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Virtual World Process Perspective Visualization

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Abstract— **Product Lifecycle Management has been developed as an approach to providing timely engineering information. However, the number of domain specializations within manufacturing makes such information communication disjointed, inefficient and error-prone. In this paper we propose an immersive 3D visualization of linked domain-specific information views for improving and accelerating communication processes in Product Lifecycle Management. With a common and yet understandable visualization of several domain views, interconnections and dependencies become obvious. The conceptual framework presented here links domain-specific information extracts from Product Lifecycle Management systems with each other and displays them via an integrated 3D representation scheme. We expect that this visualization framework should support holistic tactical decision making processes between domain-experts in operational and tactical manufacturing scenarios.**

Process Modeling, Product Lifecycle Management, Scientific Visualization

I. INTRODUCTION

The ability to deal with the increasing complexity of product manufacturing depends on mutual understanding and close collaboration between all manufacturing related domains. This level of collaboration is necessary in present day manufacturing enterprises, in order to make optimal decisions about product construction and process scheduling. This collaboration requirement leads to a strong demand for suitable information management and presentation tools as a fundamental component of successful operational and tactical decision making processes. In order to accelerate and improve holistic, integrated decision making, a conceptual framework is proposed, to provide multi-domain information visualization in a product engineering environment.

A. Motivation & Problem Description

In recent years, Product Lifecycle Management (PLM) solutions have been developed for providing engineering related information wherever it is required. In PLM Systems, as an extension of Product Data Management (PDM), all relevant information relating products, resources and processes are stored [1], [2]. The internal data structure for storing and managing this information is referred to as the "Global Product Structure" (GPS) [3] in the context of this work. As the GPS contains all technical information of several engineering-related disciplines for all products and variants, the number of elements in the structure can easily become very large. In order to have a subset of information which is understandable and manageable, domain-specific views are created for the demands of specified target audiences. A view in this context is an extract from a global information system for domain experts containing a subset of relevant information in a suitable notation [2]. These subsets, extracted from the GPS, are the information used for decision processes and require inter-domain communication for making holistically optimized decisions. The conceptual framework introduced here is based on an elementary use case for a manufacturing decision, introduced in the following. The simplicity of the use-case regards the conceptual character of this approach; more complex scenarios are considered in future research.

In this scenario, a decision making process is presented, concerning the domains of resource planning, manufacturing process planning and product construction. Between representatives of these domains, a commitment should be made to have an overall optimized (pareto-optimal) outcome. This use-case describes the discussion about an attachment process in order to manufacture a wooden bench. One manufacturing alternative would be gluing the attachment; the other is screwing the attachment. Each variant would bring benefits and disadvantages for the considered domains: construction, process scheduling and resource planning.

For benchmarking both process variants, performance indicators like manufacturing time, physical robustness, reusability or demand for several kinds of resources are identified. Following these indicators, it is plausible that the optimal choice of method could be different for each domain. In order to achieve an overall optimal choice, the benefits of each variant have to be negotiated from the point of view of all disciplines in a process of direct communication. This discussion would end in choosing one of the variants, which would bring more benefits than disadvantages when considering all regarded disciplines.

II. DOMAIN-SPECIFIC MODELS AND VISUALIZATION

Following “General Model Theory” by Stachoviak [4] the models for each discipline, created with the motivation of “Pragmatism” contain elements which are only relevant in the corresponding domain. The individual models form the basis for domain representations in decision making processes. The fundamental issue for these cross domain negotiations is the development of domain-specific models for each participant. The direct communication between representatives of participating domains should be supported by a suitable visualization, which integrates and shows information extracted from all domains. Thereby, links and dependencies between all related models become obvious, communication processes are accelerated and consequently, decision quality is improved.

Here the dilemma becomes obvious: within a common visualization on classic displays, the understandability of the extracts get lost as the number of items and their interconnections can easily get too high when the illustration is composed of several domain-specific extracts on one flat screen. Furthermore, there might be syntactic and semantic differences between the domain-specific models which could hinder understanding a combined visualization.

