Pegasus: e-Design and Realization System

National Science Foundation
Industry/University Cooperative Research Center for e-Design: IT-Enabled Design and Realization of Engineered Products and Systems

By

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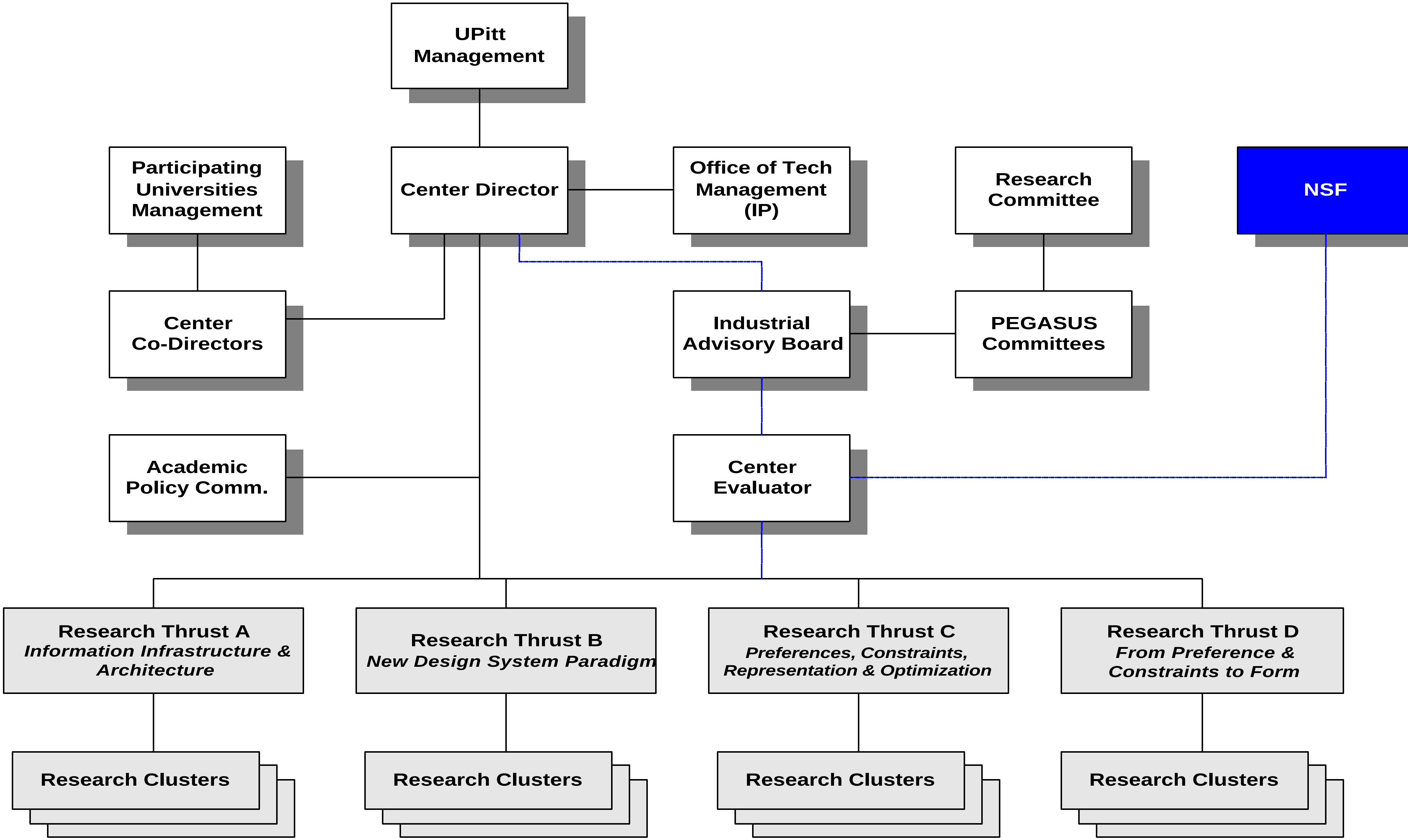
University of Pittsburgh

Structure/Organization of Center



Academic Partners

University of Pittsburgh

- Department of Industrial Engineering
- Department of Mechanical Engineering
- Department of Material Science Engineering
- Department of Computer Engineering
- Department of BioEngineering

University of Massachusetts at Amherst

- Department of Mechanical and Industrial Engineering
- Department of Computer Science

Carnegie Mellon University

- Robotics Institute
- Center for e-Commerce

Sample Partners of Center

INDUSTRIAL

- GE
- Rolls-Royce
- Ford
- TelAixs™
- ALCOA
- GM
- Apprentice Systems Inc.
- RESPIRONICS
- CATERPILLAR®
- ANSYS INCORPORATED
- BOEING
- Pratt & Whitney, A United Technologies Company
- PTC
- LOCKHEED MARTIN

FEDERAL

- Department of Defense, United States of America
- NASA
- NIST, National Institute of Standards and Technology
- NSF

ACADEMC

- University of Pittsburgh
- Carnegie Mellon
- UMASS.

e-Design Center Motivation

- Discrete mechanical products:
  - ➔ $1 trillion in U.S. revenues per year
- 70 - 80% of product's acquisition costs committed at design time
- Government and consumers need faster and cost effective product acquisition
- Industry needs to respond quickly with cost effective, high quality products
- E.g. Automotive design cycle now 36 – 48 months:
  - ➔ needs to be 12 months
- Internet-based design studio will achieve this
- Physics-based virtual prototyping will significantly reduce complex product design and realization time

Industry Technology Needs

- Design paradigm that is virtual service oriented with plug-and-play capability
- Interoperability among heterogeneous systems
- Collaboration among stakeholders (e.g. suppliers)
- Remote and distributed design via Internet
- Functionality-based conceptual design
- From concept to form
- Direct constraint imposition
- Multidisciplinary constraints
- Scalable, flexible and efficient platform

Industry Technology Needs (Contd.)

- Agent-based models for simulation
- Operation Research-based Optimization tools
- Virtual product prototyping with Physical laws realization

Research Areas

Research Thrusts and Clusters

- Information Infrastructure & Architecture
  - Information Management
    - Communication Protocols
    - Collaboration Methods
    - Information Representation
    - Information Repository
    - Security & Accessibility
    - Intellectural property rights
  - Transition/Migration Strategy
- Conceptual Design Tools
  - New Design Process
    - Design Cycle
    - Product decomposition
    - Uncertainty & risk management
    - Incentive structures
    - Design Information Representation
  - Design Tool Interfaces
    - Design Simulation
    - Human/Computer Interface
- Multidisciplinary Constraint Management & Optimization
  - Design Representation
    - Setting of Standards
    - Knowledge Representation&Retrieval
  - Preferences
  - Constraints
  - Conflict Resolution
  - Optimization
- Virtual Prototyping & Simulation
  - From function to form
  - Visualization tool
  - Virtual test & simulation
  - Virtual Prototyping

New Design System Views

- **Functionality-based design and reasoning**
- **New networking capabilities** to reduce design cycle times
- **Systematic product decomposition** for effective distributed product development
- **Definition of specification** for the decomposition elements
- **Product data management** in the supply network

Design Data Presentation

- Form generation
- Functionality embodiment and product behavior tests
- Computer visualization
- Human/computer interaction
- Design reasoning
- Semantics
- Modeling accuracy, precision, and resolution

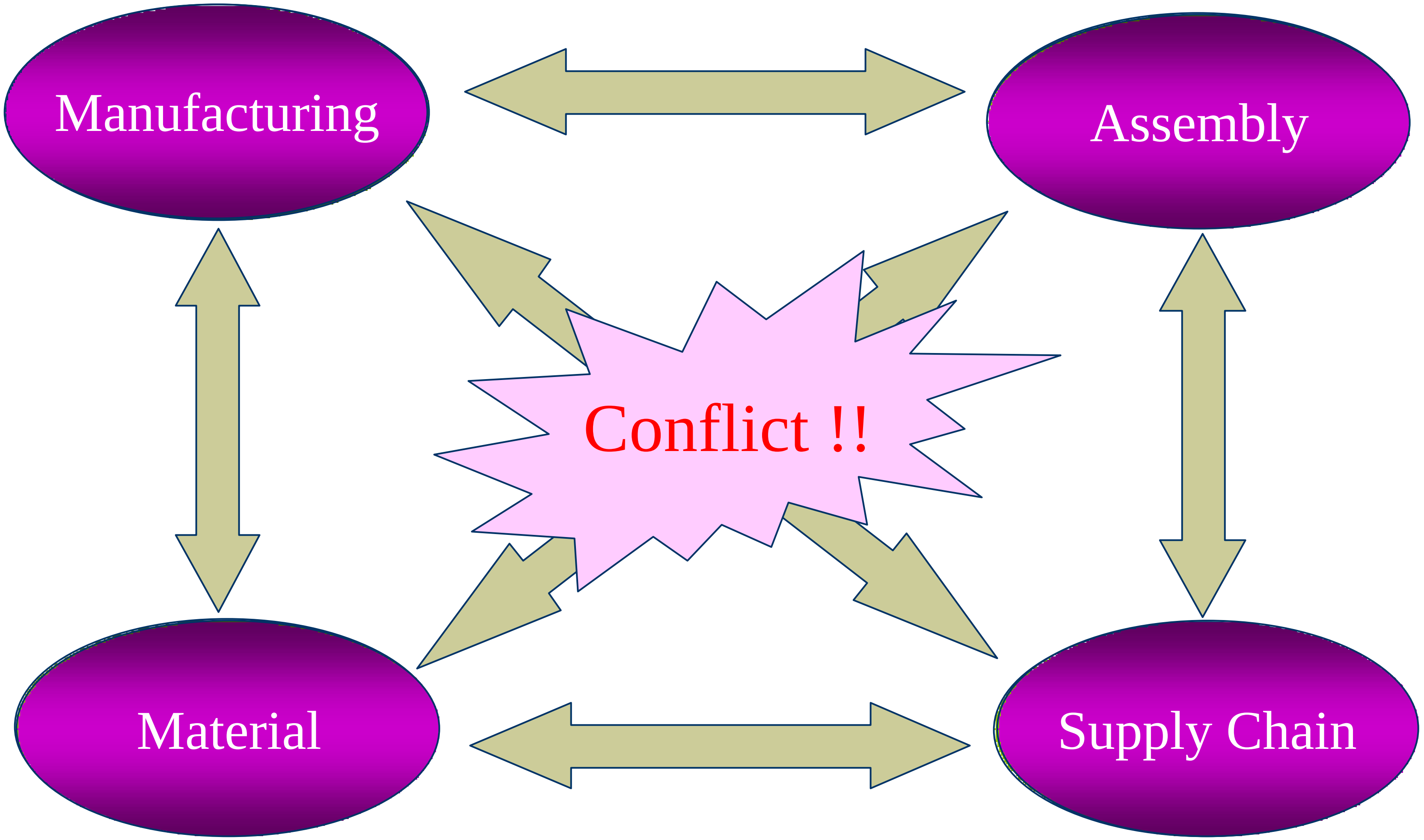
Customer View

- Direct participation of customers
- Automatic accommodation of preferences
- Scalability
- Flexibility
- Efficient collaboration
- Multidisciplinary product design evolution

Design Optimization

- Constraint representation
- Constraint propagation
- Constraint integrity
- Conflict management and negotiation
- Result interpretation
- Simulation

