REQUIREMENTS ANALYSIS FOR MODEL-BASED SIMULATION PROCESSES

Reiner Anderl, Orkun Yaman

Technische Universität Darmstadt, Faculty of Mechanical and Process Engineering,
Department of Computer Integrated Design
Petersenstraße 30, 64287 Darmstadt, Germany

yaman@dik.tu-darmstadt.de (Orkun Yaman)

Abstract

The focus of the current lifecycle research is set on system effects across the full product realization. With the increasing complexity of engineering applications, they have developed into the focus of lifecycle research. Computer-based modeling and simulation have been established as a powerful alternative to the theoretical and experimental methods of engineering. The growing complexity and diffusion of computer aided engineering (CAE) processes motivate to optimize CAE workflows from a holistic point of view.
This contribution is based on the results of a survey, which has been conducted by the Department of Computer Integrated Design of TU-Darmstadt. The survey aimed at investigating the requirements for an integration of high performance computing (HPC) processes into the PLM-environment. HPC processes are intrinsically placed within the overall CAE. Hence, a major result of the survey pointed out the missing process management within the CAE workflows. Furthermore patterns of architectures have been observed despite of the diverging product and company types.
These two results gave clues about a unified approach following the contemporary lifecycle strategies. Based on these result, this contribution is considered with a requirement analysis of CAE processes and architectures. CAE processes show a multi-X characteristic regarding applied domains, methods, physics and scales. Requirements for a CAE reference architecture and CAE process model are investigated. Finally a proposal is made towards a unified concept, which regards the multi-X characteristics of the contemporary CAE research.

Keywords: PLM, Simulation Integration, Process/Data Integration, Process Model, Reference Architecture

Presenting Author's biography

Orkun Yaman. Graduated from the Middle East Technical University (METU) in Ankara with a degree of "Bachelor of Science in Mechanical Engineering", Orkun Yaman obtained his Masters Degree in Mechanical and Process Engineering from the Technische Universität Darmstadt in the field of Numerical Methods in Mechanical Engineering. He has been working since 2004 at the Department of Computer Integrated Design as a research assistant and doctoral student. He is responsible for the CAD/CAE education. His research activities involve data and process integration of computational methods and tools into the product creation process.

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1 Introduction

Current emphasis in lifecycle research adopts a perspective that combines information management and systems integration from a holistic business strategy point of view. The focus is directed towards system effects across the full product realization process. The growing complexity and diffusion of computer aided engineering (CAE) processes motivate engineering disciplines increasingly to follow data management strategies to globally optimize the CAE workflows throughout the product lifecycle. Against this background, the need for reference models and architectures aiming at an interdisciplinary integration of CAE arises. The holistic approach would bring more added value than the sum of individual benefits, which the participating disciplines of CAE would gain by methods and tools of lifecycle research.

Towards a holistic integration of CAE a study was conducted by the department of Computer Integrated Design (DiK) of the Mechanical Engineering Faculty of TU-Darmstadt to integrate High Performance Computing (HPC) workflows into a PLM-landscape [1]. Results concentrate on HPC processes and their relation with HPC architectures. They point out a need for reference process models and architectures for HPC, which are intrinsically tied to CAE.

This contribution is considered particularly with a detailed analysis of CAE processes and architectures. Requirements for a reference architecture and reference CAE processes are derived. Based on that, a proposal for a reference architecture and reference CAE process model is made. Finally the basic information sources of a unified information model of CAE are defined.

2 State of the Art in CAE Integration

Product life cycle management is a holistic strategy to control information and data flow by means of efficient and integrated business processes and applications along with the phases of product life cycle. The objective is to couple relevant information and data flows of the virtual company [1]. PLM defines here a management activity for companies' products across their life cycle. With the increasing use and complexity of the CAE workflows, CAE related data and processes have developed into the focus of lifecycle research.

