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AN INTEGRATED CONTEXT MODEL FOR THE PRODUCT DEVELOPMENT DOMAIN AND ITS IMPLICATIONS ON DESIGN REUSE

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1. Introduction

Digital product models are an important fundament of today's product development processes. They are created and maintained in the context of activities embedded in process models. The resulting variety of information makes it difficult to retrieve the contained knowledge in an enterprise. On the other hand, companies try to cut down product development costs and development times. The crucial point in attaining these goals is to leverage reuse of existing knowledge in an enterprise. Amongst reuse of best practices, that comprises especially the reuse of existing parts or (sub-)assemblies. Current search solutions are restricted in finding appropriate solutions due to a lack of understanding of the user's information need. The paper proposes a solution, which incorporates a comprehensive description of the user and the document context. This description of the user leads to a better understanding of his or her information need viewed from the technical side of a search engine. In addition to already existing context models in the product development domain, we suggest the consideration of domain specific measures to enable a higher precision in searching.

For instance, the information about the current process phase the user is engaged in enables a context-aware search engine to retrieve more specific search results. An engineer in early phases in a development process might look for general documents whereas later phases demand for more specific documents in terms of the documents' degree of maturity.

The perspective behind this idea is that a user's information need is characterized by the query issued by the user – some keywords for example – and the current context of the user. On the other hand, the retrieved documents are represented by their content and the document context – the creation phase or the degree of maturity for example. In this situation the retrieval of the documents relevant for a given information need becomes a multi criteria matching problem. In the simplest case we can think of the content and the context as two criteria. The weighting and the matching can be performed in different ways: The weights and the metrics can be defined by human experts or they can be heuristically determined by machine learning techniques [Mitchell 1997]. Another approach would be to leave the decision to the end user and to represent the content and the context aspects in a faceted search interface [Hearst 2006]. However, before considering context aspects in the matching process, the relevant context aspects have to be identified. The present paper is a contribution to this field.

The remainder of the paper is organized as follows. Section 2 introduces the FORFLOW project where this research takes place. This is followed by related work from the field of context research and retrieval in the product development domain. In section 4 the integrated context model is introduced whereas section 5 completes this view in regard of the practical implications in product development. The paper closes with a conclusion and an outlook on future work.

2. FORFLOW Project

The FORFLOW project is a Bavarian research cooperation to improve process- and workflow support for planning and controlling processes in product development. The aim of the research cooperation is to describe approaches and decision criteria for these procedures and particularly its interfaces in order to develop the concept of a *Process Navigator*, which supports the engineer step-by-step in product development and gives assistance in decision-making support. The Process Navigator serves to reduce time of development, to make the process more transparent and traceable, to provide knowledge and suitable information and to use existent knowledge efficiently. Thus, the risk of erroneous trends can be reduced and the quality of processes and products can be significantly improved.

The projects in the research field „Conception of a multidimensional knowledge base with specific retrieval services for the product development" explore the problems concerning the purposeful provisioning of the designers with data and information in the process of product development. To achieve that goal the utilization of contextual information in similarity search is aimed at.

3. Related Work

In recent years, context research has spread to the product development domain and proposed several possibilities how to describe *context*. This chapter gives an overview of the gained conclusions and contributions.

Longueville et al. propose a three layered context definition that differentiates between the explicability and formalizability of context information [Longueville et al. 2003]. The *explicit context* depicts a formalisable context, which can be described by the means of parameters in the context model. Project prerequisites like deadlines or available CAD licenses can be easily specified in the context model. In contrary, the *implicit context* is defined by a set of rules that apply to the *cognitive context*, which was coined by the artificial intelligence community and consists of "a set of assumptions on the world and rules". As the actors learn those rules they can only partially be formalized. E.g., this information can be elicitated with data mining techniques. The most abstract layer is formed by the *overall context*, which is shaped by history, culture and education of the participating persons and their environment. No representation is possible, because that part of context falls in the category of tacit knowledge.

Kim et al. focus on the matter of design reuse in facilitating context [Kim et al. 2007]. They achieve that in collecting knowledge about *design rationales*. For that special use case, the authors define a static task model, which describes the task context. It consists of the four elements Issue (I), Answer (A), Pro Argument (PA) und Con Argument (CA) that are connected according to the IBIS method in a direct graph. Each item is assigned a state, which represents the applicability of the underlying design change. Context similarity is calculated by either path similarity or content similarity.

