Implementing Ontology-based Information Sharing in Product Lifecycle Management

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Abstract

Product Lifecycle Management (PLM) often requires the sharing of information between disparate software systems. An increase in the number of disparate systems, especially when data is used throughout the entire product's lifecycle, regularly requires custom individual interfaces to transfer the data. Custom software conversion can be time consuming and prone to conversion errors. Ontologies can be used to bridge the data interoperability gap between various software systems and disparate software systems to communicate to each other during a products lifecycle. The use of ontologies and standard file formats will allow different data types to be carried with the product, helping convey design intent and purpose later in the lifecycle. The combination of ontologies and standard file formats can be read by a machine allowing for a centralized data repository where all product data can be kept and available for automatic translation as necessary. The use of ontologies and standard file formats is also advantageous for long term archival. This research presents a repeatable methodology for creating an ontology from a native CAD file by way of STEP with currently available software. A complex model is created in 3D CAD software and exported using the ISO 10303 standard. An open source file converter is used to translate the file from EXPRESS (which STEP is written in) to XML. Then the XML file is to be converted to the OWL (Web Ontology Language) file format by way of an ontology editor, Protégé. A conceptual framework is presented and results explained as available.

Introduction

Most companies are always looking to save time and money. One solution to achieve this is to implement an all-encompassing business structure Product Lifecycle Management (PLM). PLM is an approach that involves the process of managing information about a product from concept to end-of-life. This includes managing everything from engineering data to consumer feedback. However, PLM is not an off-the-shelf solution a company can buy; instead, it is a business solution that is different for every company. Implementing PLM is ideal in today's economy, allowing companies to save money but also improve other aspects of a business like product quality. A properly implemented PLM system also allows companies to share information digitally with no paper required. A major obstacle found in implementing PLM is interoperability in disparate 3D CAD software. Companies can often have multiple CAD systems in-house or they could work with other companies that have different CAD software. A standard file format, STEP, was created to help with interoperability issues.

In 1994 the International Organization for Standardization (ISO) released a standard file format, ISO 10303, better known as STEP. STEP (STandard for the Exchange of Product model data) is a standard file format that allows for the transfer of data between disparate CAD software, which is crucial for implementing PLM successfully. There are several STEP application protocols (AP) that cover a wide range of purposes for different industries. One of the most widely used and accepted is STEP AP 203 for configuration controlled three dimensional designs of mechanical parts and assemblies. All of the STEP APs are written in the EXPRESS programming language. When the STEP standard was released in 1994, AP 203 was one of the original application protocols. In 2007, the second edition of AP 203 was released adding new functionality. However, "even STEP, the most comprehensive exchange format, has shortcomings, not least the lack of interoperability between Application Protocols, the inability of EXPRESS to convey user-defined constraints and the difficulties associated with implementing STEP" (Ball, 2008, p. 233). The EXPRESS programming language has difficulties capturing and conveying some of the design knowledge that can be critical for collaborative development.

Technology has allowed for people to work and share information around the world, seemingly traversing the geographical obstacles making the world appear smaller. With people working together in separate geographical locations and "designers no longer merely exchanging specific geometric data, but rather more knowledge about design and the product development process, including specifications, design rules, constraints, and rationale," being able to exchange this information easily has become more important (Kim, 2006, p. 1234). Being able to share and easily access design knowledge and work in a collaborative manner are at the core of PLM. The STEP standard helps, however, "ISO 10 303...does not attempt to translate the meaning associated with the design from one context to another. This associated meaning (which is usually the designer's intent) is lost during the conversion. Moreover, information that is lost in one context may be needed in another" (Patil, 2005, p. 215). In *Ontology-Based Exchange of Product Data Semantics*, Patil, et al. proposes the use of ontologies to help with STEPs inherent limitations.

An ontology provides the ability to create a repository of information with definitions and relationships. "An ontology describes the concepts and relationships that are important in a particular domain, providing a vocabulary for that domain as well as a computerized specification of the meaning of terms used in the vocabulary" (SCBIR, 2010). Ontologies are also machine interpretable, allowing for automation of translation among other things. To help in the creation of an ontology Protégé was created by the Stanford Center for Biomedical Informatics Research. "At its core, Protégé implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats" (SCBIR, 2010). OWL or Web Ontology Language is Protégé's native file format. OWL is not the only language available for creating ontologies but it "is the most expressive semantic markup language" (Zhang, 2007, p. 835).

Background

The use of ontologies to help with capturing and sharing design knowledge is not new. The focus of previous research has been on describing conceptual models for the development, organization, and design of an ontology. Engineering design knowledge can come from CAD/CAE software, from electronic documents, scanned paper sources, or from outsourced work that may not be in a compatible format. Most of the research focuses on designing and use of an ontology. A majority of the research also fails to propose a framework or proof of concept for retrieving design information for an ontology to use.

