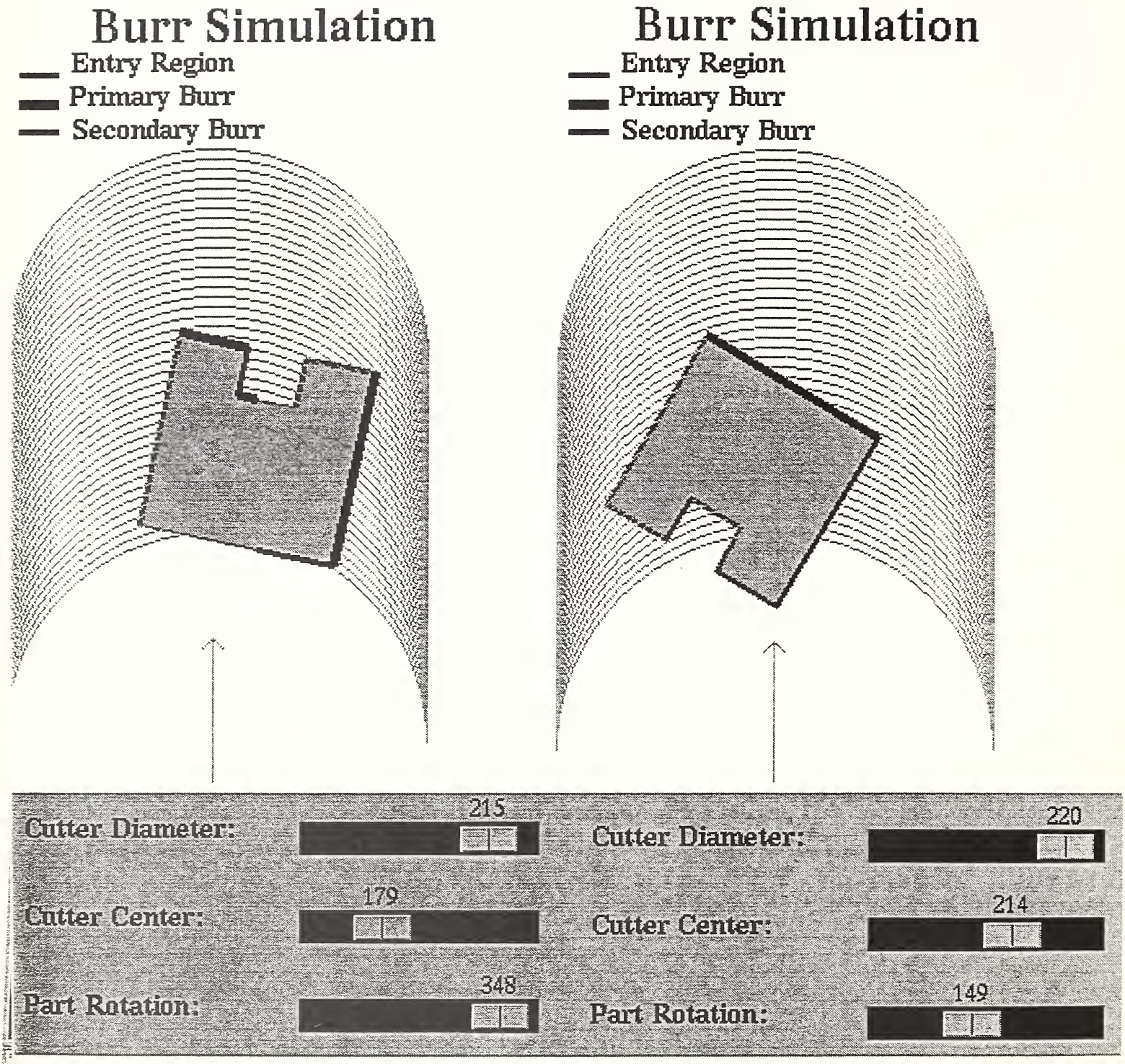
Left Side View

Back View


File Edit View Go Bookmarks Options Directory Window Help
Back Forward Home Reload Images Open Print Find Stop
Location: http://tool.ie.psu.edu/~fixture/runs/test/U0000000229/graph837902840.html
What's New? What's Cool? Destinations Net Search People Software
Define Contact Region Model (under construction)
Done
Upload Data
Add Element
View Data
Point Locator
[Cancel][Help]
1st. Select a face then choose the Next button.
Next
2nd. Choose a point with your mouse.
Point Accepted
3rd. Enter a coefficient of friction for the locator.
0.7
4th. Choose the Ok button.
Ok
Face:
Front
Applet FixtureCoord running

Edge Quality

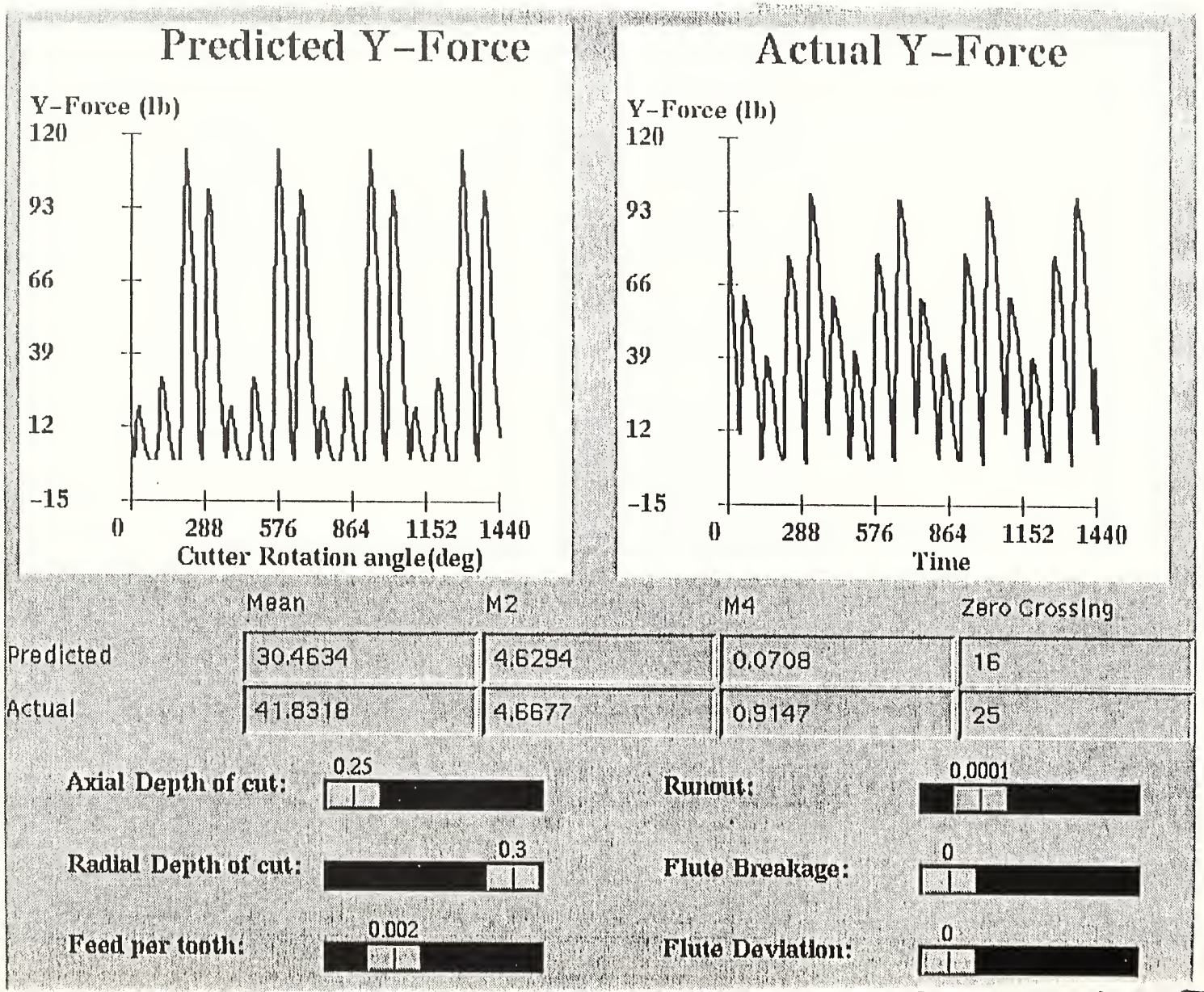



Burr Simulation
Entry Region
Primary Burr
Secondary Burr
Burr Simulation
Entry Region
Primary Burr
Secondary Burr
Cutter Diameter:
215
Cutter Center:
179
Part Rotation:
348
Cutter Diameter:
220
Cutter Center:
214
Part Rotation:
149