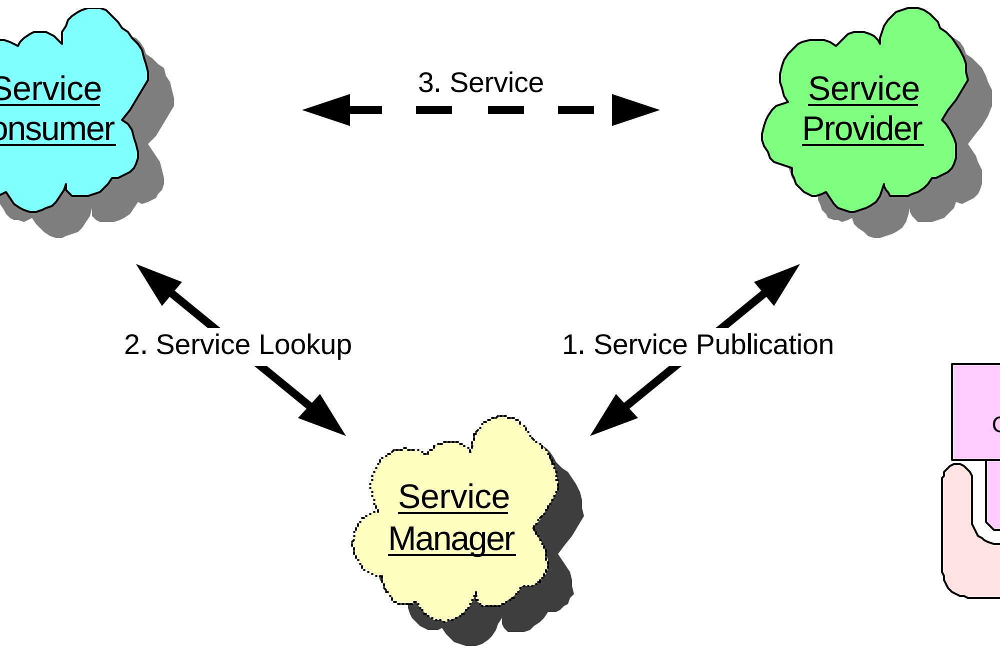
Conflict Management and Negotiation

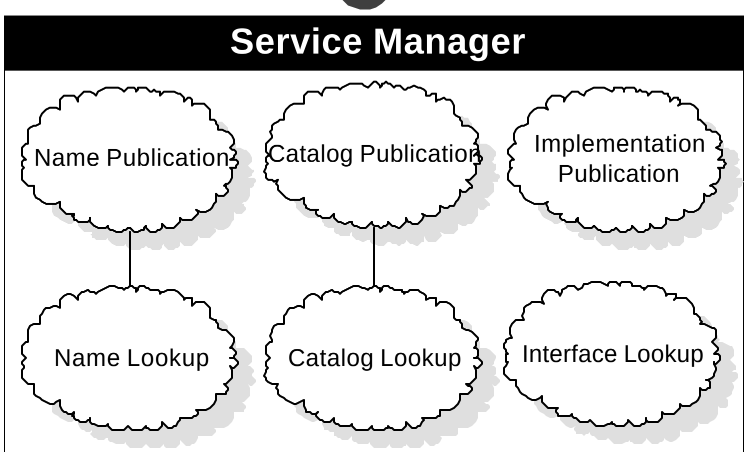


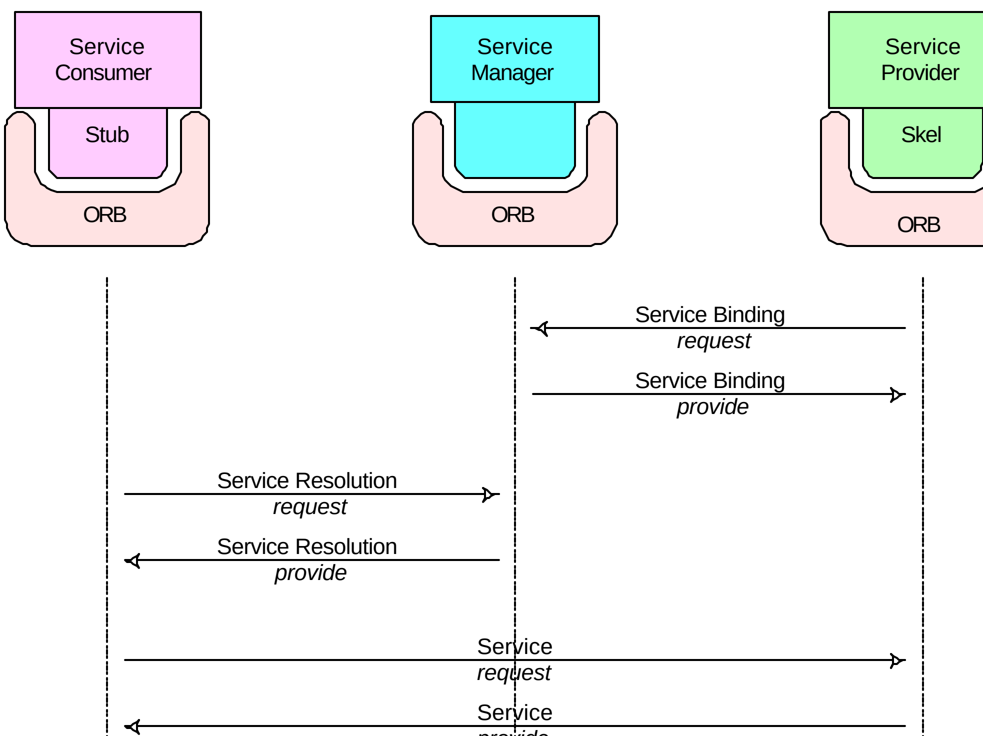
Information Infrastructure and Architecture

- **What is the information** needed throughout the life cycle?
- Information **protection and security** (at the product attribute characterization and specification levels)
- **Seamless sharing of information** across internationa boundaries
- Information **storage/retrieval** and **data mining** strategies
- Creation of a **knowledge depository**
- **Classification of Information** in the depository (Proprietary Public and Shared)
- **Maintaining and representing the interpretation o information** for use by down stream applications an processes.
- **Record of Reasoning process**, how results were derived

