Ontology in Engineering Big Systems

Matthew West
Henson Graves
April 12, 2012
Status of Modeling in Engineering

• Models are getting larger and more complex
  – Model integration and management brings new problems

• The role of models in engineering is changing
  – from auxiliary information to authoritative source

• Results in reexamination of old questions
  – Are the models precise and correct
  – How do we establish the semantics of models
  – Where does ontology fit

• Conclusions?
Models Are Getting Increasingly Large

**Example: Air Vehicle Design Model**

- **Subsystems**
- **Top Level Design**
- **Detailed Design**
- **Product Configuration**

400 Class Tree (subsystem relation)
- 2000 Classes
- 4000 Associations
- 10000 Classes
- 40000 Associations
- 22,000 unique part numbers and over 300,000 part counts

- PowerPoint
- Excel
- • PowerPoint
- • Excel
- • UML/SysML
- UML/SysML
- MatLab
- CATIA
- Database

...the design models are only the tip of the iceberg
Product Data Has Broad Scope, Is Stored In Multiple Places And Has Overlap & Dependences

- Concurrent work on all lifecycle activities
- 500+ tools with few common formats
- 30+ persistent data storage systems
- A terabyte of data growing to 100s of terabytes
- Little support for maintaining design traceability
- Little support for maintaining and publishing in progress designs
Data Integrity is a Critical Problem

- Each design step
  - Processes previously derived data

- Data dependency chains are long

- Difficult to maintain pedigree information
  - Owner (guarantor of integrity)
  - Applicability
  - Limitations of use
  - Source
  - Technical data attributes and relationships

...even with the difficulty of model management models are becoming the authoritative source of information
Models Are Becoming The Authoritative Source Of Data

Model of interaction between pilot and aircraft contains
- Physics based air vehicle motion model
- Instantiated for specific type of aircraft
- Empirically derived models of pilot capability
- Weather models

Model is the authoritative source
- Flight test is only used to validate the model
- Impossible to exhaustively test all conditions
Engineering Viewpoint

• How do we establish that the models are precise and correct
  – Good practice on model validation

• How can we justify analysis and reasoning based on models
  – How do we integrate formal semantics and reasoning with modeling

• How can we build reusable models
  – Can we develop patterns/templates that can be reused
Ontology Viewpoint

• What ontologies provide the most leverage and how do we establish their correctness
  – The reusable patterns are ontologies

• How can we give our modeling languages a formal semantics that is in accord with informal semantics
  – Requires careful analysis of logic needed to capture engineering conceptualizations
Ontological Analysis of Distillation System

- Matthew West Presented an analysis of replacing a pump within a distillation unit
- The analysis has been used to motivate development of the engineering modeling language standard ISO 15926
- This is the kind of analysis needed and the results need to be incorporated in other modeling languages

Ontological Analysis

1. Distinction between parts and components is useful
2. Spatial-temporal aspects are important
3. Distinctions of kinds of relations are useful
4. Notion of identity is extremely important
Conclusions?

... three personal observations

• How ontology fits in

• Choice of logical foundations for modeling languages

• Use of foundation ontologies
How Ontology Fits

Ontology for system

Distillation Unit

Formalized In

Subject

Ontology

In Modeling Language

Model in Modeling Language

?
What Logic To Use For Embedding Models?

SysML model of water molecule

Parts
Water ⊆ ∃ hasOxygentAtom[1].Oxygen

∀x ∃y. Water(x)
implies hasOxygentAtom(x,y)

One can replace the existential quantifier with a Skolem function
∀x Water(x)
implies hasOxygentAtom(x,x.a)

Connections
What one wants is that the oxygen part is connected to the hydrogen part

... the answer is not best determined by ideology
You Could Reinvent the Wheel, but …

… but most of the concepts and relations needed to produce a metadata specification have already been defined in, for example, the Foundation Ontology, DUL.