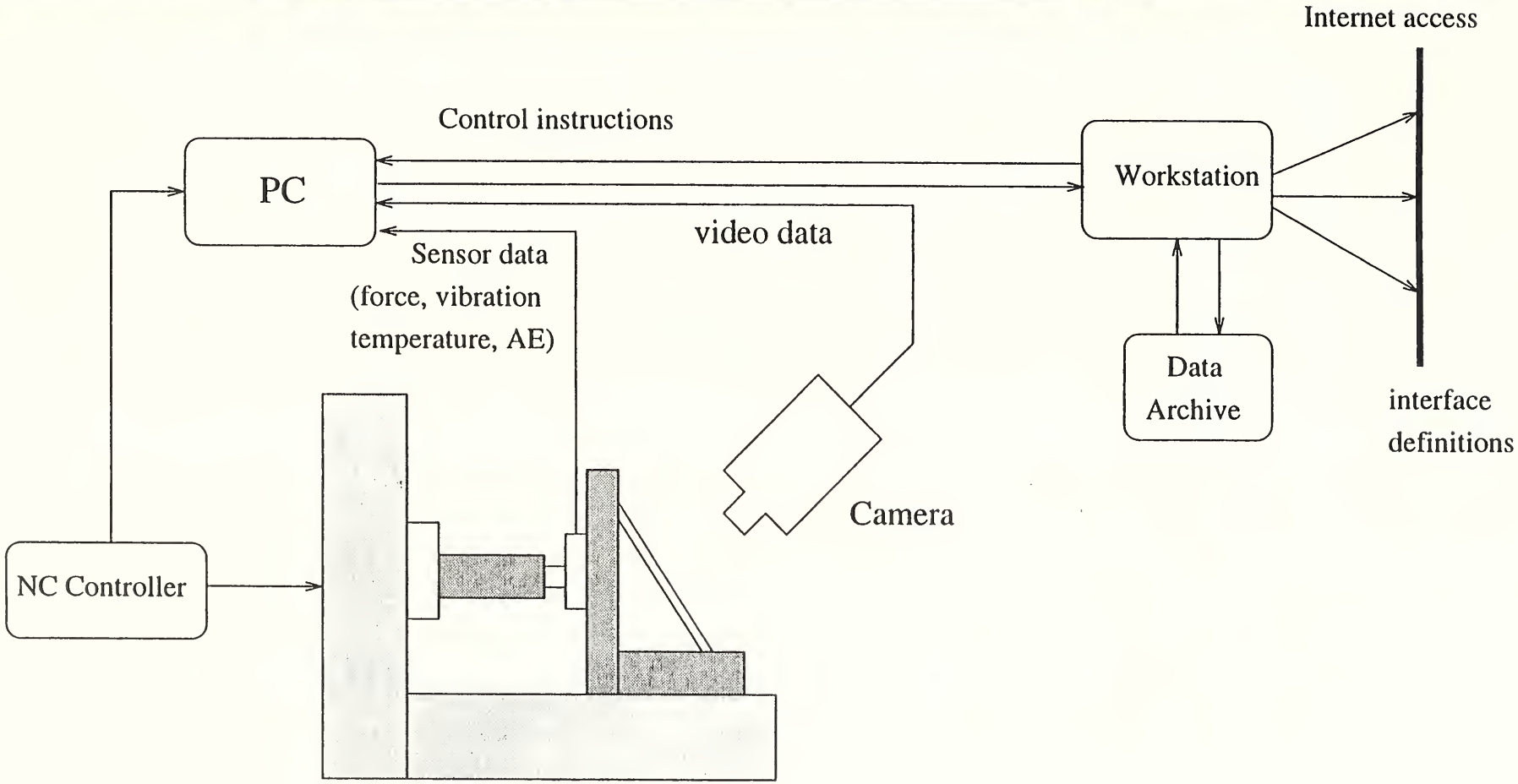
Integration of Machining Models

- Multi-objective optimization
- Prioritization
- Iterative strategies
- Design/tolerance changes

Process Monitoring for Fault Diagnosis



Telepresence/Hardware Testbeds



Experimental Machine Tool

National Industrial Information Infrastructure Protocols (NIIIP)

Mr. Tony Blazej, National Industrial Information Infrastructure Protocols (blazej@vnet.ibm.com)

The summary for this presentation can be found on page 60
24 full-page slides follow

National Industrial Information Infrastructure Protocols(NIIIP)

Enabling the Virtual Enterprise

A.J. (Tony) Blazej
Manager of Technology & Deployment
Email: blazej@ibm.net
URL: http://www.niiip.org

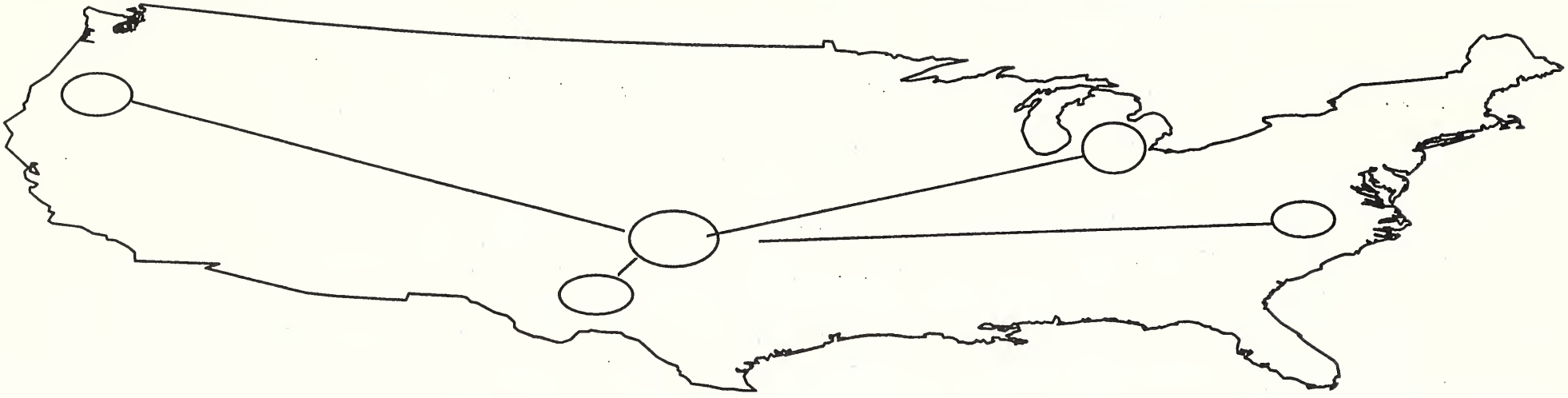
Purpose /Agenda

NIIIP
National Industrial Information Infrastructure Protocols

- **PURPOSE**
  - » Introduce the NIIIP Project
  - » Vision, Goals, and Objectives
  - » Deliverables/Contributions
- **Topics**
  - » NIIIP Overview--
    - – Enabling the Virtual Enterprise
  - » NIIIP Technologies--
    - – Origin, Application,Building Blocks
  - » Results to Date--
    - – Challenge Problems and Demonstrations
  - » NIIIP Application to the Manufacturing Community

