Towards Knowledge Driven Adaptive Product Representations

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Abstract. Highly integrated engineering models are developed for lifecycle of industrial products towards increased self-development capabilities. Adaptive model has the capability to change itself in accordance with changed circumstances and events. Knowledge content in product model gives this capability for the modification of affected model entities as a result of changed parameters in the modeled product objects or the environment of the modeled product. This capability of the model is based among others on the well proven feature principle. According to this principle, product model is developed in the course of a series modification feature definitions. Modification by a feature is propagated through contextual connection chains of parameters of the modifying and modified features. Considering the recent development history of product modeling, product object feature driven models have been developed towards knowledge feature driven models where product object representations are generated and modified by active knowledge features. At the same time, lifecycle models of products are more and more interdisciplinary where product objects from mechanical, electrical, electronic, computer and other areas of engineering are included in a single model and handled by the same mechanism of modeling. However, interdisciplinary product model needs representations on higher abstraction levels than product object features. This chapter introduces some works and results from recent research activities contributing to the above sketched development history. It starts with scenario of current product modeling and the self-development capability of product models. Following this, the concept of product model affect zone and method to organize context definitions are proposed. The main contribution in the chapter includes introduction of different concepts for the abstraction levels in product model as well as abstraction levels and the related knowledge representations in the proposed coordinated request driven product model (CRPM). Finally, possible integration of the CRPM method into PLM systems is discussed.

Keywords: Product lifecycle management (PLM), feature driven product model, adaptive product representations, abstraction levels in product model.

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1 Introduction

The history of computer application in product development started with urgent need for mathematically represented shapes in aircraft and rocket industries during the 50s of the past century. Starting from this point, a fantastic development started with computer assisted engineering in the past century and resulted computer centered engineering in the beginning of this century. The author of this chapter participated in this history and knows that it is not easy to understand results of advanced mathematics, physics, computational intelligence, object modeling, and other leading research results in the every day industrial engineering processes. Similarly to other high technology intensive areas of industry, advanced solutions are needed to establish quick and reliable product prototyping in virtual space replacing the restricted, time consuming, and expensive conventional methods of product development. Engineering oriented virtual spaces have the capabilities to accommodate and apply accumulated expertise and experience at companies.

Recent and future development of industrial product modeling is determined by four critical market demands. They are extensive info-communication during the entire lifecycle of product, representation of objects for different engineering areas in a single model, quick response of the model for changed situations and events, and representation of active corporate knowledge in product model. This chapter is organized around recent advanced product modeling theories, concepts, and methods to fulfill the above four demands. Because integration is one of the main issues in product modeling, own results in integration are discussed together with recent achievements in leading product lifecycle management (PLM) system development. Beyond classical problems and solutions in product modeling, higher level knowledge driven product definition and modeling on higher level of abstraction are emphasized. In close connection with abstraction and its knowledge background, application of soft computing methods and methods from systems engineering are also discussed in this chapter.

It is important to avoid the common mistake of considering the proposed methods as part of new methodology for a stand alone new modeling system. The currently representative product modeling is result of more than sixty years research and development work at the competitive edge in the world. It would be impossible to develop appropriate and enough precise experimental environment for our modeling methods. This is why we consider application of theoretically and methodically appropriate and enough high level modeling in a PLM system product for the experimental purpose. In this view, development of the proposed methods in order to prepare a laboratory for verification and application purpose needs only implementation. Open PLM architectures provide integrated means to define new object classes together with the required parameter, relationship, and procedure definitions. At the same time, recent PLM systems inherently provide features for the representation of wide range knowledge and other abstraction content.

2 Developing Product Representations

Understanding recent quick changes of concepts and methods in product representations is often made more difficult by a mistake that the current advanced PLM systems are the advanced versions of the computer aided (CAD/CAM/-CAE, etc.) systems from the past century. At the same time, it is inevitable that the currently representative PLM technology was developed on the basis of these pioneer engineering technologies. However, current PLM technology represents a new age of engineering and includes dozens of new concepts, principles, approaches, and methodologies. In the opinion of the author of [3], PLM is a new paradigm for product manufacturing industry which improves all product related activities at companies.

Research in product representations is concentrated on feature definitions, corporate knowledge representations, human-computer interactions, and application of methods from systems engineering. Lifecycle management of product data needs feature which can be applied at more or less downstream engineering activities [6]. In [6], extended life cycle definition of feature is proposed and defined. Application of soft computing in engineering design facilitates fuzzy logic, genetic algorithm, and artificial neural network representation capabilities for numerous hard-to-solve engineering tasks [9]. Methods from systems engineering help the development of abstraction in product model. In [12], application of the requirements, functions, logical connections, and physical representations (RFLP) structure is introduced for abstract product representation as baseline for systems engineering supported PLM. This enhances interaction and collaboration between disciplines in product engineering. It seems that application of system of systems engineering (SoSE) methods can not be avoided in PLM developments where independent systems are to be handled [17]. Authors of [10] emphasize importance of standards in systems engineering and SoSE and introduces activities about management of the related standards.