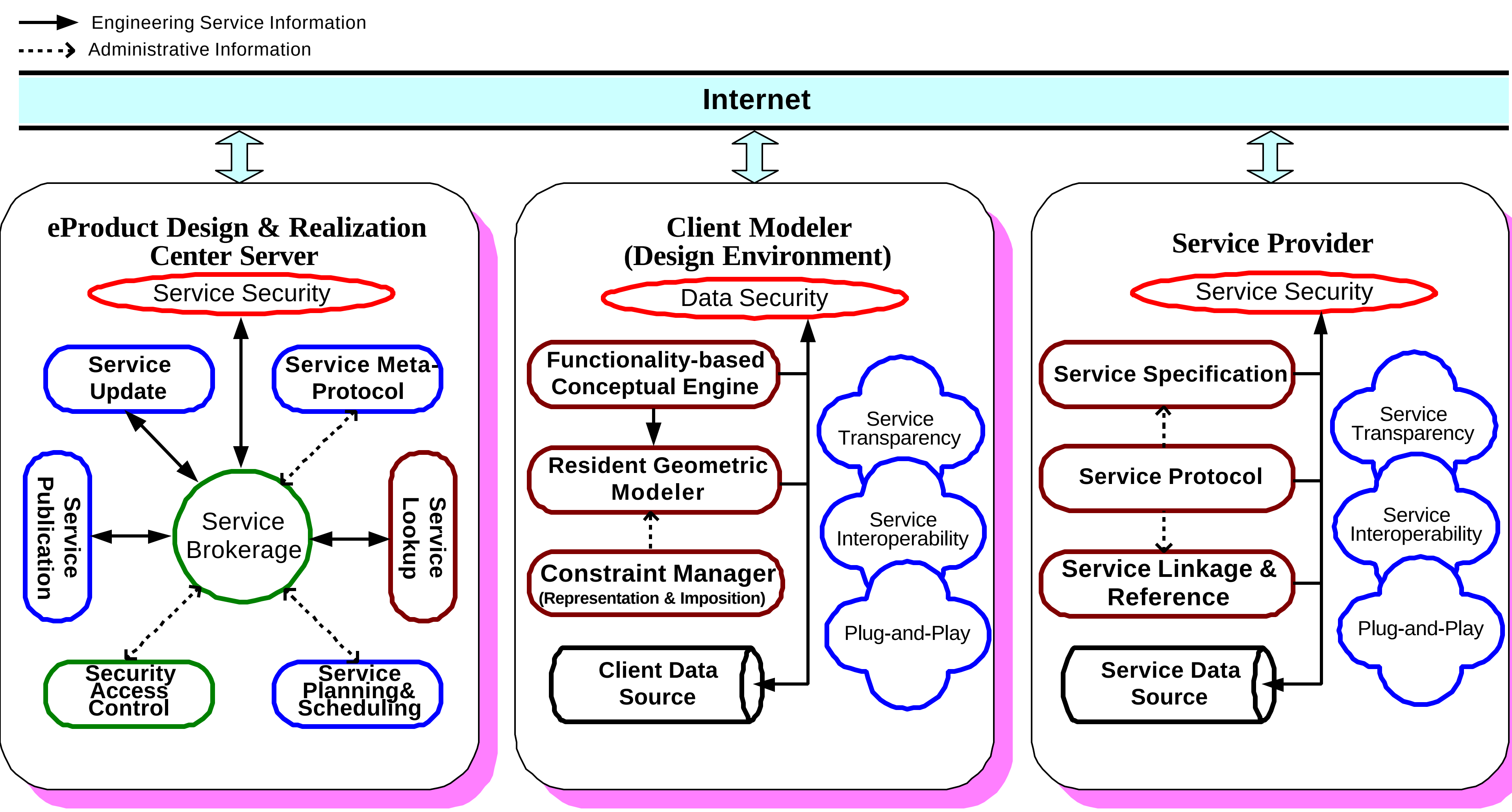
Service Triangle Relation



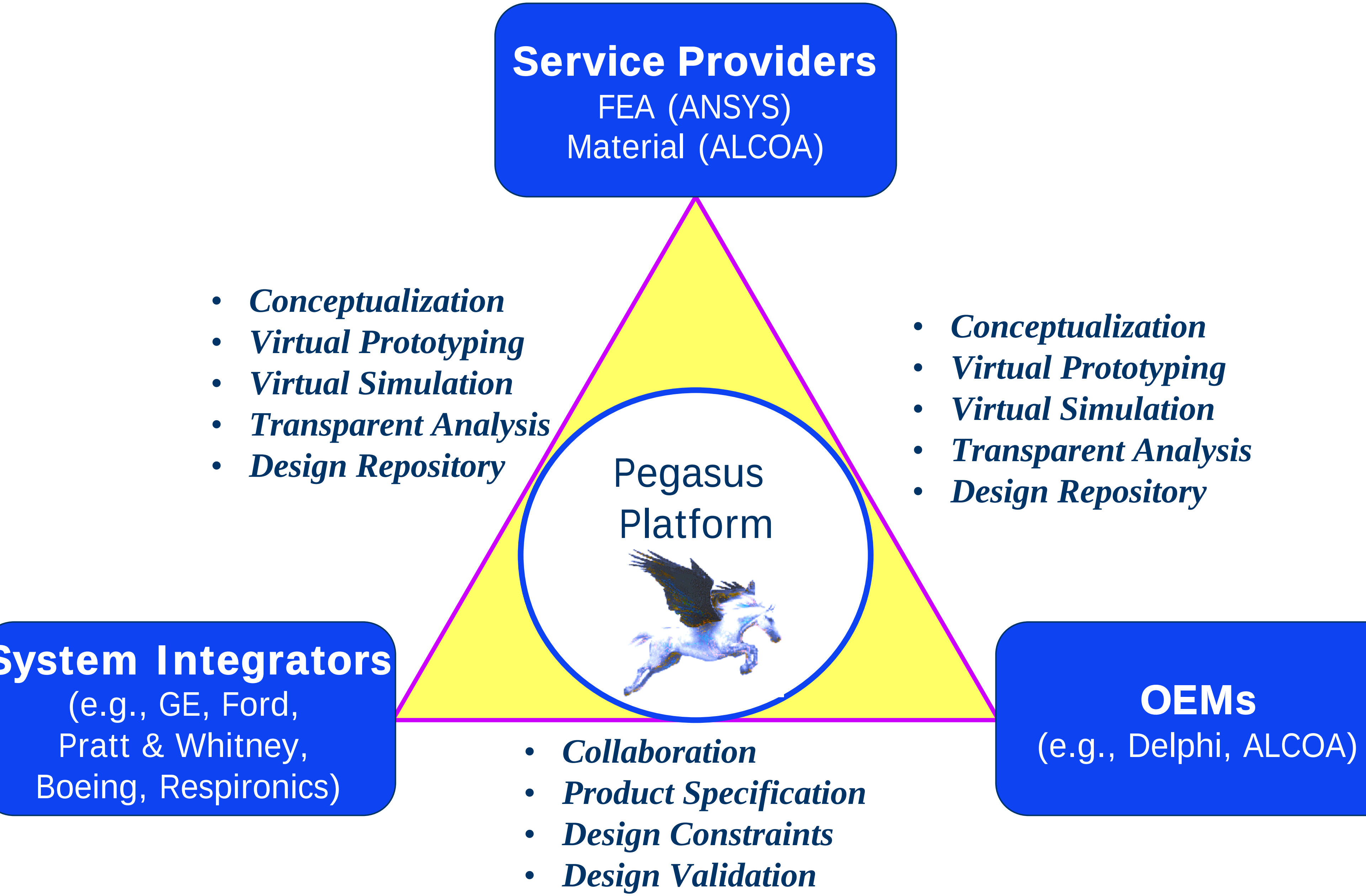




The Structure of the e-Design System Platform

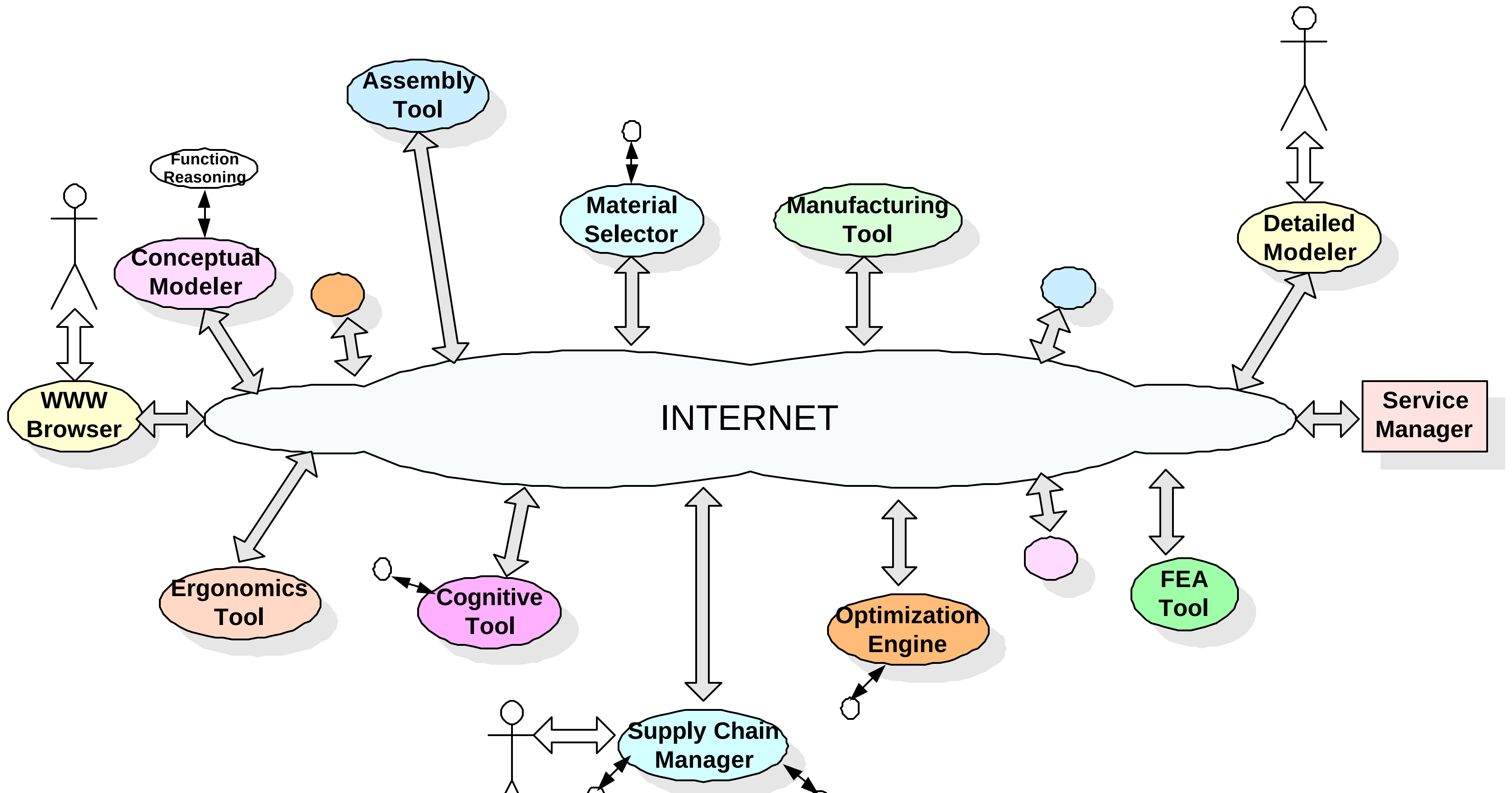


Supply Chain Interaction in Pegasus



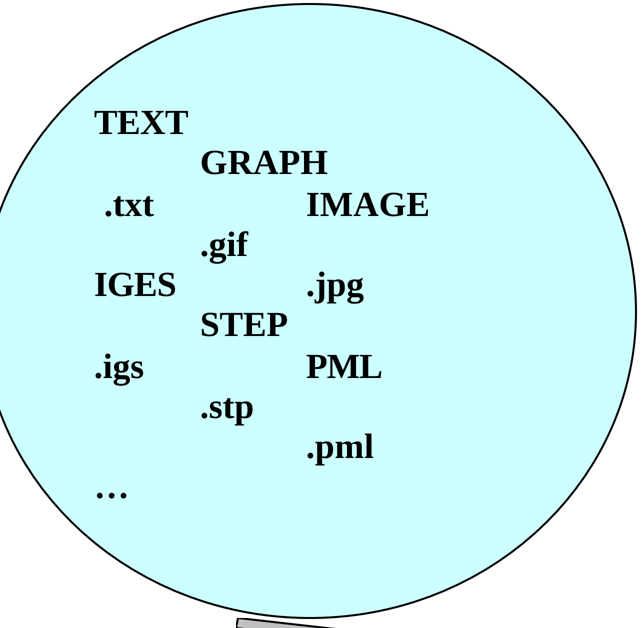
System Architecture

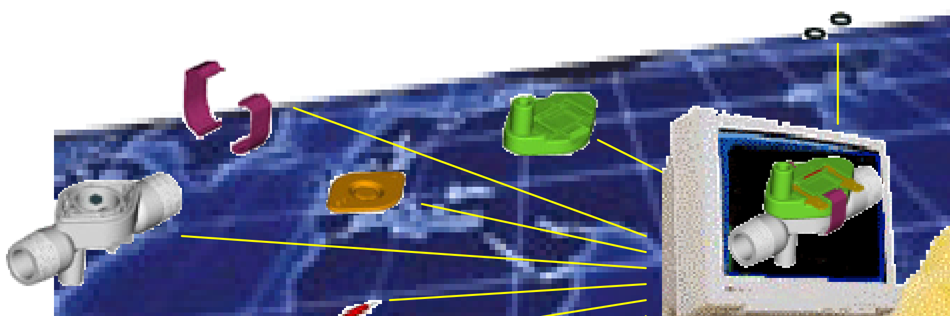
- Interoperable
- Portable
- Extensible
- Scalable
- Transparent
- Compatible
- Peer-to-peer
- Plug-and-play



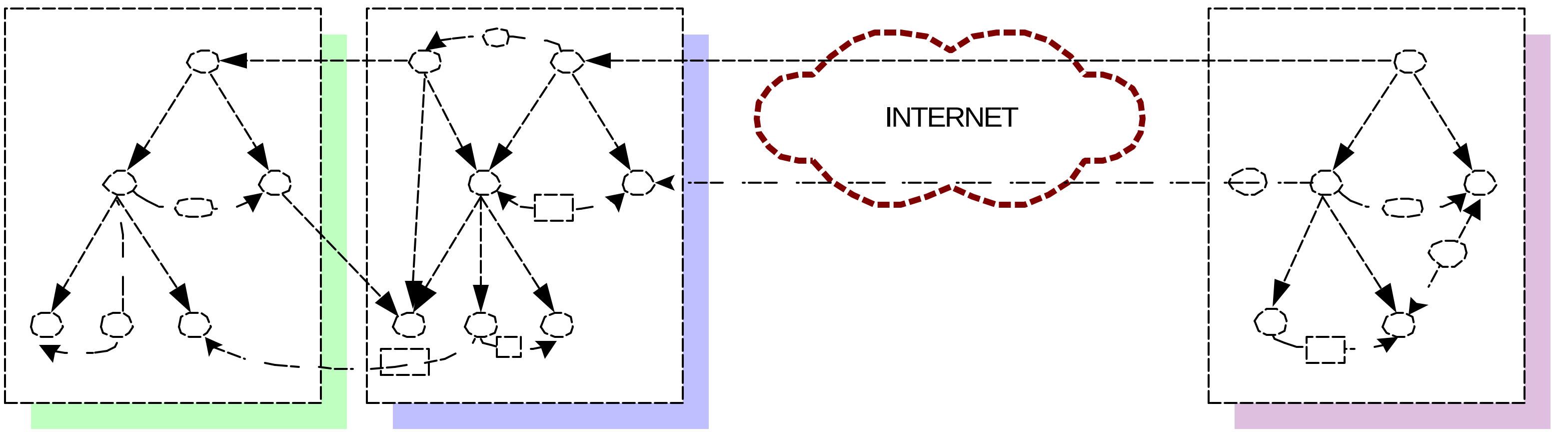
Heterogeneous Data Interoperability

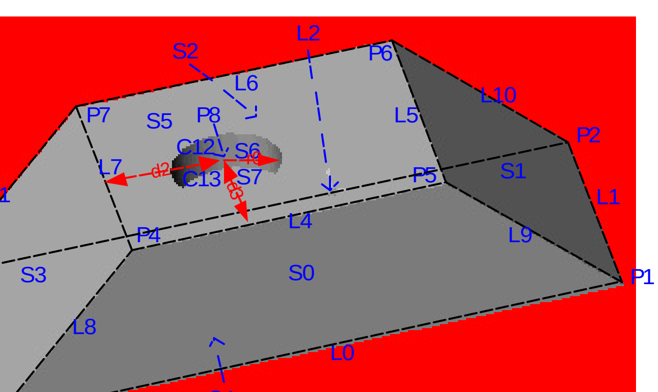
- Issues of interoperability for CAD/CAM/Analysis
- Heterogeneous data wrapped or indexed by XML, including various CAD data (.igs, .step, .sat, .x_t, .prt, ...), texts, graphs, images, etc.
- Product information linkage
- Encourage collaboration, knowledge reuse, lean engineering information exchange.