The Virtual Enterprise

NIIIP
National Industrial Information Infrastructure Protocols

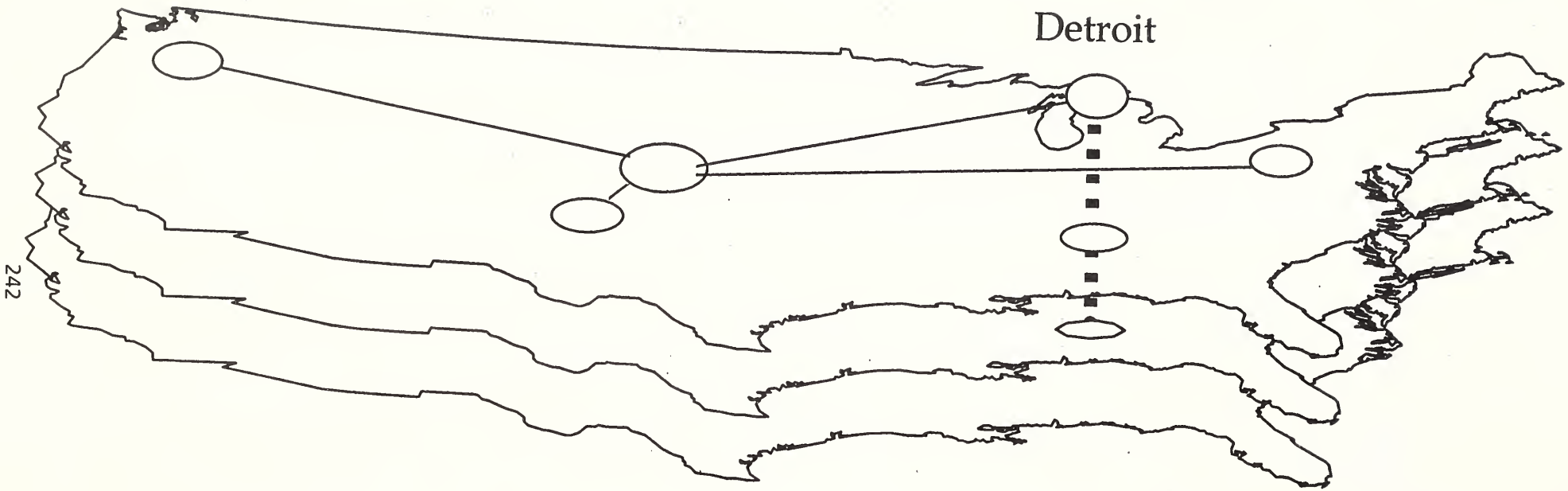


- Multiple distributed sites and multiple organizations
- Limited life span - rapid reconfiguration
- Heterogeneous processes, products, environments

- How can Virtual Enterprises
  - be established and operated?
  - deliver products and services to customers?

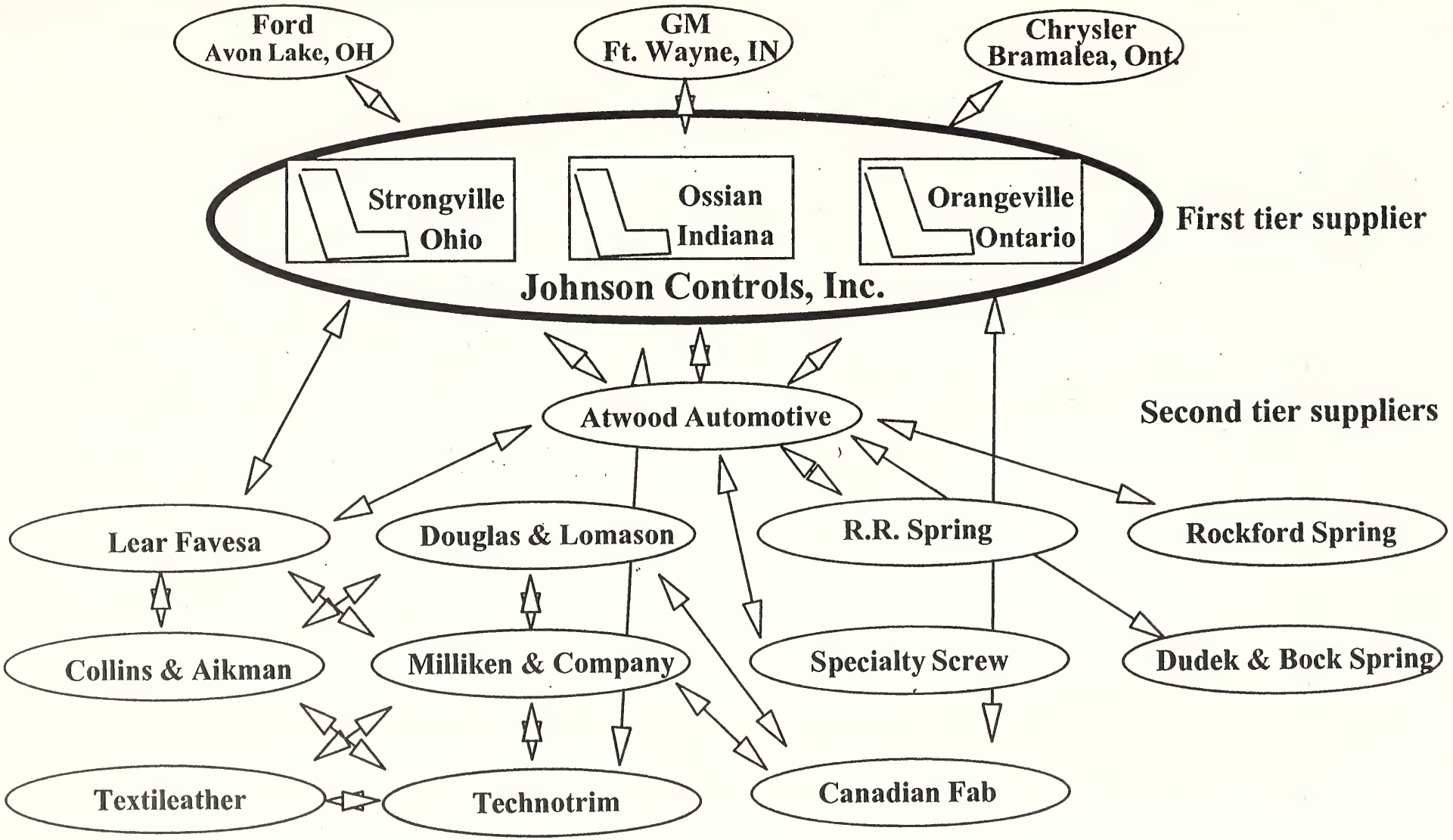
Virtual Enterprises

NIIIP
National Industrial Information Infrastructure Protocols



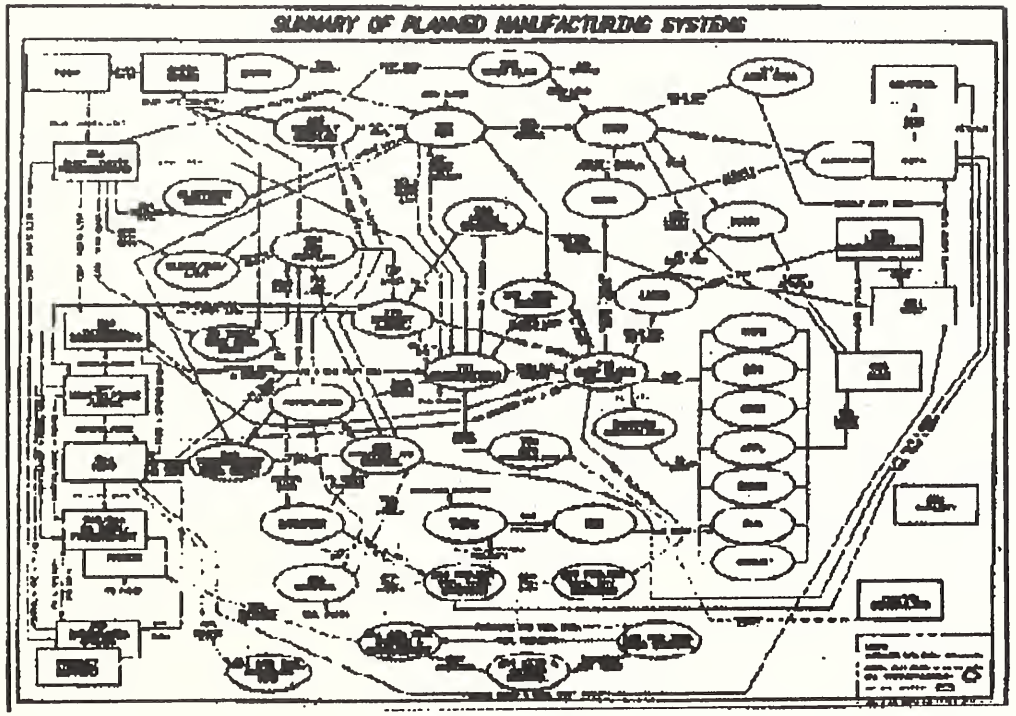
- One corporation can participate in many Virtual Enterprises
- Customers must be satisfied in all enterprises