Long research work accumulated results achieved by the authors of the publications cited below during the past twenty years in order to produce a vast of preliminaries to the work which is introduced in this chapter. Paper [18] introduces a new method for the application of machine learning methods at manufacturing process planning in order to knowledge based integration of this group of engineering activities with other activities of product engineering. In [19], the above engineering activity group is analyzed for the efficiency of computer interactions at decision making and knowledge acquisition in engineering modeling. On the way to multilevel abstraction, an early work in [20] resulted multilevel modeling of manufacturing processes. For this purpose, application of Petri Net was considered together with advanced knowledge representation. Method is conceptualized in [21] for Petri Net generation for representation of manufacturing process model entities. Process of this modeling is outlined in [22]. Importance of human intent modeling is emphasized and methodology is introduced in [23] in order to realize intelligent modeling of manufacturing processes. The simultaneous modeling aspect is analyzed in [24] where manufacturing process is modeled in collaborative environment. Feature based integration of machining process model with part model is conceptualized and manufacturing process features are defined in [25]. Strengthened virtual engineering methodology motivates application of virtual technology for integration of associative representations around mechanical parts in [26]. As result of research for the application of the feature principle in model integration, a method is given in [27] for the generation of robot assembly paths using form features and considering product variants. In close connection with this work, shape and robot process model features are connected by relationships in [28]. Product model information structure is analyzed and discussed, and engineering modeling methods for problem solving are organized in the monograph [2]. In [29], change management is analyzed in industrial engineering model considering application of intelligent computing. Human intent and knowledge are analyzed in order to establish improved means for the management of changes at product modeling in [30]. Emerging PLM technology motivates a new approach to knowledge intensive PLM product modeling in [31]. An early research result in multi-level abstraction based product representation is introduced in [7] as a new method for information content driven product definition. Paper [16] introduces new processes in order to realize global level human interaction at knowledge based product definition. Earlier findings and definitions in application of knowledge technology at product definition are summarized in a chapter of the book [4]. Issues of systems engineering are mixed with issues in product model representation in [32] for better decision making in engineering systems. As a contribution to the new trend of request driven modeling in PLM systems requested behavior driven control of product definition with initial methodology is introduced in [11]. In paper [8], methodology is introduced for the situation driven control using active knowledge at the definition of product.

In order to establish a comprehensive conceptual basis for product modeling in this chapter, Fig. 1 introduces the current representative scenario. The result of product definition consists of contextually connected features. Features are included in an object model where object classes and taxonomy serve the information technology background. Methodology of feature definitions in object oriented environments was grounded by the product model standard ISO 10303. International efforts in order to establish product model standard by International Organization for Standardization (ISO) during eighties and nineties produced connectional and methodological basics of model construction resource based and feature driven object model which can be implemented by using of engineering area specific application protocols. The AP203 for configuration controlled 3D designs of mechanical parts and assemblies, the AP214 for automotive mechanical design, and the AP212 for electrotechnical design and installation were developed in close connection strengthening the integration of product modeling areas. Many researches aimed at handling advanced knowledge representations in ISO 10303 based models. Authors of [5] state that the above standard is focused on representation of product data. They propose a framework to integrated data and knowledge models assuring reuse of expertise in product modeling environments.

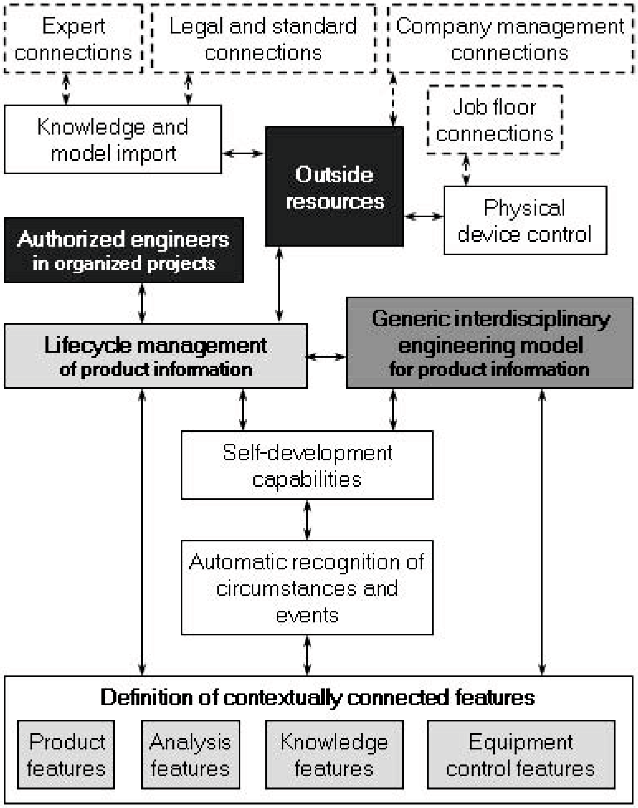

Fig. 1. Scenario of current product modeling

Product modeling processes use outside resources in less or more integration. Knowledge and model import comes from expert, legal, and standard connections. Company management connections communicate company strategies, decisions, and the related company information. Job floor connections are mainly related with physical device control.

