The Quest for Semantic Integration in the Context of Manufacturing

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Many tasks require correct and meaningful communication and integration among intelligent agents and information resources.

A major barrier to such interoperability is semantic heterogeneity: different applications, databases, and agents may ascribe disparate meanings to the same terms or use distinct terms to convey the same meaning.
Scenario

• Alice: I need someone to generate schedules for my machines and process plans.

• Bob: What are you talking about?
Information Modelling Languages

SCHEMA header_section_schema;
TYPE exchange_structure_identifier = STRING;
END_TYPE;
ENTITY file_description;
description : LIST [1:?] OF STRING (256);
implementation_level : STRING (256);
END_ENTITY;

<!ENTITY % Atomic.content
"( relation, ( term* | role* ),
 %Comment.class;*)"
>
<!ELEMENT atomic %Atomic.content;>
<!ATTLIST atomic
 %Common.attrib;
 href     %URI.datatype;
 #IMPLIED
 %logicalFormOf.attrib;
 %syntaxType.attrib;
>
Approach 1: Standardize Syntax

• XML illusion: The problem will be solved if everyone uses the same syntax and the same lexicon of terminology.
  – “XML makes it possible to tag the contents of a web page with meaning indicating properties.”
  • Extensible Markup Language (XML) 1.0
    http://www.w3.org/TR/2000/REC-xml-20001006

• Even if everyone uses the terms, the real problem is with the specification of the meaning of these terms.
You know what I mean, right?

<purchase_order>
  <product>book</product>
  <date>03/11/17</date>
  <price>19.99</price>
</purchase_order>

•

<purchase_order>
  <product>book</product>
  <date>03/11/17</date>
  <price>19.99</price>
</purchase_order>
Approach 2: Standardize Terms

• Develop standardized vocabularies of whose meanings are based on consensus of domain experts.

• STEP (ISO 10303) has been standardized within the International Standards Organization to support interoperability among manufacturing product software (such as CAD systems and process planning software) throughout the entire product lifecycle.
  – STEP provides standard data definitions for geometry (wire frame, surfaces and solid models), product identification, product structure, configuration and change management, materials, finite element analysis data, drafting, visual presentation, tolerances, kinematics, electrical properties, and process plans.
Problem: Integrating Standards

• Since the specification of semantics is informal, there is still a barrier to interoperability.

**Figure 2: ISO codes for insert and tool holder**
Approach 3: Ontologies

- In addition to the vocabulary, we must specify the meaning (semantics) of the terminology.
Problem: Plethora of Ontologies

• Everybody defines an ontology for their set of applications, but nobody shares or reuses other existing ontologies because they either disagree on the terms or their meanings.
Approach 4: Upper Ontologies

- Organize all ontologies as specializations of a standard upper ontology.
- Upper Ontology Summit 2006:
  - SUMO
  - Cyc
  - ISO 15926
  - DOLCE
  - BFO
  - PSL
Challenges

• How do we agree on the upper ontology?
• What properties should an upper ontology satisfy?
• How do we evaluate an upper ontology?
• What if an ontology disagrees with the upper ontology?
Approach 5: Ontology Mapping

• Rather than specify a single upper ontology, specify mappings between the concepts of the ontologies in an ontology repository (Ontology Summit 2008).

• The emphasis is now on domain-independent techniques to merge ontologies and identify semantically equivalent concepts between ontologies.
Story thus far …

- We started with the situation of manually generating mappings between individual software applications.
- We have come full circle -- manually generating mappings between individual ontologies.
- Have we made any progress?
Several standards exist which support interoperability among manufacturing software systems:

- ISO 10303 STEP (Standard for the Exchange of Product data),
- ISO 14694 (NC Data), ISO 15531 MANDATE (Manufacturing Data Exchange),
- ISO 5608 (Cutting Tools), ISO 1832 (Cutting Tool Inserts),
- ISO 16100 (Manufacturing Software Capability),
- ENV 12204 (Constructs for Enterprise Modelling)
- ENV 40003 (Framework for Enterprise Modelling)
Problems with Standards

• Nevertheless, these standards have many overlapping concepts, and each standard often has a different intended semantics for these concepts.