Automotive Supply Chain--AIAG MAP



NIIIP National Industrial Information Infrastructure Protocols

Information Overload



- **Morass of Data**
  - » Massive Volumes
  - » Unprocessed Details
  - » Heterogeneous Forms
  - » Legacy Systems
- **Consequences**
  - » Manual Processing
  - » Unused Information
  - » Uninformed Decisions
  - » High Cost

Data Systems for One F-22 Manufacturing Site

NIIIP OVERVIEW

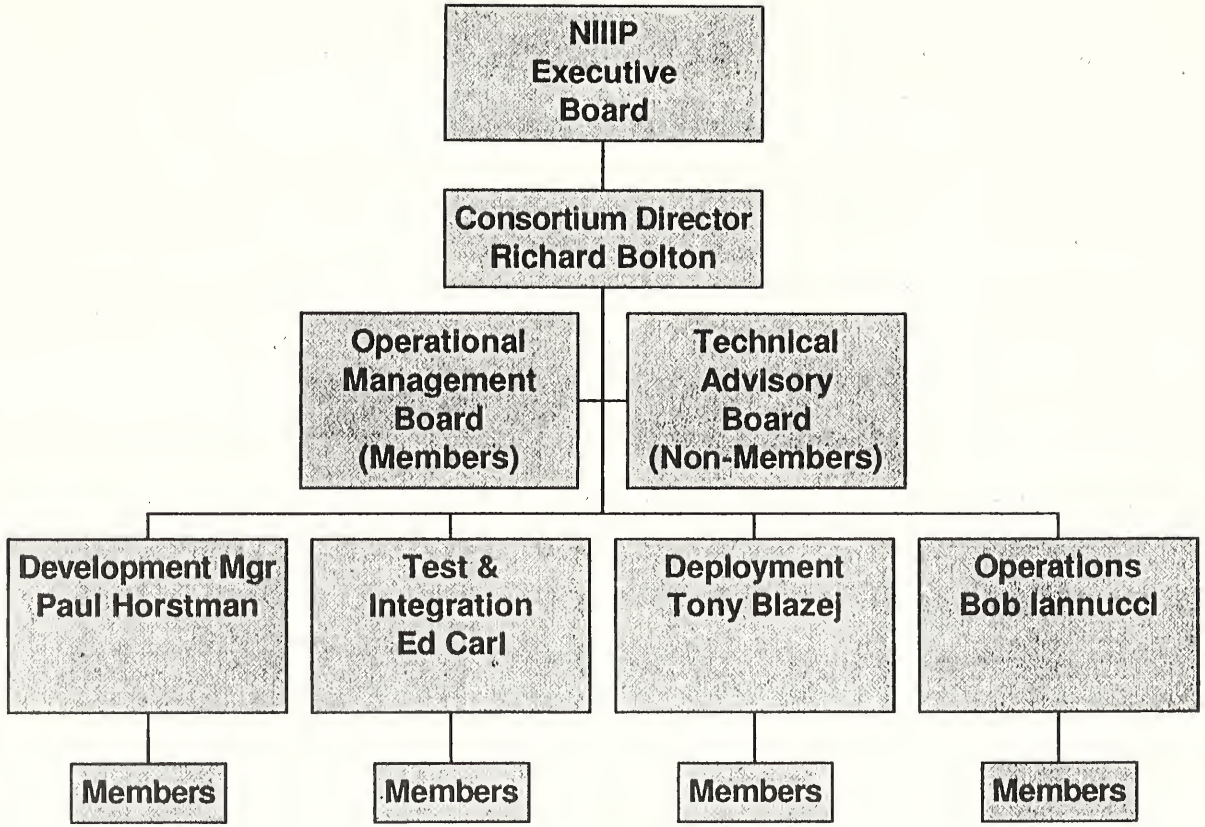
NIIIP National Industrial Information Infrastructure Protocols

- **WHAT IS NIIIP?**
  - » A Set of Industrial Information Infrastructure Protocols
    - – PROTOCOLS---Rules of behavior
  - » To enable Virtual Enterprises
    - – Interoperability of Heterogeneous data/processes/computing environments
- **Why NIIIP?**
  - » Market demand
  - » Failed efforts
    - – Single Company/Proprietary
  - » Multiple redundant efforts
- **Who is NIIIP?**
  - » A group of End-users, HW/SW Suppliers, Academia, Stds Orgs
  - » Common Interests in Enterprise Integration
  - » Pre-existing relationships
- **Committed**
  - » Financially--Skills--Resources

NIIIP MEMBERS/CONTRIBUTIONS

NIIIP MEMBER	COMMUNITY	CONTRIBUTION
Lockheed F 22	End User	Challenge Problem
Genl Dyn-EB	End User	Challenge Problem
Magnavox	End User	Challenge Problem
DEC	HW/SW Vendor	CORBA-Object Broker
IBM-SWS	SW Vendor	CORBA-SOM/DSOM/WF
IBM-NS	SW Vendor	Agents/Transport
IBM-Mfg Ind	HW/SW Vendor	Data Locator/Applic Locator
IBM-Micro Elec	SW Vendor	Task/Session
STEP Tools	SW Vendor	STEP
UES	SW Vendor	Workflow
ITI	SW Vendor/ Syst Integrator	Data Integration, IGES, STEP, Data Bridges
EIT	SW Vendor	Internet Tools/Agents
Univ of Florida	Academia	KBMS
RPI	Academia	STEP
CAD FW Initiative	Stds Orgn	Task/Session
NIST	Stds Orgn	STEP

NIIIP Governance

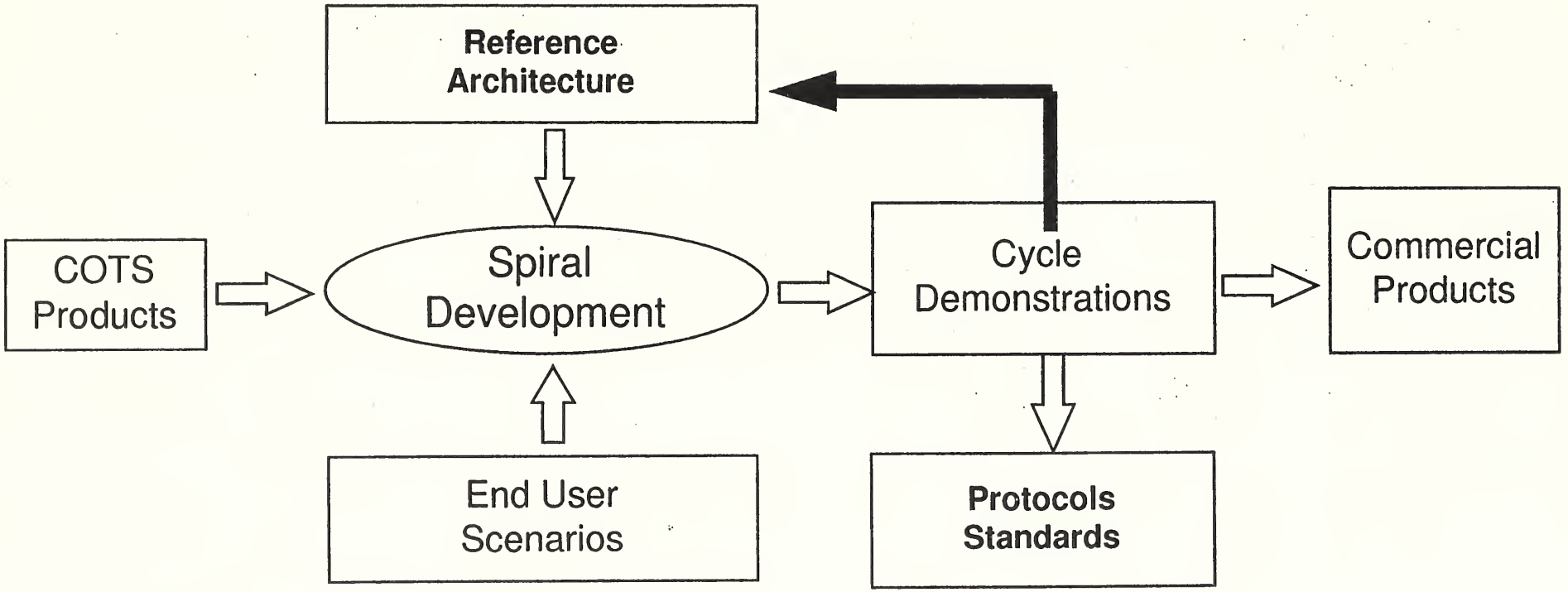


NIIIP OVERVIEW

NIIIP National Industrial Information Infrastructure Protocols

- **NIIIP VISION, GOALS, AND OBJECTIVES**
  - » Enable VE's
    - – INTER and INTRA Company/Organization
  - » Build from existing, emerging, defacto standards
    - – Invent only where necessary
  - » Open Architecture
    - – Products are not Protocols
  - » Preserve existing IT investments
    - – Legacy Systems
  - » Commercialize the results
    - – NIIIP Enabled Commercial Products
  - » Enhance/Extend existing standards
    - – Insure continuity and Consistency