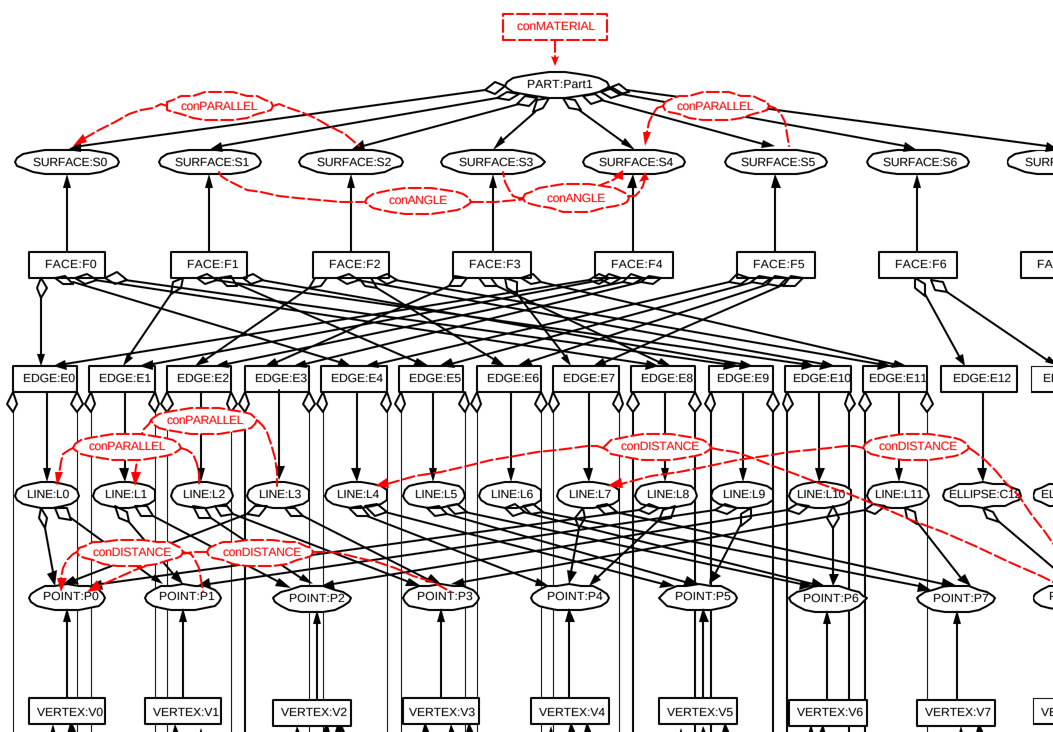




Universal Linkage Model

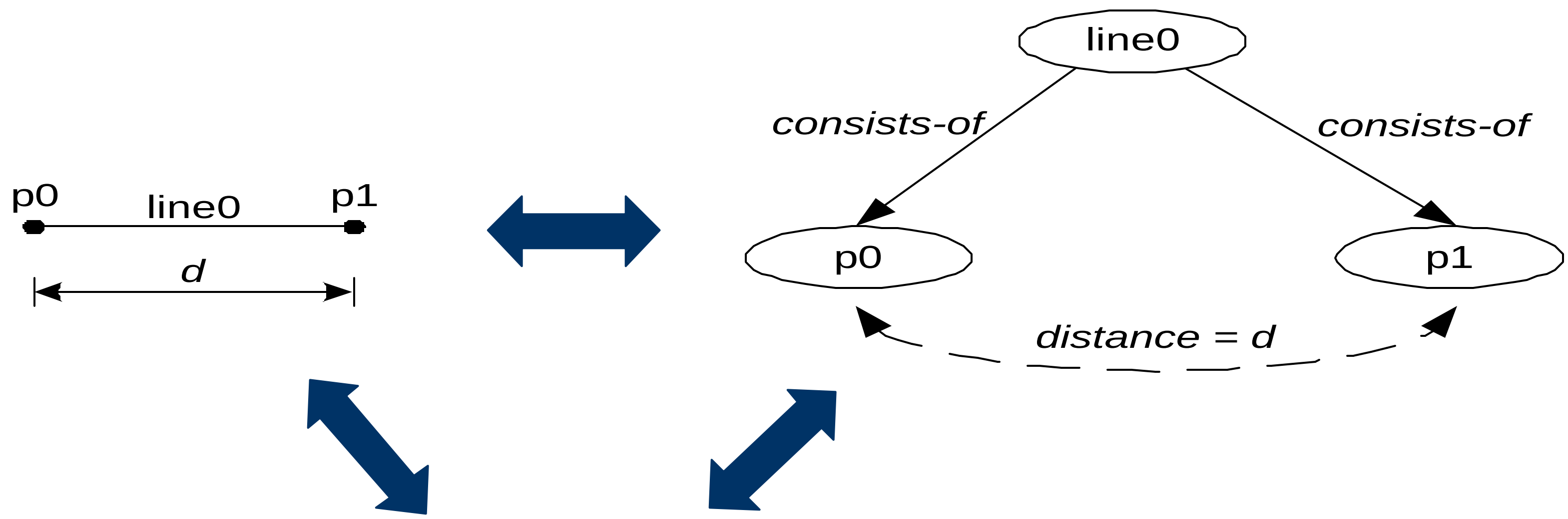






Product Markup Language

Geometry **UL Model**



PML file

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              xsi:schemaLocation=
                  "http://www.pitt.edu
                  line.xsd">
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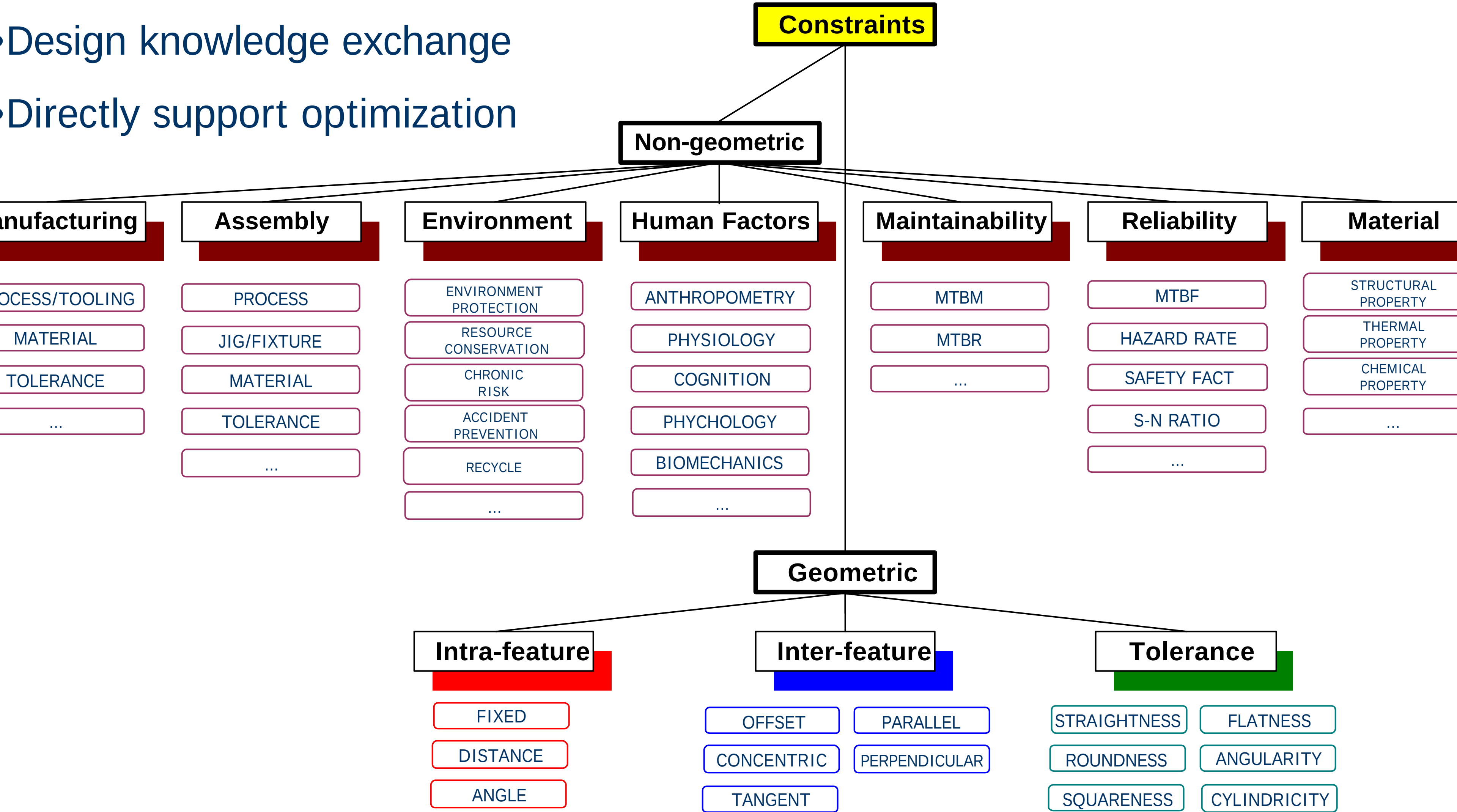
    <pml:POI NT y="1.0" y="0.0" z="0.0" id="p1">p1</pml:POINT>
    <pml:LINE>
        <pml:refPOINT xlink:type="simple" xlink:href="#p0"
                      xlink:show="embed" xlink:actuate="onLoad"/>
        <pml:refPOINT xlink:type="simple" xlink:href="#p1"
                      xlink:show="embed" xlink:actua te="onLoad"/>
    </pml:LINE>
</pml:GEOMETRY>
<pml:CONSTRAINT>
    <pml:conDISTANCE xlink:type="extended">1.0
        <loc1 xlink:type="locator" xlink:label="start" xlink:href="p0"/>
        <loc2 xlink:type="locator" xlink:label="end" xlink:href="p1"/>
        <arc1 xlink:type="arc" xlink:from="start" xlink:to="end" xlink:actuate="onRequest"/>
        <arc2 xlink:type="arc" xlink:from="end" xlink:to="start" xlink:actuate="onRequest"/>
```

Constraints Representation

- Multidisciplinary
- Directly support design participants
- Design knowledge exchange
- Directly support optimization



Product Functionality

How can components (P_{1}, P_{2} P_{3}) be described to capture functionality related issues in the design and operation of the product?