A work package from the European integrated project VIVACE dealt with contextual search for engineering knowledge [Redon et al. 2007]. The authors identified six context dimensions they further investigated, namely *activity*, *project*, *gate*, *role* and *discipline*. The connection between a knowledge element and its context can either be specified by an expert or determined automatically by the platform itself. The search process is based on a case-based reasoning system, which utilizes user context descriptions and the applying knowledge element-context associations.

Our context-aware information retrieval framework intends to support the search for all emerging product models during the development process. A system that has the same intentions is the *Design Navigator System* introduced in [Karnik et al. 2005]. It targets the management of design information. The authors distinguish between information related to the design and information related to the design's evolution and history. That leads to six different types of information: requirements and specifications, functional decomposition, assembly structure, part geometry, annotations, and interconnections. The main goal is to consider all information during the design process, which includes design rationales that can be reused in other projects by means of best practices. The system allows various access methods. The search functionality supports browsing, design rationale search and geometry-based search amongst others. However, context information is not incorporated.

In [Morgenroth 2006] Morgenroth proposes a user model, which comprises three different context views: *Interaction Context*, *Working Context* and *User Context* (cf. figure 1). That research took place in the software engineering domain and therefore lacks a proper adaptation for the product development domain. The *Work Context* as described by Morgenroth covers the current task the user is assigned to. Hereby a differentiation between structured and unstructured tasks has to be made. As our search scope also covers process support in recommending the next process steps and appropriate methods this branch of contextual information has to be extended by several dimensions.

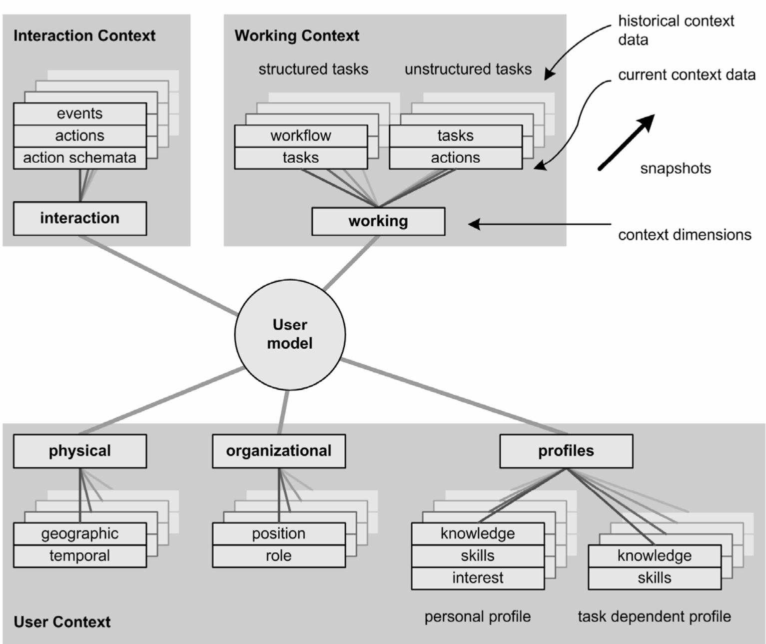

Figure 1. The context model from [Morgenroth 2006]

4. Context Model

To enable a more thorough search than existing solutions can provide our goal is to describe the user's information need more precisely by its context. Primarily it is crucial to identify all different aspects to be modeled, which influence the context in product development. Figure 2 shows the seven identified models which cannot be seen independently, as they are affecting each other. For instance, the task model is linked to the process model that connects several tasks with roles, documents and so on. The description of context happens at different times. The user model information is usually collected on runtime of the system and the document model on build time. In an indexing step, the main context information is gathered and put into a context repository. If document context changes occur during runtime this information is adjusted to ensure current data.

The hereinafter presented context model was derived from three different pillars: literature review, academic discourse with other participating subprojects from the FORFLOW project and interviews with our industry partners which are positioned in the automotive supply domain.

For a context-aware search engine, which aims at delivering relevant documents for a certain user in a certain situation, it is necessary to describe the user context as well as the document context. The identified context dimensions apply to a varying degree to those two contexts. Although presented independent of each other the different models that yield the context of product development are highly interlinked.

