Towards an Enhancement of Relationships Browsing in Mature PLM Systems

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Abstract. Product Lifecycle Management (PLM) domain is at a key point in its development: its concepts and technologies are mature. PLM systems not only manage documents but information associated to a product along its lifecycle, such as Bills-Of-Material (BOM) or require- ments at different levels of granularity. All the dependencies between concepts lead to complex relationships from which it is not easy to get a coherent overview. The purpose of the paper is to know whether PLM systems are able to deal relationships complexity. Two case studies – one form manufacturing industry and the other one from a new application domain of PLM, Bio-Medical Imaging - are developed in the paper. They show that hierarchical browsing of existing PLM systems is not suitable to manage relationships complexity and must evolve to graph browsing.

Keywords: Product Lifecycle Management (PLM), Heterogeneous Data, Information Visualisation, Graph Theory, Bio-Medical Imaging (BMI).

1 Introduction

Product Lifecycle Management (PLM) began to emerge in the late 1980s as an integrated approach for the design management of products developed by automotive and aerospace industries [11]. The complexity of products in these domains, as well as the increasing competition caused by global markets, posed the need for a better product management system [12]. To stay competitive by reducing product lifecycle duration, the main concern was to provide the right information in the right context at the right time among the global flow of information and throughout the lifecycle of the product [3].

PLM can be defined as a ”product centric - lifecycle-oriented business model, [...] in which product data are shared among actors, processes and organizations in the

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different stages of the product lifecycle" [19]. PLM integrates modelling, engineering, manufacturing and project management software into one collaborative platform [12]. When PLM concepts matured from Product Data Management (PDM), manufacturing companies evolved from managing documents to the management of enterprise concepts. Indeed, users at different stages along the product lifecycle need to access to different information, and PLM systems manage product data at many levels of granularity. Some of them are Bill Of Material (BOM) which describes assemblies and parts that constitute the product, engineering BOM (eBOM) which decomposes the product as it is designed, and manufacturing BOM (mBOM) as it is built. The relationships that link the product information levels are of major importance to be able to manage in a consistent way all the phases of the product lifecycle and to enable collaboration between the different teams.

PDM systems were initially designed to manage Computer Aided Design (CAD) files, thus PLM systems were developed mostly around this type of data in the context of manufacturing industry. However, more and more works address other domains, such as Computer Aided Engineering (CAE), Mechatronics, Architecture Engineering and Construction (AEC), Services and Bio-Medical Imaging (BMI). These domains are multidisciplinary and handle heterogeneous data linked by complex relationships inside which it is not easy to browse. The specific needs coming from new application domains of PLM have been overlooked so far, but the whole PLM community could benefit from them.

Because the complexity of data relationships is growing in manufacturing industry and new application domains of PLM, it is important to study relationships management in PLM systems so as to improve their understanding and analysis. Current data visualisation and relationships browsing in PLM sys- tems are presented in the paper. Then two case studies are developed. They were chosen to show two current challenges of applications of PLM. The first case study deals with the migration from one PLM system to another inside the manufacturing company ACME[1]. The second case study focuses on specific needs of a new application domain of PLM: neuroimaging. A discussion about the conclusions from the two case studies ends the paper.

2 Visualisation and Browsing in Mature PLM Systems

2.1 PLM Data Models

PLM is a mature technology known to increase productivity, maximise product value and reduce cost in organisations [17]. Object-oriented approach was shown to be adequate to model and integrate product, process and resource data through UML diagrams [8]. The Core Product Model (CPM), which defined form, function and behaviour of a product, has been extended [9] and enables the design of product

[1] ACME is a French company designing and manufacturing thermal systems. The name is modified, as the authorisation of the company to use their name in the paper is under approval.

information-modelling framework to support the full range of PLM requirements [18]. Data organisation models in PLM systems are now well-tried.