Authorized engineers work in organized projects. Wide range of less or more integrated function sets serve group work of engineers who are in task and role specific contexts. Hundreds even thousands of engineers work on product ranges in organizations at companies and their subsidiaries. Various virtual company management methods are applied. Recently, integration of features from this area into product model is one of the main promising developments in engineering.

Engineering activities for a range or family of products are concentrated in lifecycle management of product information. For these activities, PLM systems provide development environments in order to facilitate third party and application developments. This is important because knowledge is available at the companies. Knowledge in the product model is property of companies and it is protected.

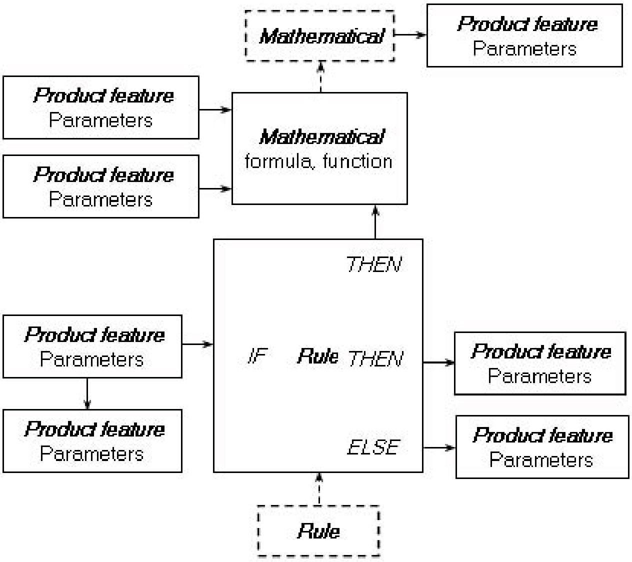

Fig. 2. Self-development capability

Generic interdisciplinary engineering model (Fig. 1) accommodates product information. Definition of product features from the viewport of the modeling system is important mainly at the beginning of a product development. It is gradually replaced by self-development capabilities of the product model. These capabilities take the control from humans and utilize active knowledge in product model. Knowledge is activated by automatic recognition of circumstances and events.

As it is explained above, contextually connected features are defined by human interaction or knowledge activation. Product features represent product units and elements together with their relationships. Analysis features describe analysis activities and results in order to representation of actual product behavior in the application environment. Equipment control features represents control programs and specific objects of production systems, equipment, and devices. Recently, production environment is considered as organic part of PLM systems providing physical end users. Knowledge features represent relationships and other knowledge items for the definition of the other three groups of features.

Self-development capabilities of the product model utilize knowledge at the definition of contextual parameter connections amongst product features. The example in Fig. 2 is a typical configuration in current product models. Parameters of a product feature are selected as conditions for a rule. At the same time, these parameters are in direct connection with some parameters of other product feature. Direct connection is defined where a feature or its parameters are applied at the definition of other feature. For example, a curve is a parameter of a surface shape of which is controlled by the curve. On the THEN branch of rule product feature parameters are defined and mathematical formula or function is connected to other mathematical entity which controls parameters of other product feature. On the ELSE branch, product parameters are defined. The above rule is controlled by other rule. This is the case, for example, when different situations require different rules.

3 Organizing Contextual Connections in Product Model

Increasing number of product features and associated unarranged contextual connections makes handling of model changes including definition of new product features more and more difficult. This is one of the problems in modeling for extensive product development products and motivates important researches. First problem is finding organized means for tracking change propagation. In [29], change affect zone (CAZ) was defined as entity to record connections of a product object in the product model. Recently, this method was evaluated and revised considering actually representative PLM models. The revised method is sketched in Fig. 3.