NIIIP Processes

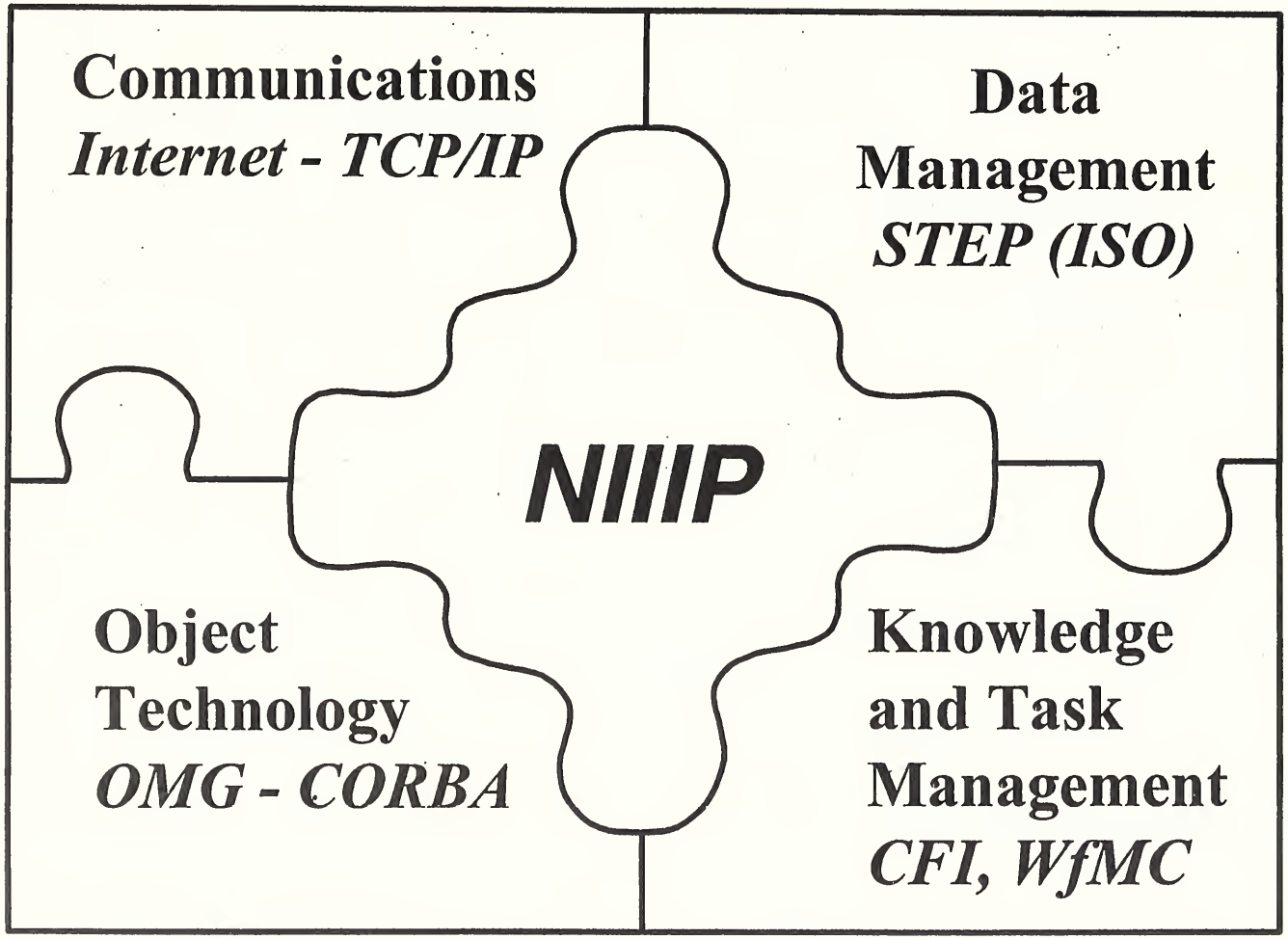


NIIIP OVERVIEW

NIIIP
National Industrial Information Infrastructure Protocols

- **NIIIP Processes**
  - » **Reference Architecture**
    - – Published
  - » **Scenario Driven**
    - – End User Driven
  - » **Reference Implementation**
    - – NIIIP Protocols on COTS Products
  - » **Spiral Development**
    - – Incremental Risk
  - » **Standards submissions**
    - – OMG and ISO STEP in process
  - » **Deliverables**
    - – Reference Architecture
    - – Reference Implementation
    - – Demonstrations