To overcome the dilemma of complexity and understandability, a 3D visualization is proposed in this paper, to display the information from various domains simultaneously in an understandable and intuitive manner. Human spatial visualization capabilities give the opportunity to place domain-specific views in a 3D virtual space. Users can see domain-specific information models in the foreground or background, according to their position and orientation in the virtual space. This fact alone motivates the development of visualization within a Virtual Reality (VR) environment, to increase understandability by full immersion and interaction, and has indeed led to an initial implementation[1].

A process-oriented use-case has been chosen to illustrate this integrated visualization challenge. The manufacturing process is used as the major information model with which other domain-specific data-structures are linked. A process oriented approach is followed in industry and science due to its relevance in product manufacturing [5].

A. 3D Domain Visualization Structure

In order to integrate and show cross domain PLM data in a coherent manner, we propose to use a 3D Cylinder structure modified to suit the particular requirements of PLM process data [6], see Fig. 2.

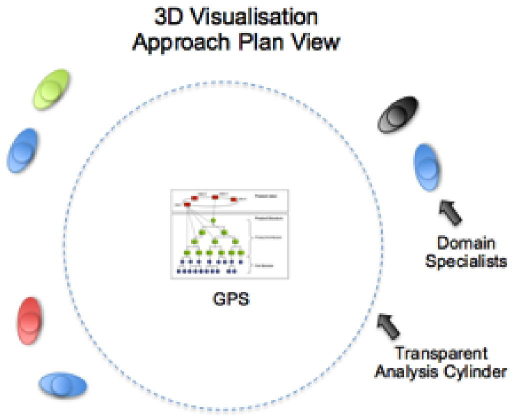

Figure 1: Plan View of 3D Cylinder-based PLM visualization structure with the outer cylinder used for analysis, and the inner GPS structure to provide context with regards to the entire GPS.

A plan view of the cylinder-based representation is shown in Fig. 1, using an inner representation of the GPS data structures related to a production process and an outer cylinder surface devoted to showing analytical representations. The intention is that such a representation is used within a fully immersive VR facility, as previously mentioned. Using this visualization approach, production domain specialists are able to stand around the cylinder and view domain relevant analytic representations, seeing how they relate to the inner data structure used as a representation of the PLM processes. This approach provides two key functions, *Context* and *Collaboration*.

Context is provided by a representation of the PLM GPS within the cylinder, showing the GPS in entirety, using appropriate representations, supports traversal of its large hierarchical data structures. Or conversely, the interior GPS representation may be via a visualization of the product itself. This internal representation will be described in detail later.

Secondly, the analytic surface facilitates collaboration and comparison via the close juxtaposition of multiple, different, domain representations. Domain specialists may gather around and compare values, based upon the domain representations that suit each viewer, enabling cross-domain discussion and collaboration.

We consider that a full virtual reality representation of the cylinder would work best, due to the large scale of the visualization lending itself to traversal of large scale data sets, such as those found in manufacturing [2], [3]. The visualizations in this paper are mockups shown in a virtual world that indicate the scale of the system to be devised by using an avatar for size comparison. It also should be noted that the representations on the surfaces of the cylinder in the figures are images used to convey the basis of the future implementation, and so should be considered proof of concept in nature.

Interactions with the cylinder system occur at two main points, with the external structure, via rotating the outer layer around the *y* axis, and by selecting and filtering information

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[1] An initial VR implementation is under development in the Lifecycle Solutions Center, in Karlsruhe Institute of Technology, Karlsruhe, Germany.

from the internal GPS structure. One person in the analysis team would typically be in control of these interactions and visual representations used in the visualization.

The outer layer can be spun, and is intended to be related to the internal GPS via visible linkages, shown as red arrows in our example figures. The internal GPS is interactive and can be used as an information source, to extract domain-specific representation to be displayed on the outer cylinder. We now discuss the representations in detail.