The practice of CAE has been changed in the last decade drastically. CAE driven functional verification has experienced massive advancements. CAE applications diffused into the product development ever prevalently [2]. Reasons are manifold. Beyond the fact that time to verify a product virtually is generally of many orders of magnitude shorter while remaining far more cheaper, the methods and tools of CAE have become mature and user friendly [3]. As a result, methods are applied by a larger community of engineers throughout diverse engineering domains including cross-domain applications.

Parallel to the developments, described above, the quantity and complexity of data produced by CAE-applications have been increased considerably. Thus data related with CAE-applications has to be managed synchronously as with the product data [4]. The major challenge of today's CAE systems in product development is to close the interoperability gaps between diverging domains within the product development process. The special focus is being directed towards to the gap between analysis and design [5]. Numerous research activities have been initiated recently both by research institutes, companies and industrial consortiums [6] - [8], which may have slightly different focus but same objective of increasing integrity of computation data.

The lifecycle approach structures the engineering activities into so called lifecycle phases to leverage data and processes. Despite the ubiqutization of methods and tools of CAE within all lifecycle phases, a systematic approach to implement seamless information flows is not yet the state of the art [9]. Along the process chain in product development the main gap exists currently between analysis and design. This significant issue is on the one hand side based on missing process models for CAE. On the other side, the incompatibility of digital models sets barriers against effective sharing of model information [10]. Reference software architectures for CAE applications are missing. This fact hinders effective reuse and integration of applications and hence causes challenges in developing complex coupled simulation codes in industrial content [5].

The Department of Computer Integrated Design (DiK) has been involved in research activities focusing on domain integration since the end of nineties, [4] [11] [12]. The emphasis has been set on information modeling of cross-discipline artifacts, such as mechatronic product development as well as multi-representation architectures. Here, change management is stressed as a crucial problem, which requires knowledge and awareness of modeling approaches used as a basis for analysis, simulation and optimization. Within this context process modeling plays a key role to synchronize data flow throughout the CAE workflows.

Towards integrating the CAE workflows, a further study was conducted by the department of DiK. The focus was set on HPC processes in industrial content [13]. However, results enable further conclusions about the overall CAE processes as well as architectures in the participating companies. Consequently, a unified approach following the contemporary lifecycle strategies can be derived. The survey and the results are summarized in the following section.

3 CAE Processes in the Industrial Use

The survey "Integration of High Performance Computing in PLM" has been conducted from August to November 2006 to identify the requirements for integration of HPC-relevant data and processes concerning primarily German car manufacturers and service and component suppliers. Intensive efforts are currently invested on CAE-data management. However, an approach to systematic data management of HPC does not exist. The motivation of this study was principally to add this missing link and to develop a framework to implement HPC-data management into the existing PLM landscape. Requirements on key functionalities and interfaces have been defined as well as an architectural framework for a reference information model has been proposed.

The survey is considered as the preliminary study. The involvement in manifold domains for a divergent application spectrum as well as working on cross-site activities were two main criteria for the selection of the participating companies. A further comparison has been made by adding a governmental research institute with a focus on natural sciences.

For the survey a questionnaire has been constructed, which constitutes 4 parts covering the organization, CAE activities, CAE Data Management, and further open-end questions that highlight the bottle necks of the current processes. The survey has been conducted all with the division executives and/or department directors. CAE-strategies of the companies have been discussed rather than focusing into the detailed domain analysis. Main results are summarized in the following:

- CAE processes are aligned along the traditional organization structures of the companies.
- Organizations include inherently process flow schemes.
- Processes are driven by the service type of the companies as well. For example, car manufacturers have a product-driven approach, while CAE service suppliers have an order driven approach. This fact influences also the data and process management strategies in the companies.
- Despite the divergence in organizational structures and products, patterns are observed regarding the HPC workflows, which are organized within the overall CAE workflows.
- CAE workflows are organized in multi-disciplinary domains, which are rarely optimized.
- Planning the effort to design CAE workflows requires a multi-purpose feedback from individual domains and resources.

