Science based Information Metrology for Engineering Informatics

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***Abstract*—** Engineering informatics is the discipline of creating, codifying (structure and behavior that is syntax and semantics), exchanging (interactions and sharing), processing (decision making), storing and retrieving (archive and access) the digital objects that characterize the cross-disciplinary domains of engineering discourse. It is absolutely critical that a sharing mechanism should preserve correctness (semantics), be efficient (for example, representation, storage and retrieval, interface), inexpensive (for example, resources, cost, time), and secure. In order to create such a sharing mechanism, we need a science-based approach for understanding significant relationships among the concepts and consistent standards, measurements, and specifications. To develop this science, it is essential to understand the interactions among the theory of languages, representation theory, and domain theory. Creating the science of information metrology will require a fundamental and formal approach to metrology, measurement methods and testing and validation similar to the physical sciences.

***Keywords*:** *Engineering informatics, product lifecycle, standards, interoperability, metrics, semantics*

I. Introduction

A prerequisite for competitive advantage in manufacturing is a good and sustained investment in Engineering Informatics to describe a common product description that is shared among all stakeholders throughout the lifecycle of the product. Informatics is a conceptual synthesis of mathematics, computing science, and applications as implemented by information technology. Engineering informatics is the discipline of creating, codifying (structure and behavior that is syntax and semantics), exchanging (interactions and sharing), processing (decision making), storing and retrieving (archive and access) the digital objects that characterize the cross-disciplinary domains of engineering discourse. This is a relatively hard problem, as it requires combining a diverse set of emerging theories and technologies: namely, information science, information technology and product engineering, and many different cross-disciplinary domains.

The environment in which products are designed and produced is constantly changing, requiring timely identification and communication of failures, anomalies, changes in technology and other important influences. For such an adaptable organization to function, an information infrastructure that supports well-defined information exchange processes among the participants is critical. The IT industry that supplies engineering informatics support systems is currently vertically integrated. Vertically integrated support systems do not provide for opportunity of full diffusion of new innovations across the entire community of users. A study of engineering informatics support provided by a representative set of major software vendors shows that the availability of support tools is partial and incomplete. Some vendors cover several areas, while there are areas that are poorly covered or not covered at all by any vendor. Relying on a single vendor to cover all areas of support for engineering informatics would not provide the kind of innovation needed by the customers. There is a lack of interoperability across tools and that there are barriers to entry for software developers that could provide a plug and play approach to engineering informatics support. Currently only a few IT companies with vertically integrated tool sets are able to provide facilities that are even partially integrated.

The Product Lifecycle Management (PLM) concept holds the promise of seamlessly integrating all the information produced throughout all phases of a product's life cycle to everyone in an organization at every managerial and technical level, along with key suppliers and customers. PLM systems are tools that implement the PLM concept. As such, they need the capability to serve up the information referred to above, and they need to ensure the cohesion and traceability of product data.

A critical aspect of PLM systems is their product information modeling architecture [1]. Here, the traditional hierarchical approach to building software tools presents a serious potential pitfall: if PLM systems continue to access product information via Product Data Management (PDM) systems which, in turn, obtain geometric descriptions from Computer-Aided Design (CAD) systems, the information that becomes available will only be that which is supported by these latter systems.

II. PRODUCT REPRESENRATION AND INTEROPERABILITY

Interoperability is pervasive problem in today's information systems and the cost of the problem of managing interoperability is a major economic drain to most industries. The problem of supporting interoperability requires the development of standards through which different systems would communicate with each other. These standards vary from purely syntactical standards to standards for representing the semantics of the information being exchanged. However, for multiple systems to interoperate these systems will have to be tested for conformance, implementation and inter-operability among each other. These tests will have to encompass syntactic, content and semantic aspects of exchange between these systems.