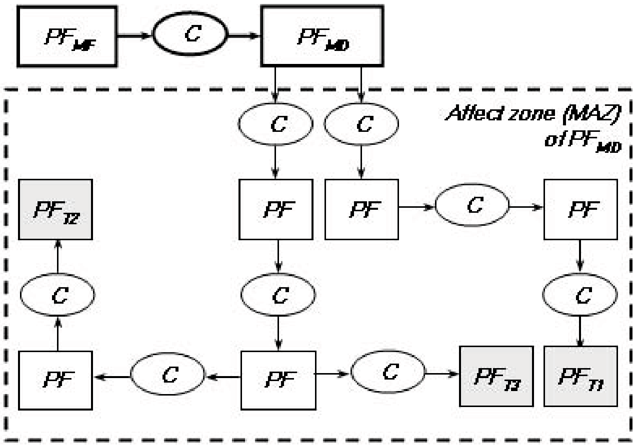

Fig. 3. Affect zone of a modification by feature

Fig. 3 shows an example for affect zone of product feature PF_{MD}. PF_{MD} modifies the product model detail of which is shown in Fig. 3. PF_{MD} is defined in the context of product feature PF_{MF}. C is for an arbitrary contextual connection. Modification by PF_{MD} is propagated along three branches of product features. The product features PF_{T1}, PF_{T2}, and PF_{T3} have special role. The propagation is terminated at these features. This as the modification affect zone (MAZ) referring to the application of mod-ification of model on the principle of contextual features.

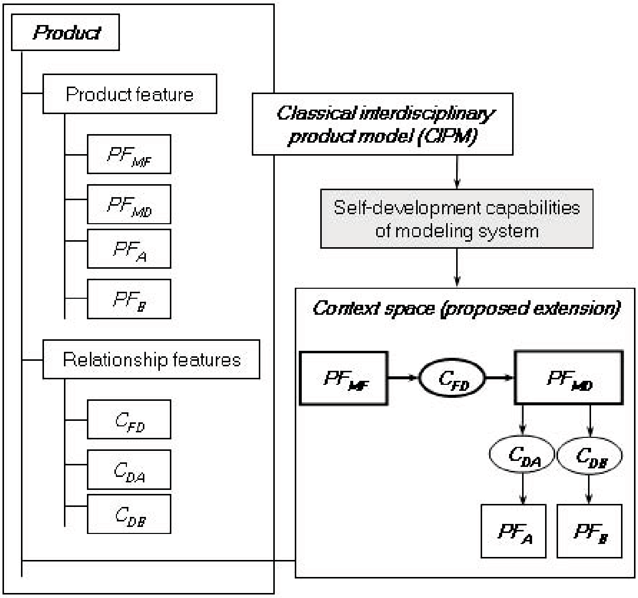

Fig. 4. Organizing context definitions

The next question is how organizing entities can be included in a product model as features. For this purpose, the classical product model (CPM) was defined in [7]. At the time of that publication, CPM was considered as a representative state-of-the-art product model which serves as starting point for the research in organized relationships within product model. By now, product models include features for the representation of active knowledge and abstraction levels. In order to develop the CPM idea, classical interdisciplinary feature driven product model (CIPM) was defined (Fig. 6).

The main principle of organizing context definitions is sketched in Fig. 4. Detail of a CIPM includes four product (PF) and three relationship (C) features. In a typical CIPM, these features are included in two groups. Position within the groups represents the place at which the model is modified by the actual feature. While this information in essential in a feature derive product model, it does not assist tracking of indirect modification affects. As a possible solution, Fig. 4 introduces the feature context space (CS) which is proposed to extend the CIPM. Really, CS is a map of contexts in which product features PF_{MF}, PF_{MD}, PF_A, and PF_B are connected by relationship features C_{FD}, C_{DA}, and C_{DB}. Relationship features act as contextual connections in the product model. CP is connected to the product model by using of self-development capabilities of the CIPM modeling system.

4 Abstraction Levels in Product Model

The need for more advanced decision assistance, the advances in integration of knowledge driven model definition, the increasing emphasis on handling of product behaviors and nonlinear problems, and the need for multidisciplinary product model motivate researches to establish abstraction levels in the product model.

As an early contribution to efforts in establishment of abstraction levels, a new concept and method was introduced to include content which is behind CPM object information in product model [7]. The main objective was to produce interactive knowledge transfer from humans to information based modeling procedures in order to better explanation and evaluation of engineering objects at decision making during product definition.

Information content facilitated new adaptive characteristics in product model [7]. Information content was placed in an abstraction structure which included five levels (Fig. 5). Intent of humans included knowledge to fulfill engineering objectives. Meaning of new concepts which were unknown for the modeling system was introduced on the second level. Engineering objectives were modeled by expected product behavior on the third level. A suitable extended definition of product behavior was published in [31]. The fourth level included contextual connections. Decisions on features as engineering objects were placed on the fifth level. It is obvious that all levels must be mapped to feature definitions in the CPM model. For this purpose, intent, behavior, and decision contextual spaces were defined. Spaces and their contextual connections were published in [16]. In the recent years, the most advanced PLM systems started to involve abstraction levels mainly for unified handling of abstract features in multidisciplinary product models. These systems apply integrated feature driven adaptive product model abstraction which is based on the RFLP [12] structure. RFLP structure is well known in systems engineering. Consequently, it can be stated that abstraction is a step towards enhanced application of systems engineering in PLM product definitions. The RFLP [12] structure consists of requirements against the product, functions to fulfill requirements, structure of logical components, and representations of real world product (Fig. 5). In other words, the abstraction is done on the requirement, function, logical, and physical levels. In Fig. 5, the dashed lines show logical connections of pairs of levels. The real connection is realized through the integrated product model.