4 Objectives

Computer Aided Engineering CAE describes an interdisciplinary area integrating applied mathematics, computer sciences and engineering sciences. Domains from different disciplines[i] apply same methods with different scopes, for example FEA is used for structural problems as well as for magnetic field problems. Realistic simulations can be achieved by coupling methods of different physical domains, for exampled fluid-structure-interaction (FSI) may use coupled FEA and CFD. A method can be applied both on the assembly level and on the part level. Even smaller scales are investigated, for example to analyze molecular effects, cp. Fig. 1.

This multi-x characteristic of CAE (multi-domain, multi-disciplinary[ii], multi-scale, multi-physics etc.) leads to a huge number of different existing workflows, for which a reference process model is missing currently. The goal of this contribution is to define a requirements profile for a multi-x CAE process model that can serve as the *"CAE lifecycle enabler"* of a product.

Analysis, simulation and optimization methods applied in engineering are not a single computation process. In practice, variations with respect to boundary conditions, physical constraints or even shape are typically computed. This classifies CAE as a multi-criteria optimization application and often decisions are made on the basis of sub-optimal solutions that result from missing information input. Within lifecycle research using CE approaches it is also intended to capture decision making and to communicate decision backgrounds for automated reasoning.

Analysis methods are based on domain-specific representations, which cause frequent model transformations through the workflows. Even within a specific domain numerous and mostly proprietary representations have been developed for various purposes or specific platforms based on incompatible SW-architectures. Considering the complex information interdependence a core model and reference architecture are required to network the individual domain representations for a seamless information flow throughout the computational processes. The core model provides a basis for

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[i] The term "domain" is used here for computational fields, e.g. CFD, FEM, and Multi-Body Simulations (MBS). Disciplines refer to technical disciplines, e.g. Mechanical Engineering, Information Technologies, Electrics and Electronics, etc.

[ii] The terms interdisciplinary vs. multidisciplinary characteristics of CAE emphasize the active coordination and communication of processes. While an interdisciplinary process implies a close synthesis of disciplines and thus an integrative approach, multidisciplinary process means contribution from different disciplines, mainly subdivided into concurrent processes.