In a report for the National Institute of Standards and Technology and another article, Patil, Dutta, and Sriram (2005) propose a framework for exchanging semantic data within several domains in product development. These papers discuss current engineering systems lack of interoperability and the manner in which semantics can be used to solve this, but there is no current standard. The Product Semantic Representation Language (PSRL) is proposed as a standard for seamless interoperability by way of ontologies. “The intent of our work is to create a strong foundation for the formalization of product semantics. It does not focus on the development of a new product representation model, or new terminologies and semantics” (Patil, 2005, p. 2). The application of the proposed PSRL standard has been limited and the actual process to capture the design knowledge for the creation of the ontology is unclear.

Kim, Manley, and Yang (2006) discuss a new paradigm for the use of ontologies with assembly design. The research describes a framework for going from a CAD program to a CAE program and creating an ontology as a result. The paper focuses on assembly and joining constraints and how they can successfully be represented in an ontology. The paper discusses how to create a semantically sound ontology with information that appears to be manually created. The paper fails to list any specific CAD or CAE software used. The paper also fails to mention the translation process used from the CAD software to the CAE software.

Zhang and Yin (2008) discuss the “need to develop an ontology-based modeling framework that supports representation of multidisciplinary engineering design knowledge in an unambiguous yet flexible way, and that facilitates autonomous deployment, reuse, and federation of design knowledge in a meaningful and scalable way.” The paper focuses on a framework for ontology modeling and queries for the application and distribution of engineering design knowledge. The ontology was created manually with information found from interviews with industry experts.

Seo, et al. (2005) discusses sharing an ontology based on the same model created in two different CAD programs. CATIA and Solidworks were used to create the same model in their native file formats. The modeling techniques complied with the STEP AP224 standard used for defining machining processes for manufacturing. The native files were exported as script files, translated into the programming language of F-Logic, and used to create a shared ontology that can be used by both CAD programs. Manually defined maps were created to combine the separate ontologies because each of the CAD programs defines the same product feature differently. The ontology can be modified, translated, and imported back into the CAD programs by way of the respective native script files. These script files are imported and the CAD program automatically makes the appropriate changes to the model.

Zhu, Jayaram, Jayaram, and Kim (2009) expand upon research in *Knowledge Representation and Ontology Mapping Methods for Product Data in Engineering Applications* originally presented in 2008 at the ASME IDETC/CIE Conference, using ontologies presented as the solution for the general interoperability problem of disparate CAD systems. A 3-tier system is used to help solve domain semantics. One ontology is created for each specific software program. A larger ontology is created for a specific domain, product design, comprised of all the ontologies from programs used in that domain. One large ontology is finally created for a specific product comprised of all the domain ontologies. The ontologies used are created directly from a CAD model and other software. The models used were made in Pro/E and CATIA. Ontologies are then created automatically from the translation of the model into Protégé. However, STEP is not used in the process. A software specific application programming interface (API) is used to create a temporary representation of the model, and another API is used to import the represented model into Protégé and an ontology is automatically created. In order to combine ontologies several mapping rules were created to address how the desperate CAD programs define the same product features differently. Ontologies in all 3-tiers were successfully created from CAD models.

Gupta and Gurumoorthy (2008) present the idea of using STEP to aid in the creation of an ontology. The paper presents the use of a domain independent form feature (DIFF) model created either directly from a CAD system or from a CAD system by way of STEP. The DIFF model is then used to create an ontology in the XML programming language. However, a conceptual model is never described for the conversion process from CAD to XML. Instead "the present implementation has been done using an ontology editor in the interests of quick prototyping" (Gupta, 2008, p. 450). The ontology editor used is Protégé. The paper focuses on defining what the DIFF model is and on the creation of an ontology from a DIFF model. The process did not incorporate the use of STEP.

Previously mentioned literatures present conceptual models of how to create or share design knowledge with limited application. Seo, et al. demonstrated a proof of concept that a shared ontology can be applied to disparate CAD programs. However, Seo, et al. used modeling techniques defined by STEP AP224. AP224's defined modeling techniques limit how a model can be created when compared to AP203 edition 2. AP224 is not as widely accepted or used as AP203 edition 2. The scripts used in the translation process only describe how the model was made and do not capture the volume of design knowledge AP203 edition 2 is capable of capturing. F-Logic is not as robust as OWL and is also not as widely used or accepted.

Zhu, et al. proves an ontology can be automatically created from a CAD model and ontologies can be joined to create a larger body of knowledge. However, the process used to create the ontologies is very specific and highly customized resulting in a significant amount of overhead to maintain a proper translation process. Applying APIs, application programming interfaces, requires programming. After every new program update is released, any related program specific APIs will have to be updated. At best the updating process will require testing and validation processes. If anything changes, then coding, testing, and validation must be performed. If multiple APIs are used and each of them is written in a different programming language, the customization and maintenance overhead becomes more difficult.