How can the relationship of P_1 with components P_2 and P_3 be described?

How can functionality description be modeled in computer system?

How can functionality be propagated to downstream design activities?

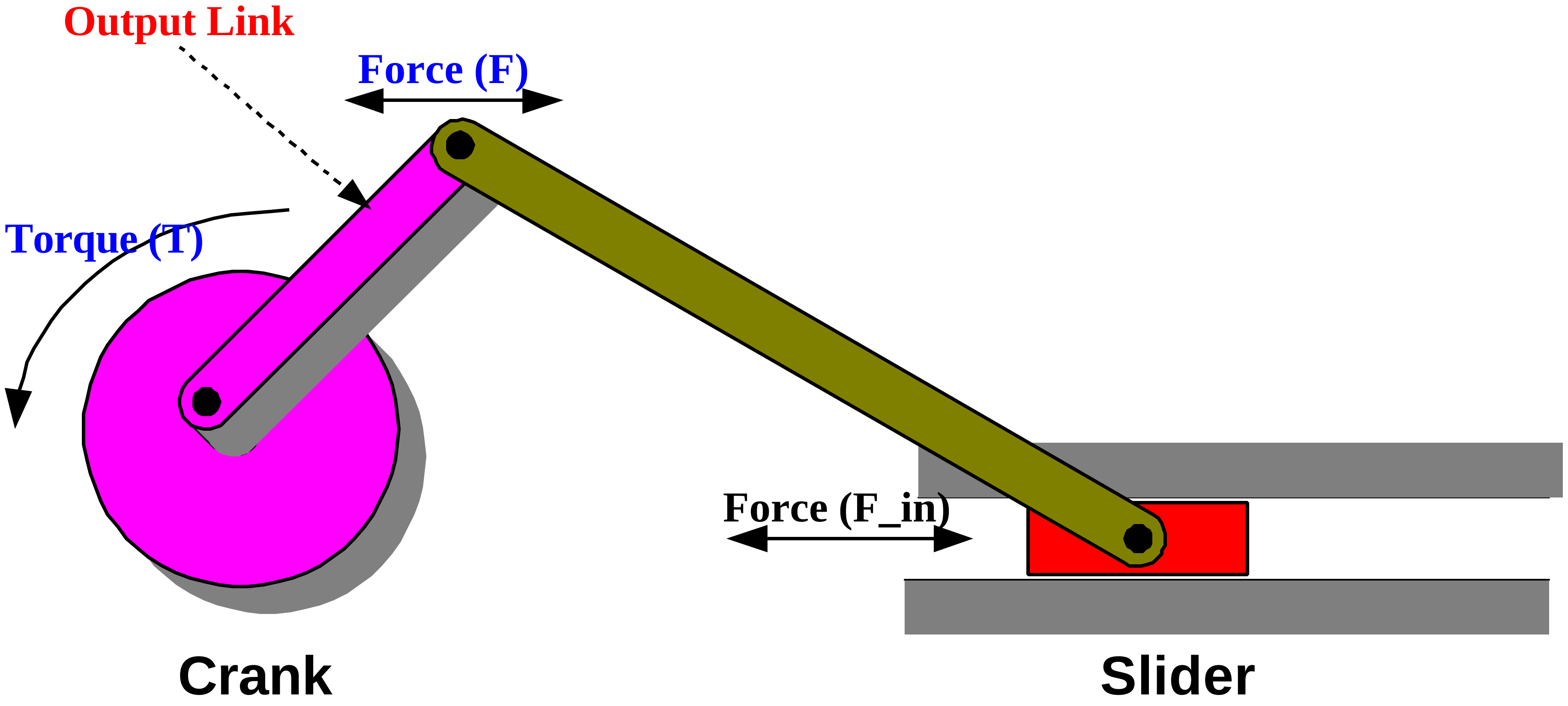
Functionality Primitives

Recurring product functionalities can be modeled as a primitive, and used as a repository of reusable product knowledge.

Specific products can be modeled through their constituent functionality primitives, providing a more natural basis of interaction with the designer.

Transformation; Transmission; Joint; Load bearing; Energy Conversion; Frictional; Offset; Guard; and Block.

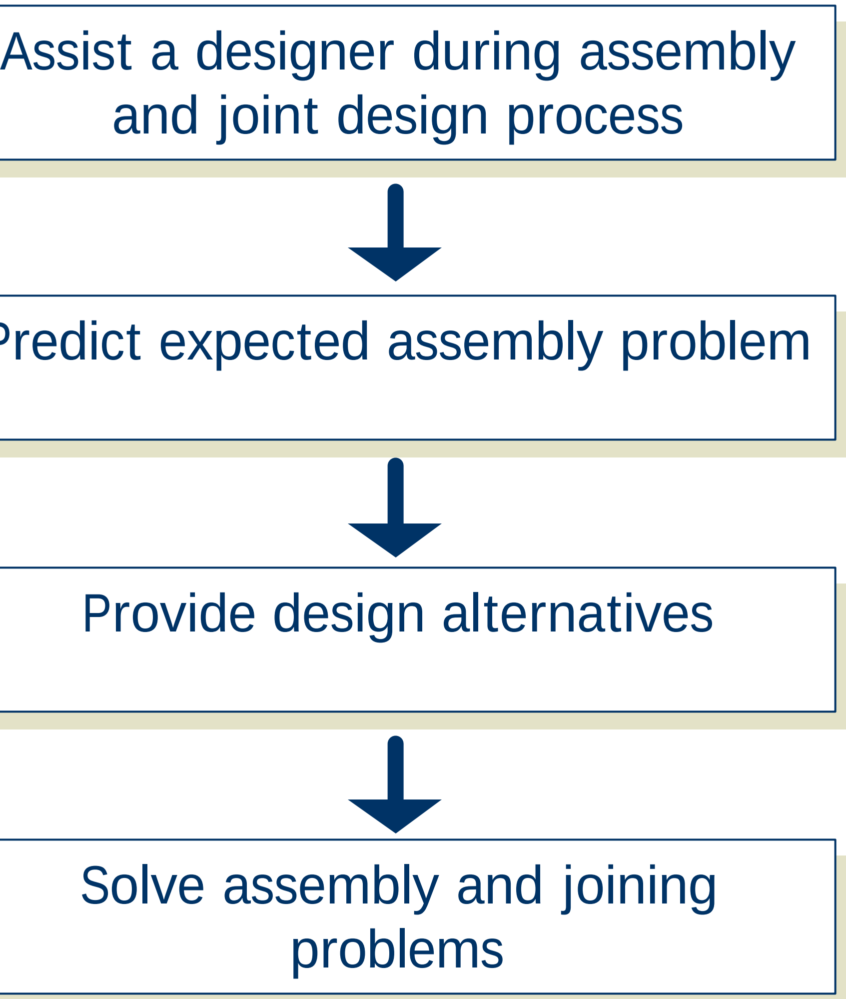
Slider-Crank Functionality



Output Link-Crank Functionality Definition

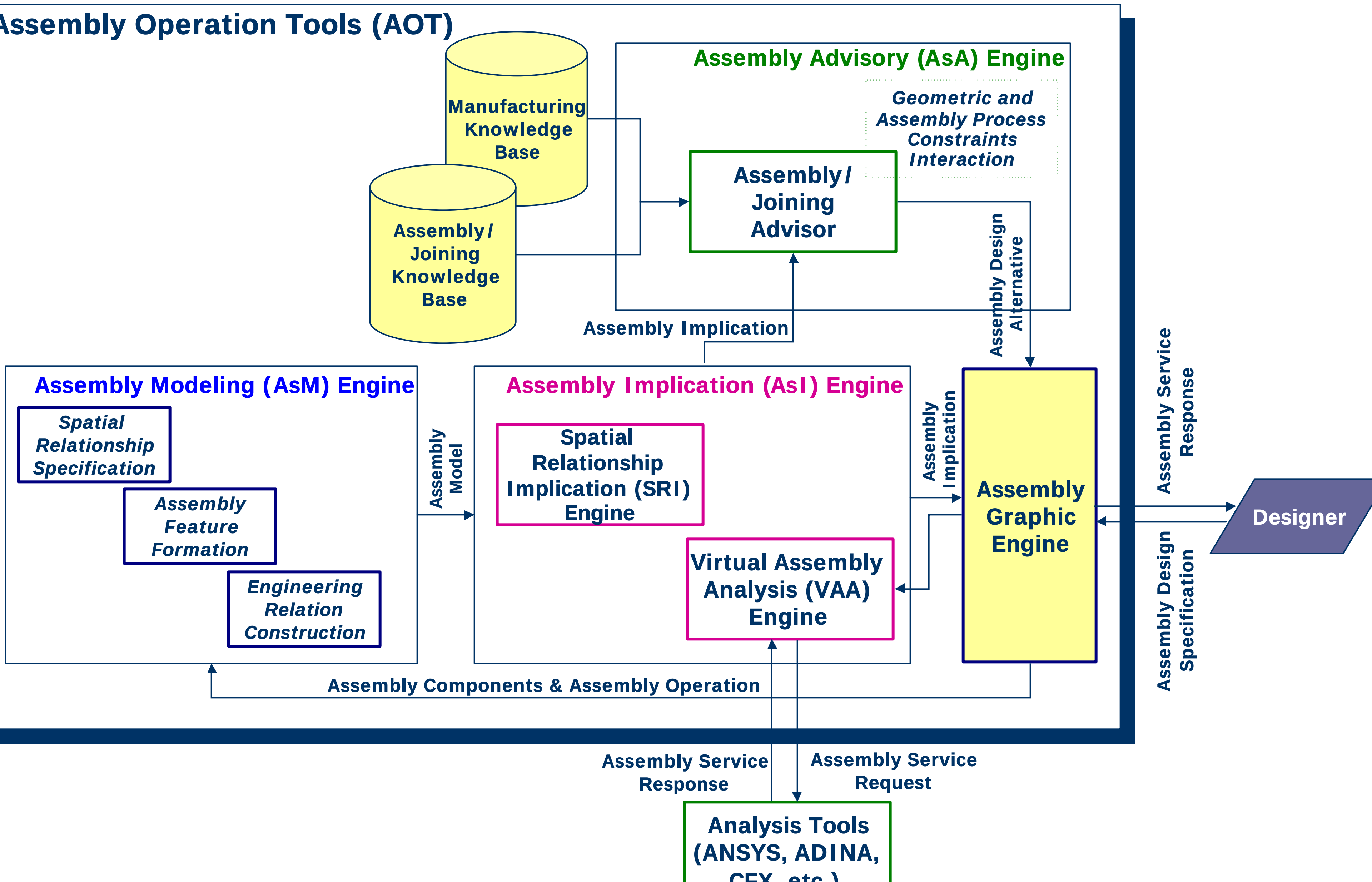
Functionality Entity	*Functionality object 1 (j=1)*	*Functionality object 2 (k = 2)*
Object (O_1)	$\mathbf{O}_{11}$ = Force (**F**)	$\mathbf{O}_{12}$ = Torque (**T**)
Attributes (A_{iq})	$\mathbf{A}_{111} =$ |**F**|, $\mathbf{A}_{112} =$ dir, $\mathbf{A}_{113} =$ nature, $\mathbf{A}_{114} =$ location	$\mathbf{A}_{121} =$ |**T**|, $\mathbf{A}_{122} =$ dir
Attribute value (V_{1qs})	e.g. $\mathbf{V}_{111}$ = [3, 12]N; $\mathbf{V}_{112}$ = $(\alpha, \gamma, \lambda)$ rad; etc	$\mathbf{V}_{121}$ = [12, 46]Nm $\mathbf{V}_{122}$ = [clockwise]