Three phases define PLM: the design and manufacturing phase is the Beginning- of-life (BOL), the distribution and use phase is the Middle-of-life (MOL), and the retired phase is the End-of-life (EOL) [10]. Only the BOL phase -with few exceptions - is managed in PLM systems, as most of the research work focuses on this phase. However, many teams need to collaborate and interact during the BOL phase. So they require to access to different levels of information that have to be properly connected, for instance requirement specifications, design or manufacturing.

2.2 Product Modelling in PLM Systems

Important information about a product is stored in product representation or modelling. In manufacturing companies, product modelling is mostly composed of Computer-Aided Design (CAD) models, but these last are heavy, application dependent and focus on one information level. Some lightweight product modelling, on which Ding et al. [7] made a survey, support users at different stages of the product lifecycle in rapidly browsing, retrieving and manipulating product information across platforms. They constitute interesting exchange formats. Examples of CAD lightweight modelling available in PLM systems are U3D, JT format and XML-based formats (X3D, 3D XML and PLMXML). However these product modelling only address one degree of information complexity for a product. Some works address the design of a multi viewpoints framework [5, 6] with semantics and relationships management, but they do not indicate how to visually read and understand the relationships complexity.

2.3 Interface and Browsing in Current PLM Systems

The interfaces of PLM systems have not been studied by the PLM research community up to now, although they are widely and daily used. It is nothing to say that PLM software interfaces are overall not ergonomic nor intuitive. Compa- nies spend too much time and money in training their employees on information systems, PLM not being an exception. The main critics on the interface are the number of sub-windows and the profusion of menus and icons. Product data instances are presented under the shape of a list and only one level of product information can be displayed at a time. Besides, the interface vocabulary is too manufacturing-industry oriented, which limits the extensibility of PLM systems to other domains.

Rich client installed as a standalone application on local device is widespread among the PLM systems. However, web-based clients are little by little becoming a unavoidable evolution of PLM systems in manufacturing industry in order to access data everywhere and on new mediums such as tablets. The main purpose of web-based clients is to enable easy browsing and retrieval of data, but their interface is not suitable enough. Some interesting PLM web clients have been developed recently - for instance web ARAS system or new Teamcenter 10 active workspace client -, but they still propose an overloaded interface.

Therefore the study of two case studies is proposed to decide whether:

1. The interfaces of PLM systems both comply with the requirements of manufacturing industry and of a new application domain of PLM, such as Bio-Medical Imaging,
2. The PLM research community should address more work on PLM interfaces.

3 Case Study 1: Migration of ACME PLM System

Manufacturing companies are now mostly equipped with PLM systems, and because of information management strategies or costs, they decide to change their PLM system more and more frequently. Therefore, new issues come out such as data consistency in source PLM systems and data import in target PLM systems. In this section, the migration of ACME PLM system is developed to highlight the need for relationships management and visualisation.

3.1 Context and Data to Migrate

In 2011, ACME decided to migrate its Windchill PLM system to Teamcenter PLM system. The CAD software Pro/E remained the same after the migration, so there was no conversion operation. A PLM system handles two distinct types of data: metadata which are stored in a relational database, and data files which are stored in the vault, a securised file system accessible only through PLM. Relationships between data files and metadata are described in the PLM system. In the case of ACME migration, data files are drawings and 3D CAD assemblies. An Extract Transform Load (ETL) type of implementation was set up for the migration. Indeed, Windchill and Teamcenter do not have the same concepts and data models, so an intermediate migration platform is needed to transform the data. The migration platform is composed of a temporary data files storage and a Graph DataBase (GDB), Neo4J. PLMXQuery tool [16] is used to populate the migration platform, which constitutes the Extract phase of ETL. Through XQuery language, the metadata are converted into PLMXML language [14] and the data files are represented with their dependencies in a ASCII instruction file. Finally, during the load phase of ETL, the target Teamcenter platform is populated thanks to PLMXML Import Tool for the metadata and IPEM tool for the data files.

A GDB was chosen to store temporarily the metadata, because a PLM system can be seen as a set of unique objects having a set of attributes (key or value) and being linked together by typed relationships. A graph corresponds as well to this definition, as it is composed of nodes and edges having attributes. Moreover, it is easy to populate a GDB through standard formats. A screenshot of an item extracted from Windchill and displayed in Neo4J is shown in figure 1.

