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What are features? An ontology-based review of the literature

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ABSTRACT

Feature-based product modeling is the leading approach for the integrated representation of engineering product data. On the one side, this approach has stimulated the development of formal models and vocabularies, data standards and computational ontologies. On the other side, the current ways to model features are considered problematic since it lacks a principled and uniform methodology for feature representation.

This paper reviews the state of art of feature-based modeling approaches by concentrating on how features are conceptualized. It points out the drawbacks of current approaches and proposes a high-level ontology-based perspective to harmonize the definition of feature.

1. Introduction

Product Lifecycle Management (PLM) deals with the entire spectrum of data and knowledge concerning the lifespan of industrial products, from the initial phases of requirements elicitation and design, to later phases like manufacturing,[1] selling and product's disposal [1]. In order to be machine-processable and cognitively transparent to software agents and to the variety of stakeholders involved in PLM tasks, product knowledge needs to be specified in languages with formal semantics and driven by experts' conceptualizations about their domains of expertise [2–4].

Computer-based technologies, generically called CAx, used for engineering purposes, like Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), Computer-Aided Manufacturing (CAM), and Computer-Aided Process Planning (CAPP) systems, are traditionally focused on specific modeling tasks. Hence, they are used by different expert communities at different stages of the PLM cycle [5,6]. As a consequence, the conceptual models behind these systems can differ on the type of data they allow to specify and on how such data is organized. For instance, from a CAD perspective, a product is a (possibly complex) geometric entity, while from the CAPP perspective, it is the result of production activities carried out by production tools [7,8].

In order to facilitate PLM tasks, as well as heterogeneous data sharing, multiple-views representation and engineering models interoperability, CAx technologies are asked to be more integrated [9–11]. Additionally, they need to answer the need for embedding qualitative specifications about the engineering intents into quantitative models. Information about what the product is useful for, what are the costs for its production, or the environmental impacts of the manufacturing processes should be coherently available in the models used across the PLM cycle [12–16].

Feature-based modeling approaches have played a relevant role for qualitative knowledge specification and integration since the '70s [17,5,18], and feature-based CAx systems are currently considered the state-of-art technologies for product modeling [6,19]. Much of the research work in this area has been focused on the development of algorithms for the recognition of features in design models, as well as on the development of design-by-features technologies [7,20].

Despite the efforts in the last 40 years, feature-based approaches still have not led to a common understanding of what counts as feature, nor to a principled methodology for feature knowledge specification in formal languages. Each community has proposed its own classification and data model, suitable for their specific tasks, and has built CAx systems on top of such models. As a result, features remain entities differently understood by the different stakeholders. Furthermore, their description is limited to specific modeling concerns and, typically, application-driven.

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[1] We use the term 'manufacturing' in a broad sense to cover various tasks related to product realization like machining and verification.

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In this scenario, the product models used at different phases can hardly be integrated and shared within and across communities.

In this paper we review the literature concerning the conceptualization of feature notions. Our review is guided by an ontology-based reading of features. For this reason, we will pay particular attention to ontology inspired works which are today widely employed for product data classification and knowledge representation, and are used in advanced CAx systems to foster data sharing and inter-systems interoperability. Differently from previous reviews, which analyze algorithmic procedures for features recognition, feature-based CAx systems or design-by-features methodologies, we focus primarily on the semantics of feature notions, namely on how they are understood across communities, rather than how they are computationally treated in implementation systems. The review is motivated by the lack of progress in understanding the semantics of features. The development and formalization of a broadly applicable knowledge base for PLM requires indeed to systematically analyze the concepts at stake, and that of feature foremost, before moving into application concerns.

2. Research methodology

The initial motivation for this review was the observation that after 40 years of feature-based modeling, there is no unifying view, not to say understanding, of features. If today we ask experts about what a feature is, what properties it has, how we should classify it and, finally, how to model it, we would get puzzled by the variety of answers, by the impossibility to harmonize the answers, even by the lack of a common core for feature understanding. Given the emphasis on feature modeling that we find in the literature and the number of tools based on feature representation that are available, this situation shows that the problem of feature understanding and modeling is deeper than what has been thought so far, and that it does not seem possible to converge to a coherent feature framework by simply exploiting a naïve view of features. In short, we need a feature theory.