Because the modeling methods which are proposed in this chapter are devoted to integrate in PLM environments, equivalence of levels in the two abstraction of the Fig. 5 is important. Equivalences are illustrated by dotted lines. Requirements for the RFLP structure can be produced by the levels of intent of humans and meaning of concepts. Engineering objectives are represented by behaviors considering product functions. Structure of logical connections are covered by appropriately defined contexts. Finally, decisions include information for product features so that this level can be connected to the physical level.

Development of the above introduced abstraction by using of five levels of information content was applied at the concept and method of coordinated request

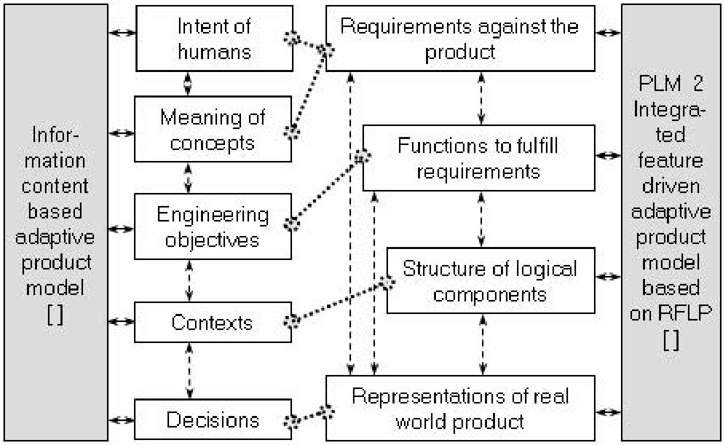

Fig. 5. Comparison of the information content based and the RFLP concepts

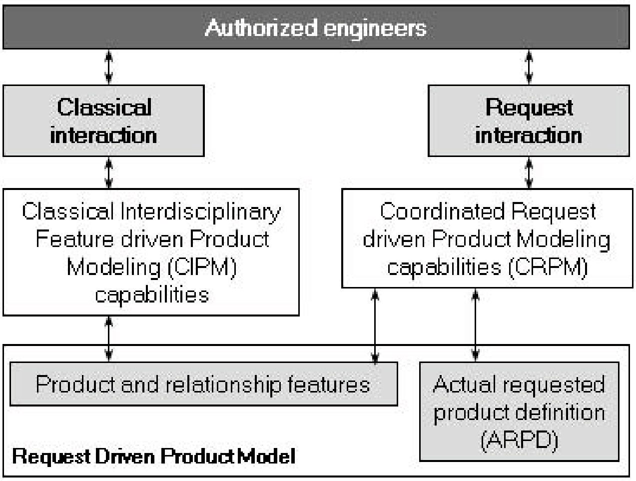

Fig. 6. Coordinated Request driven Product Modeling

driven product modeling (CRPM). Fig. 6 explains the cooperation of CIPM and CRPM. Authorized engineers must have the choice of classical and request interaction. CIPM capabilities generate product and relationship features on the basis of interacted feature definitions. Capabilities for CRPM are in communication with CIPM capabilities through product and relationship features. At he same time, they generate abstraction level features in the actual requested product definition (ARPD) extending the CIPM model to request driven product model.

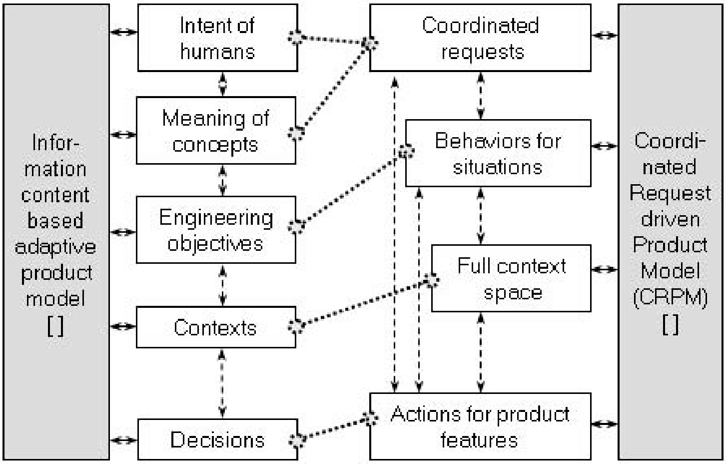

Fig. 7. Comparison of the information content based and the CRPM concepts

Establishment of the CIPM-CRPM connection requires extensive research in the future especially for the features through which the communication is done in case of various representative professional industrial PLM modeling methodologies.