3.2 Issues during the Migration

CAD files are by nature tricky data: when they are opened by appropriate CAD software, some CAD files require other dependent CAD files to be opened. This means that these dependency relationships are described somewhere in the CAD files, but must also be described in the PLM systems. When a user asks the PLM system to open a CAD file locally, the target CAD file and all dependant CAD files are downloaded from the vault. The relationships dependency must be taken in account during the migration, as data files with dependencies can only be migrated after the dependent files. Thus, the imports have to be scheduled in the right order.

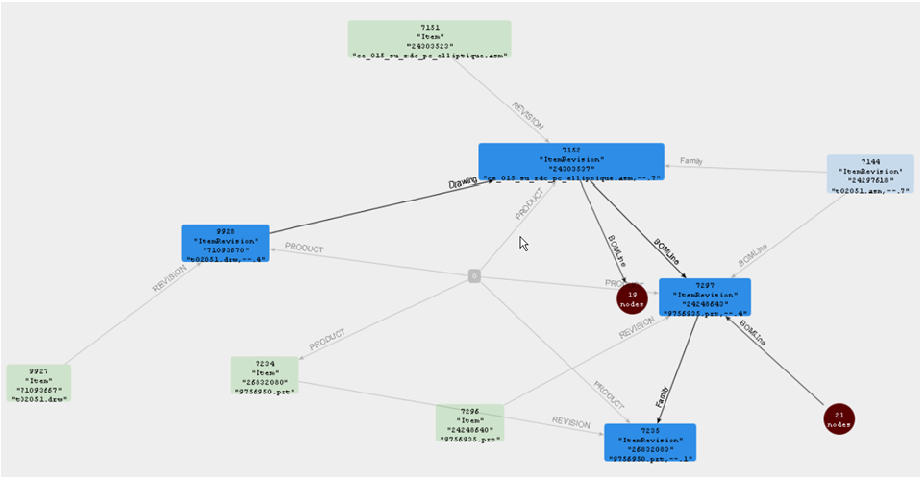

Fig. 1. Screenshot in Neo4J of an item extracted from Windchill with relationships to its revisions, drawing, relatives (family items) and BOM components

Many errors occurred during the migration, due to wrong referencing between objects: obsolete instances, missing references between CAD files and between templates and drawings, dependency cycles. These issues were a real burden during the migration process which lasted for one year instead of the few months planned initially, because the initial data had to be ”cleaned”. An algorithm - called Kdeep - was designed to analyse referencing errors on the GDB. It is able to locate when the errors occurred in time, and to solve automatically these issues. This algorithm was applied on the Neo4J database. Once the Kdeep algorithm had passed through the whole database, there were still some errors due to inconsistency of complex relationships, and they had to be solved by hand.

The main lesson from the migration is the unexpected number of wrong referencing of the relationships between the levels of granularity in PLM systems. The ACME company was not aware that these issues were existing in its PLM system. Obviously, it is difficult to analyse dependencies and identify referencing problems between objects in a PLM system. Besides, the Neo4J GDB used for the migration turned out to be useful to do the job. Indeed, algorithms can be easily computed on graphs to retrieve statistics and apply display filters for a better understanding of the relationships between graph nodes. Some of the errors could not have been solved out without a visual representation of the dependencies.

4 Case Study 2: Management of GIN Research Studies

A growing number of domains outside manufacturing industry are implementing PLM systems. Most of these domains handle heterogeneous data with complex relationships, which require to browse, retrieve and visualise information efficiently. Browsing needs of neuroimaging domain are developed in this section.

