ENPM 692
MANUFACTURING AND AUTOMATION

Digital Manufacturing - Information modeling in design & manufacturing

Time: Wednesdays 7:00pm - 9:40pm
Room: JMP 2222

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Email: mmani@umd.edu

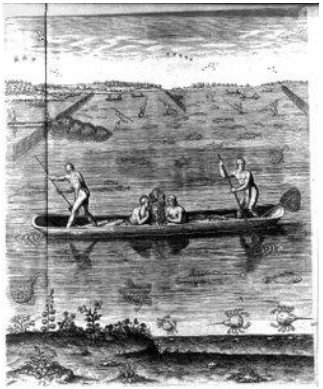
Final Project Report

- Technical report presenting proposals for making production more efficient.
  - Choose any relevant manufacturing scenario
  - Technical report summarizes
    - problem definition, goal and scope of the production scenario,
    - research and analysis,
    - smart manufacturing recommendations.
  - Oral presentation with clear illustrations, within allotted time
  - Reflect on classmates presentations and provide feedback

Outline

- Information
  - Economics of Information
- Information Model
  - What is it?
  - Why do we need it?
  - Fundamentals
- Product Modeling
  - Core Product Model
  - Open Assembly Model
- Distributed Digital Manufacturing
  - Examples and discussion

What is the value of information?



Yesterday

"Where the fish were biting was an important piece of information to tribal societies. They shared this information because it was in the interests of the community to do so, and the catch was shared by all members of the tribe."

Today

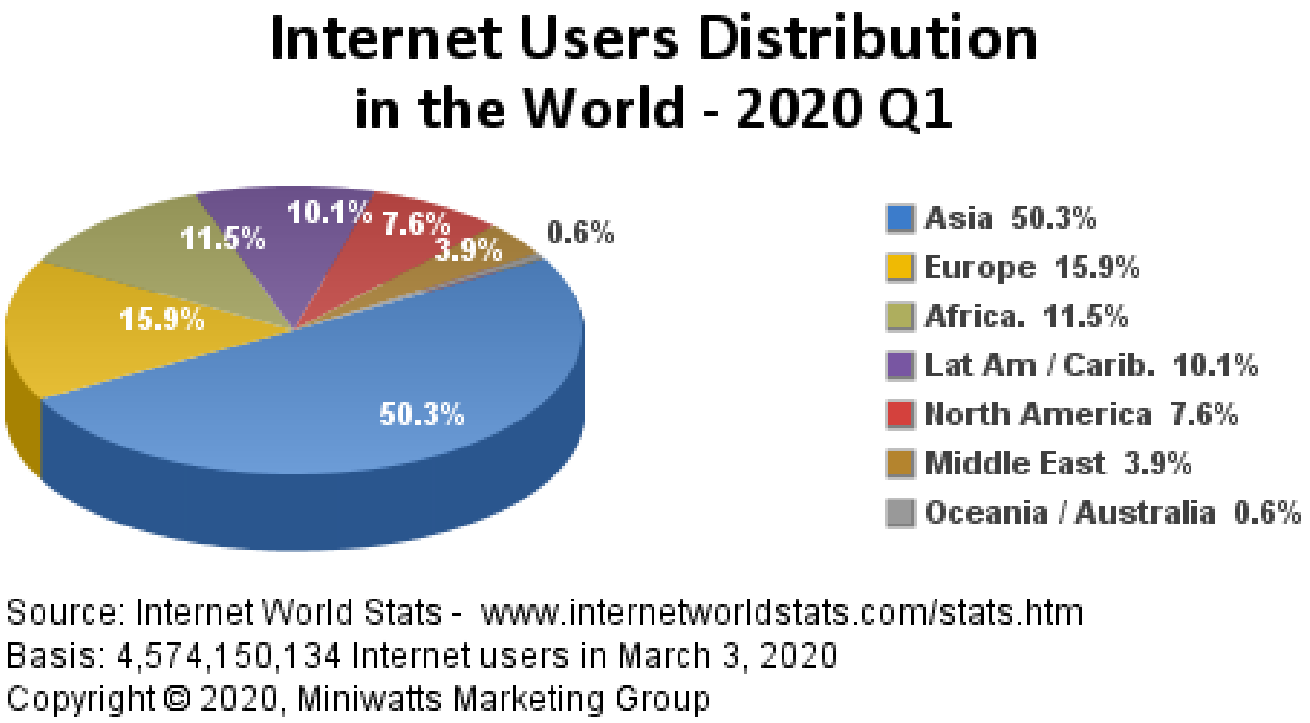
"Today where the fish are biting is a carefully guarded secret by fishermen who store the longitude and latitude in the memories of their Loran equipment on their fishing boats. Their boats come equipped with satellite antenna in order to obtain access to the remote sensing satellite data that discloses where the schools of fish are concentrating and what prices are offered for their catch on the global markets."

Branscomb, Anne Wells. "The Economics of Information Public and Private Domains of Information: Defining the Legal Boundaries." *Retrieved September* 12 (1994): 2014

Image Source: WWW

Do you agree?

"No matter how in the past, today information is being treated more and more as a commodity that can be owned, controlled, and traded in the market."



Source: Internet World Stats - www.internetworldstats.com/stats.htm
Basis: 4,574,150,134 Internet users in March 3, 2020

Information Economics

Economics

- Study of the production, distribution and consumption of goods and services, and the management of these processes
- Study of how people choose to allocate scarce resources to satisfy competing uses or wants

Design

- Transformation of *information* from requirements to product description

Information Economics in Design

- Which information should be created to support design decisions?
- What is the cost (*value)* of information?
- How can one generate more valuable information at a lower cost?

Information comes with a price

- Is the price we pay for information reflective of the quality of information?
- How do we price information in our daily lives?
- What is the value to us if we buy a book or a magazine or print a document?

Role of Information Technology

Information technology (IT) refers to the management and use of information using computer-based tools. It includes acquiring, processing, storing, and distributing information.

Applications of Information Technology

Manufacturing and industry use information technology

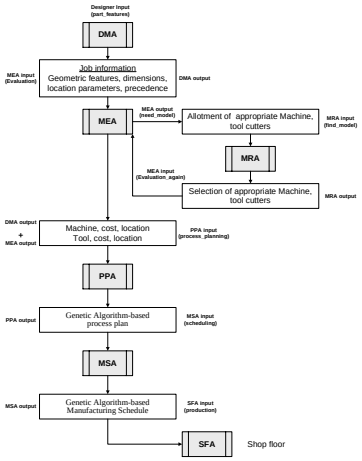
- to improve timeline estimates on projects
- to enhance competitiveness by saving money for customers by meeting or beating deadlines.

Note: The use of better gathering and implementation of information from point of sale by large retailers improves product purchasing, helps maintain balance of inventory, identifies regional product preferences.

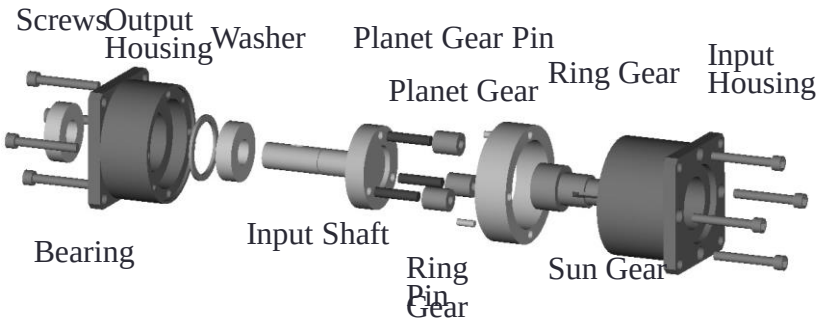
Discussion

- Have you noticed companies that have changed to or evolved to help the consumers needs and wants?
- Do we need a structure to information in design?

What is a Model?



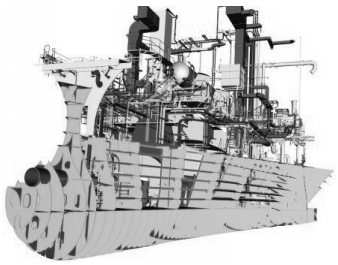
- a representation
  - models represent items, that appear in real or virtual worlds
- an abstraction
  - models only capture relevant properties of the items
- a subjective interpretation
  - the selection and the projection of relevant properties is done with subjective judgment



What is an Information Model?

definition:

- *a **formal description of types** of ideas, facts and processes which together form a model of a **portion of interest** of the real world and which provides an **explicit set of interpretation rules***

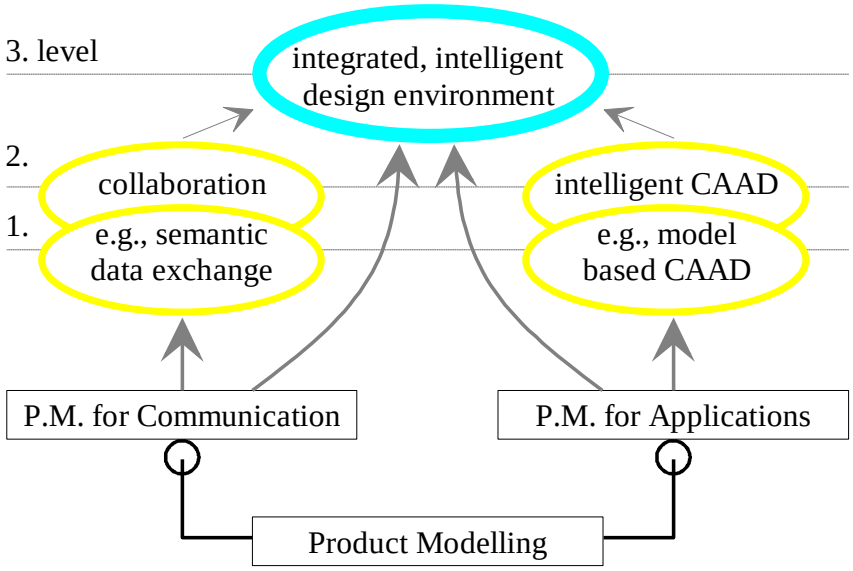


Is a formal representation useful?