Object State $S_{1q} = (a_{iqs}, v_{iqs})$	$\mathbf{S}_{11\text{mag}}$ = {0, 3, …} $\mathbf{S}_{11dir}$ = {(dir,(*a*,*b*,*c*)), (dir,(*d*,*e*,*f*)), …}	$\mathbf{S}_{12mag}$ = {(T, 0), (T,18), …} $\mathbf{S}_{12dir}$ = {(dir, clock), (dir, anti-clock), …}
Relation (R_1)	$\mathbf{R}_1 = \{\mathbf{r}_{112}\,(\mathbf{o}_{11}, \mathbf{o}_{12}) \mid 1/l\}$	
Form Mapping (F_1)	$\mathbf{F}_1 = \{(r_{112}, f_{112l}) \mid \mathbf{FF}_{l=1}, \mathbf{FF}_{l=2}, \ldots\}$	

Assembly Operation Tools (AOT)



- Generate design for assembly and joining
- Represent an assembly and imply the various effects, i.e., physical and mathematical effects of joining operations
- Assembly operation analysis process imbedded into assembly design process
- Formalism to specify the assembly relations symbolically, which has mathematically solvable implications.
- Designer's intent preserved by using spatial relationship-based representation
- "Plug and play" capability with a designer system, such as *Pegasus*

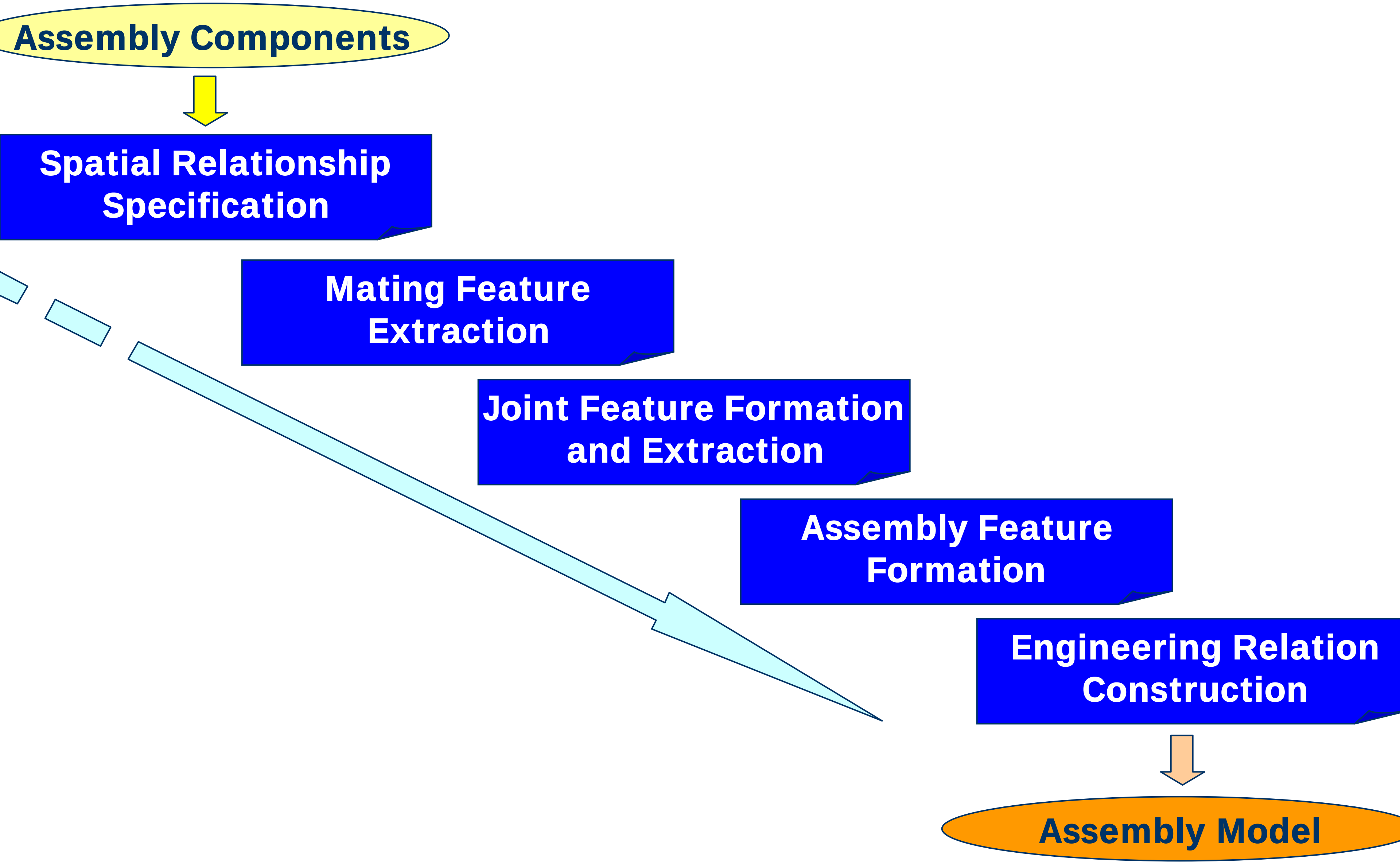
Architecture of AOT



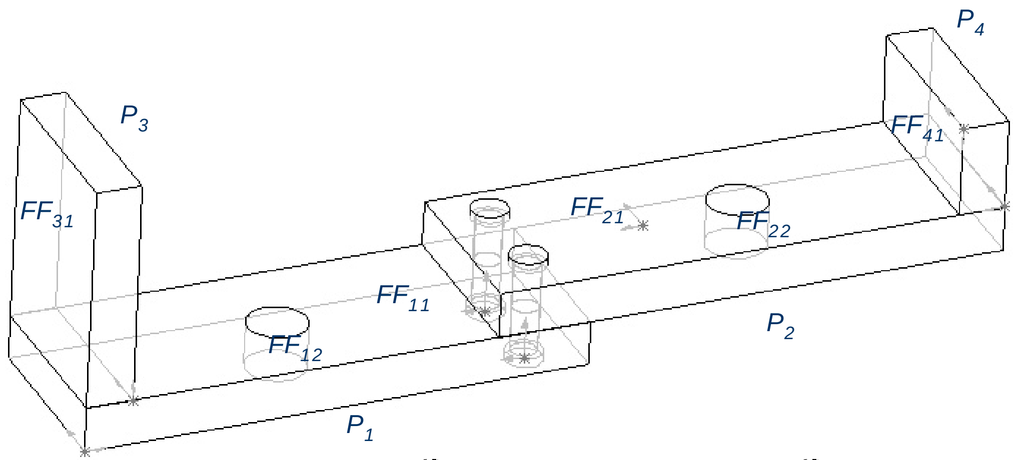
AsM Engine

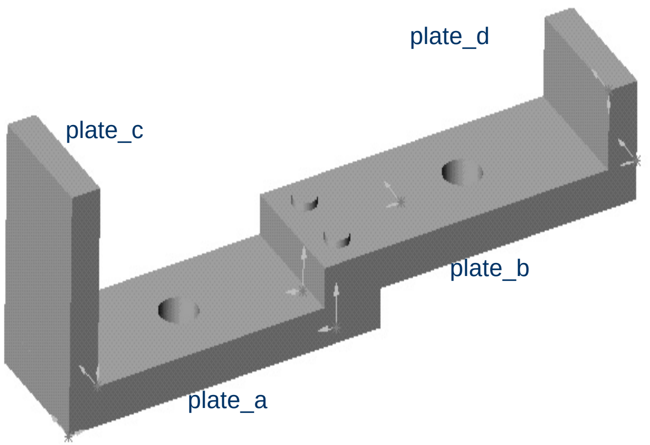
- Assembly generation based on the assembly design formalism
- Joining method specification
- Additional geometric feature generation (e.g., weld bead, rivet, etc.)
- Geometry preprocess for analysis

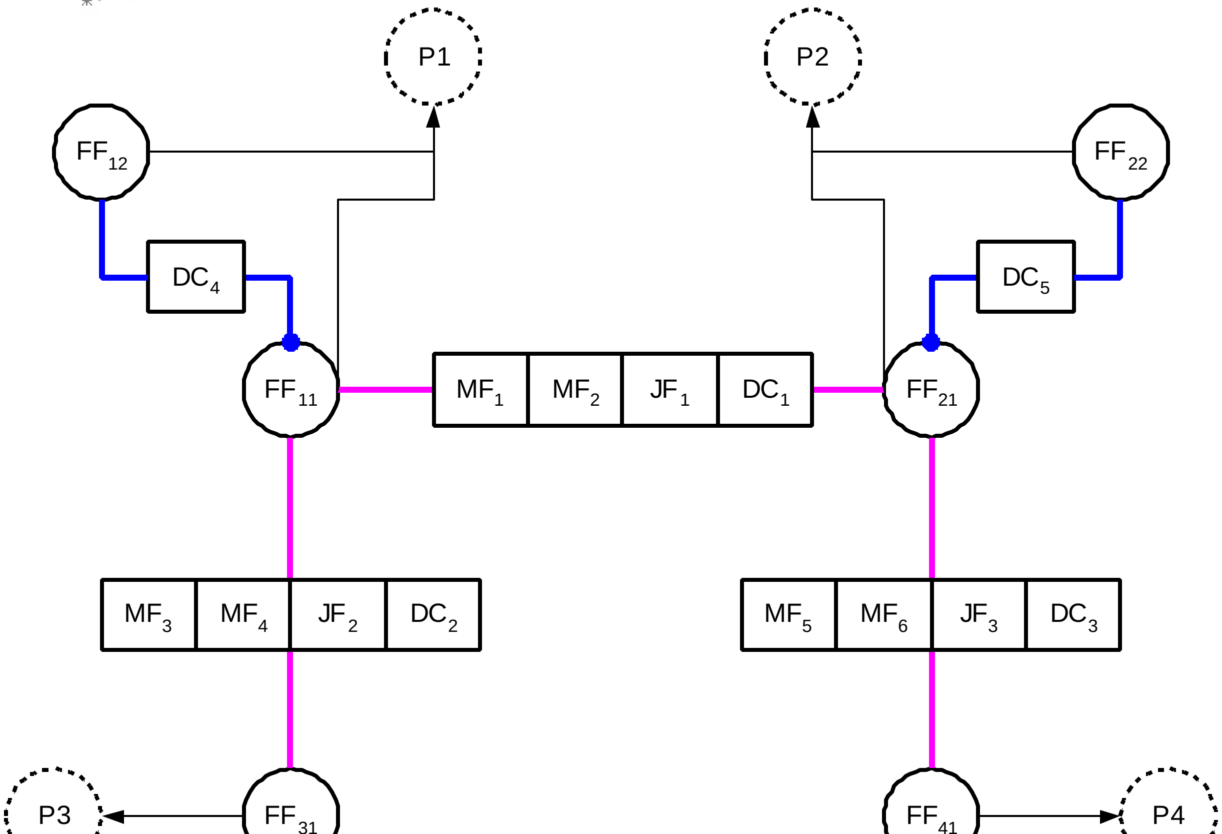
Procedures of the assembly design formalism



Example of GARD – Generic Assembly Relationship Diagram





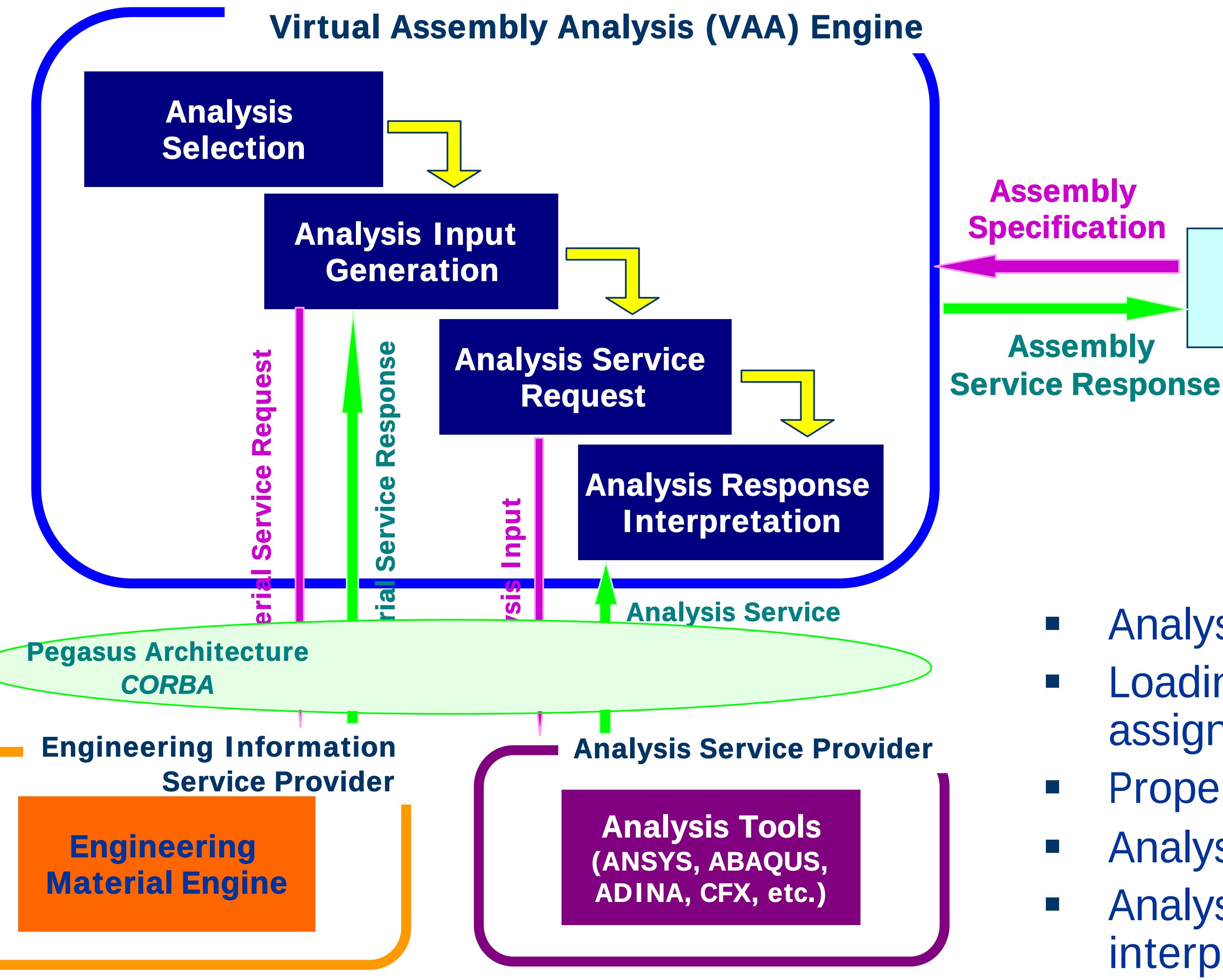


Example of assembly design formalism

- Plate_a & plate_c
- welded joint