1) Cylinder Surface Related Representations

For domain analysis purposes, different representations are applied from the central GPS from a PLM System onto an outer cylinder. We add domains and processes into the top levels above the views, with indicators of differences in the graphs [7] for comparisons of processes and their influences on the results of the PLM processes. The flow on cost effects can be viewed in the lower level, or over the elements of the process model, applied to another part of the cylinder surface.

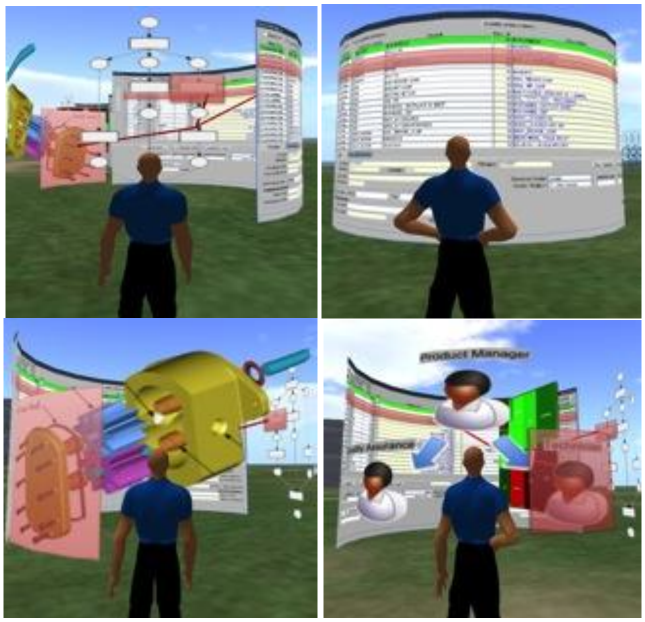

Figure 2: Analysis representations that can be applied to the surface of the cylinder regarding: Production Processes (top left), Bill Of Materials (BOM) (top right), Product Schematics (bottom left) and Human Resources (bottom right). Red highlighted areas indicate links to select information in the central GPS.

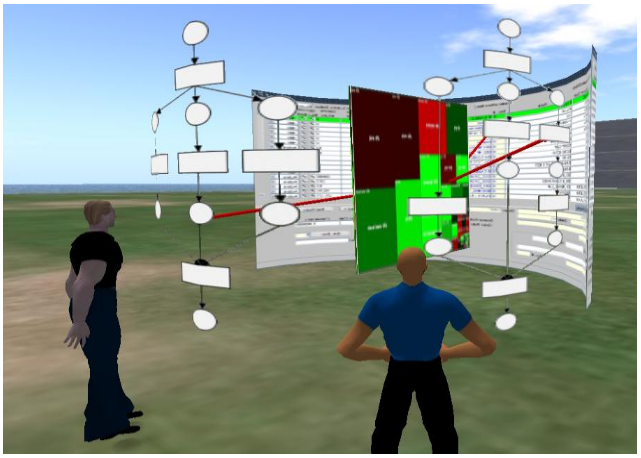

Figure 3: Initial use-cases in Petri-Net notation with further manufacturing information

Each of these can be either drilled down upon in the central GPS representation, or specifically selected by the viewing session controller using a search interface. Models describing a certain region of interest are extracted from GPS, following the pragmatism (demand for information) of several domains. Interconnections are taken from the PLM System, there the links are stored within the Global Product Structure [3], augmented with the process linkages we specified in Section A. The extracted models are then processed to identify grouping relationships or pivotal elements. These elements are taken as links between the information models. Linking the elements of the models with 3D representations following defined mapping specifications between the abstract model and graphical representations. The mapping specifications include a rule-set for spatial arrangements, to assist in providing an optimal layout.