Purposes of an Information Model

- used to define interface models for data exchange and data access
- used to define data models for applications dealing with semantics
- used to define the correspondence between application and interface

Example: Production Information Modeling

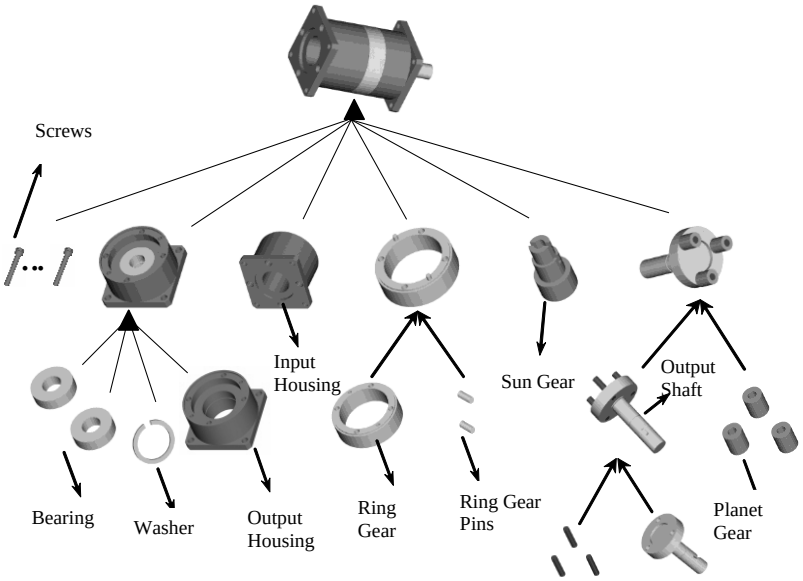


Source: NIST

Fundamentals of Information Models

- need to ***represent the information together*** with the interpretation rules, i.e. the syntax (or symbols) together with the semantics (or meanings)
- need to ***abstract the type***, i.e. the common behavior of a set of comparable real world items, from its particular appearance, the instance
- need to ***classify the information in categories*** of information at different levels of abstraction

What kind of Information is captured?



static properties
- description of classes
- description of attributes
- description of relationships

dynamic properties
- description of operations
- description of events and transactions

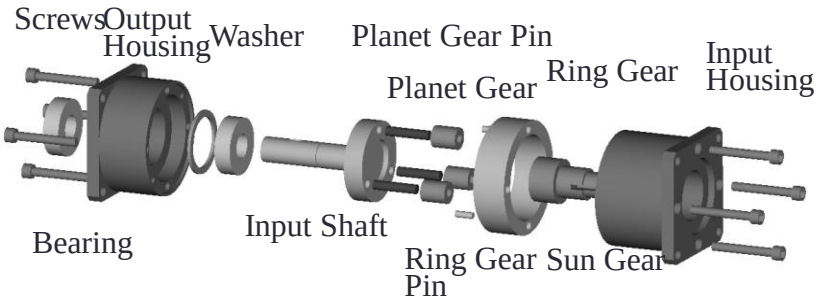
integrity
- local constraints
- global constraints

Objects in Information Models

- any item of interest, e.g.:
  - -- things (physical objects)
  - -- ideas (non-physical concepts)
  - -- processes (activities, schedules, ...)
  - -- etc.

generic information sets describing products

- -- systems and system parts
- -- versions or states during life cycle
- -- requirement and solution attributes
- -- component structure (whole - part)
- -- context, relations to other products
- -- shape information
- -- placement



Attributes in Information Model

- *a characteristic, quality or property of an object*

-- Explicit attributes - the attribute value is populated by the application

--- Mandatory explicit attributes - the attribute value has to exist

--- Optional explicit attributes - the attribute value may exist or be not determined (the attribute definition has to be always recognized!)

-- Inverse attributes - the existence of an instance may depend on the existence of another instance which uses this entity for definition.

--- Inverse attributes are not explicitly exchange, they are re-associated on the receiving end

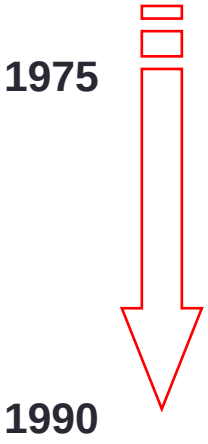
Levels of Information

- conceptual level
  - totally independent from implementation concerns
- design level
  - take implementation constraints into account
- implementation level
  - build application according to the model

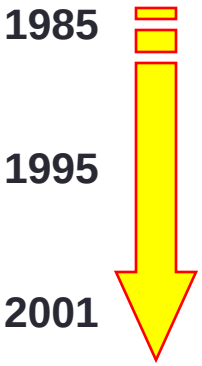
Discussion

- What is the usefulness of a product model as an information model?
- Where do you see it useful?
- What do you expect in product model?

History of Product Models



- first predevelopment phase
  - database views, modular systems, CAD
- second predevelopment phase
  - expert systems

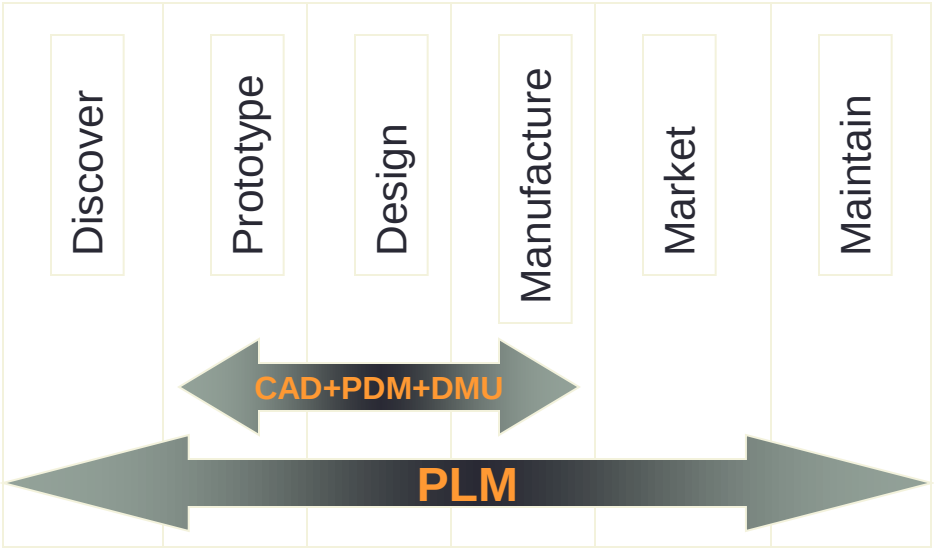


- first generation of product models
- second generation of product models
- third generation of product models

Interoperability Framework

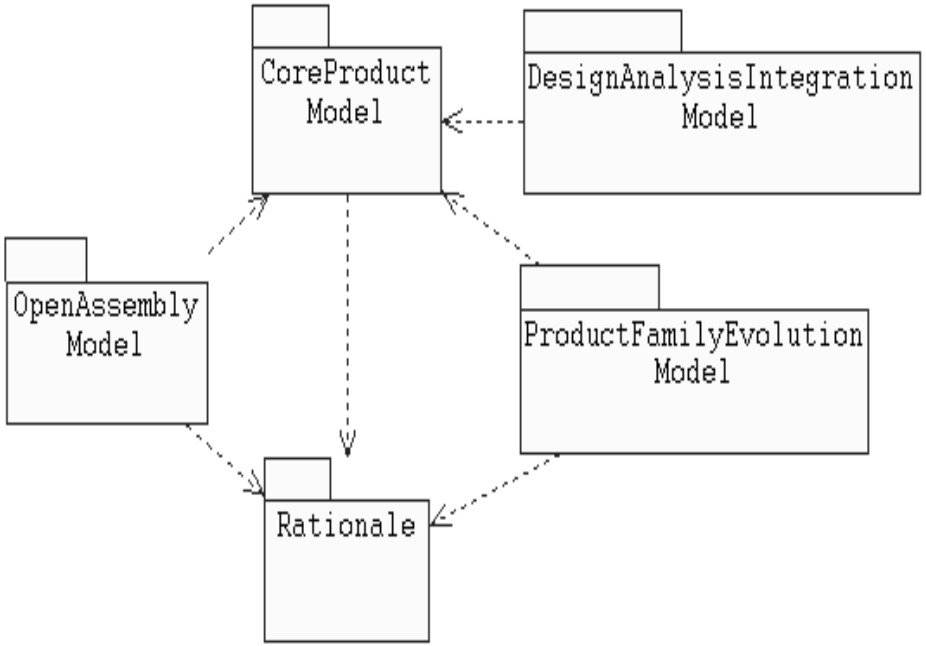
Objectives

- serve as generic depository of all product information at all stages
- deliver all product description information to PLM and subsidiary systems using a single, uniform information exchange protocol
- support direct interoperability among CAD, CAE, CAM and other interrelated systems



Framework Components

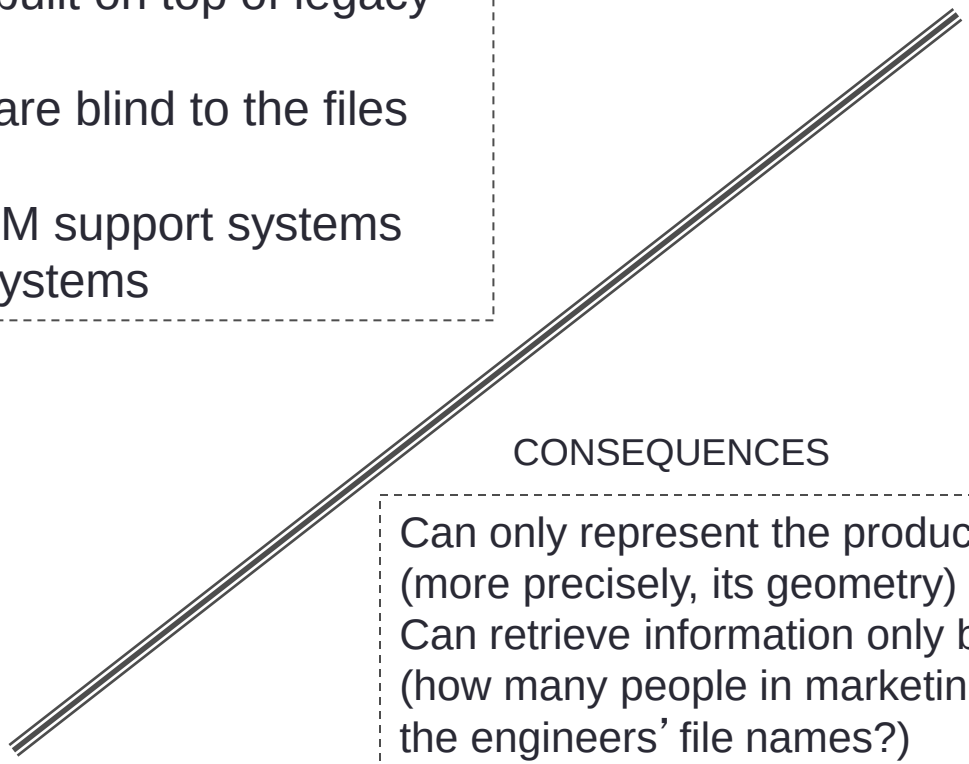
- ✓**Core Product model**
- ✓**Open Assembly Model**
- ✓Design Analysis Integration Model
- ✓Product Family Evolution Model
- ✓Rationale



Towards a Core Product Model

STATUS

Many PDM systems built on top of legacy CAD systems
Many PDM systems are blind to the files they manage
Many commercial PLM support systems built on top of PDM systems



CONSEQUENCES

Can only represent the product's form (more precisely, its geometry)
Can retrieve information only by file name (how many people in marketing etc., know the engineers' file names?)
Can support only that segment of design process that deals with the product's form (embodiment design and later)