F	▪ MF3 = {S/R, [*mating components* (*mating entities*)]} = {against, [P_1 (top_surface), P_3 (bottom_surface)]} ▪ MF4 = {aligned, [P_1 (l_1), P_3 (l_1)]}
F	▪ JF2 = {*joining method* | [*joining components* (*joining entities*)] |[joining constraints]} = {GMAW | [P_1 (e_{a1}), P_3 (e_{c1}) | P_1 (e_{a2}), P_3 (e_{c2}) | [welding_condition], [fixture_location]}
F	▪ AF2 = {*mating features* | *mating bonds* | *joint features* | [*material*] | [*implied d.o.f. before assembly*], [*implied d.o.f. after assembly*] | [*implied constraints*]} = {MF_3 , MF_4 | MB_3, MB_4 | JF_2 | [Aluminum Alloy 6061 - T6] | [{plate_z::rot_z}, {lin_l_1:: lin_l_1}], [{fix} | [tolerance]}
B	▪ MB3 = {*mating pair* (*mating features* [*form features* (*parental relationships*, *dimensional constraints*)] | *mating conditions* (*S/R*, [*d.o.f.*], [*implied constraints*])} = {MP_3 (MF_3 [FF_{11} (FF_{21}, P_1(100.72, 23.34, .), $\pm\Delta_1$; FF_{12}, P_1(50, 20, .), $\pm\Delta_1$), F_{31} (.)]) | MC_3 (against, [{plane_z::rot_z}], [tolerance]))} ▪ MB4(aligned) = {MP_4 (MF_4 [FF_{11} (FF_{21}, P_1(100.72, 23.34, .), $\pm\Delta_1$; FF_{12}, P_1(50, 20, .), $\pm\Delta_1$), F_{31} (.)]) | MC_4(aligned, [{lin_l_1::lin_l_1}], [tolerance]))}

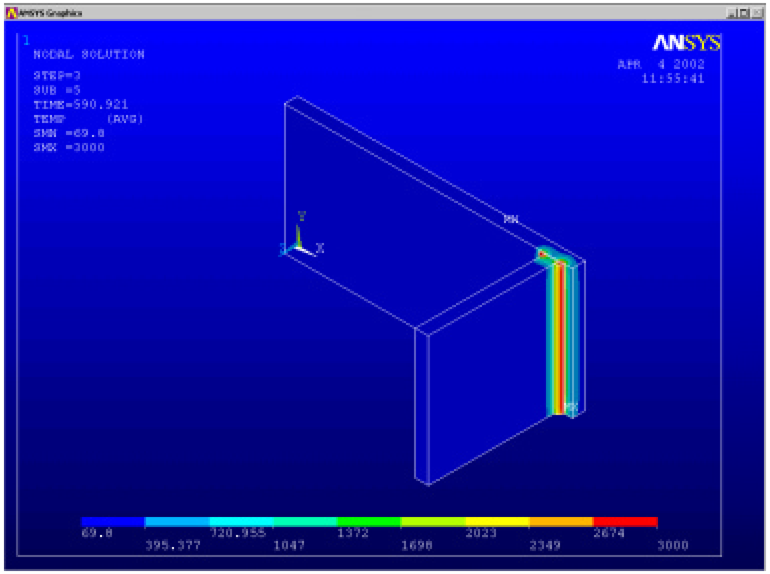
VAA Engine

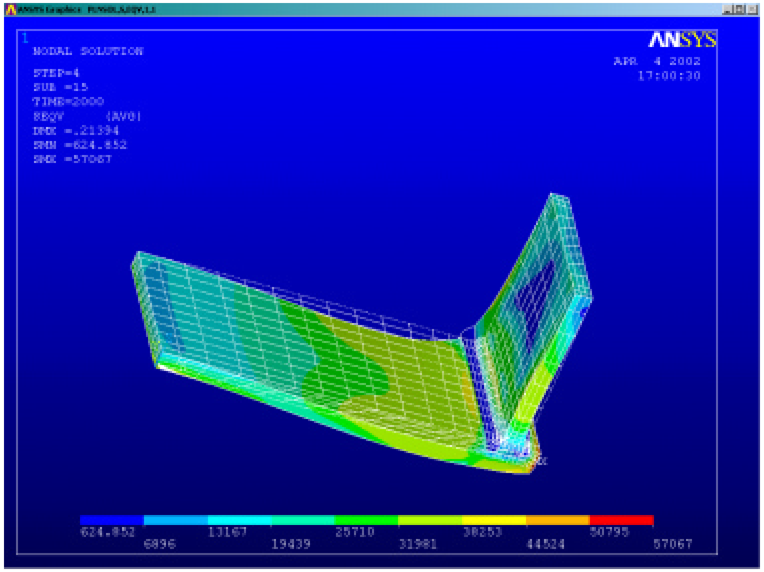


- Analysis type specificatio
- Loading and B.C.'s assignment
- Proper solver determinat
- Analysis input generatior
- Analysis result interpretation