2) Internal Cylinder GPS Data Representations

We propose two internal representations for the PLM data: Tree-Map Hierarchy Stack and a Product Centric view. Each of these is chosen to represent the complex production data in a manner that provides context and complexity reduction when seeking to traverse and extract other representations to be displayed on the outer surface of the cylinder for domain analysis. Each of these representations also provides the key abilities of context, drill down and interaction required to traverse wide and deep GPS hierarchy information.

a) Tree-Map Hierarchy Stack

The Tree-Map Hierarchy Stack representation consists of layers from each level of the GPS, summarized to provide context data. Such an overview is often used for strategic views of data in other applications enabling parallax at each level to easily identify the planar position of objects. Such an approach provides complexity management by the spatial arrangement of the objects in a manner so that constrained camera motion reinforces the categories instinctively. This approach has been applied to large-scale process visualization approaches in Biology and we expect this approach to scale to large PLM Systems with multiple sources of data.

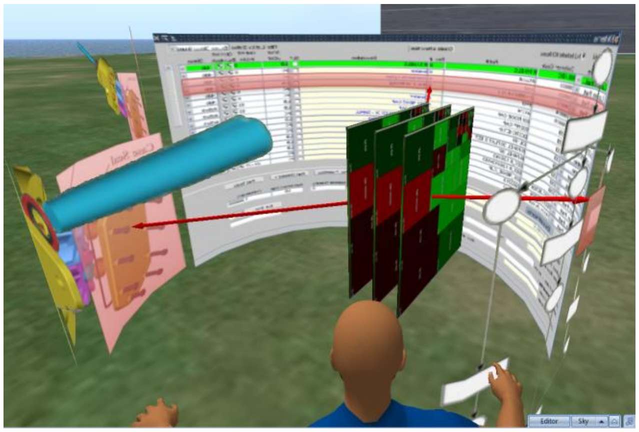

Figure 4 Example showing the inner structure as a Hierarchy Stack, made up of summarized Tree-Map levels within the GPS.

Each level of the hierarchy is composed of a Tree-Map structure. The Tree-Map GPS representation (refer to Fig. 5) is a popular 2D embedded hierarchy representation that can facilitate display and traversal of large hierarchical data structures, showing the path through the hierarchy, and allowing drill down capabilities [8]. This representation will allow domain specialists to see the contents of the GPS levels at a glance, and still enable sense making of the relationships between each component, interactively. In particular, the path through the hierarchy can be traced across the surface of the Tree-Map, so its contextual capabilities give it an ability to facilitate transitions to areas of interest (see Fig. 7).

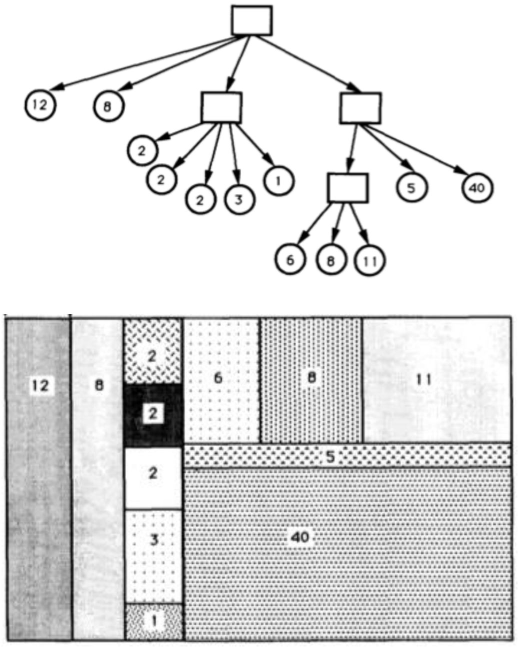

Figure 5 Simple example of a Tree-Map converting a tree structure (top) represented as a map structure (below) from [8]

b) Product Centric

A product centric representation (refer to Fig. 6), provides a hierarchical representation of the production process, from the point of view of the physical product components. 3D exploded representations of the product are shown in the central area of the cylinder, as a form of hierarchical representation. This representation is expected to be useful as a domain specialist independent view of the GPS, as it can be reasonable assumed that all stakeholders in a production facility are able to identify physical products and their components.