4.1 User model

The user model focuses on a thorough description of the user. Thereby a user profile can provide information about the domain knowledge of the user. From that the expertise of the user with the current task can be derived which plays a role in recommending common description documents about the process. The user's experience with the search tool as well plays a role when it comes to the presentation of the search results. If search results are delivered it should be understandable why those results were returned. A more experienced user might better comprehend the results whereas an inexperienced user needs explanations that are more detailed. Furthermore, the user profile saves information about preferences, abilities and interests of a user, which e.g. explain the user's approach developing a product. That can be reasonable when providing the user with method proposals to support his or her current task. The search engine knows which methods are common to the user and which of those the user prefers. As nowadays product development is highly supported by software applications, the interactions with those systems can provide valuable information about the user and his current task. That information has to be captured through plug-ins in the involved software systems.

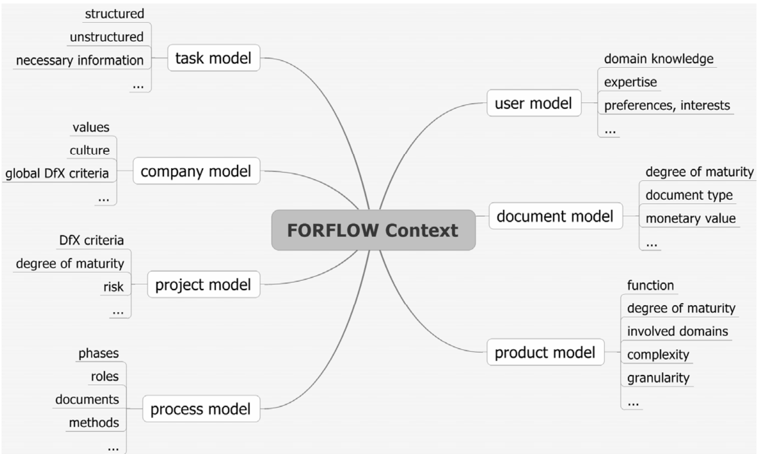

Figure 2. The FORFLOW context dimensions

Information about the user's position and his roles in an enterprise have to be considered as well. This information is linked to the *company model* explained in section 4.5.
The roles as well are related to the *process model* (cf. section 4.2) since they describe the tasks a user is responsible for in a process in the company and therewith complete the user model.

4.2 Process model

Each project usually follows a certain process model, which describes the sequence of phases and activities, the documents that can/must be created therein, the responsible roles and the applicable methods. Product Data Management (PDM) systems or the Process Navigator mentioned in section 2 allow the creation of process models to fit the company's infrastructure and their process approach. This modeling includes a partial description of the user's information need as documents are assigned to phases or tasks and accompanying roles. Thus documents might be entry or exit criteria for a phase, they might be revised in a phase or just needed for reference like company guidelines. This knowledge provides a much deeper understanding of a document and its purpose in a process for a search engine.
The classification of the user into a process model is of high significance for a context-aware search engine as the user's information need has a strong relation to the process phase the user is currently working in (cf. figure 3). Whereas during early phases more general documents are needed, later phases require documents that are more specific. The creative process in the beginning motivates this

where potential solutions are evaluated. When the chosen solution is going to be constructed, the designing engineer needs specific documents and partial solutions that meet the defined requirements.
Considering the file types, it shows that each phase requires specific documents, which should be taken into account when ranking documents. In the planning phase the dominating product models are text-based while in the design phase specific CAE models (2D/3D models, simulations etc.) are generated.
By knowing the affiliation of a document to a task or process phase a search engine can then deliver search results which help the user in his current task. This connection can be inferred through the assignment of roles to users that denote the tasks the user is responsible for. This permits the search engine to better infer the user's information need. Additionally, the interactions of the user with the used applications are analyzed and taken as input. If the task demands the existence of a finished document, the search engine can look for similar entry documents and then deliver the inferred result documents from past projects.