Using an API or a script file in a translation process means that however each of the CAD systems natively defines a product feature is how that product feature will be defined in the ontology. As a simplified example, if CATIA and Pro/E define a cylinder differently, when an ontology from CATIA and an ontology from Pro/E are made of the same cylinder, the ontologies will be different. If these ontologies of the same cylinder need to translated or combined custom mapping must be developed and validated. If STEP is used to create an ontology, all of a product's features will be defined consistently no matter the source.

Previous research has shown that an ontology can be created directly from a CAD model and multiple ontologies can be successfully integrated into one larger ontology. However, none of the previous research uses STEP as a medium. Gupta and Gurumoorthy suggest the idea of incorporating STEP into the process of creating an ontology, but take the suggestion no further. STEP is an international standard which most of the commonly used CAD packages can read and write. If a CAD package cannot natively translate to STEP, a third party translation software can be utilized. By using STEP, the overhead of having to maintain APIs and mapping rules is eliminated. Currently available software should be able to provide a process for creating an ontology from a STEP file.

This research focuses on providing a repeatable methodology for creating an ontology from a native CAD file by way of STEP with currently available software. Simple information will be added to the ontology to determine if STEP can retain the information after translation. Developing the ontology to be industry ready, semantically correct, or modifying the translation process to better capture design knowledge is not within the scope of this research.

Methodology

Protégé 3.4.4 is used to create and manage the ontology. In an ideal world Protégé would be able to read each native 3D CAD file format and create an ontology, as seen in Figure 1. However, this is not the case. In order to get an ontology from one of the CAD's native file format several steps have to be taken. Figure 2 displays the route that is going to be taken. Protégé has a plug-in that allows for it to read XML files. STEP can be translated into XML by way of third party translators.

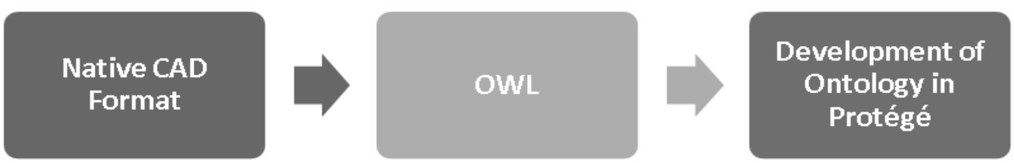

Figure 1. Ideal translation process.

Figure 2. Actual translation process to be used.

Part 1: native file formats to OWL.

Models to be used for translation are created in three separate 3D CAD software packages. The models are originally created in the native file format of each CAD package. The three CAD packages are: CATIA V5, Pro/ENGINEER, and Siemens NX6. Three different CAD packages are used because they all have different interpretations of the STEP standard and how they translate into the format. Each model is then translated into the STEP AP203 edition 2 format.

A third party translator is used to convert the STEP files, written in EXPRESS, to the XML format. The third party translator is available at no cost and was created by Electric Boat called StepXML Translator v4.0. After the files have been converted to the XML format they are loaded into Protégé by way of the XML plug-in available. Protégé is then utilized to convert of the three models, in XML format, into the OWL file format.

Part 2: creating a simple ontology.

Protégé is then used to create a working ontology using what was imported and converted from the models. Protégé should automatically create classes and relationships between different parts of the model. Terms and concepts are also defined. Since ontologies are usually highly customized, once the files are loaded into Protégé they will be customized to a certain extent. Since this is a proof of concept, an extensive all-encompassing ontology is not necessary. However, the ontology will contain most of what Protégé allows: definitions, parent/child relationships, etc.

Part 3: OWL to native file formats.

This process is the reverse of the process seen in Figure 2 above. The new ontology is exported as an XML file. This XML file is then translated into a STEP file, to be loaded into each of the three CAD packages. But first these STEP files are compared to the initial STEP files converted from the native CAD file formats. Once these files have been thoroughly compared to determine any differences they are loaded into each of their respective CAD packages and converted back into the native format. They are checked for accuracy and changes in the model compared to the original model.

Results & Analysis

The research is not complete. Research is still in Part 1. The translator to translate EXPRESS to XML is not working consistently. This is in part due to the translator itself and is also due to the STEP files that each separate CAD package exports. Since each of the CAD companies interprets and applies the STEP AP203 Edition 2 standard differently, the translator either cannot complete the process or creates an XML file with missing data. The translator is being modified because other third party translators are not currently accessible. The original idea is to utilize existing software for translation without any modifications.