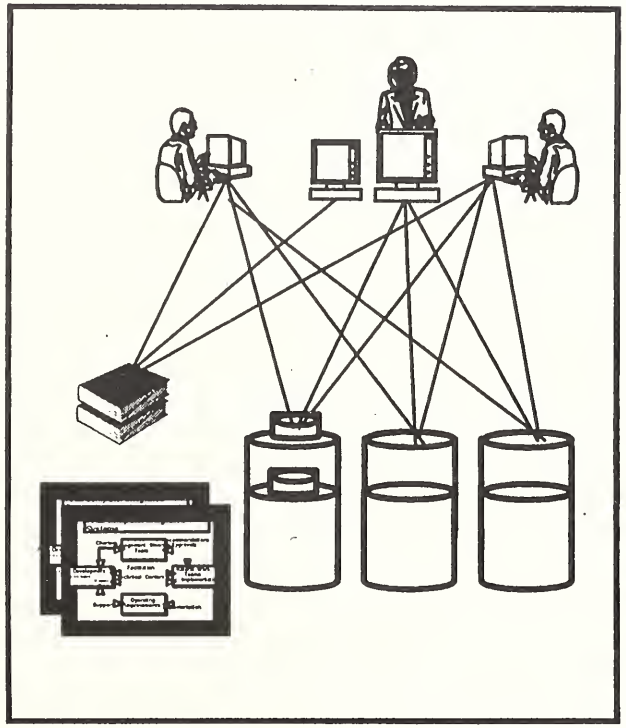
Basic Building Blocks



NIIIP Architecture Alternatives

NIIIP National Industrial Information Infrastructure Protocols

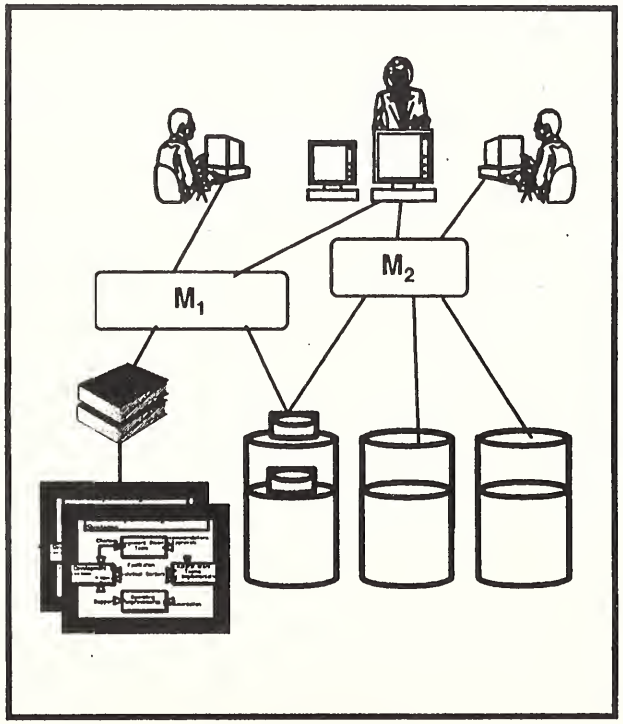
Point-to-Point



One "Integration" Module per Application

$(N_{MODULES} = N_{APPS})\ N_{APPS})$

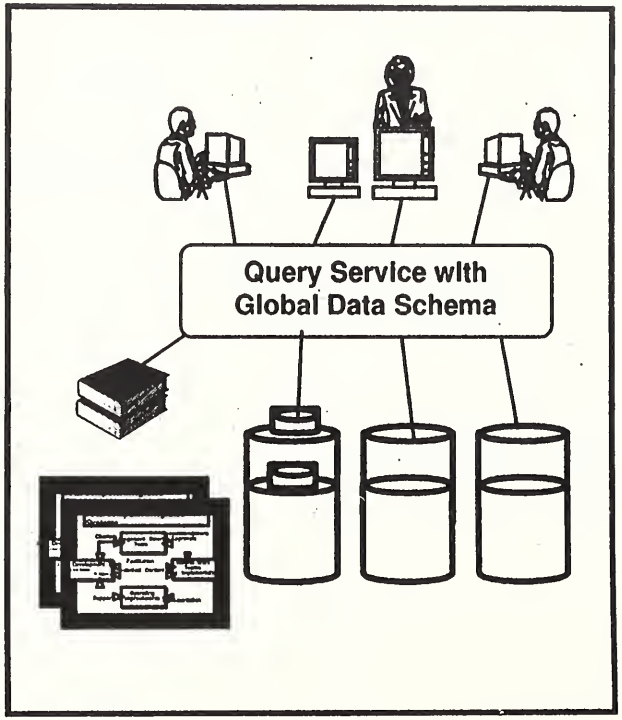
Mediated



One Mediation Module per Domain

$(N_{APPS} > N_{MODULES} > 1)$

Fully Integrated



One, Global, Integration Module

$(N_{MODULES} = 1)$

NIIIP Mediated Architecture

Application Interoperation

NIIIP Services

Unprocessed, Unintegrated Details

User Applications

KBMS

Mediator

Mediator

Wrapper

Wrapper

SQL

ORB

Text, Images/Video, Spreadsheets

Hierarchical & Network Databases

Relational Databases

Object & Knowledge Bases

Heterogeneous Data Sources

NIIIP Services

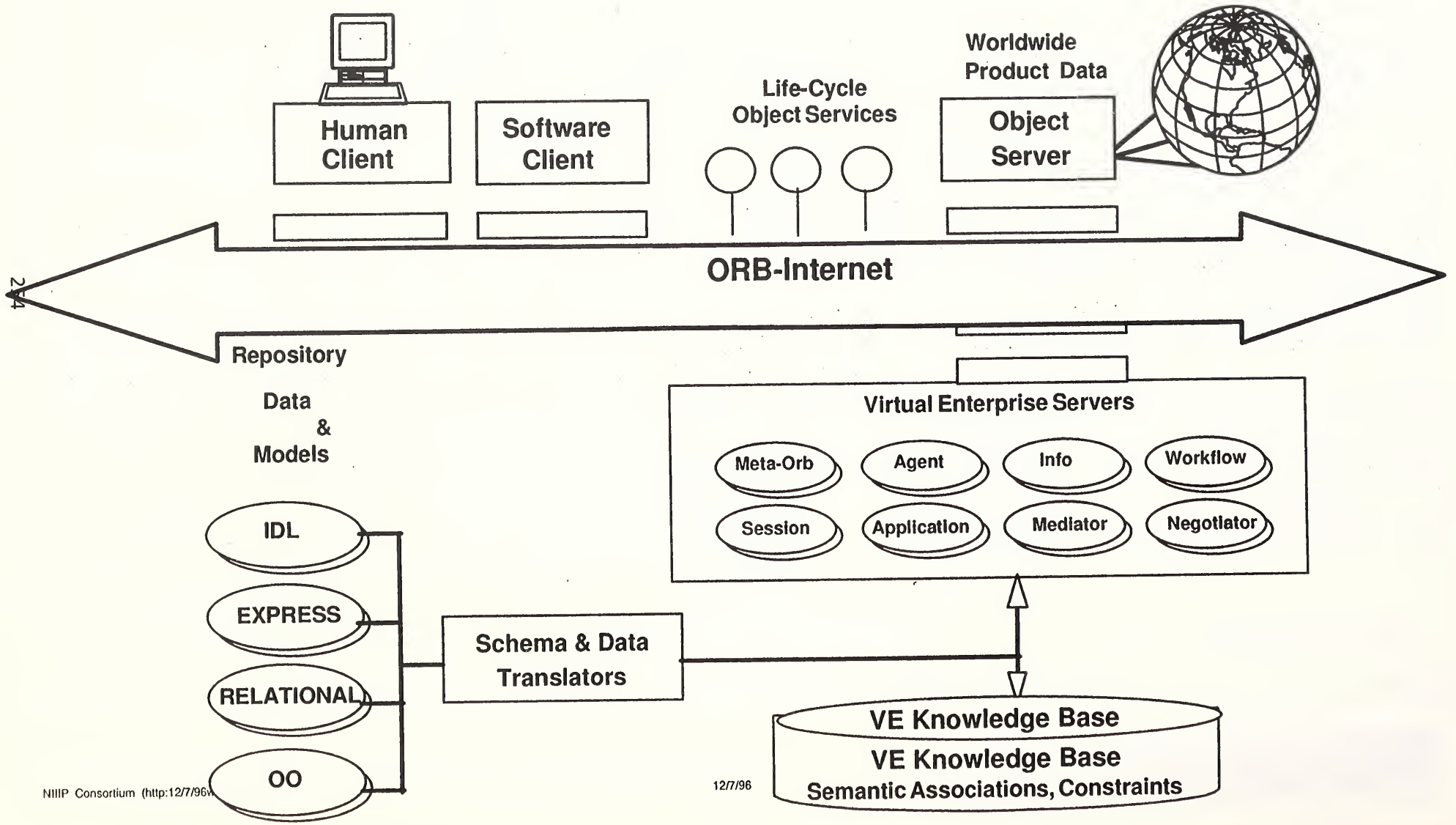
Agent Coordination & Management

Semantic Integration & Abstraction

Data Wrapping, Accessing & Restructuring

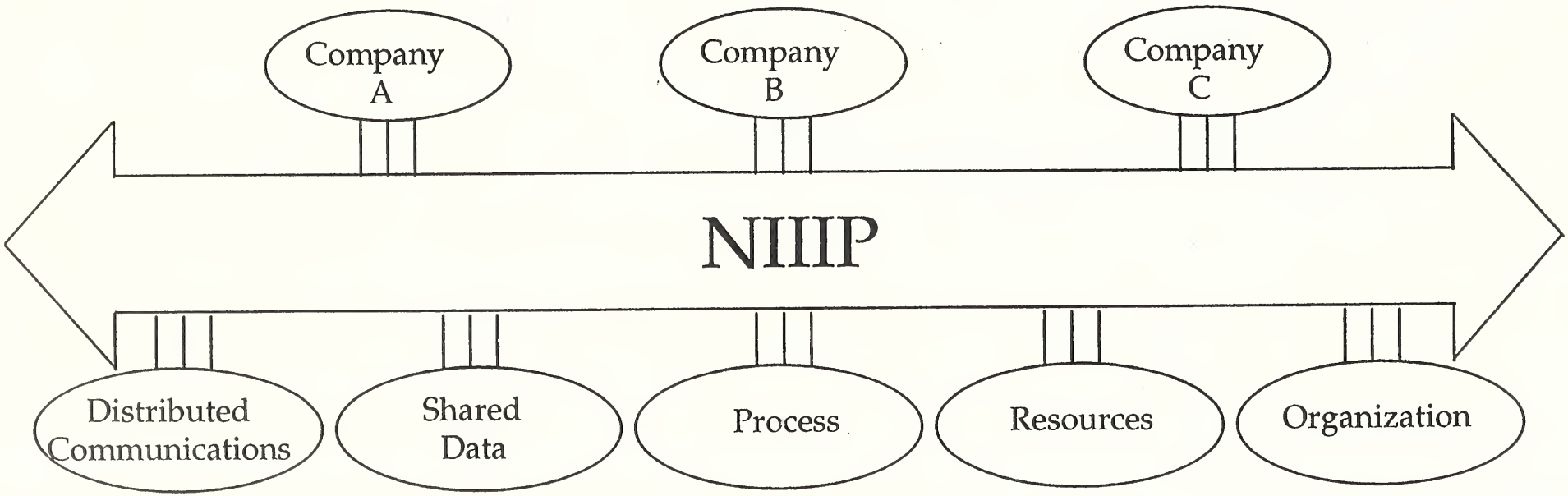
NIIIP Consortium (http:12/7/96www.niiip.org)