This paper aims to look at what we have learned in these years of feature studies: what types of features have been used, what problems have been faced, what is shared among the different views. We consider this is a preliminary step to find a way to move on, perhaps in terms of a change of perspective.

We consider a wide spectrum of publications related to the organization, representation and management of product knowledge and data. The references span from traditional approaches for geometric and parametric feature modeling, to feature taxonomies, object-oriented feature modeling, the development of advanced CAx systems, the application of feature-based approaches to e.g. production costs evaluation, manufacturing verification, machining, functional specification, assembly, among others. A variety of papers dealing with the formal representation of feature knowledge via ontologies is particularly relevant here. Ontologies are today the state of art for transparent modeling, for handling human knowledge in a computer tractable way, for reliably sharing data without loss of relevant information, and for enabling system interoperability. Since there are different types of ontologies, and these can be applied in different ways, we will try to see how successful they have been and what is still missing.

Our analysis of the literature is driven by theoretical insights and formal approaches in ontology engineering [21,22]. In particular, we will point out that the approaches exploited so far in this area of engineering are limited to the so-called semantic technologies, which are quite weak when dealing with sophisticated notions like, we claim, that of feature. Therefore, the state of art presented in Section 3, instead of evaluating technological solutions or algorithmic procedures by which most product models are implemented, focuses on the conceptual models behind these implementations and aims to isolate the foundational assumptions by which features are identified and represented. Accordingly, we investigate how people and organizations understand the domain where they are used and reveal which assumptions drive the development of a certain application [23].

3. State of art: a critical analysis

This section consists of three parts: a report on existing state-of-art reviews concerning feature-based approaches (Section 3.1); an overview of feature definitions focusing on the different understandings of feature notions for PLM purposes (Section 3.2)[2]; and a description of how features are formally represented in information models (Section 3.3).

3.1. Reviews of feature-based approaches

Several survey papers concerning the development and application of feature-based modeling approaches have been presented. The works of Salomon and colleagues [18] and of Bronsvoort and Jansen [24] are amongst the first surveys concerning research issues in feature-based methodologies and technologies. From these publications, it emerges that feature-based models were conceived as being dependent on application constraints and on specific expertise modeling views already at the beginning of the 1990s. As a consequence, engineering models were reusable only at the expense of large re-engineering procedures. To cope with these and other modeling issues, [18,24] proposed to look at methodologies and technologies allowing multiple views integration.

In 1995, van Leeuwen and colleagues [25] discussed the application of feature-based methods for Architecture and Building Information Models and provided a brief review of the state of art of feature-based approaches across mechanical engineering. In this paper they firstly addressed the need of unambiguous and conceptually clear formal models for data modeling and data sharing in engineering; secondly, they addressed the heterogeneous views integration as a main bottleneck for engineering modeling tasks; lastly, they emphasized the necessity to embed qualitative data into quantitative models to allow the formal representation of the designers' intents.

The situation has changed only slightly since then and the described shortcomings can be found in today's modeling methodologies as well. Bronsvoort and colleagues [26] highlight similar shortcomings in existing commercial feature-based systems like the lack of clear semantic specifications for feature notions and the lack of integration for multiple views. According to the authors, features are typically treated in CAx systems as shape macros and, behind morphological aspects, do not support specification of the intents. Amongst the open issues that require further research work, the authors point out the need of new approaches to allow feature models exchange across systems without losing semantic information.

Ma et al. [6] provide an overview of current research issues related to feature modeling, spanning from CAx technologies and methods for feature recognition to data interoperability issues. On the one hand, the authors stress the difficulty of developing shared conceptualizations and formal representations of feature knowledge, given that these tend to be application-dependent; on the other hand, they propose a general layout for feature definition that aims to be application independent (see Section 3.3).

2 Feature-based approaches in software engineering are behind the purposes of this work.