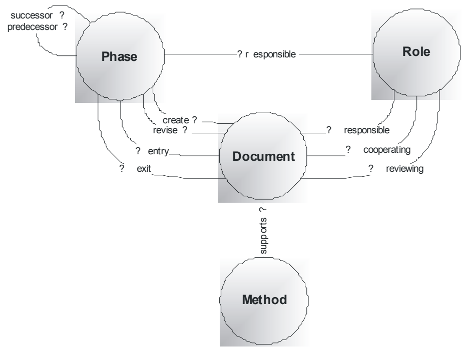

Figure 3. The process meta model

4.3 Task model

Deeply linked with the process model is the task model. The consideration of direct process knowledge delivers not only information about the current task the user is working on, but e.g. provides information about input and output documents, applicable methods and subsequent process steps and dependencies on other tasks as well. The underlying process model keeps this information, which is exemplarily presented in figure 3. A differentiation of tasks has to be made in regard of their structuring. Tasks can be fully structured which includes their dependencies to other tasks, the input information and the documents and the information which should evolve. Unstructured tasks are vaguely specified which may result in a less precise description of the user's information need in that certain task.
Time tracking and the (financial) acquisition of amounts of work are additional factors a context-aware search engine can use in ranking documents.
If it is known how much time a work package or task will approximately take a search engine can upvalue documents from other projects with similar prerequisites to allow skipping this phase or at least to diminish the expenses. For example, simulations can take a long time to complete, especially acoustic simulations, which make it impossible to carry out too many change and test cycles. If simulation results are presented to the engineering designer, he may postpone the actual simulation that is still needed but does not have to be executed unnecessarily.

4.4 Project model

The project model describes project-specific parameters that are valid throughout the project. Roelofsen et al. describe the project situation from a process planning point of view [Roelofsen et al. 2007]. Although the intended use of the considered parameters is a different one, the transfer of

these parameters to the context description of a document is highly valuable. For the project level the authors examine the *customer*, the *project risk*, *project constraints*, the *structure of the design problem* and the *number of units produced*.
In addition, we consider global project specific *Design for X* (DfX) criteria, which have to be met. Those can be useful in a search in a current project with similar DfX criteria where documents from other fitting projects can be returned due to their DfX similarity, which of course is not a single criterion but still can contribute to more precise search results. That can support searches where some similar search results occur and the DfX criteria plays the pivotal criterion.
The *degree of maturity* of a project can be expressed in terms of achieved percentage of documents, milestones or the compliance with the cost and time estimates. Depending on the user's information need the results from finished projects can be preferred as they imply a higher degree of completion which may be desired if looking for parts which can be reused as-is.
The last introduced part of the project model is the *kind of development*, which is viewed according to Pahl / Beitz as original design, adaptive design, and variant design. This factor has a high influence on the amount of reuse in product development [Pahl et al. 1999].

4.5 Company model

Another part of context in product development is the company model, which e.g. can be specified by the company's culture and values. A company that focuses on environment friendly products has to consider values like sustainability and environmental compatibility. These values are reflected in product development in terms of certain methods, choice of special materials etc. Other influences are company-wide DfX criteria, which have to be met in all developments efforts in the company. Furthermore, the model comprises a geographical and temporal dimension, which has to be considered in collaborative projects where project members are geographically distributed.

4.6 Product model

Many documents in a development process represent a partial view of the final product. Therefore, it seems coherent to imply that the product view onto a document leads to a more comprehensive description of a document and its context. Each part or assembly has a *function* it delivers. Research brought up several function classifications [Hirtz et al. 2002] that can be used for that matter. A user searching for a part has in mind a certain function the sought part should fulfill. A search engine, which has access to this information, can gain higher precision in the search task.
Depending on the development progress, the *degree of maturity* for a part can be calculated with different measures [Pfeifer 2004]. E.g., it can be derived in various ways, which include the ratio of finished tasks to the number of all tasks, the ratio of finished requirements to all requirements amongst others. That information abstracts from the measurement of the process progress in terms of finished tasks or documents and focuses on a more product-centric degree of progress. That information can be beneficial in a search situation if an engineering designer is situated in early design phases and is looking for ideas and inspirations. In a situation like this, it seems appropriate to reveal parts whose degree of maturity not necessarily needs to be too high. If a purchasing engineer searches for parts, a high *degree of maturity* is required.
The *Design for X* (DfX) approach in product development subsumes methods, strategies and tools to consider influences that usually are shaped by several product requirements or company guidelines throughout the development process [Pahl et al. 1999]. Since the part under development has to fulfill those criteria, their influence on the document context is undeniable. As different DfX criteria imply different methods for their realization, the search engine can then give adequate support.
The context also partially depends on the *involved domains* of the product, i.e. is the part only dealing with mechanical parts or is it cross-domain development in a mechatronic setting. The latter e.g. requires additional artifacts that have to be created. When the user searches for a certain part all directly involved other product models can be delivered as well. The *complexity of the product* as distinct from the task complexity can be measured in the number of parts that have to be designed, or the number of interfaces to other parts. A differentiation has to be made about the *granularity* of the product. Is the final product a small part, an assembly or a full product?