Each of the STEP files from the CAD packages is run through a free STEP checker, provided online by STEP Tools, Inc. The Pro/E STEP file has no errors and appears to conform to the standard correctly. The CATIA and NX STEP files are initially not able to be analyzed by the STEP checker because it cannot read them. After changing the file schema from AP203_CONFIGURATION_CONTROLLED_3D_DESIGN_OF_MECHANICAL_PARTS_AND_ASSEMBLIES_MIM_LF to CONFIG_CONTROL_DESIGN, which is what the Pro/E STEP file has from the start, the STEP checker is able to read the files. The CATIA STEP file has several errors and appears to have added entities that are not defined by the standard along with several rule failures. The NX STEP file appears to have added entities not defined by the standard as well as having several rule failures. The XML file created from the Pro/E STEP file is being tested to determine if it is in the correct format and if all data has been translated correctly from the STEP file. The translator is continually being tested and modified since other third party software is not currently accessible.

Conclusions

With more global business collaborating regardless of geographical location, implementing the business model of Product Lifecycle Management will be critical in the efficient communication of ideas and knowledge. In order for information to move proficiently in any industry that uses 3D CAD, companies will need to utilize ontologies with STEP, because STEP alone is inadequate. In order to create an ontology, STEP potentially provides the best medium between native CAD file formats and OWL.

The research presented is not complete nor is it finished. Once it has been determined that the translator works correctly the XML files will be loaded into Protégé and then Part two and Part three of the research will be conducted. It is anticipated the future results will demonstrate the accuracy of the file translations and possibly how the varying interpretations of the STEP standard influence the outcome. The results will also show how the ontological metadata affects the file translation, if this metadata can be carried back to the 3D CAD software, and if this specific path to capture what STEP can leave out is possible, providing an opportunity to build upon this research in the future.

References

Ball, A., Ding, L., & Patel, M., (2008). An approach to accessing product data across system and software revisions. *Advanced Engineering Informatics*, 22(2), 222-235. doi:10.1016/j.aei.2007.10.003

Electric Boat, (n.d.). StepXMLTranslator (Version 4.0) [Software]. Available from http://pdesinc.aticorp.org/vendor/stepxml.html

Gielingh, W., (2008). An assessment of the current state of product data technologies. *Computer-Aided Design*, 40(7), 750-759. doi:10.1016/j.cad.2008.06.003

Gupta, R.K., Gurumoorthy, B., (2008). A feature-based framework for semantic interoperability of product models. *Journal of Mechanical Engineering*, 54(2008)6, 446-457. UDC 658.5:659.2. Retrieved from http://www.sv-jme.eu/archive

Kim, KY., Manley, D.G., Yang, H., (2006). Ontology-based assembly design and information sharing for collaborative product development. *Computer-Aided Design*, 38(12), 1233-1250. doi: 10.1016/j.cad.2006.08.004

Ma, H., Ha, K.M.E., Chung, C.K.J. & Amor, R., (2006). Testing semantic interoperability, *Proceedings of the JICCDMCBE*, Montreal, Canada. Retrieved from http://www.cs.auckland.ac.nz/~trebor/pubs-06.htm#MA06

Patil, L. Dutta, D., Sriram, R., (July 2005). Ontology-based exchange of product data semantics, *IEEE Transactions on Automation Science and Engineering*, 2(3), 213-225. doi: 10.1109/TASE.2005.849087

Patil, L. Dutta, D., Sriram, R., (November 2005). Ontology formalization of product semantics for product lifecycle management, *Proceedings of ASME/IDETC&CIE Conference*, Long Beach, CA.

Seo, TS., Lee, Y., Cheo, S.U., Han, S., Patil, L., & Dutta, D., (2005). Sharing CAD models based on feature ontology of command history. *International Journal of CAD/CAM*, 5(1). Retrieved from http://www.ijcc.org/

(SCBIR) Stanford Center for Biomedical Informatics Research, (2010). Protégé (Version 3.4.4) [Software] Available from http://protege.stanford.edu/download/download.html

Zhan, P., Jayaram, U., Kim, O., Zhu, L., (2010). Knowledge representation and ontology mapping methods for product data in engineering applications. *Journal of Computing and Information Science in Engineering*, 10(2), 021004. doi: 10.1115/1.3330432

Zhang, W.Y., Yin, J.W., (2008). Exploring semantic web technologies for ontology-based modeling in collaborative engineering design. *International Journal of Advanced Manufacturing Technology*, 36(9), 833-843. doi: 10.1007/s00170-006-0896-5

Zhu, L., Jayaram, U., Jayaram, S., Kim, O., (2009). Ontology-driven integration of CAD/CAE applications: strategies and comparisons. *Proceedings of the ASME IDETC/CIE Conference*, San Diego, California, 1461-1472, doi: 10.1115/DETC2009-87768