Thermo-structural analysis for arc welded joints

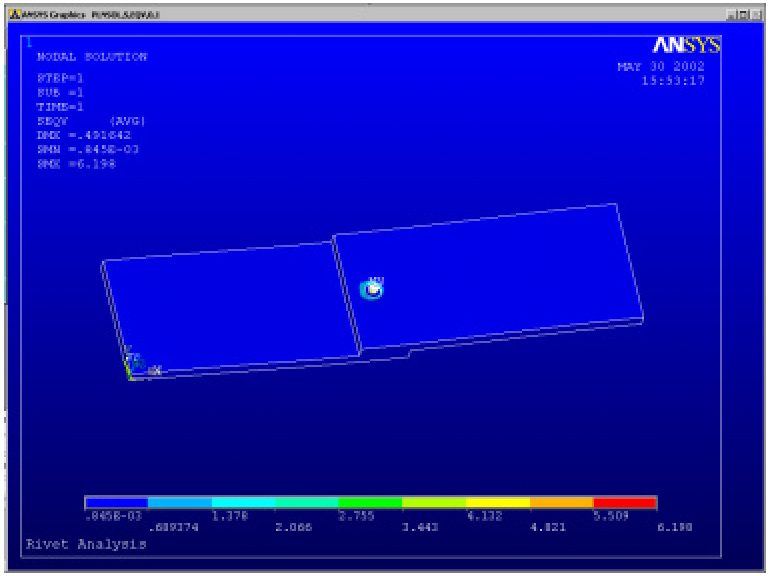
- Coupled by nonlinear heat conduction analysis and steady-state structural analysis
- SOLID 70 element (for thermal analyses) and SOLID 45 element(for structural analyses)

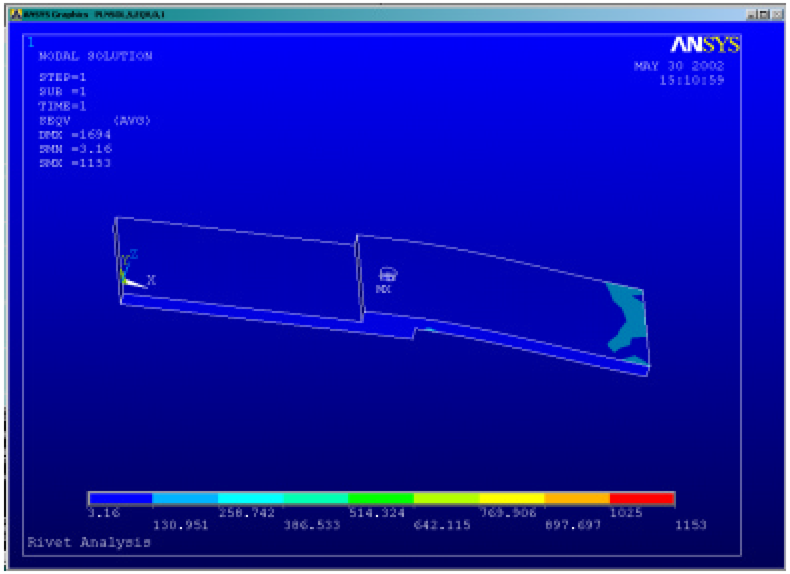




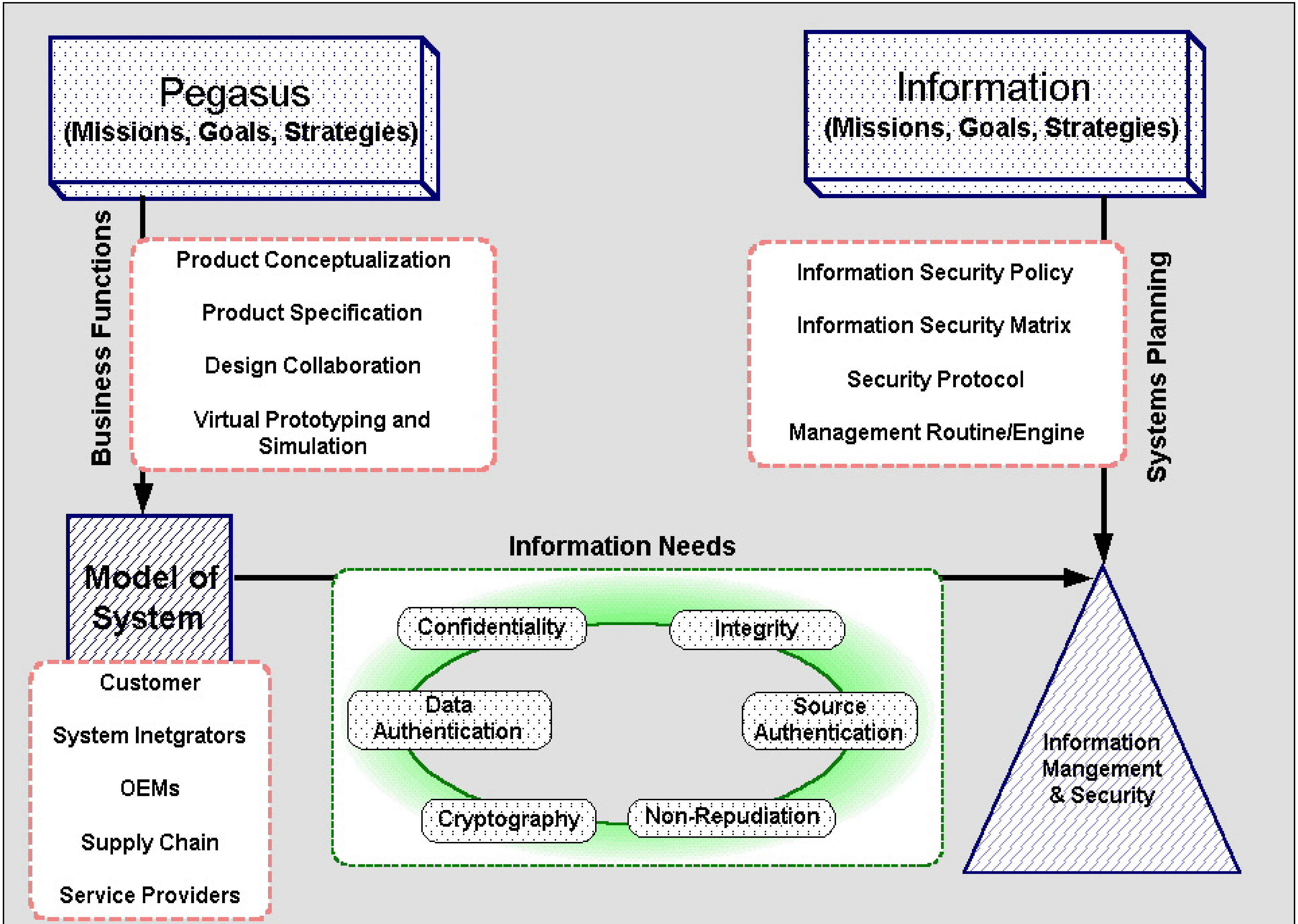
Structural analysis for rivet/bolted joints

- Elastic-plastic structural analysis
- SOLID 45 element (for structural analysis) and PRETS179 pretension element (for upsetting processes)

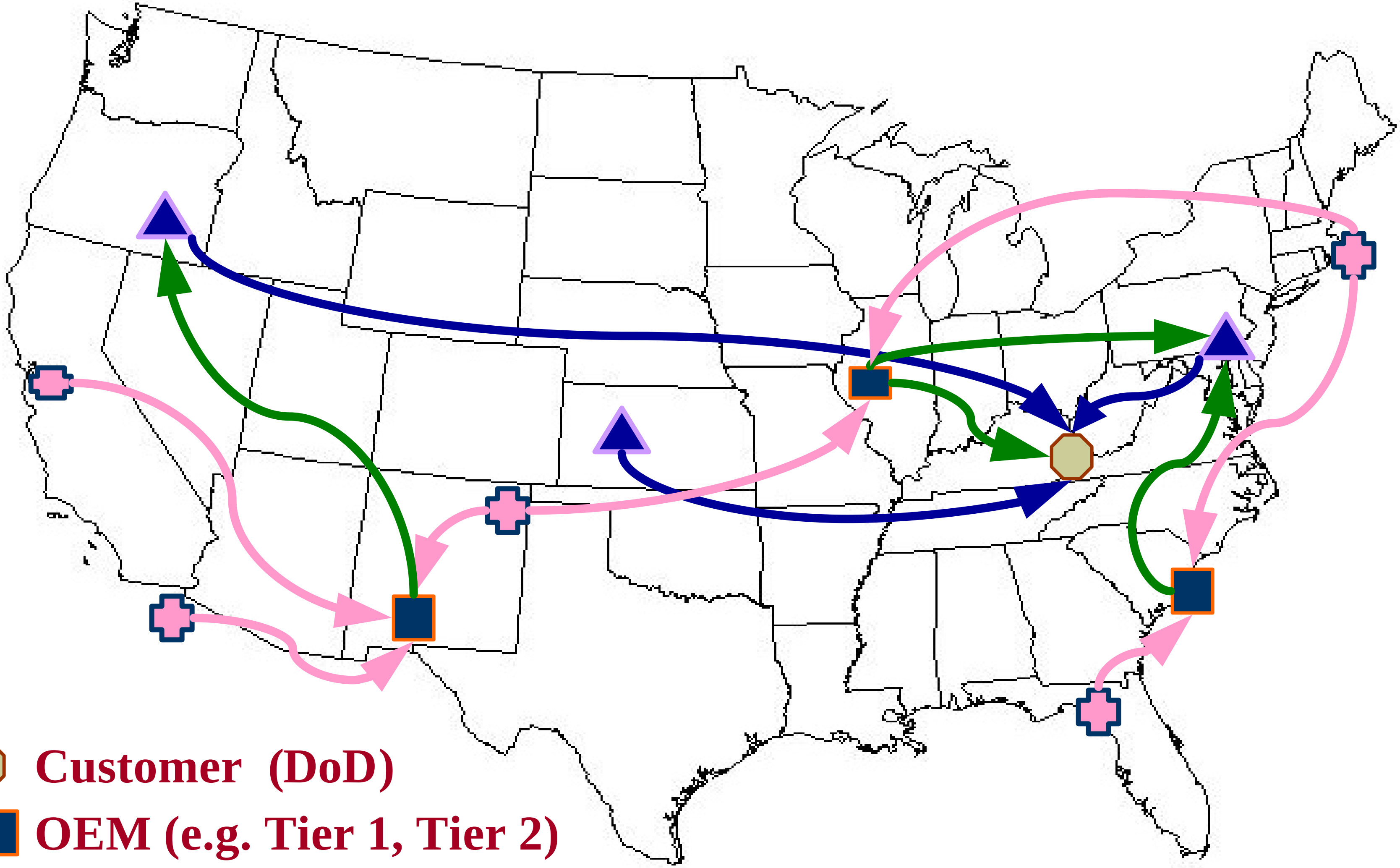




PEGASUS ENTERPRISE-WIDE INFORMATION MANAGEMENT ARCHITECTURE

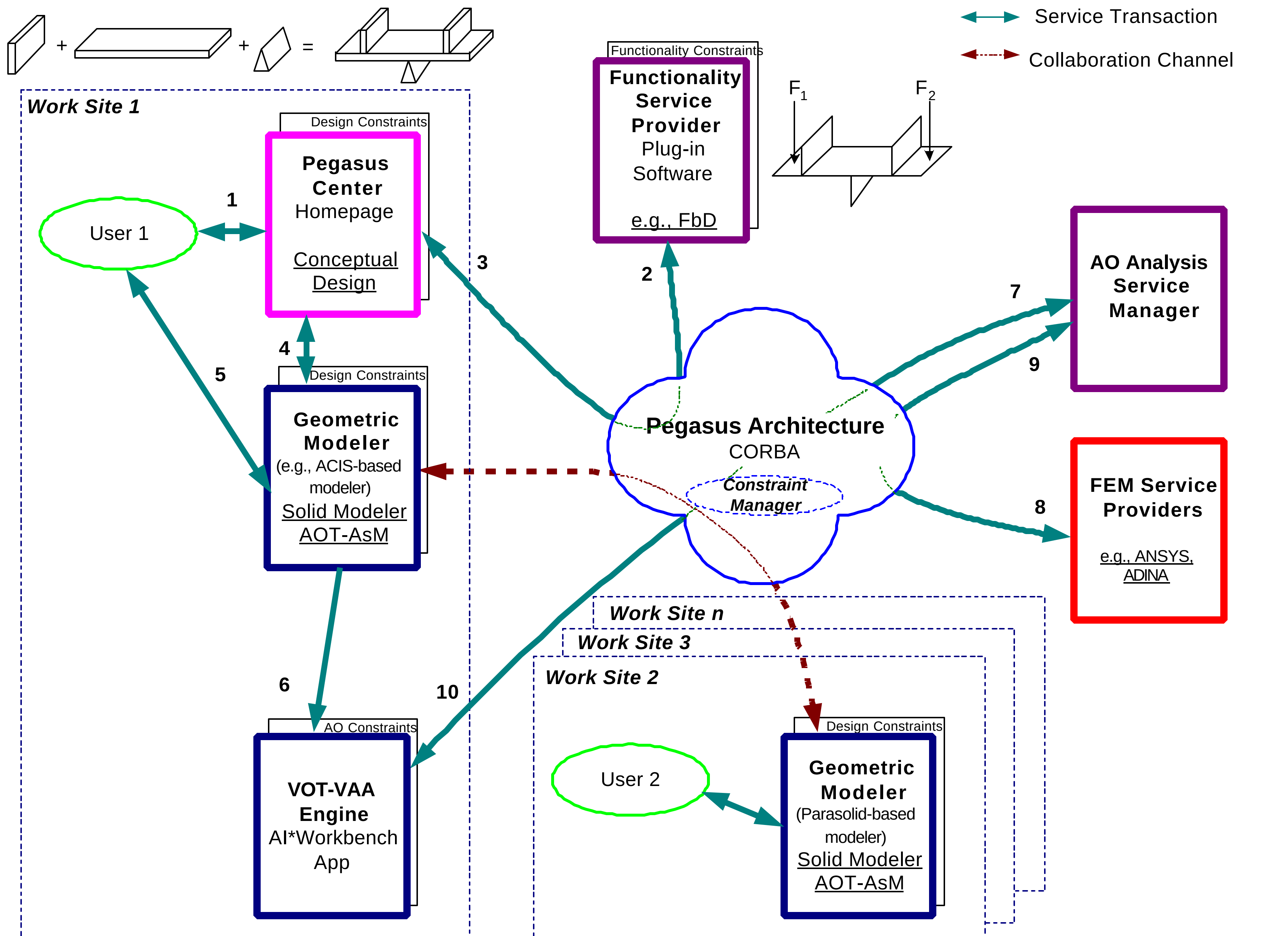


Supply Chain Network

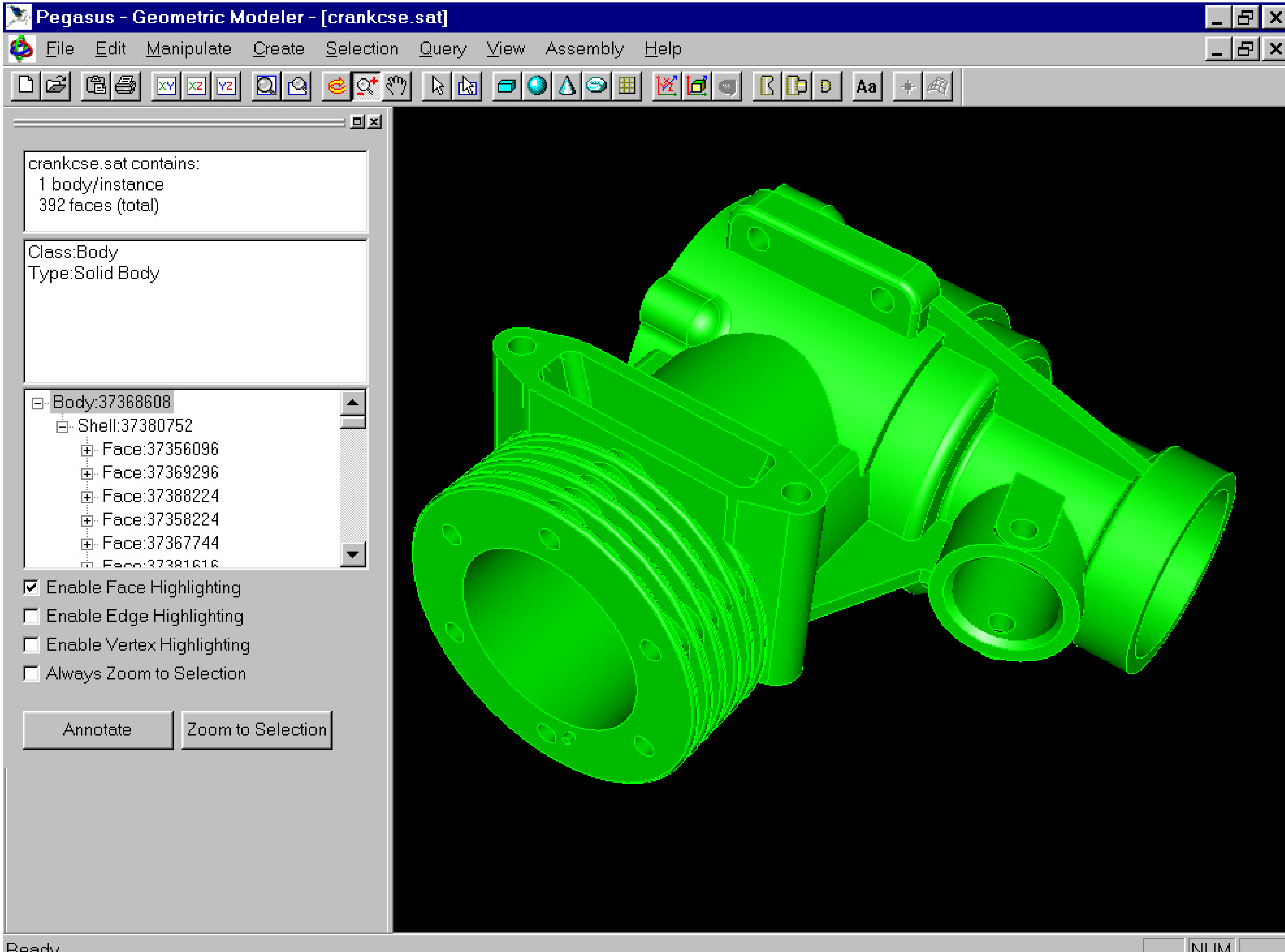


- Customer (DoD)
- OEM (e.g. Tier 1, Tier 2)
- Supplier (e.g.Tier 3)
- System Integrators (GE, BOEING, LOCKHEED MARTIN etc.)

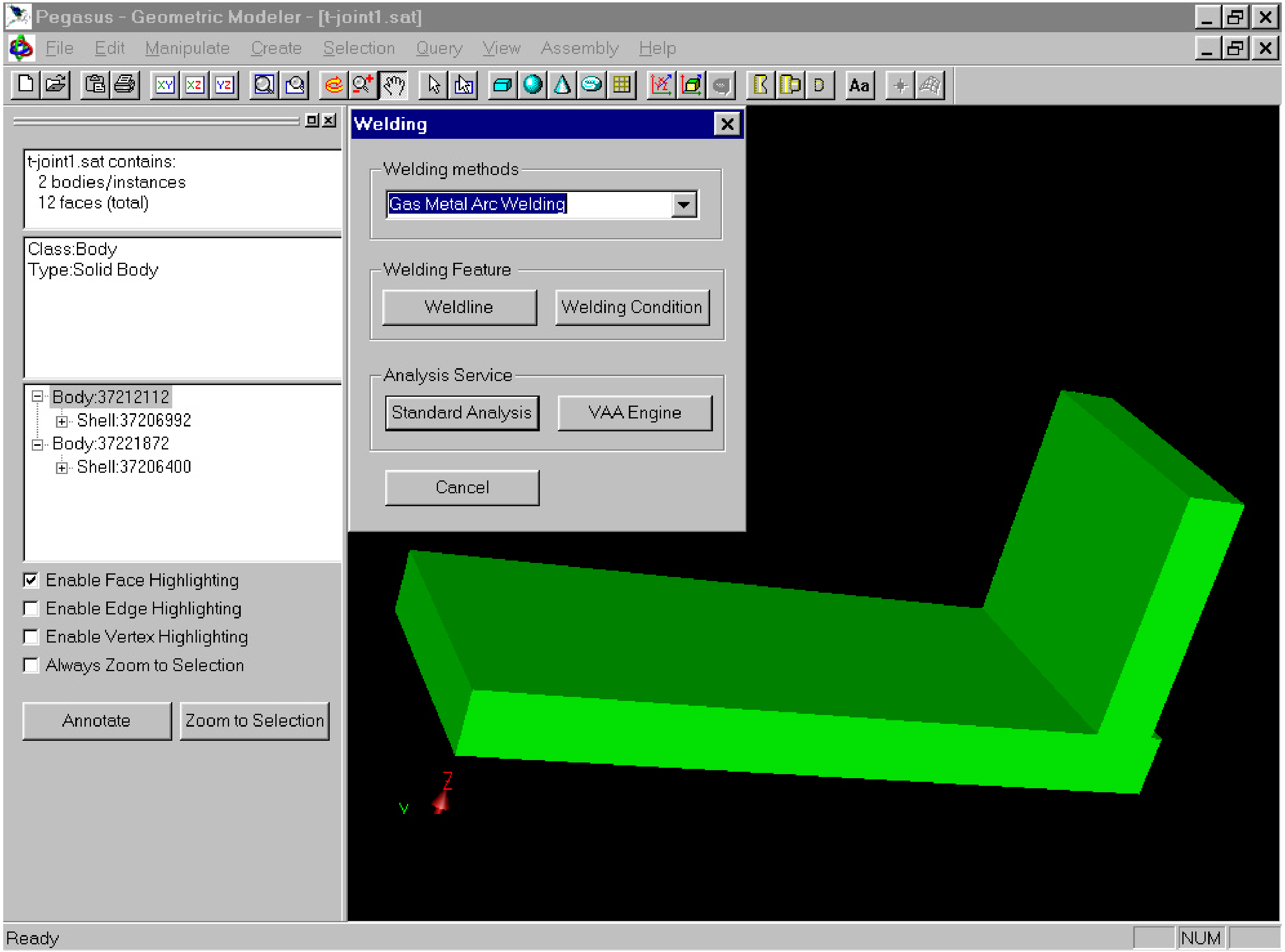
Pegasus System Version 1.0



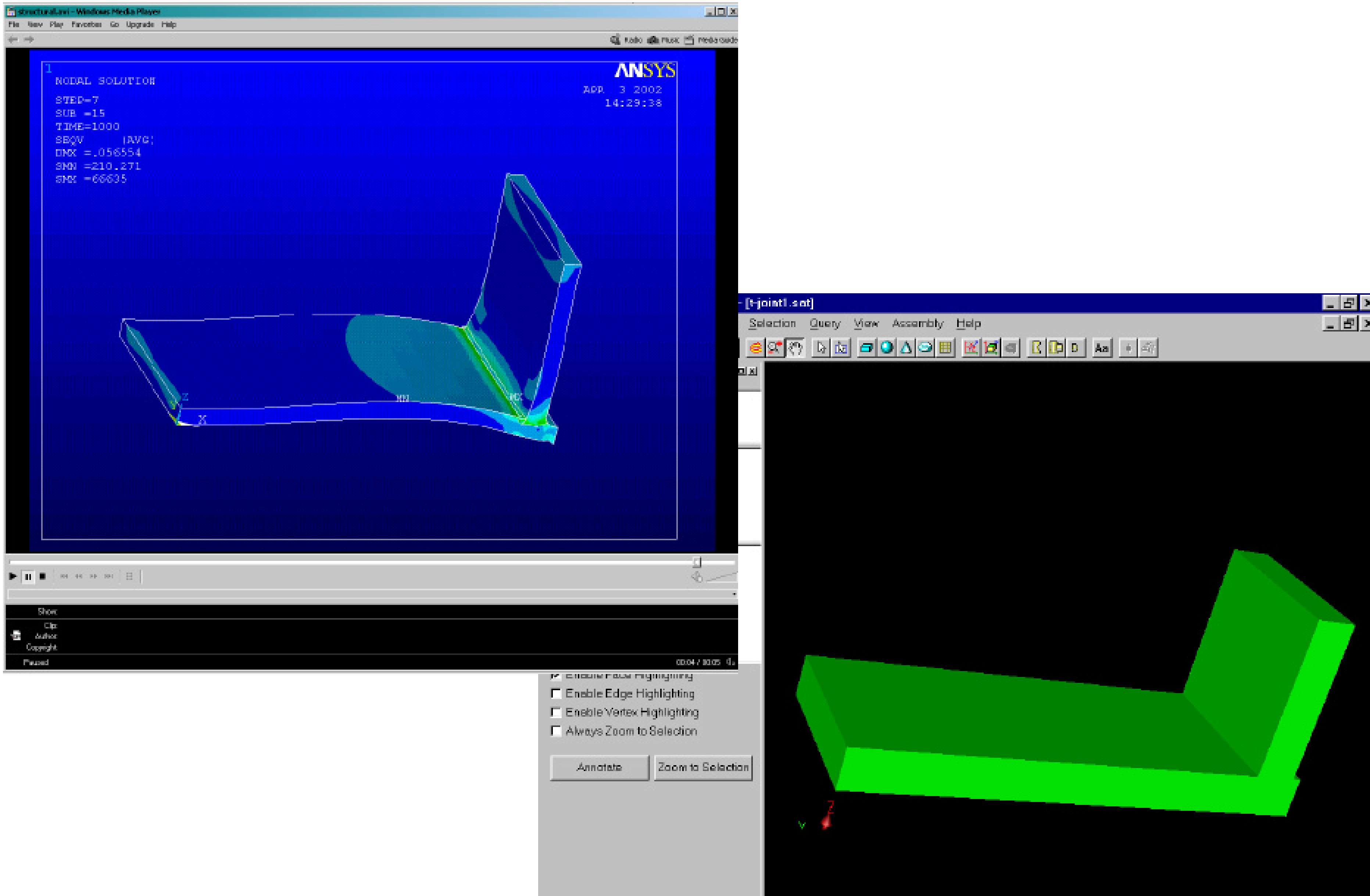
Geometric Modeler



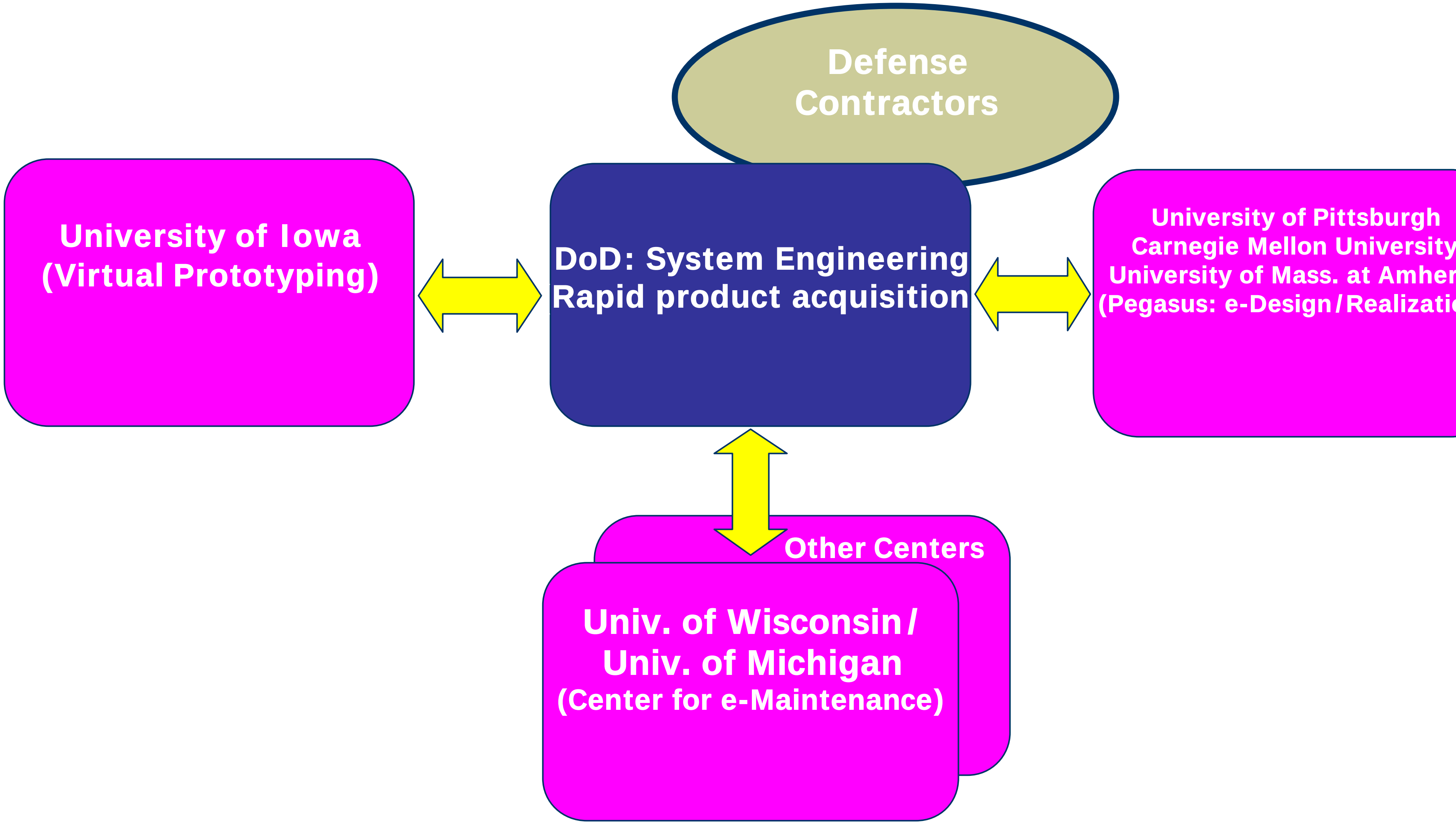
Analysis Service Request



Analysis Service Response



Joint DoD/Academia/Industry System Engineering for SBA



Summary

- A design paradigm that accommodates life cycle considerations for a product
- Rapid product acquisition at significantly reduced cost with six-sigma quality
- Virtual and transparent analyses and tests that are physics-based and with ergonomic and cognitive attributes
- System-to-system interoperability and collaboration