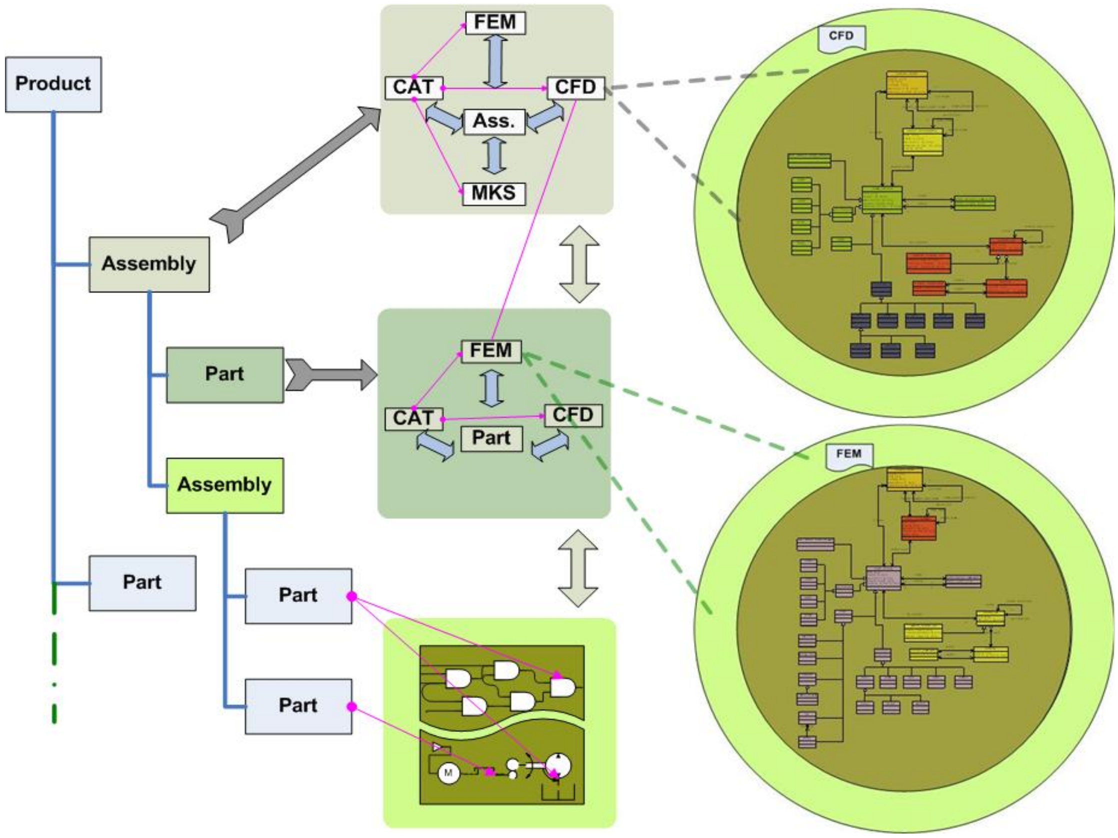

Fig. 1 Multi-x characteristics of CAE.

the common data of specific representations and defines interfaces for different domains, physics and disciplines. Consequently, coupling properties of disparate application programs and the reuse of codes are improved.

High level of detail representations to facilitate intelligent handling of design process enable conventions for multi-disciplinary modeling. Specific representations of different disciplines, which are compatible with the core model and its multi-representation architecture, will enable a common understanding of languages used by other disciplines.

To overcome the challenges emphasized by the survey and explained in detail above requirements for a CAE reference model and architecture are analyzed. ´The following chapter present the requirements for a reference-based approach.

5 Requirements Profile

The product development process is organized in well defined stages for domain specific products, such as mechanical engineering design [14]. Recently new approaches have been developed to cover also multidisciplinary product development, such as mechatronic product development, [15]. Regardless of the product type, the development process undergoes an iterative flow from functional design to detail design. The function structure defines rather functional dependencies on an abstract level, i.e. without considering the physical realization. The conceptual phase, however, gives clues about the physics and topology of components. The forthcoming CAE processes are mainly decided implicitly in the conceptual phase. A process model should pick up information already parallel to conceptual design and prepare corresponding information containers for the possible upcoming CAE processes. The flow of information among CAE processes can be designed accordingly. This would increase the reusability of data, decrease the redundancies in data exchange and increase the predictability of the CAE processes

Multi-x processes requires model transformations across domains and disciplines frequently. The incompatibility of CAE data structures, which are based mainly on proprietary representation formats, makes the exchange of data as well as information difficult. A core information model, based on the reference process scheme, should serve as the basis for information transformation across different phases and computational domains within the CAE lifecycle of a product. It contains both the information flow properties and the global view of the CAE processes.

In the development of complex products in interdisciplinary teams communication and collaboration are two important issues. From in-house teams to globally distributed collaborations of companies a platform is missing to coordinate the CAE processes to a specific product. The process model should provide a frame for the collaboration across distant sites and organizational units. Difficult iterations should be minimized and the overall task is tried to be as much decoupled as possible.

The process model of CAE should be adopted for discipline specific as well as discipline independent parts. A generic scheme provides the frame for the independent parts. For the dependent and interdependent parts a customizing approach is to be adopted based on scenario drive relations, [16]. The multi-x characteristics of CAE processes generates a vast amount of interdependencies among CAE processes. The interdependencies among CAE processes are to be clearly defined and should be portrayed in order to make the complex CAE workflows manageable.

A major difficulty stated by the CAE departments of companies, which have participated in the survey [13], was the problem of non-compatible hardware and software. Introduction of new software or hardware means for departments of information systems a challenging and time-consuming optimization and automation process. Based on reference architecture, the introduction phase would be a standardized workflow. Indeed, during the purchase the constraints can be taken into consideration. PDM/SDM and other relevant PLM-software can be linked to the new processes and data based on the standardized information flow model. Archiving and upwards compatibility of legacy data is supported by the reference architecture as well. Information flow in CAE defines a complex network of sources and sinks. The proposed architecture links the organizational form to the process representation allowing a manageable information flow scheme.