4.1 A PLM Database in Neuroimaging Domain

Neuroimaging domain is multidisciplinary ”by its very nature” [20]: the study of brain require an active interaction between many specialities - physics, medicine, mathematics and engineering among others. Magnetic Resonance Imaging (MRI) is one of the most promising imaging technique to study brain complexity. Structural MRI examines brain anatomy, whereas functional MRI analyses what happens while a subject is performing a given task. A Bio-Medical Imaging (BMI) research study can be represented by four stages that constitute a cycle [1]: study specifications (stage 1), raw data (stage 2), derived data (stage 3) and published results (stage 4). Between stages, it is crucial to keep all the information to be able to understand the context of computing and the history of data, which is a requirement to reproduce derived data result or to reuse them. What a piece of data is, when, where and how it was produced, why and for whom it was per- formed is called provenance [15]. Due to costs, trends to huge cohorts of subjects and growing complexity of analyses, neuroimaging researchers must collaborate and share data between disciplines and laboratories [21], which are similar issues than the one of manufacturing industry.

PLM was proposed and shown to be relevant to manage efficiently neuroimag- ing heterogeneous data and to enable the conditions of sharing and reuse of data [2]. Since 2010, the GIN[2] has been using the GIN first Brain Imaging Laterality (BIL&GIN1) dataset, which is composed of 300 subjects - balanced by gender and handedness - and which was acquired between 2009 and 2011 [13]. In 2013 a PLM system – Teamcenter 9 – was installed at the GIN, populated with the BIL&GIN1 dataset.

4.2 Limits of PLM Systems Browsing

The figure 2 shows the two main ways of browsing information in Teamcenter – the concepts are similar in other PLM systems –: hierarchy view (descending) and impact

[2] Groupe d’Imagerie Neurofonctionnelle - Neurofunctional Imaging Research Group.

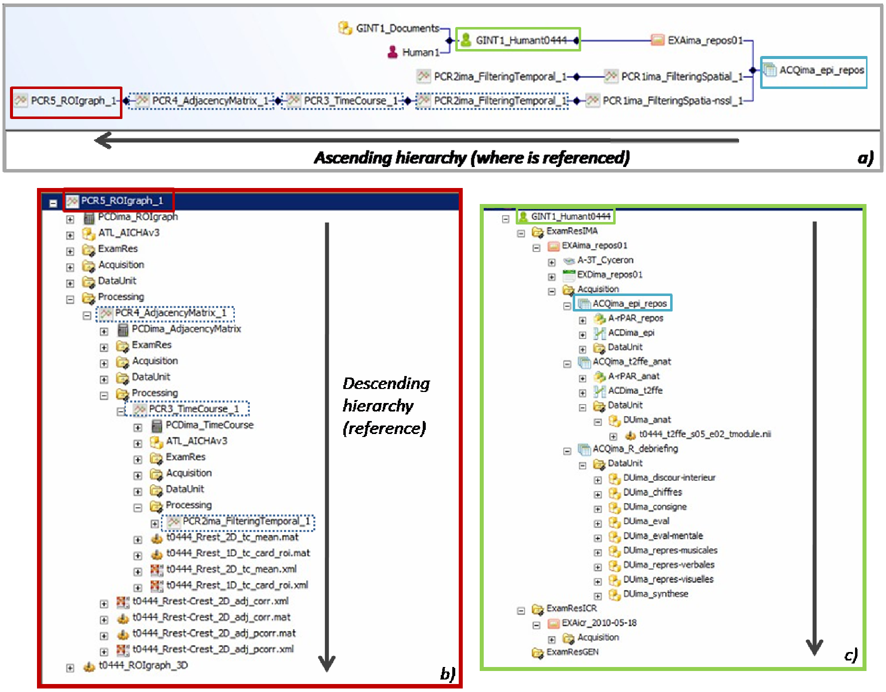

Fig. 2. Screenshots of Teamcenter rich client browsing interfaces. Impact analysis view shows that acquisition AЄQima_epi repos is referenced in a raw data branch and two processing sequence branches(a) Similar information in shown in hierarchy view from top - objects PCR_ROIgraph_1 (b) and GINT1 Humant0444 (c) through descending hierarchy.

analysis view (ascending). It is easy to see where an object has been used on close levels, as well as referencing sequences, with a limited number of relationships. However, users have to switch from one view to another to be able to navigate freely among objects relationships. Indeed, research work requires data exploration to build new hypotheses, but the PLM system allows no overall view of the complexity.