Figure 6 Example using a product representation as the inner structure.

The GPS views can be constructed by attribute filtering, architecture references, component hierarchy, zone of interest, structure compression and enumerations of alternate configurations [3]. In effect, visual queries, or text queries can be applied to the GPS structure, to extract representations for analysis on the cylinder surface. Design decisions are then made based upon multiple domain views emanating from the GPS. Each of these may be chosen to suit the domain expertise of the people viewing the information. A product centric internal representation will suit product designers, while process models are suitable for manufacturing management personnel.

Relationship information proceeds from the outer surface, and recedes into the centre, being deprecated/ escalated as required by the user. The central representation adapts in structure to eliminate clutter and pushes the relevant selected information to the outer cylinder. The path through the structure can be highlighted assisting traversal through the centre of the cylinder (see the red arrows in Fig. 2 to 5). Analysis using such a structure is kept to the surface of the outer cylinder, where the following representations can be placed to support product process analysis. The internal representation provides a visual, summarized representation of the complex GPS hierarchies present in the PLM data, and thus allows the viewers to relate different components of the GPS to each other visually, while maintaining a sense of its whole structure.

3) *Hierarchy Structure*

We now describe in detail how the internal GPS organizes itself with regards to user queries. As previously described in Section II A, we divide the views up into a hierarchy, with roles determining views at the highest level. Deep hierarchies are reduced due to pragmatics as a form of structure compression that facilitates insight and speedier traversals. Thus the techniques use by Eichhorn [9] are integrated into the visualization, with an enforcement of role levels onto planes, overcoming issues with the complexity of the hierarchy and its interaction with the process models at lower levels.

In addition, each representation can be filtered either via a direct semantic querying, or by ordering in the natural hierarchy of the components. Each level "group" can be related to, in order from top down:

- Domains – as defined previously in Pools and Roles [9],[6].
- Views - related to the previous roles, derived from [10]
- Processes - and their respective perspectives [11], [12], 13]
- Product Architectures - levels of hierarchies in structure of the product [14]
- Components - from base level to complex assemblies can be added to levels [14]

4) *Level Membership*

When displaying the GPS hierarchy, some of the major issues to address are the choice of the number of levels and their summarized contents. Due to the large data sets involved in a PLM GPS, this level membership becomes a complex issue of summarization [15] and selection [8] that will assist in reducing the complexity of the internal structures, and will help with interacting with the complex database present in the GPS. Two key factors in this presentation process are, the visual representations and the visual interactions provided by the adaptive level management.

The summarization process is intended to be adaptive in granularity. Objects and linkages can be adaptively summarized for each level to collapse complex multi-level hierarchies into simpler forms to populate each level [15]. This summarization process, however, will differ depending on the level being processed. Some levels in the GPS, such as the role hierarchies, are orders of magnitude less in complexity than say the deep and wide component hierarchies composing the product itself; this is especially due to people having responsibilities for more than one product or one component of a product. The number of levels visualized will be constrained to main levels identified: Domains, Views, Processes Product and Components. Each layer can be expanded and contracted as required, using an interactive animation.

Thus, the level membership is adaptive, but constrained to be within major organizational levels. The divisions are planar in nature, in order to promote a parallax effect when analyzing the structure of the GPS. For example, while a product hierarchy can be expanded to different levels across its tree, the hierarchy is constrained to the product level. These level hierarchies are then visualized within each level of the hierarchy using the previously mentioned Tree-Map technique. If such planar constraints are not implemented, then a feasible clear summary of the entire GPS would be problematic, due to imbalanced trees in the data model not being projected correctly onto each level plane, preventing parallax effects from providing insights into structures [8].