The abstraction levels of the information content based adaptive product model had to be modified in order to integration with PLM product models. The modified sequence of levels is applied in the coordinated request driven product model (CRPM). Levels are shown in Fig. 7 in comparison with the original information content based levels. Equivalences are illustrated by dotted lines. Levels of intent of humans and meaning of concepts are merged in coordinated request. Engineering objectives are represented as behaviors for situations. Contexts are represented in full context space in order to facilitate any structure of logical connections to include. Finally, decisions are represented as actions for product features.

5 Coordinated Request Driven Product Modeling

Main capabilities of the modeling by using of the CRPM together with the main connections are introduced in Fig. 8. Request interaction drives request definition. The defined request features are generated and placed in the actual requested product definition (ARPD). At the same time, request interaction communicates with the request feature generation directly. Request interaction by authorized engineers can define features in the CIPM model. Regardless the level of abstraction and automation of product definition, the project leaders may allow this direct feature definition. Requests are coordinated. This coordination is supported by consequence analysis. Method of consequence analysis was published in [30]. Coordinated requests drive behavior feature generation.

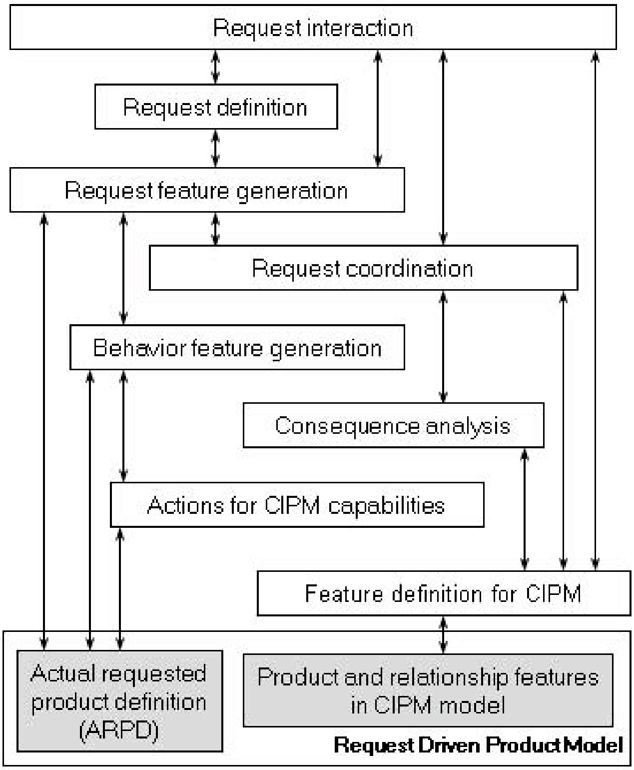

Fig. 8. Coordinated request driven product modeling (CRPM) capabilities

Behavior includes actions. These actions are configured to drive CIPM capabilities. Request coordination and consequence analysis also can communicate with the feature definition for CIPM directly.

PLM systems provide very flexible means of feature and contextual connection definitions. However, threshold knowledge can not be broken. Threshold knowledge is defined in [4] as the knowledge which inevitably applies to avoid definite deterioration in the quality of model or product.

Request consists of product function, specification, procedure, and configuration features. Product function is defined individually, in a set, or in product or product unit specific structure. Specification may be independent of function or function related. It may be defined in set or structure. Configuration is a pattern of product features. Procedure carries knowledge and process for the definition of function, specification, and configuration. Request definition utilizes the contextual feature drive principle. Request may be arbitrary incomplete. When a coordinated request is mapped in a behavior, it is completed by stored corporate knowledge and knowledge assisted human decision. At the same time, feature generations are done by knowledge in procedures.