Core Product Model

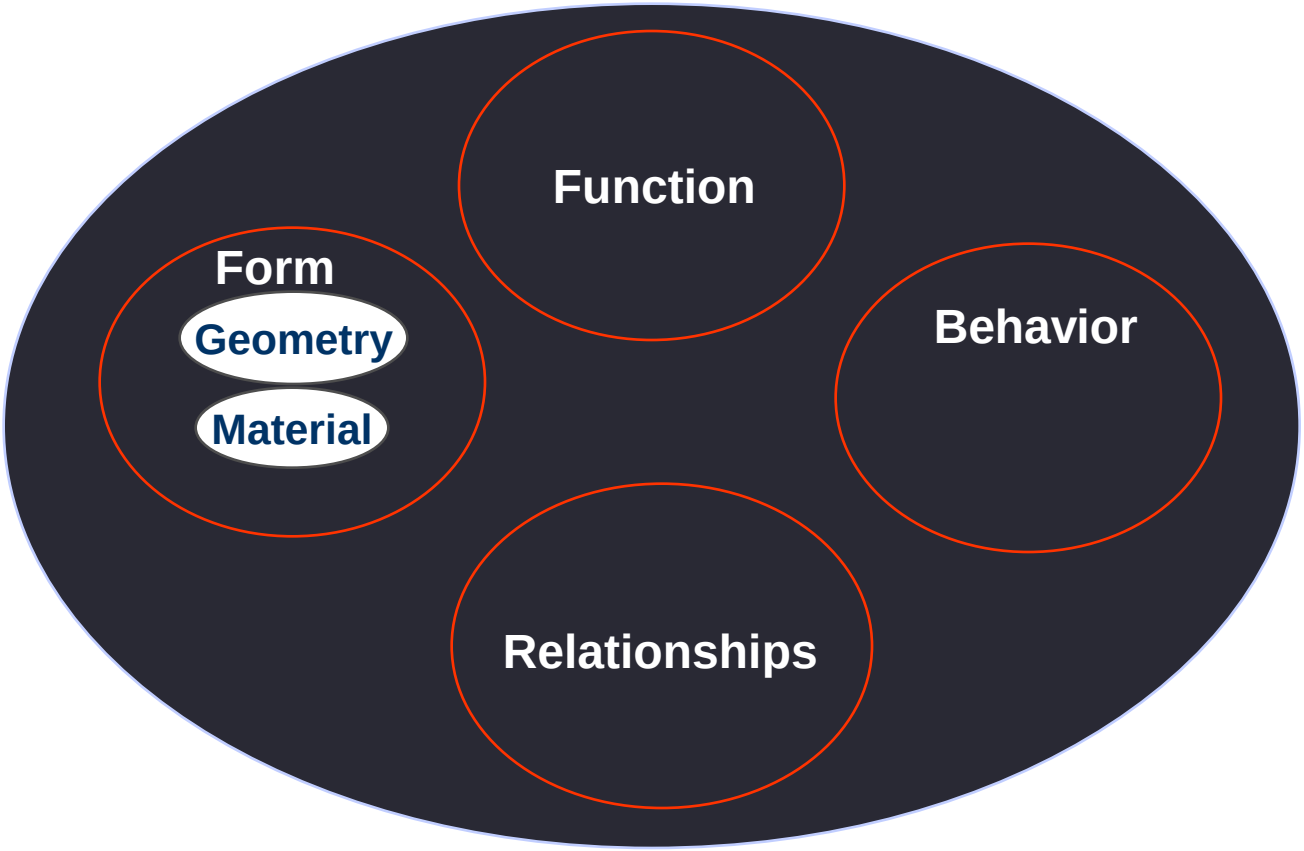
Objective:

a base-level product model that is:

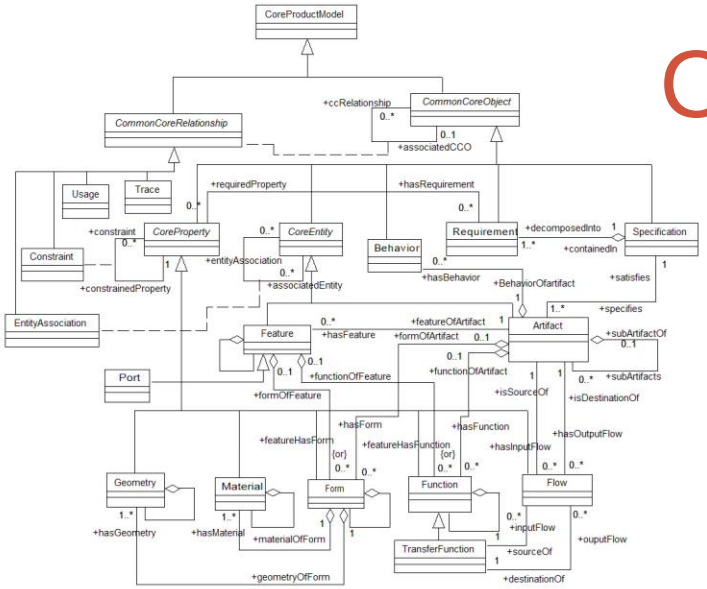
- generic
- extensible
- independent of any one product development process
- capable of capturing full engineering context

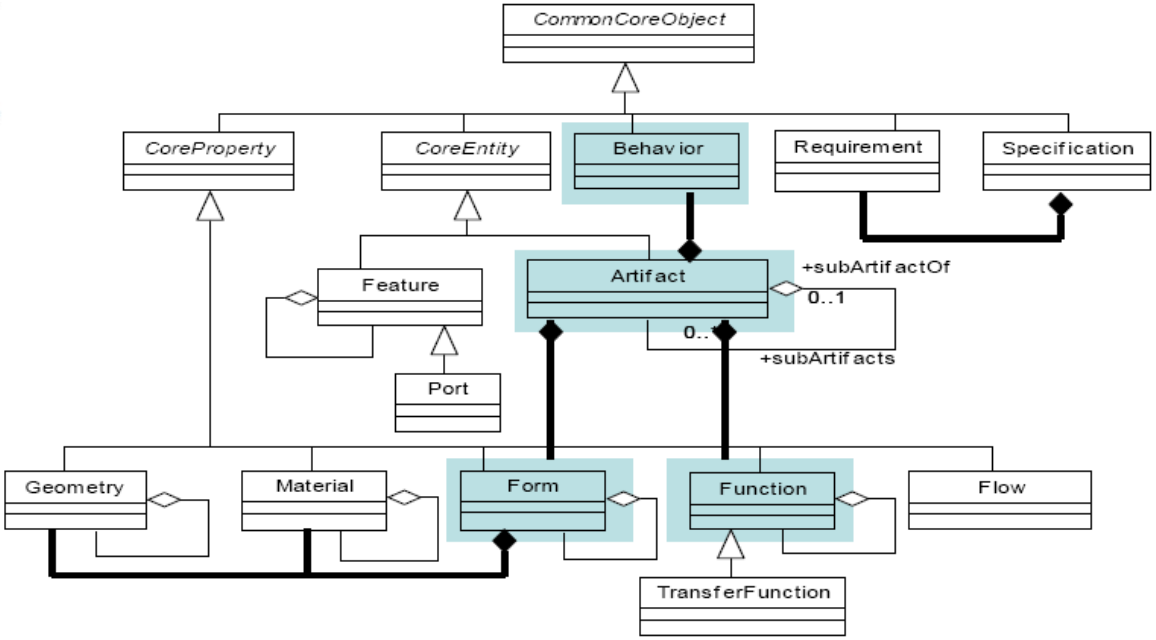
Key feature: explicit representation of
Function – Form - Behavior
(in contrast to STEP AP 209 that essentially represents only form)

Knowledge Representation in CPM

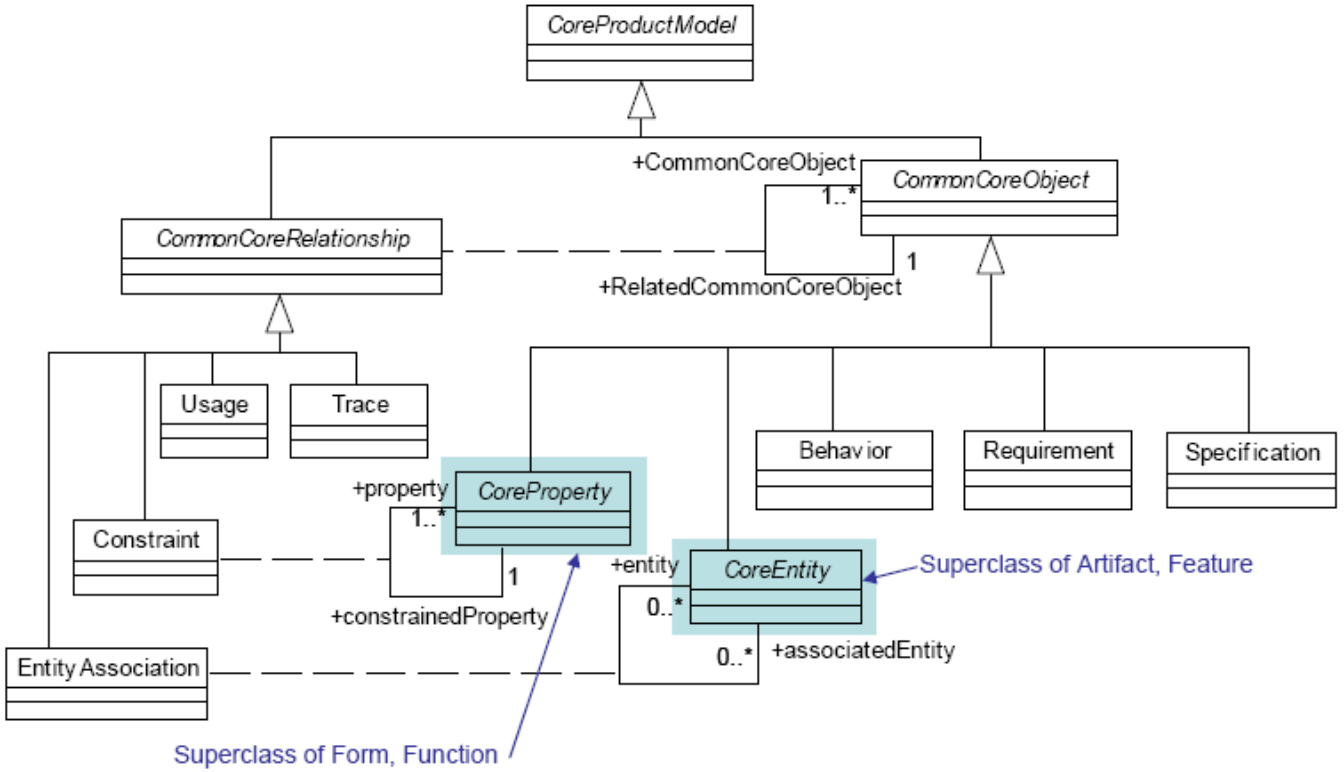


CPM Objects


CoreProductModel
CommonCoreRelationship
+ccRelationship
CommonCoreObject
0..*
0..1
+associatedCCO
Usage
Trace
+requiredProperty
+hasRequirement
0..*
+constraint
CoreProperty
0..*
CoreEntity
Behavior
Requirement
+decomposedInto
1
Specification
1..*
+containedIn
Constraint
+entityAssociation
+constrainedProperty
+associatedEntity
+hasBehavior
+BehaviorOfartifact
+satisfies
+specifies
EntityAssociation
Feature
+hasFeature
+featureOfArtifact
+formOfArtifact
Artifact
+subArtifactOf
+functionOfFeature
+functionOfArtifact
+subArtifacts
Port
+formOfFeature
+isSourceOf
+isDestinationOf
+hasForm
+hasFunction
+hasOutputFlow
+featureHasForm
+featureHasFunction
+hasInputFlow
{or}
Geometry
Material
Form
Function
Flow
+hasGeometry
+hasMaterial
+materialOfForm
+inputFlow
+ouputFlow
TransferFunction
+sourceOf
+destinationOf
+geometryOfForm

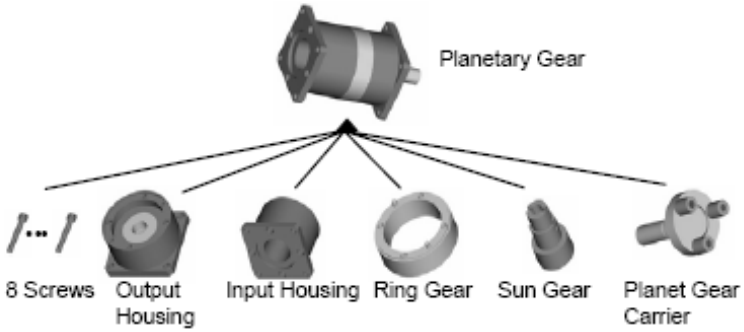

CommonCoreObject
CoreProperty
CoreEntity
Behavior
Requirement
Specification
Feature
Artifact
+subArtifactOf
0..1
0..*
+subArtifacts
Port
Geometry
Material
Form
Function
Flow
TransferFunction