Another enhancement of the document context would be the storage and traceability of design rationales, which denote the rational background why an artifact is designed the way it is [Lee 1991]. This information is valuable in several situations. If design changes are necessary in later phases mutual interactions between part functions are better visible and explained by design rationales. That helps avoiding modifications that are impractical or impossible concerning other product functionality. Furthermore, this information encapsulates design knowledge, which should be reused in other projects to benefit from past experiences.

If additional systems connect with the Process Navigator or with the context-aware search framework, more precise contextual information could be derived about specific artifacts like parts or assemblies. An Enterprise Resource Planning (ERP) system can deliver information about order and lot sizes as well as manufacturing costs, which can play a role in document ranking. That pays off if parts that are already purchased in high quantities can be incorporated in new assemblies, which are under construction.

4.7 Document model

The *degree of maturity* of a document has an impact on the document model. An engineering designer searching for a partial description of a part he can use in his current development project, e.g. a technical drawing, seeks for documents, which are already completely finished whereas an engineer who looks for solutions and ideas might be satisfied by parts that are still under construction.

The *document type* is considered for filtering purposes, e.g. if a projects demands usage of a certain CAD system, only parts understood by that application are returned.

Monetary values of documents can have an influence on the ranking as well. If the user is currently creating a document of high value – because of the required manual effort or the costly simulations, prototypes etc. – it seems to be beneficial to present similar or related documents as early as possible in order to boost reuse and the exploitation of analogies. To this end, the “value” of a document as well as its fit for the current situation of the user should be considered by the search system.

A context-aware search algorithm can take advantage of these factors when ranking documents because the search query comprises a more precise description of the user’s information need. That leads to more precise answers and helps the user to deal with the information overflow.

5. Benefits of context-aware searching in product development

In the search process the user’s information need has to be matched against the documents in the index. Since current search engines only consider the user’s given query – mostly keyword or an example file – search results can only be determined by that partial description of the user’s information need. The search engine can only match text queries to textual data in files, e.g. metadata or descriptive elements. The gathering of document context information allows a more precise ranking process that is capable of returning more precise results for a given user query. The search engine derives a thorough document description including dependencies between documents through incorporation of contextual information.

A context-aware search engine can employ context information in two ways. The context can be utilized as a filtering criterion. Considering the current role of an engineer a filtering on document types seems reasonable. A project manager needs different documents in a certain project phase than an employee doing simulations. The more complex utilization of context lies in incorporating this information into the ranking process and adapting the ranking model context-dependently.

Due to the analysis of the user’s context, the search engine can also try to deduce an information need and return search results proactively, i.e. without the necessity of user interaction. Although that may not always be desired, this alternate way of query issuing supports design and knowledge reuse. Engineers might not be aware of existing parts and therefore omit a search, which seems to be costly in terms of time. The context-aware search engine can bypass this situation and return parts the engineer can apply in the current project. Another incisive point is the integration of several information sources which are considered during searching and which enable a more complete coverage of knowledge. The given contextual information can lead to the below-mentioned heuristics, which are far from complete but show a perspective of what the search engine can achieve:

- Recommendation of documents from projects with a high degree of maturity
- Recommendation of documents from projects with similar DfX criteria
- Recommendation of documents which denote results from the same project phase from other projects with similar input documents
- More experienced users may get more specific documents
- Milestone documents get higher ranking score as they influence the critical path

6. Conclusion and future work

In the present paper we have proposed an integrated context model for the product development domain. This model can be applied as a basis for the consideration of context aspects when searching for relevant documents. Of course, the generic model has to be tailored for the individual situation. To this end, the employed process model as well as the applied software tools and their ability to automatically derive context metadata for documents have to be considered. Furthermore, the use of the context information in a search engine and the assessment of the possible improvements in result quality are important directions for future work.

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