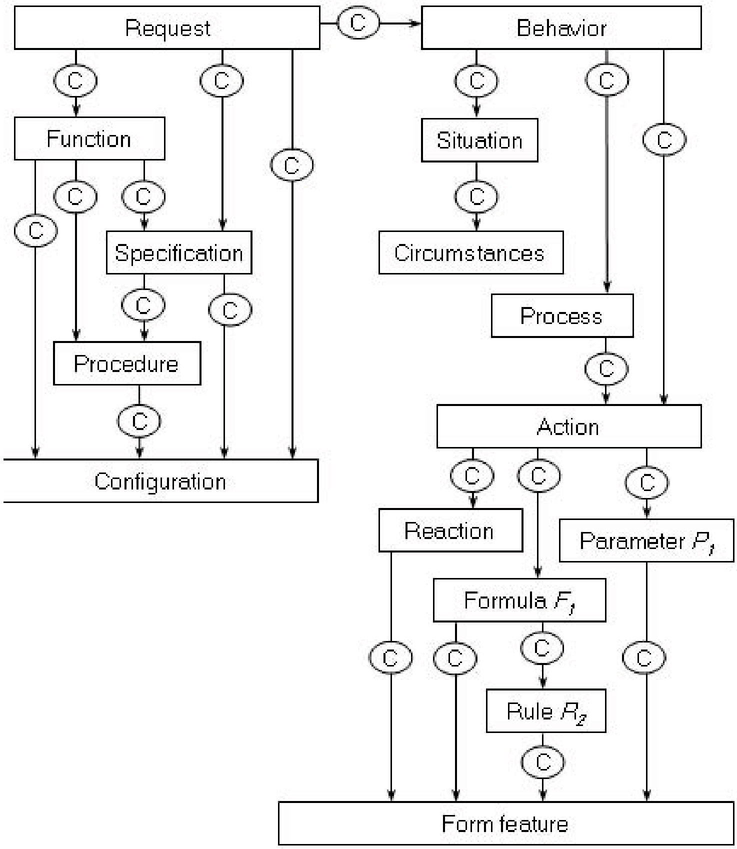

Fig. 9. Contextual connections in the request driven product model

Fig. 8 shows an inherently configured contextual structure of request driven product model features. Product function, specification, procedure, and configuration features are defined in the context of request. At the same time, these features also have contextual connection definitions. Behavior is defined in the context of request. Situation is defined in the context of behavior while circumstances are defined in the context of situation. Circumstances for a situation are mapped to features in the relevant request. However, this can be done only through the request-behavior contextual connection.

Fig. 9 shows the contextual connection between action feature in the CRPM and the knowledge carrier features in the CIPM. In the example in Fig. 9, a reaction, parameter P_1, and formula F_1, features are generated in the context of the definition carried by the action feature. Rule R_2 is generated in the context of formula F_1. The above knowledge features drive appropriate features in the CIPM.

6 Knowledge in the CRPM Model

As it was explained and discussed above, knowledge is defined by authorized engineers and communicated with the model generation environment in the course of request interaction (Fig. 10). At the decisions for product definition human applies stored engineering experience and add personal experience and expertise. In a simplified schema, human communicates with problem solution method. This method is strongly supported by corporate knowledge representations. Most of these representations can be included in the CIPM. However, definition of knowledge content requires research on its various levels. PLM systems are being increasingly prepared for this work. Virtual prototyping simulations are organized by planned experiments. Numerical methods are widely applied at shape representations, finite element analysis, etc. Rules, checks are applied at situation, while reactions are applied at event driven product feature definition as it is illustrated in Fig. 9. Main optimization algorithms are available in PLM systems and new algorithms can be defined in application environments.

Individual and mixed application of fuzzy logic, genetic algorithms, and neural networks is an important way towards more intelligent product models. Because their integration in CIPM model is presently at its initial stage, more attention is advised to devote their integration into CRPM model as method.

The success story of soft computing motivates its application in product definition where the problem solving often requires strengths and features of soft computing [1]. Tolerance for imprecision and uncertainty is often necessary in engineering problem solving. Consequently, fuzzy logic, neuro-computing, and probabilistic reasoning must be considered at definition of methods for CRPM modeling.

Problem solving processes often can utilize fuzzy rule base and the associated reasoning at product development. The most important processes are for decision support, expert knowledge processing, and definition of equipment and device control. However, known operators are often not able to follow the modeled phenomena. Authors of [13] propose generalization of conventional operators to include them in the sophisticated intelligent engineering systems.

Information aggregation well fits into numerous problem-solving processes in engineering where various types of information items must be handled [14]. In order to solve the problem caused by information types, authors of [14] propose an extension of fuzzy set membership functions for the reinterpretation information items in approximate formal setting using profiles. Consequently, appropriate profile aggregation is applied at modeling.

Authors of [15] concentrate on study of information aggregation in engineering related intelligent systems. Considering characteristics of problems in the engineering practice, they propose procedures to identify aggregation function in order to best fit to empirical data.