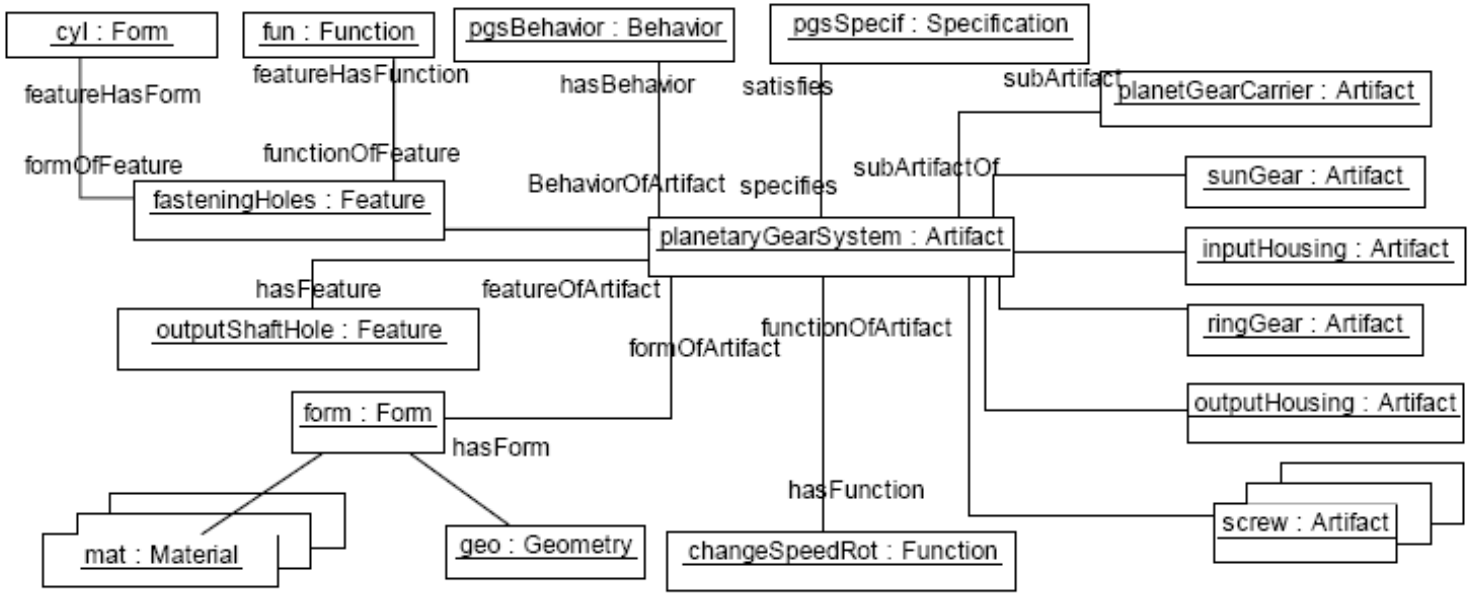
CPM Relationship Classes



https://asmedigitalcollection.asme.org/computingengineering/article/8/1/014501/460770/CPM2-A-Core-Model-for-Product-Data

An Example


Planetary Gear
8 Screws
Output Housing
Input Housing
Ring Gear
Sun Gear
Planet Gear Carrier


cyl : Form
fun : Function
pgsBehavior : Behavior
pgsSpecif : Specification
featureHasForm
featureHasFunction
hasBehavior
satisfies
subArtifact
planetGearCarrier : Artifact
formOfFeature
functionOfFeature
BehaviorOfArtifact
specifies
subArtifactOf
sunGear : Artifact
fasteningHoles : Feature
planetaryGearSystem : Artifact
inputHousing : Artifact
hasFeature
featureOfArtifact
outputShaftHole : Feature
functionOfArtifact
formOfArtifact
ringGear : Artifact
outputHousing : Artifact
form : Form
hasForm
hasFunction
screw : Artifact
mat : Material
geo : Geometry
changeSpeedRot : Function

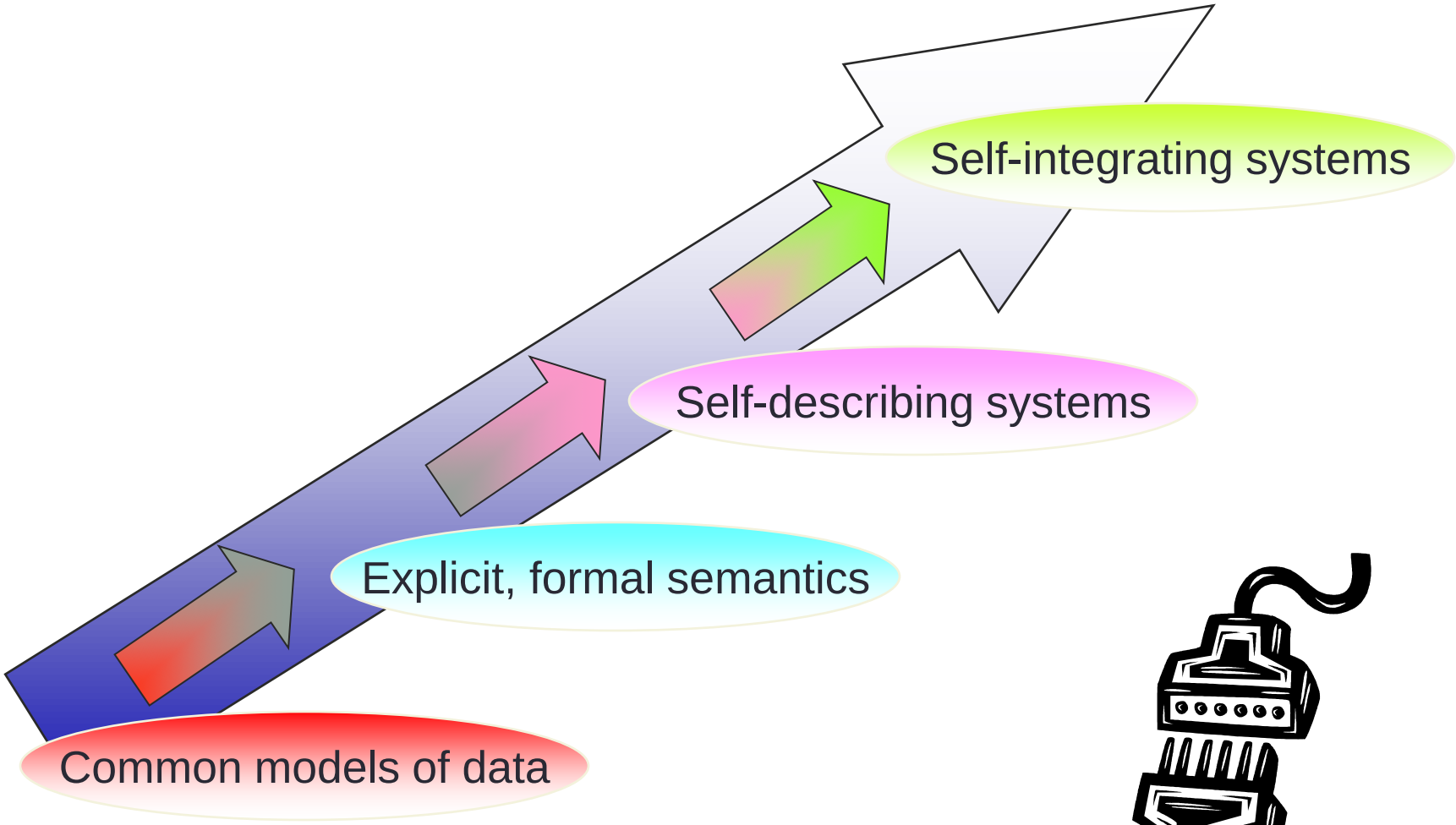
Information Modeling Languages

- EXPRESS and EXPRESS-G (ISO 10303-11).
- Unified Modeling Language (UML)
- IDEF
- SysML
- Process Specification Language (PSL)
- Energy Systems Language (ESL)
- Business Process Modeling Notation (BPMN, and the XML form BPML)
- Fundamental Modeling Concepts (FMC)
- Ontology Web Language (OWL)
- Petri nets …

Thoughts

- **abstract models** and hence implementation issues
- identify **framework components** needed
- clarify **product information needs** of PLM process
- consider **interactions** between product data provided by framework and metadata maintained by PLM system
- identify **information exchange standards** that can provide needed degree of interoperability

Future


Self-integrating systems
Self-describing systems
Explicit, formal semantics
Common models of data

Related Reading

Fenves, Steven J., Sebti Foufou, Conrad Bock, and Ram D. Sriram. "CPM2: a core model for product data." *Journal of Computing and Information Science in Engineering* 8, no. 1 (2008): 014501

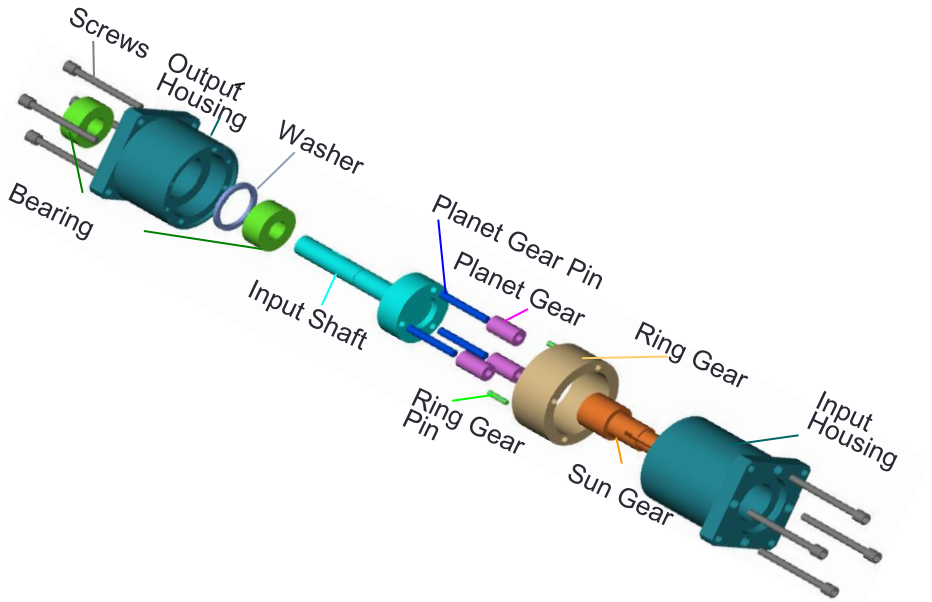
https://www.nist.gov/publications/cpm-2-revised-core-product-model-representing-design-information

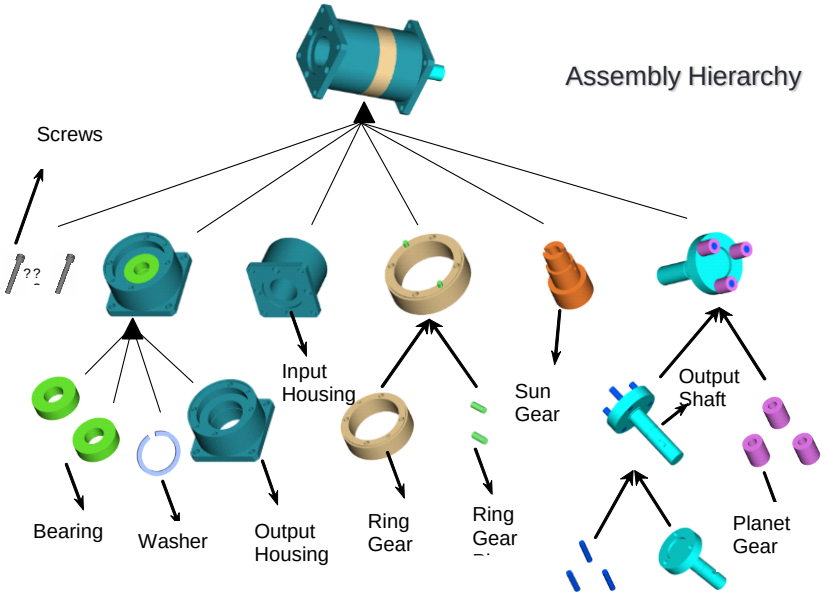
https://www.nist.gov/publications

Key words like: product model, core product model, open assembly model, product ontology, SysML, PSL, etc.