NIIIP Reference Architecture



NIIIP "Plug and Play"

- Traditional Plug and Play:
  - » Application <-> application, eg. CFI, CDE
  - » Hardware <-> hardware, eg. EISA, PCI, ISA, etc.
- Corporate Plug and Play:
  - » Company <-> company, Standards based

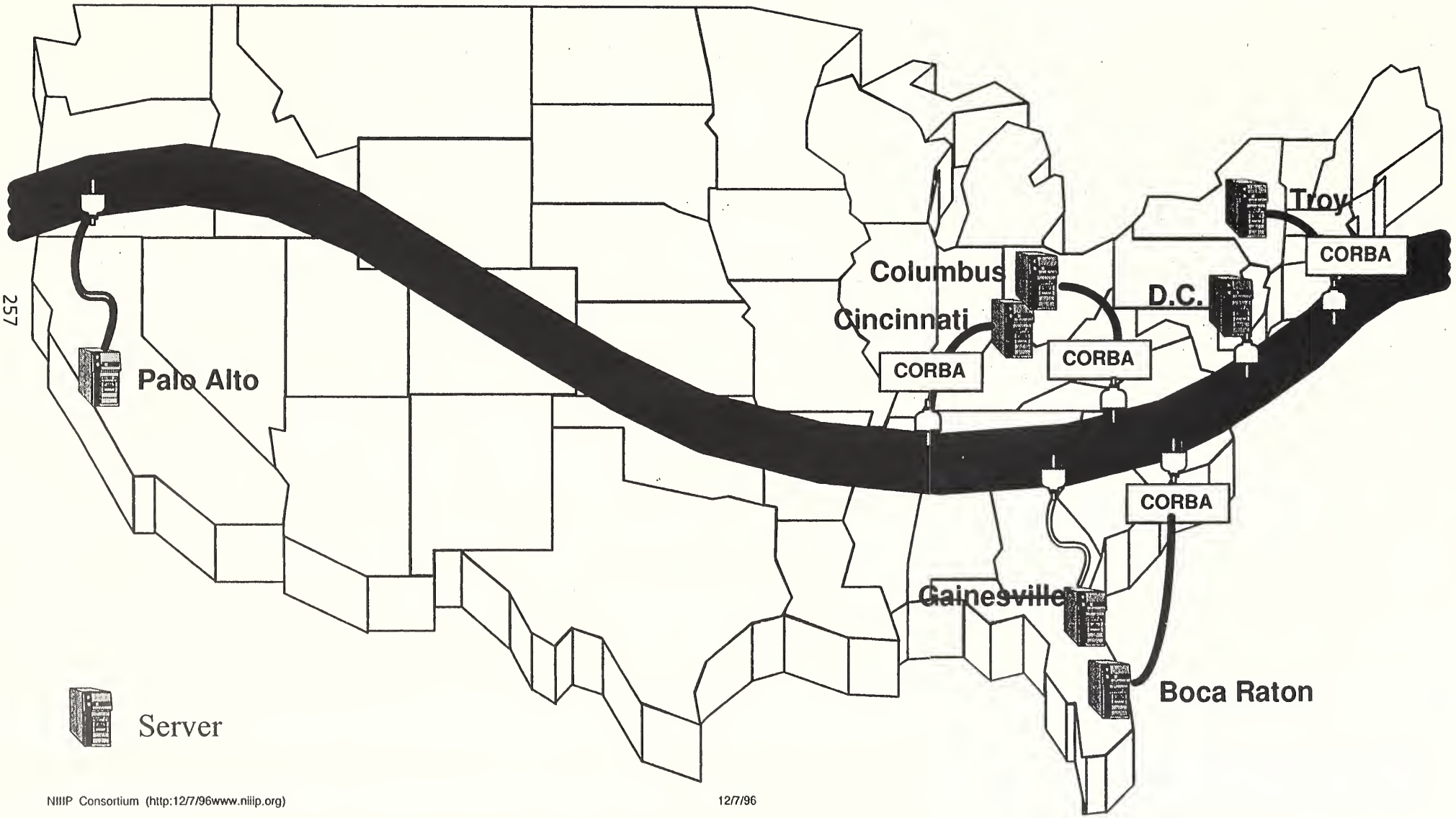


NIIIP SPIRAL DEVELOPMENT

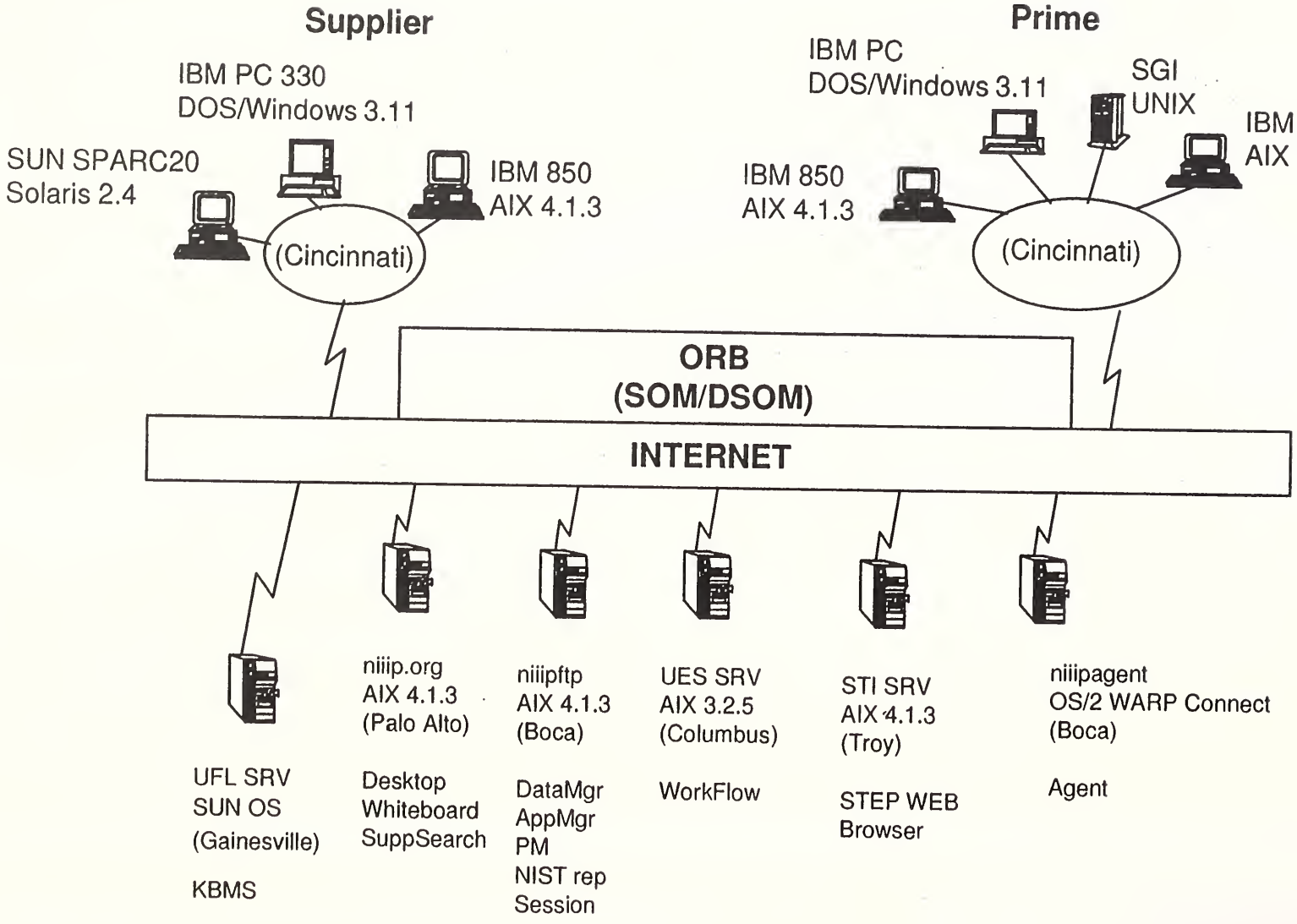
NIIIP
National Industrial Information Infrastructure Protocols