The feedback of the GIN researchers on the PLM system was good concerning the capacities of the system to manage neuroimaging data organisation. How- ever, they were very critical about the interface of the software (basic Teamcenter rich client display): there are too many menus, icons and sub-windows in the en- vironment. Besides, the actions of searching for information is not immediate. What they are looking for in terms of ergonomics is an over-simplified interface with few choices to make for each options, as well as a relationships full manage- ment (browsing, consistency checking, visual information retrieval. In addition, they express the will to handle the system almost without any training. In the end, the GIN researchers are reluctant to use the PLM database, even if they recognise that it is of great benefits for storing and sharing data and associated provenance.

5 Discussion

The two case studies developed in the paper show some limits of the interfaces of current PLM systems. This section discusses the limits divided in three cate- gories: query, analyse and browsing. Leads for future work are proposed at the end of each subsection.

5.1 Information Access: Query

In neuroimaging there is a trend for cross-domain analyses: imaging results are correlated with demographical, clinical, psychological and genetics data. There- fore, numerous joins between concepts are required for one single query, which make the search process complex. Indeed, to design customized queries, users have to know the exact data model organisation. From user's point of view, querying is textual browsing: the search fields that are filled in make the query engine browsing among data relationships. Without efficient retrieval capacities, a database is just a storage room. Apart from the limitation of users' daily data search, the lack of effective querying in PLM systems has an impact on the understanding of data provenance and therefore data reuse.

PLM data models should be transparent to the users and a proposal is to design a graphical query builder, with which users would be query-autonomous. Another future work would be semantic enrichment of PLM systems, based on ontology, and which handles the management of relationships between objects in a flexible way [4]. This would improve performances. Besides, managing PLM concept as a graph would facilitate search processes as well as query perfor- mances, thanks to graph theory algorithms.

5.2 Information Visualisation: Reading and Analyse

The way the information is displayed inside the space of the PLM systems win- dows is meaningless. Only one information level is displayed at a time, under the shape of a list. As a result, it is difficult to read and understand two information levels, especially because they do not require the same display format. PLM systems interfaces are not ergonomic nor intuitive, and companies spend significant time and money in training. If in the manufacturing industry world companies have to use a PLM system to stay competitive, other PLM application domains would be reluctant to use PLM systems because of their current interfaces, which is emphasised by the case study 2 of the paper. So it is of importance that the PLM community addresses the limits of PLM interfaces. Moreover, reducing users' training time on information systems would be obviously a competitive advantage for companies.

Some future work should address new ways of information display in data management systems, particularly focusing on multi viewpoints display. On figure 1, different levels of information are displayed in the Neo4J graph. The positive aspect is that it is easy to access to all the relationships between data and concepts, but the positive aspect is that all the edges look the same, and nothing distinguishes one level of information from the other, for instance CAD files view and product view. So multi viewpoints developments should take this remark into account.

5.3 Information Access and Visualisation: Browsing

The two case studies developed in the paper show that graphical relationships browsers in current PLM systems are not satisfactory. Ascending and descending data relationships hierarchy can only be browsed in two different windows, which prevent from consulting two product information levels at a time or from checking relationships consistency between information levels throughout product lifecycle. As shown in the case study 1, there exists no way to analyse references consistency in a PLM system, which implies a loss of information that could be important for the competitiveness of a company.

Therefore, a major concern in the upcoming works is to visualise data relationships by graphs in one single sub-window, in order to improve browsing and visualisation of every component of data provenance in PLM systems. Further researches should be conducted regarding the application of graph theory to the analysis of relationships in PLM systems.

6 Conclusion

Current PLM systems present limits, notably relationships browsing and analysis, as well as meaningful information visualisation. PLM community would gain to address the design of a simplified graphical user interface that presents multi viewpoints product information. Leads of future work include semantic enrichment and application of graph theory. It is time to make PLM systems evolve towards a more adequate relationships browsing and visualisation.

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