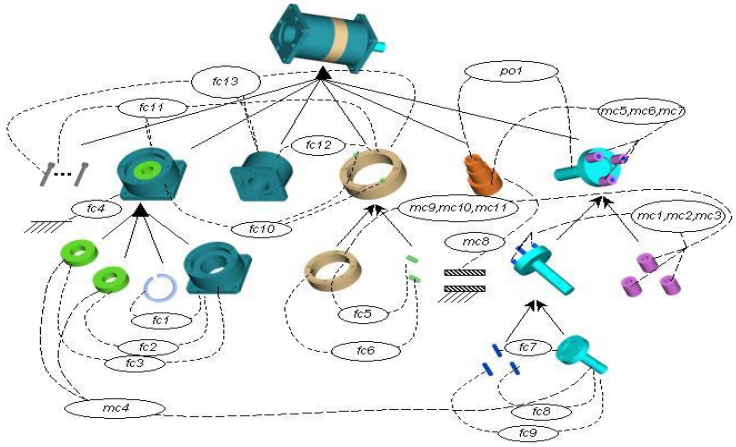
Smith, Barry. "Ontology." (2003)
http://philpapers.org/archive/SMIO-2.pdf

Planetary Gear Example





Assembly Associations



fc: fixed connection
mc: movable connection
po: position and orientation

Example of a distributed manufacturing scenario

Agent Based Systems

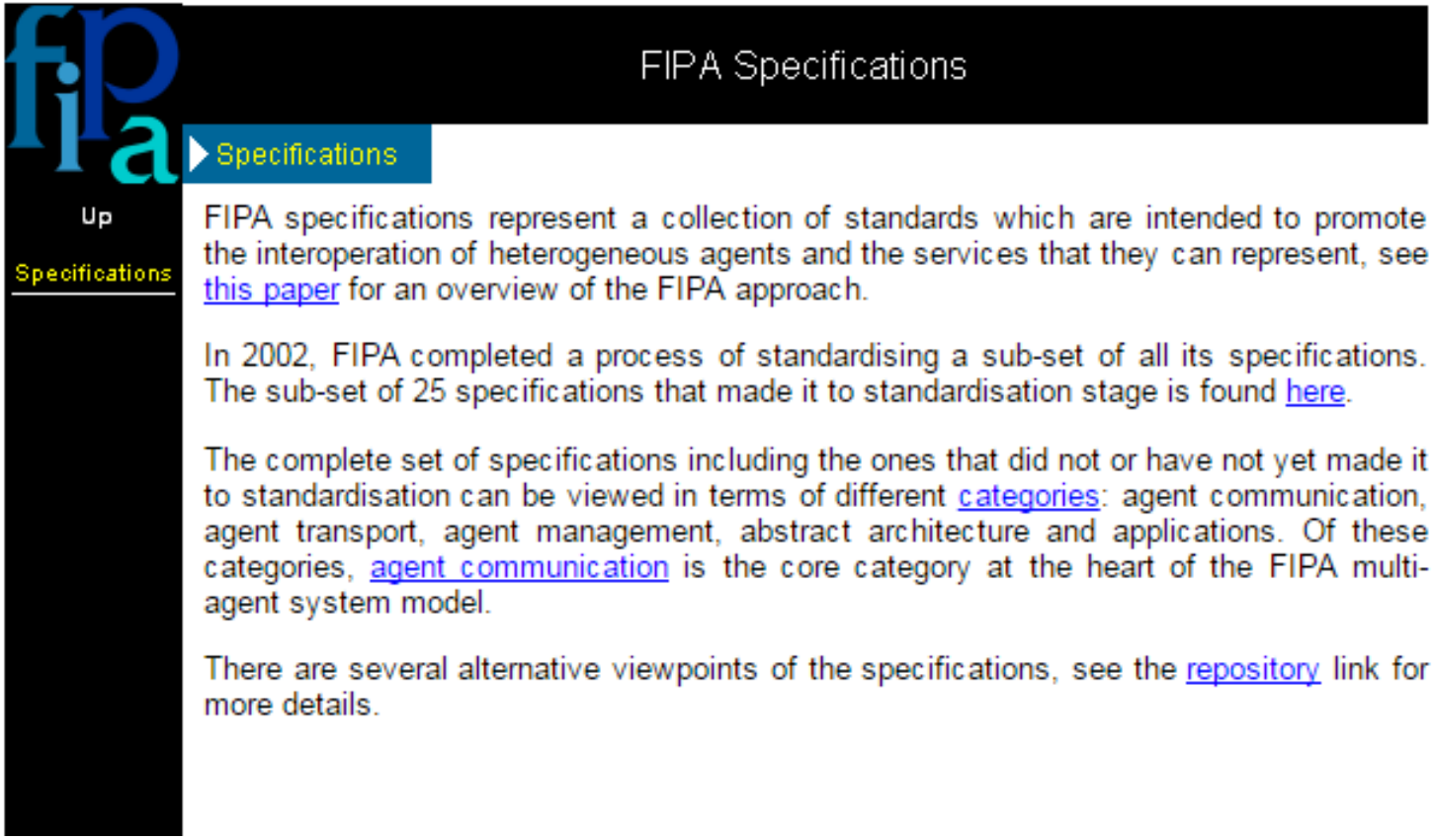
Introduction

- Essence of Agent Based Systems
- Development of Multi-Agent System
- Role of information modelling

Essence of Agent Based Systems

- Definition
  - A software program that specifically performs
  - a user-delegated task
  - Characteristics
    - ☑ Delegation
    - ☑ Autonomy
    - ☑ Communication
    - ☑ Monitoring
    - ☑ Intelligence

FIPA



FIPA Specifications

Specifications

Up

Specifications

FIPA specifications represent a collection of standards which are intended to promote the interoperation of heterogeneous agents and the services that they can represent, see this paper for an overview of the FIPA approach.

In 2002, FIPA completed a process of standardising a sub-set of all its specifications. The sub-set of 25 specifications that made it to standardisation stage is found here.

The complete set of specifications including the ones that did not or have not yet made it to standardisation can be viewed in terms of different categories: agent communication, agent transport, agent management, abstract architecture and applications. Of these categories, agent communication is the core category at the heart of the FIPA multi-agent system model.

There are several alternative viewpoints of the specifications, see the repository link for more details.

http://www.fipa.org/specifications/index.html

Development of Multi-Agent System

- Complexity of products
- Geographically distributed facilities
- Necessity of collaboration among facilities

- **Solution**
  - Development of Functional Agents
  - Distributed Agent Coordination (Multi-Agent System)

Agent based research

- Development of a Multi-Agent System for Distributed Manufacturing from Product-design → Final part

Involves:

- Independent Functional agents
- Distributed Framework
- Communication Ontology
- Coordinated Architecture
- Prototype System

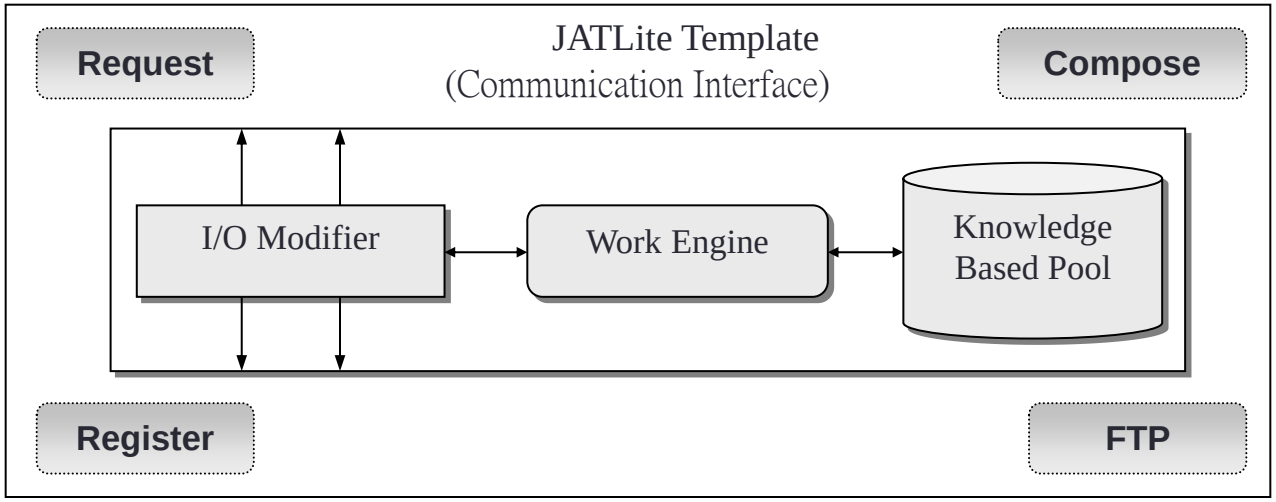
Independent Functional agents

- Design Mediator Agent (DMA)
- Manufacturability Evaluation Agent (MEA)
- Manufacturing Resource Agent (MRA)
- Process Planning Agent (PPA)
- Manufacturing Scheduling Agent (MSA)
- Shop Floor Agent (SFA)
- Fault Diagnosis Agent (FDA)..etc

+

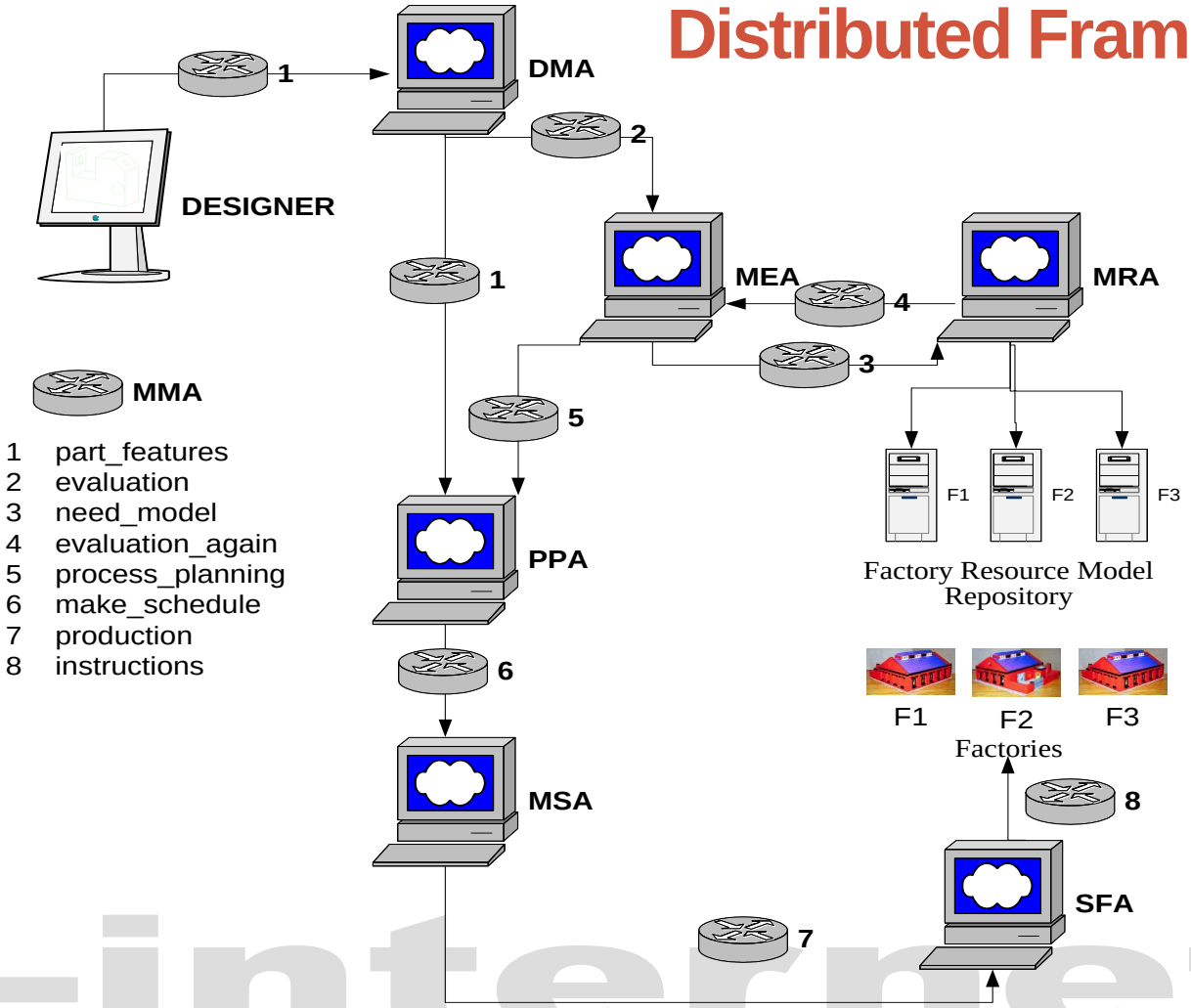
- Manufacturing Managing Agent (MMA)