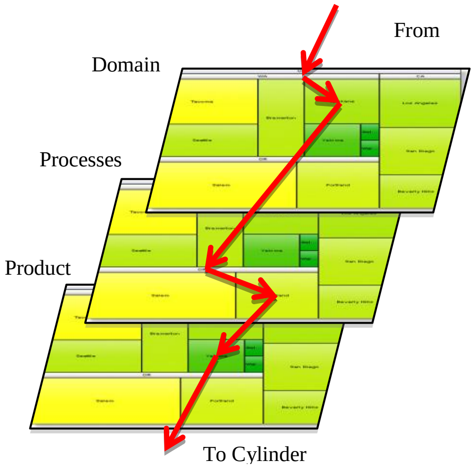

Figure 7: Hierarchy of Information Layers in of the cylinder

In this simplified example, we show Domains, Processes, and Product as a selection of layers. The red arrows in Fig. 7 illustrate an example path through the hierarchy that indicates the context of the information presented on the outer cylinder; i.e. this is a detailed example of the coarsely illustrated red arrows shown in Fig. 2-7)

Tree-Maps are designed for large scale hierarchy representations, and so other methods for level selection and summarization can be exploited easily. The Product Hierarchy representation is simpler to process, due to its inherently hierarchical, not planar, nature. Indeed, products and components lend themselves to such spatial 3D representations, as the manufactured products will have that structure on production, providing intuitive insight into the components under examination.

Product hierarchies can be summarized via the use of selective components in the product; that is, the choice of subcomponents as the key representation, such as a suspension unit, within an entire car. In addition, the summarization can be performed using selective exploded views on the complex subassemblies [14]; which can be intuitively performed via click or touch-based interactions, or by searches based on component or product key terms; eg. strut, spring, cylinder.

Another issue to address with the PLM structure will be the maintenance of a sensible path through the internal data structure, to link together the outer cylindrical analysis visualizations, with the GPS. Thus, any of the highlighting mechanisms must allow for unbroken paths through the hierarchies, in order to facilitate user understanding of the context of the information as it is presented from the GPS.

We show in Fig. 7, how the Tree-Map stack allows a summarized view of the relationships of each outer cylinder representation to the internal GPS structure.

Smooth interactions with the internal GPS will require progressive rendering algorithms applied to the large hierarchy structures, in order to promote high levels of real-time interactivity. Animations of the modification of the environment will allow the extraction of relevant product representations, and will enable the visual tracking of changes by users in the structure of the GPS.

III. CONCLUSION

Tight production process collaboration between experts of different domains is required for successful operative decision processes. To improve this decision process, we have developed a conceptual framework, which enables a sophisticated visualization of multi-domain information in an engineering environment. Our framework should support the experts in their decision process by giving a holistic overview of the different domains, showing the impacts of changes in one domain to other domains. Although our framework is generic for multiple dimensions, we chose as examples the three domains resource planning, manufacturing process planning and product construction.

Our framework is intended to be process oriented, due to a lack of domain independent process model representations in PLM. We connect the different domains to the process model domain. Therefore we evaluate modeling notations Petri Net, BPMN and YAWL as to their suitability to relate them to the resource and manufacturing domain.

We based our visualization approach on information retrieval mechanisms provided by PLM Systems. The items contained in a PLM can be assembled into a Global Product Structure. Using the GPS, views can be generated, according to different domain specialties. Based on these views, we developed our new 3D production process model representation. For the 3D presentation we proposed to use a cylinder structure. With this structure it is possible for different domain experts to stand around the cylinder and view domain relevant analytic representations.

We discussed, and showed as mock-ups, two different representations for the inner structure (Product Centric, Tree-Map Stack). With these structures it is also possible to show the connection between the elements of the different views by highlighted assisted traversal through the inner center.

Future work will involve developing the system further, so it can also display the inner cylinder and show the connections between the elements of the different views in a fully interactive manner. Afterwards, we plan to perform an evaluation with domain experts about the usability of our visualization approach.

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