A standardized exchange behavior within a specified set of conventions has a form (syntax), function (scope) and the ability to convey as unambiguously as possible an interpretation (semantics) when transferred from one participant to the other. The design of a standardized exchange in the context of information metrology is dictated by:

1. **Language**: the symbols, conventions and rules for encoding content with known expressiveness. Examples include First Order Logic [2], Knowledge Representation [2], OWL [3], UML [4], SysML [5], and EXPRESS [6].
2. **Processible Expressiveness**: the degree to which a language mechanism supports machine understanding or semantic interpretation. Expressiveness is closely connected to the scope of the content that can be expressed and to the precision associated with that content. Support of standardized exchange requires a set of complementary and interoperable standards.
3. **Content**: the information to be communicated. Content includes the model of information in the domain and the instances in the domain and explicates the relationship between the message and the behavior it intends to elicit from the recipient. Examples of content, include Standard for the Exchange of Product model data (STEP) [7], NIST Core Product Model (CPM) [8] and its extensions, the Open Assembly Model (OAM) [9], the Design-Analysis Integration model (DAIM) and the Product Family Evolution Model (PFEM).
4. **Interface**: User interface concerns efficiency of communication between the system and humans. Software interface concerns accurateness and completeness of communication between systems.

III. LONG TERM KNOWLEDGE RETENTION AND ARCHIVAL

These digital objects in engineering need to be preserved and shared in a collaborative and secure manner across the global enterprise and its extended value chain. The problem of digital preservation is very complex and open-ended (dynamic situations or scenarios that allow the individual users to determine the outcome). To understand the problem of digital archiving we need to define a taxonomy of usage scenarios as an initial guide to categorize different end-user access scenarios. The scenarios, which we call the "three Rs", are: (i) reference, (ii) reuse and (iii) rationale. The primary driver for the above categorization is the special retrieval needs for each of these scenarios. For example a collection intended primarily for reference may need to be organized differently than one intended for reuse, where not only the geometric aspects of the product are sought but also other information regarding manufacturing, part performance, assembly and other aspects. In a similar vein, rationale information may have to be packaged differently in that it may include requirements information along with other performance data on the part or the assembly. Given the range of uses and perspectives of the end-users will have large impact on the process of archiving and retrieval.

IV. SCIENCE-BASED INFORMATION METROLOGY

It is absolutely critical that a sharing mechanism should preserve correctness (semantics), be efficient (for example, representation, storage and retrieval, interface), inexpensive (for example, resources, cost, time), and secure (such as Role-Based Access Control). In order to create such a sharing mechanism, we need a science-based approach for understanding significant relationships among the concepts and consistent standards, measurements, and specifications. To develop this science, it is essential to understand the interactions among the theory of languages, representation theory, and domain theory. Creating the science of information metrology will require a fundamental and formal approach to metrology, measurement methods and testing and validation similar to the physical sciences. The effort involved will be cross-disciplinary in nature because 1) supply chain and engineering informatics are complex endeavors involving artifacts in several business areas 2) the industry does not have an established interoperability testing approach at the semantic level and 3) testing can consume a lot of time and there is no clear methodology to suggest what kinds of testing are essential.

Even though several disparate attempts were made in the past to understand this problem, the primary reasons that we can succeed now are: (1) The new sets of technical ideas that have emerged like the semantic web technologies, (2) better collaborative tools, and new models of software and standards development that have become dominant in the IT world, and (3) advanced mathematics, computer science, and logic-based systems. Besides, these developments the IT industry in large parts is moving away from products with only proprietary software components to a mixture of open source and proprietary components. The awareness and benefit of open source models are being embraced by large parts of the industry. The timing and attitude towards open standards and open source models have gained currency. The primary reason for the call for open standards is the current environment in the IT industry and the rise of the global network-based manufacturing. Both economic efficiency of global firms and design and manufacturing capabilities of these firms in the future will depend on the smooth functioning of the design and manufacturing information network especially for the small and medium enterprises (SMEs) to take advantage of the global and local markets.

V. CONCLUSIONS

The potential impacts of information metrology for engineering informatics include: (1) assistance to manufacturing industry end users and software vendors in ensuring conformance to information exchange standards; (2) creation of science of information metrology [10], (3) development of a fundamental and formal approach to information metrology, and (4) measurement, testing and validation methods similar to the physical sciences.

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