Internal Structure of each Agent



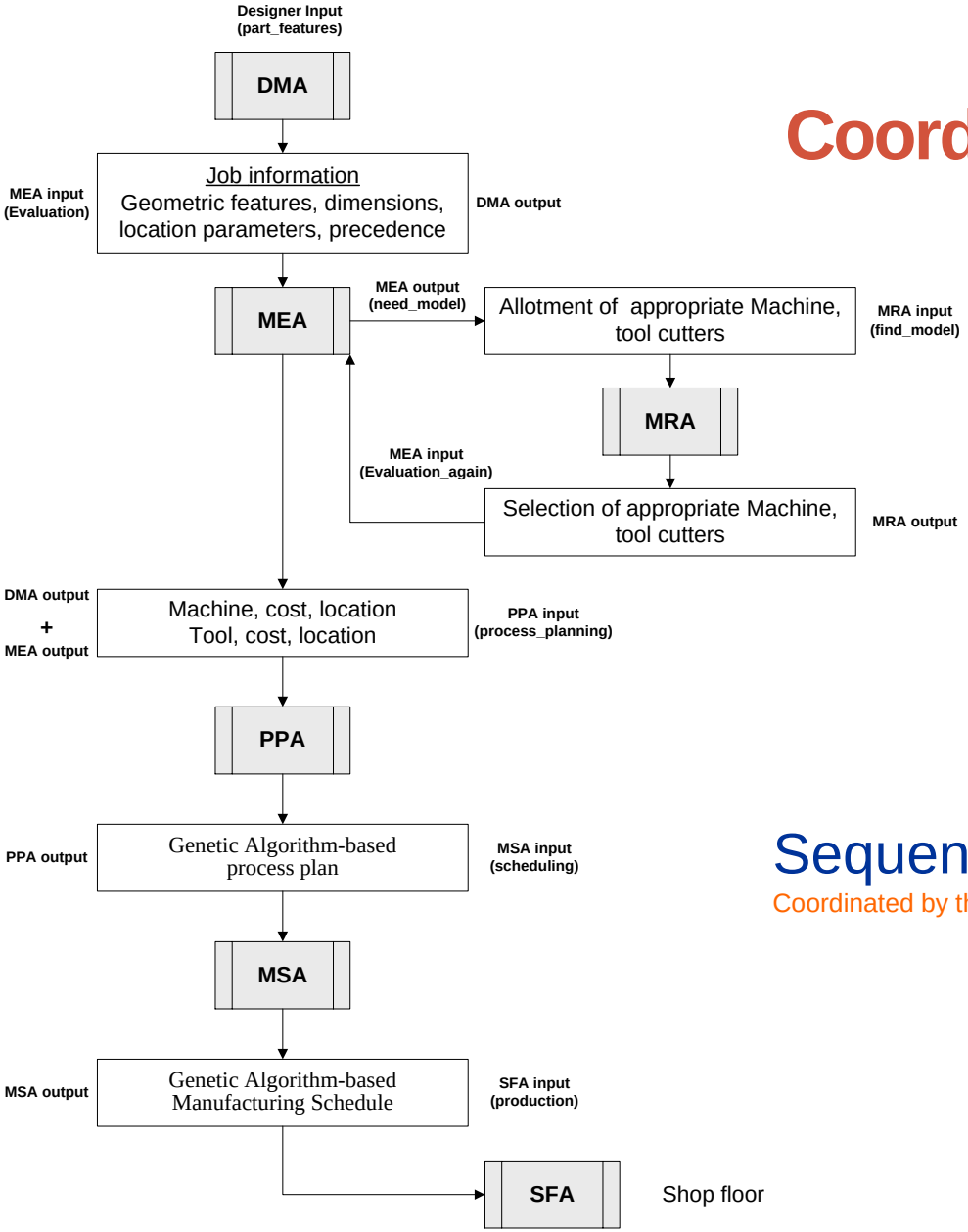
- Communication
  - Knowledge Query Manipulation Language (KQML)
- Agent Language
  - Predefined performatives for message interpretations

Distributed Framework



1 part_features
2 evaluation
3 need_model
4 evaluation_again
5 process_planning
6 make_schedule
7 production
8 instructions

Coordinated Architecture



Sequenced Input –Output

Coordinated by the Manufacturing Managing Agent

Information flow in the Integrated System

Steps	Data flow	Message type	Performatives	Operation
1	DMA→MMA	Feature-based design	*Part_features*	Feature-based product design goes into the multi-agent system with the assistance of the DMA.
2	MMA←→MEA	Feature-based design	*Evaluation*	MEA evaluates the manufacturability of the design and infers the required manufacturing processes and resources.
3	MMA←→MRA	Required resources	*Find_model*	MRA searches for suitable factories in the database.
3’	MRA→MMA→PPA	Factory information	*Undate_info*	Factory, machine, tool information for process planning and subsequently scheduling.
4	MMA←→MEA	Suitable factories	*Evaluation_again*	MEA evaluates the factory models and selects an optimal model.
5	MMA←→PPA	Part features and selected factory model	*Make_plan*	PPA generates an optimal process plan.
6	MMA←→MSA	Process plan	*Make_schedule*	MSA generates an optimal production schedule.
7	MMA→Factory	Production schedule	*Production*	Product manufacturing is started in the selected factory.
*	FDA→MMA	Manufacturing data	*Tool_fault*	FDA monitors the manufacturing process in real-time and sends the abnormal data to the MMA.

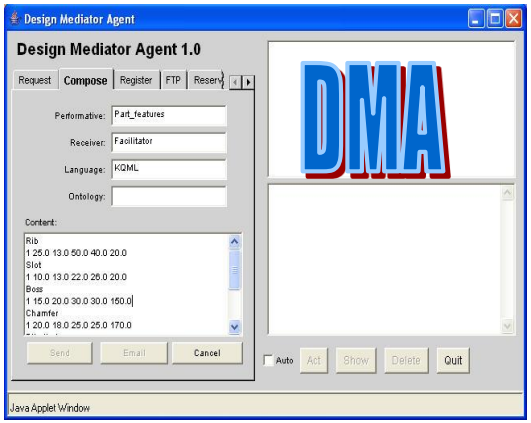
Prototype system

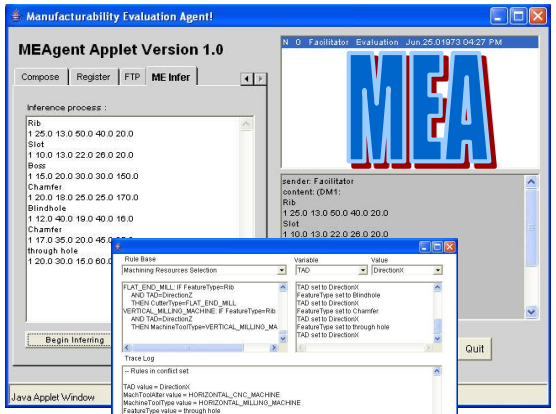
Implementation

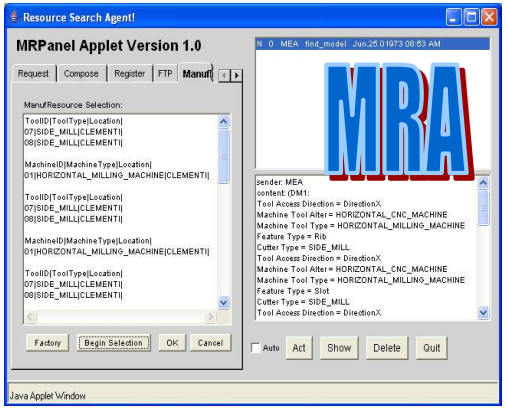
- ☑ JATLite used as the agent template
- ☑ Whole system developed using Java programming
- ☑ Database management: MySQL, SQL Adaptive Server
- ☑ Communication through Router
- ☑ Coordination through MMA

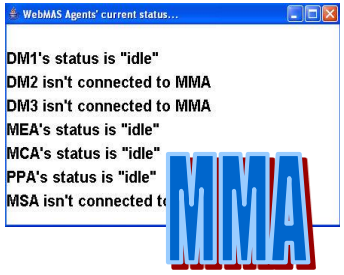
Successfully tested on the Intranet

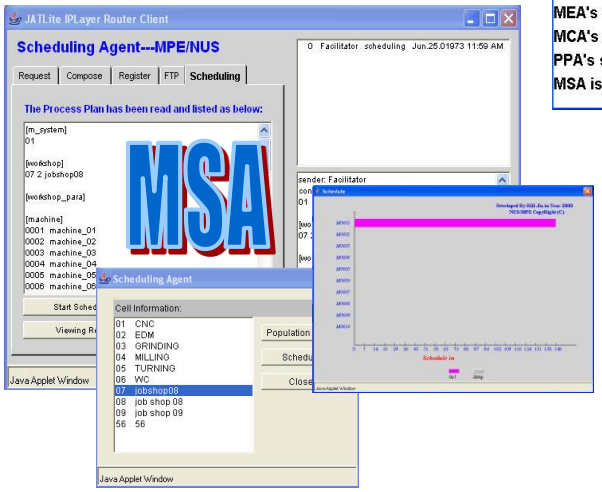
Snapshots

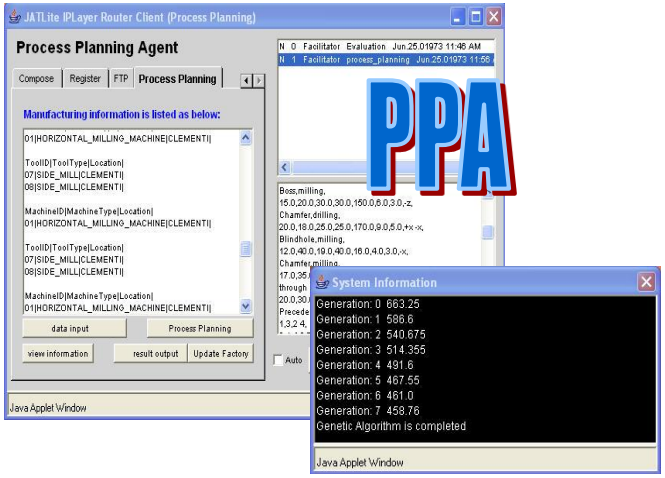

Design Mediator Agent
Design Mediator Agent 1.0
DMA


Manufacturability Evaluation Agent!
MEAgent Applet Version 1.0
MEA


Resource Search Agent!
MRPanel Applet Version 1.0
MRA


WebMAS Agents' current status...
DM1's status is "idle"
DM2 isn't connected to MMA
DM3 isn't connected to MMA
MEA's status is "idle"
MCA's status is "idle"
PPA's status is "idle"
MMA