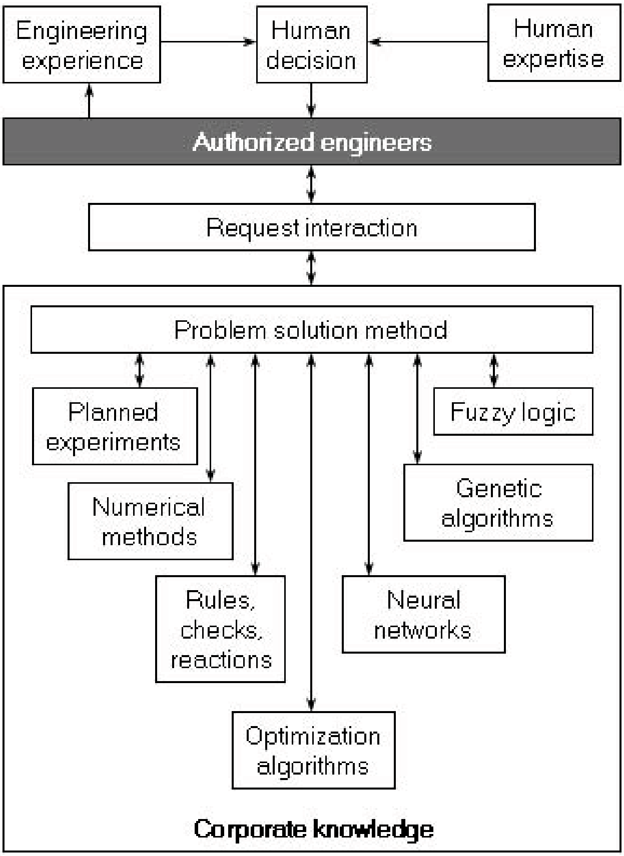

Fig. 10. Knowledge in the CRPM model

7 Integration CRPM into PLM System

In the above introduced request driven product model includes the proposed actual requested product definition (ARPD) in integration with the CIPM model (Fig. 11). CIPM represents the current PLM modeling technology. The ARPD includes request, behavior, and action features, while CIPM consists of product, analysis, knowledge, and equipment control features.

The main question is that how can the above integration be realized in an industrial PLM system. The generally applicable solution is seen in Fig. 11. Besides this solution, more engineer friendly means are being developed for direct extension by using of normal feature definition within a PLM system.

In case of the generally applicable solution of integration, request driven modeling procedures communicate through application programming interface (API) services of the PLM system. This means communication with product and rela-

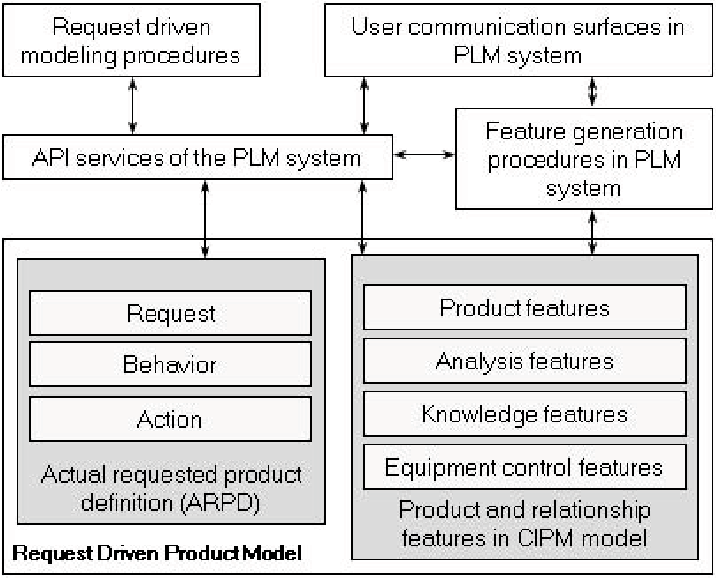

Fig. 11. Integration in PLM model

tionship features in CIPM model, ARPD features, as well as feature generation procedures and user communication surfaces in the actual PLM system.

8 Conclusions

Definition processes and means for representation of product information were undergone essential development during the past decade. This chapter introduces this development and emphasizes improvements in product definition capabilities of PLM systems. Former publications are cited in order to give a survey on the grounding of the recent results in knowledge supported modeling which are introduced in this chapter.

On the way towards smart self-development product model, adaptive capabilities must be strengthened. This work utilizes organized contextual connections of features, application of abstraction levels, and typical contextual connection chains in product model. The contributions in this chapter are aimed to solve these problems.

The classical interdisciplinary feature driven product model (CIPM) was defined in order to distinct it from the proposed coordinated request driven product model (CRPM). CIPM represents the currently representative product model and is extended by the CRPM. New abstraction levels are proposed in order to support this extension.

A former result for abstraction levels in product model was defined as content of product information. These levels are compared with RFLP structure which is well known in systems engineering and recently applied at PLM modeling practice. In order to facilitate connection of the CRPM based modeling to the modeling systems with RFLP structure, a modified set of abstraction levels is proposed as a revision of the abstraction by product information content.

The proposed CRPM modeling requires representative PLM system environment which is suitable for the integration with the CRPM extension. For this purpose, PLM research environment is under development. In this installation, a suitable PLM system will serve the work of the Laboratory of Intelligent Engineering System (LIES). Mission of this laboratory of the Institute of Applied Mathematics, John von Neumann Faculty of Informatics, Óbuda University is bridging theory, methodology, and industrial practice.

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