• This clash of semantics arises from the lack of an explicit formal axiomatization of the terminology within an ontology.

• Furthermore, the formalisms currently being used to represent manufacturing concepts are weak; consequently, the standards are difficult to verify by customers, complex to maintain, and costly to harmonize.
Standards as Ontology Seeds

• Manufacturing standards provide an excellent opportunity for the design and evaluation of new ontologies.

• The terminology of the standard and its intended semantics are the result of consensus within the community that developed the standard; the ontology for the standard is the axiomatization of this intended semantics.
Challenges

• Support the automatic verification of conformance of a software application to the standards

• Semi-automatic integration of software applications that use the standards

• Elimination of hidden assumptions that are implicit within a standard and that hinder harmonization with other standards.

• Reasoning with the axioms of the ontology alone, without the introduction of additional algorithms or assumptions that are not formally specified.
Approach

• Design and analysis of verified ontologies
  – Satisfiability and Axiomatizability Theorems
  – Representation theorems
  – Classification theorems
• Relationships between ontologies
• COLORE (COmmon Logic Ontology REpository)
The first step in the integration of a set of ontologies is to understand the logical relationships between ontologies, that is, relationships that can be determined from the axioms alone.

- Mutual consistency;
- Extension (one ontology stronger than another in the sense that any sentence in the first ontology entails the sentences in the second);
- Theory $T_1$ is definably interpretable in a theory $T_2$ iff for each symbol in the nonlogical lexicon of $T_1$ the relation/function/constant denoted by the symbol is definable by a sentence $S$ in the language of $T_2$. 
Computer-aided Design

AutoCAD

Tarski’s Geometry

Hilbert’s Geometry

ProEngineer
Geometry Ontologies

- Hilbert’s Ontology
  - Primitives:
    * Points, lines, planes
  - Subtheories:
    * Incidence: in(x,y)
    * Ordering (betweenness)
    * Congruence for line segments
    * Congruence for angles

- Tarski’s Ontology
  - Primitives:
    * Points only.
  - Axioms:
    * 24 axioms for
      - Betweenness: between(x,y,z)
      - Equidistance: equid(x,y,z,w)
Motivation

- One obstacle to the development of expressive formal ontologies for manufacturing domains has been the lack of an adequate set of generic ontologies that can be used to specify the semantics of primitive concepts.
  - For example, any product ontology must refer to relationships from geometry and topology, and different manufacturing standards may require different ontologies for time.

- Identify existing ontologies within the research community that will be able to provide these foundations for manufacturing ontologies, and then to integrate these ontologies with the semantics for the terminology of the manufacturing standards.
A repository of first-order ontologies that serves as a testbed for ontology evaluation and integration techniques, and that can support the design, evaluation, and application of ontologies in first-order logic.

All ontologies are specified using Common Logic (ISO 24707).
Foundational Ontologies

• The foundation of the repository consists of ontologies for general mathematical structures:
  – geometry,
  – algebraic structures (e.g. semigroups, groups, rings, vector spaces);
  – combinatorial structures (e.g. orderings, lattices, graphs).

• These ontologies serve as the basis for the representation theorems.
The next part of the repository consists of generic ontologies for domains such as:
- process,
- time,
- mereotopology,
- resources,
- products,

which are required by existing and emerging manufacturing standards.
The final part of the repository consists of generic ontologies for manufacturing standards that are integrated extensions of ontologies designed and evaluated in the second part of the repository.
Ontologies for Manufacturing Standards

- mereotopologies
- time
- process
- resource
- orderings
- algebraic structures
- graphs
- geometries
Applications of the Repository

• We can use the relationships among ontologies within the repository to guide the axiomatization of new ontologies and to propose semantic mappings between ontologies.
Summary

• By providing ontologies for manufacturing standards, we can enable the integration of manufacturing software applications in domains that require the use of multiple standards.

• COLORE will be a repository of first-order ontologies that will serve as a testbed for ontology evaluation and integration techniques, and that can support the design, evaluation, and application of ontologies in first-order logic.