JATLite IPLayer Router Client
Scheduling Agent---MPE/NUS
MSA


JATLite IPLayer Router Client (Process Planning)
Process Planning Agent
PPA
System Information

WebMAS Case Study

WebMAS Plot:

Part-design to Part-Production Schedule

Participating Functional Agents:

Design Mediator Agent (DMA)
Manufacturing Evaluation Agent (MEA)
Manufacturing Resource Agent (MRA)
Process Planning Agent (PPA)
Manufacturing Scheduling Agent (MSA)

Agent Registration/ Connection:

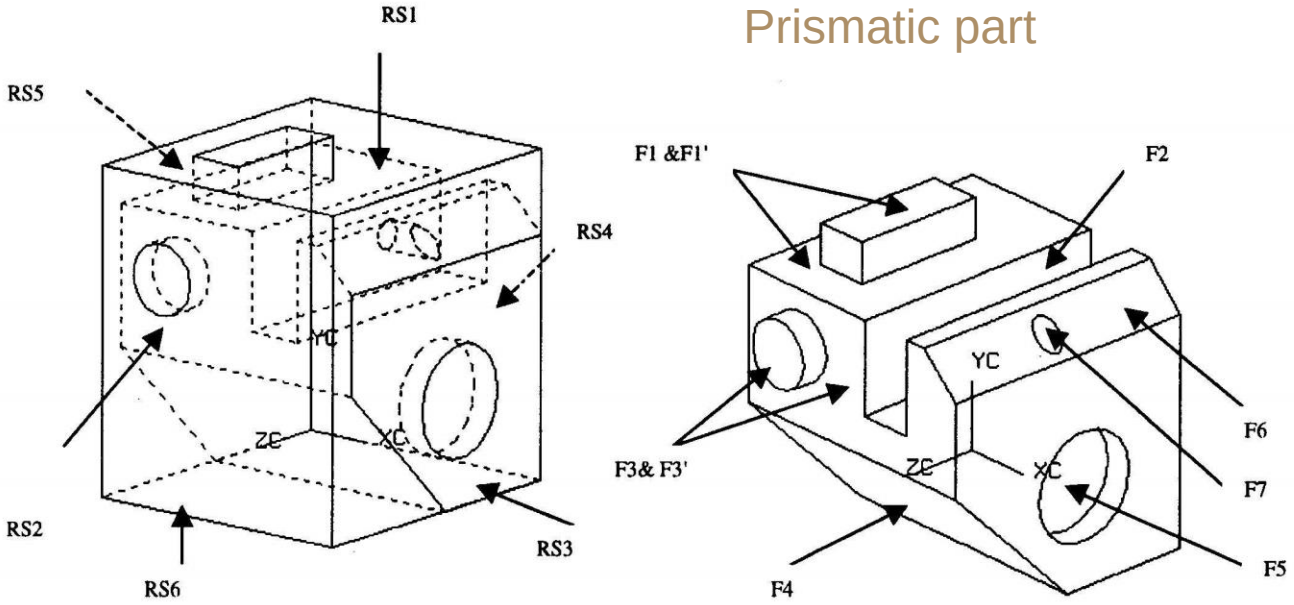
Router

WebMAS Coordination:

Manufacturing Managing Agent (MMA) alias Facilitator

Part-design

Prismatic part



(a) Row stock (b) The final product

F1 Machining feature to create F1'	F1' Rib	F2 Slot
F3 Machining feature to create F3'	F3' Boss	F4 Chamfer
F5 Blind hole	F6 Chamfer	F7 Through hole

Design Details

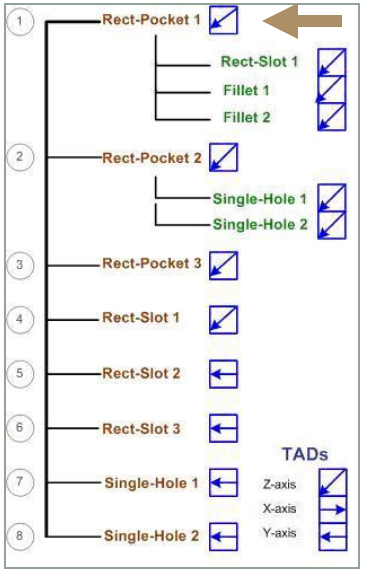
Geometric features

Simple Hole
Rectangular Pocket
Rectangular Slot
Block
Fillet
Rib
…
etc.

Relevant part design details like:

- Geometric features
- Possible Tool Access Direction (TAD)
- Dimension parameters
- Location Parameters
- Precedence Information

Precedence TAD



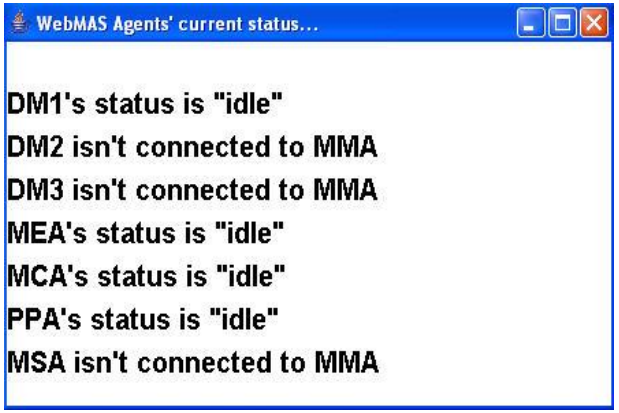
Geometric Feature Representation

```
Rect_Slot
2 25.0 13.0 50.0 40.0 20.0
```