- **Cycle 0 Start Up 9/94--3/95**
  - » Reference Architecture
  - » Cycle 1 End User Scenarios/Cycle 1 Development Plan
  - » Cycle 0--NIIIP as a VE(Whiteboard/Workflow/Document Management)
- **Cycle 1 Baseline 4/95--9/95**
  - » Collaborative Design
  - » Desktop/Workflow/Transport/Data Mgmt/Applic Mgmt/Internet/STEP
- **Cycle 2 Extensions 10/95--6/96**
  - » Heterogeneous Environment
  - » VE Knowledge base/Mediators
- **Cycle 3 Full NIIIP Cycle 7/96--6/97**
  - » Mediated Architecture
  - » Full Protocols

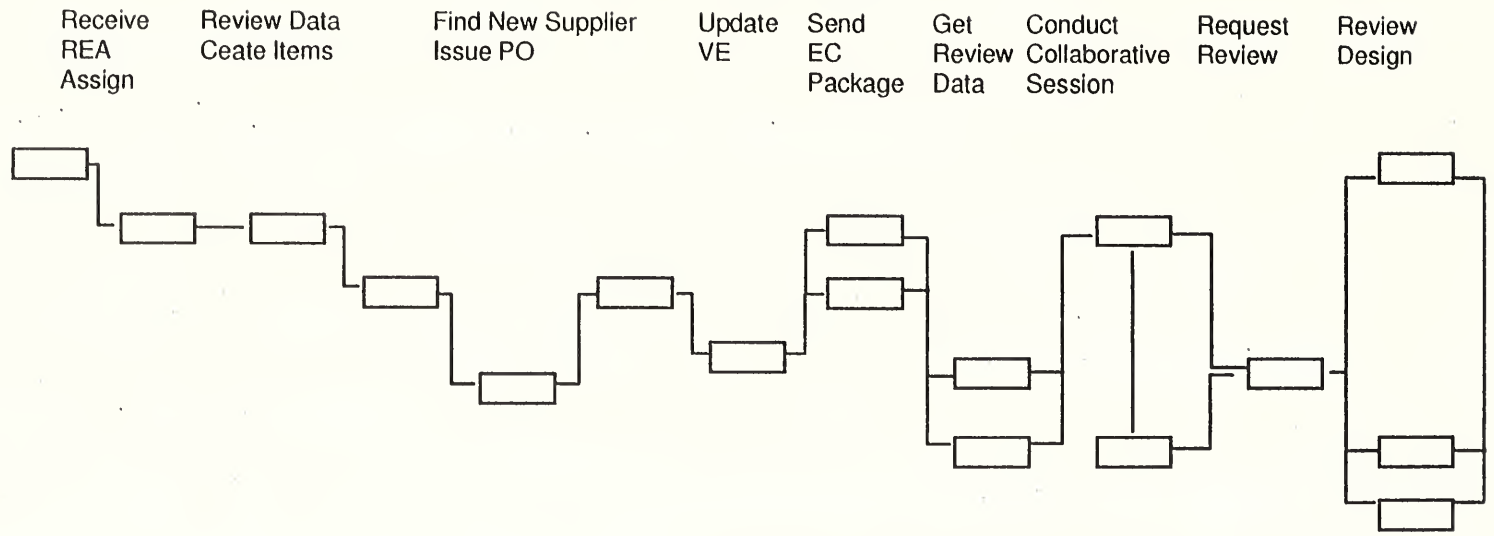
Test System Geography



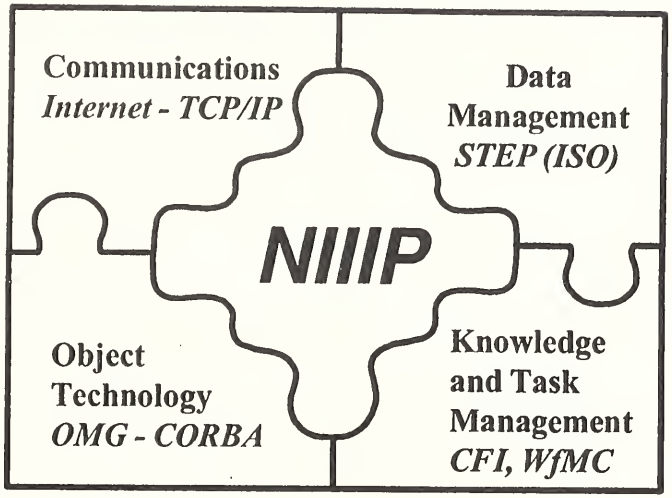
Test System Infrastructure



Demonstration Process Flow



Accomplishment Summary



- OMG's CORBA over the Internet
- STEP/CORBA bindings for level I data
- WWW Desktop access to VE tools, tasks, and data
- Task Management core protocols implemented
- Existing applications enabled via NIIIP protocols
  - » Mercator
  - » AutoCAD
  - » SPDS
  - » ProductManager
  - » STEP/Works
  - » CATIA
- Impacted other standards
  - » OMG
  - » STEP
  - » CFI
  - » WfMC

NIIIP Overview

- **NIIIP UNIQUES--Programmatic**
  - » Customer Scenario Driven
  - » Consortium Management Structure
  - » Technical Advisory Board
  - » Affiliates Program
    - – CALS, PDES Inc, OMG, OAG, AIT
  - » "Harvesting" Technology
    - – ARPA I3, Agile Manufacturing, MADE
- **NIIIP UNIQUES--Technical Approach**
  - » Permissive as opposed to Prescriptive
  - » Loosely Coupled as opposed to Tightly Coupled
  - » Mediated in addition to Integrated
  - » Rules in addition to API's
  - » Process as opposed to Transaction

NIIIP Success Criteria

NIIIP
National Industrial Information Infrastructure Protocols

- **NIIIP PHASE 1 9/94--12/97**
  - » TECHNICAL--80%
    - – Publish Reference Architecture
    - – Reference Implementations
    - – Demonstrate toolkits/integration
    - – Submit Standards
  - » DEPLOYMENT--20%
    - – Endorsement by Pilots/Follow on Commitments
    - – Forum/Conference Activity
- **NIIIP PHASE 2 1/98--12/99**
  - » TECHNICAL--40%
    - – Standards Acceptance
    - – Full NIIIP VE Capability
  - » DEPLOYMENT--60%
    - – Enabled Commercial SW
    - – Support Infrastructure
    - – Operational NIIIP based VE's

The National Advanced Manufacturing Testbed: NAMT Framework for Discrete Parts Manufacturing

Dr. Edward Barkmeyer, NIST (edbark@nist.gov)
(presentation on behalf of Mr. Neil Christopher, NIST (neilc@nist.gov)

The summary for this presentation can be found on page 62
5 full-page slides follow

NAMT Framework for Discrete Parts Manufacturing

PDES Inc. Offsite Meeting

Palm Springs, CA

September 25, 1996

Neil Christopher
National Institute of Standards and Technology
Manufacturing Engineering Laboratory
neilc@nist.gov or 301.975.3888

NAMT

Problem Statement

- Project Contribution
  - Analysis, implementation, and validation testing of consortia specifications for NIIIP, TEAM, & Sematech.
  - Development of specification validation testbed.
  - Development of "gap" information models for inspection operations (STEP AP219).
  - Specification standardization in ISO and OMG.
  - Enterprise representation to establish relationships between specifications.

Technical Approach

- Statement of Work Summary
  - Build specification validation testbed for inspection
    - Inspection operations in FY96
    - Hexapod operations in FY97
    - Wide area distributed systems in out years.
  - Analyze and implement consortia specifications
    - Sematech, NIIIP, TEAM in FY96
    - ATP and others in out years.
  - Feedback results to consortia.
    - Sematech Focus Groups, NIIIP Architecture, TEAM Thrusts
  - Work on formal standardization of specifications.
    - ISO STEP, ISO Enterprise Integration, OMG MfgTF

Technical Approach

- Typical System Execution Scenario
  - Factory job is initiated via Guardian User Interface.
  - Shop Controller retrieves lot information from Production Information Base.
  - Shop Controller retrieves routing from Product Data Manager.
  - Shop Controller sends task to Workcell Controller.
  - Workcell Controller initiates hierarchical control of Coordinate Measuring Machine.
  - Simulation of operations using TGrip.
  - Video link to CORDAX CMM operations over ATM

Framework Component System Diagram — 1997