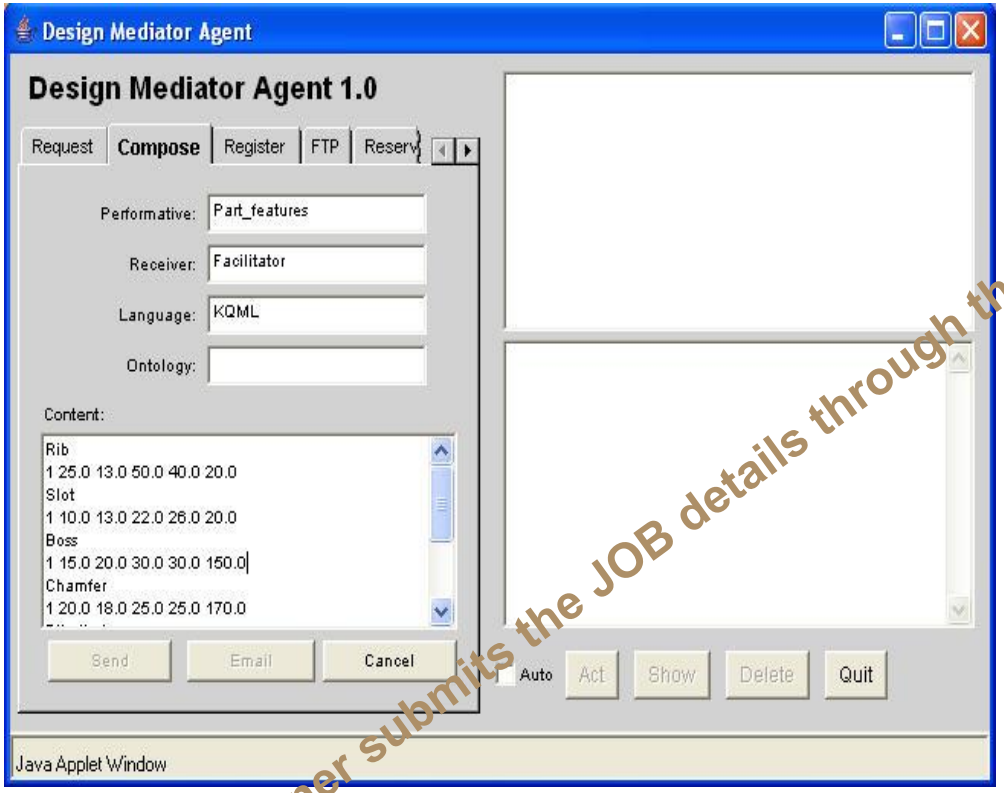
WebMAS Initialization

- Initialization of Router

- Initialization of MMA



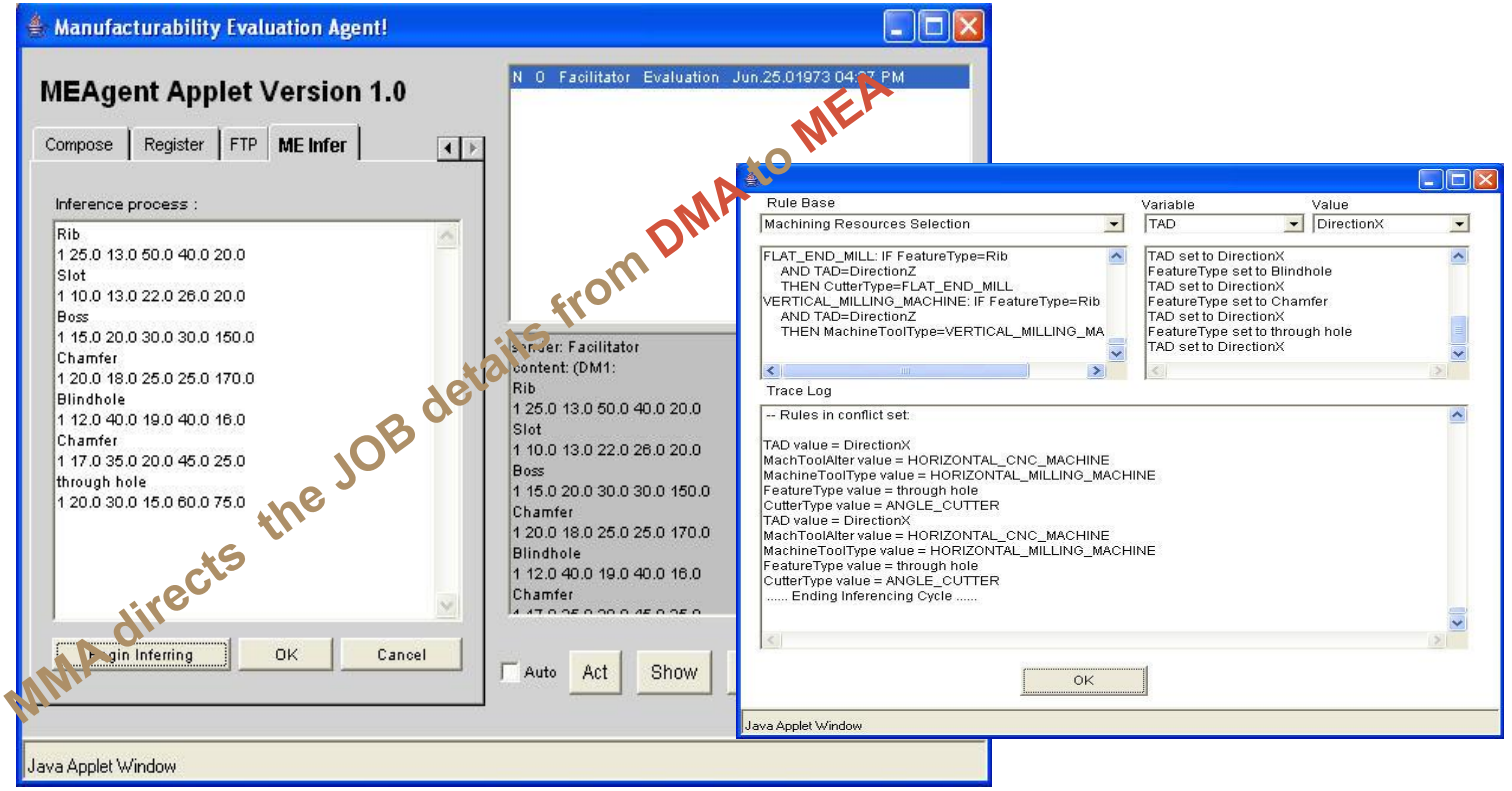
Design Mediator Agent



Designer submits the JOB details through the DMA

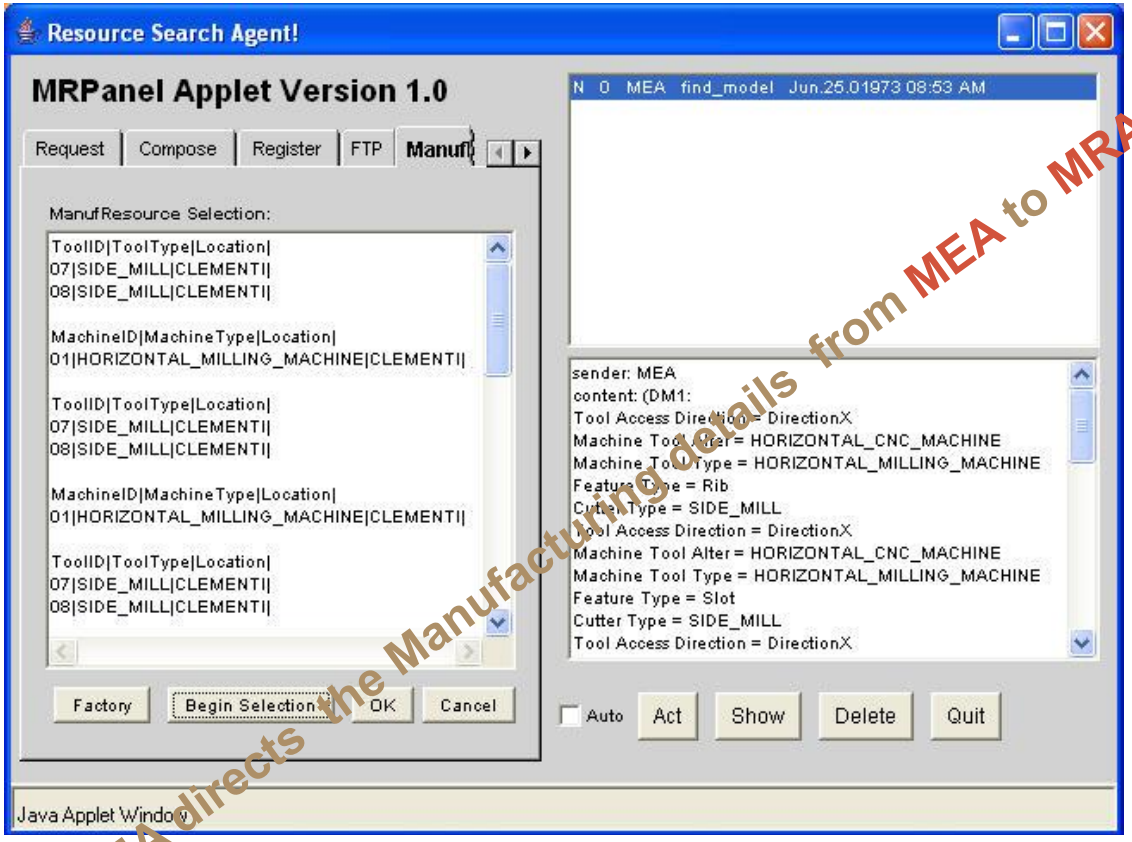
Performative: *Part_features*

Manufacturability Evaluation Agent



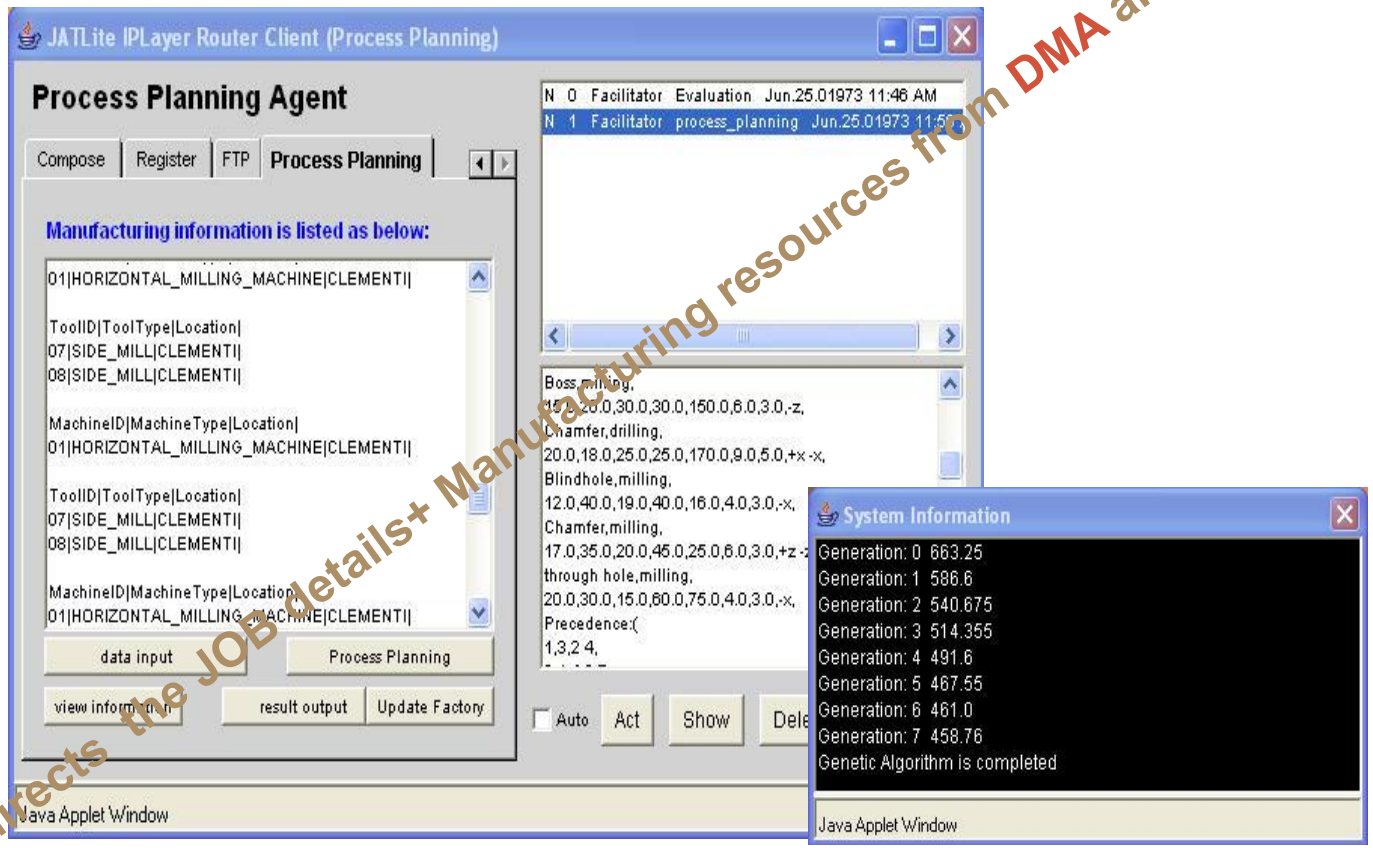
Performative: *Evaluation*

Manufacturing Resource Agent



Performative: *need_model*

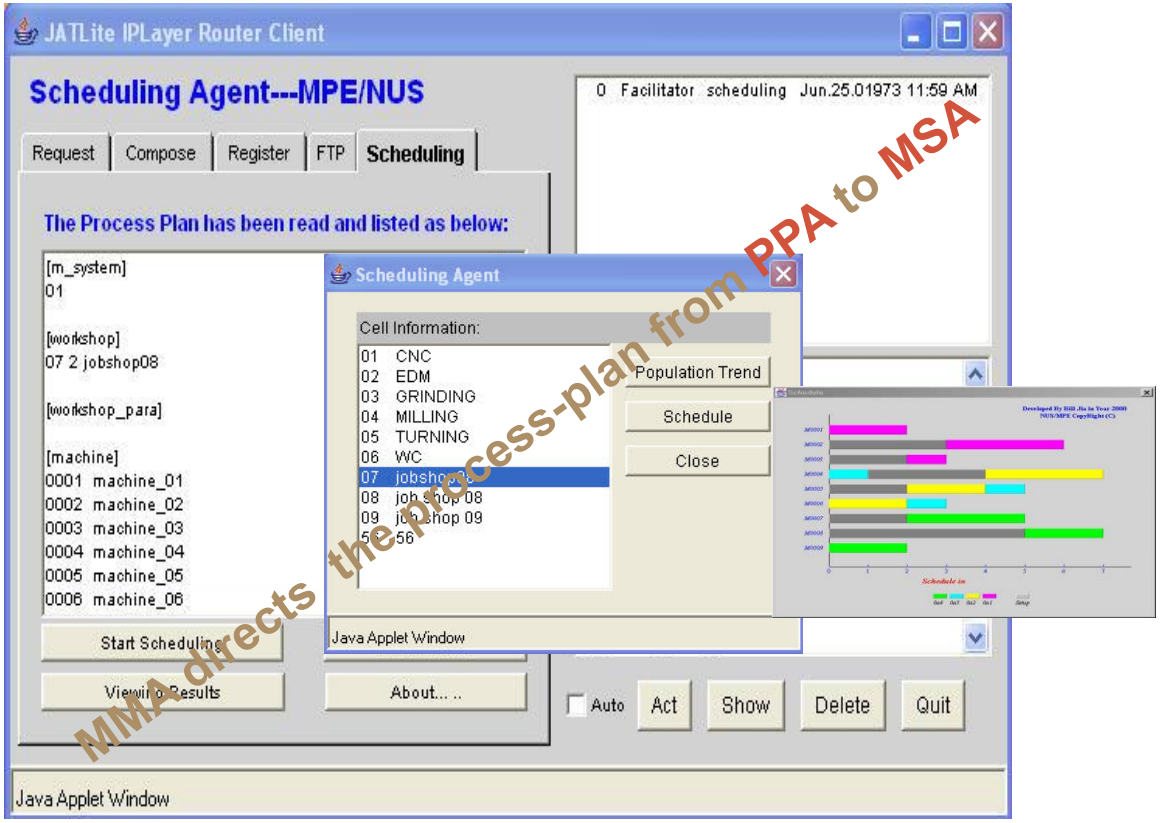
Process Planning Agent



MMA directs the JOB details+ Manufacturing resources from DMA and MEA

Performative: *process_planning*

Manufacturing Scheduling Agent



Performative: *make_schedule*

Information relevance to MAS

Overall web-based integrated multi-agent system

- ✓Information considered logical and inter-dependant
- ✓Customization of input-output messages
- ✓Dynamic information updates of the participating agents for efficient planning and scheduling
- ✓With the proposed framework involving centralized coordination, it will be easier to concentrate on the functional modules of the participating agents.
- ✓Independent agent-to agent communication should there be break down with the facilitating MMA

Information integration and improvements?

- Improvement of the existing system to extend its integration with the shop floor in real time
- Research efforts to be focused on further improving the manufacturability evaluation agent with extended knowledge base for design conflicts and manufacturability
- Possibility of customizing the proposed framework to extend its applications beyond engineering manufacturing, such as logistics, design reuse, etc

Questions?