6 Conceptual Framework

Major requirements regarding a process and architecture model for CAE have been discussed in the previous section. Information flow among the nodes of a process network should be enabled for this concept. To this purpose a matrix approach is adopted and enhanced into further dimension to describe the multi-x characteristics as well.

In the literature several matrix approaches have been suggested to organize the information flow within the product development process [18], [19]. Eppinger et al. suggested the Design Structure Matrix (DSM) to capture the technical information flow by modeling the interdependencies among product development tasks, [20], [21]. This contribution applies the matrix representation approach to generically design CAE processes. It is aimed to structure CAE processes into a matrix to map information flow schemes. The 2D structure of the matrix is extended into further dimensions, for which each dimension illustrates the multi-X characteristics of CAE. Fig. 2 shows a 3D illustration of the concept.

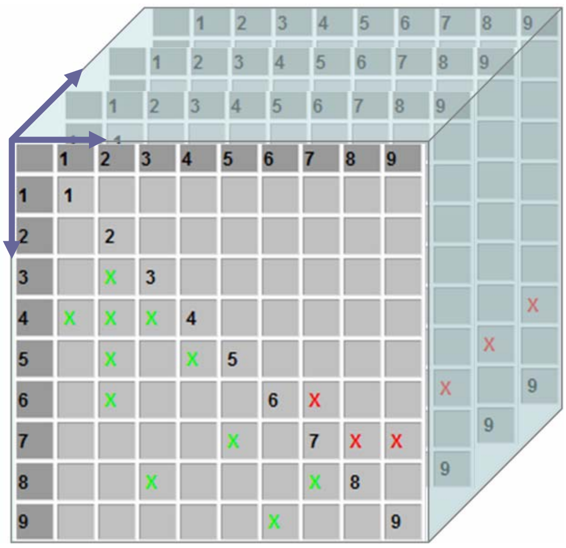

Fig. 2: Multi-dimensional dependencies using DSM

It is aimed that the CAE lifecycle of a product is designed and managed by using tasks connected by the CAE "meta-cube" of processes, cp. Fig. 4.

CAE is a network of activities, which are positioned in organizational units and executed using hardware and software. A complex sum of intellectual frameworks accompanies the overall process. All of these systems are described by architectures and need to use them. Intellectual frameworks are categorized according to [16], into organizational forms, data structures, knowledge representation and canonical architectures. For the purpose of reference CAE architecture, especially the intellectual frameworks are relevant. The proposed concept builds on these frameworks of architecture. Fig. 3 shows the dependencies in a low level of detail.

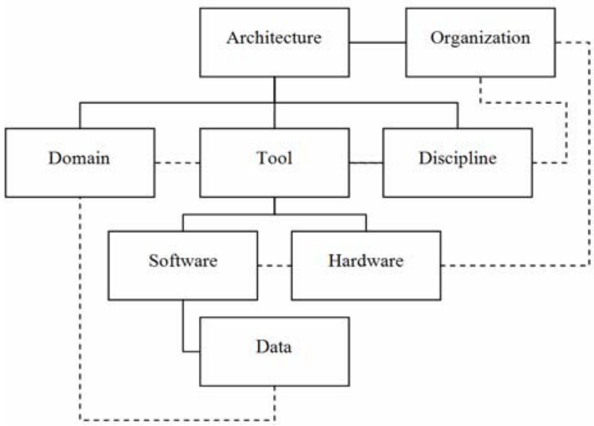

Fig. 3: Architectural relevance for CAE.

Information integrity of multi-x CAE processes are provided by a core information model. The core information model allocates information clusters defining the form, function and the behavior. These abstract classes are common to all kind of products. Fig. 5 illustrates a multidisciplinary information mapping among different disciplines. The common content for a pure multidisciplinary analysis can be

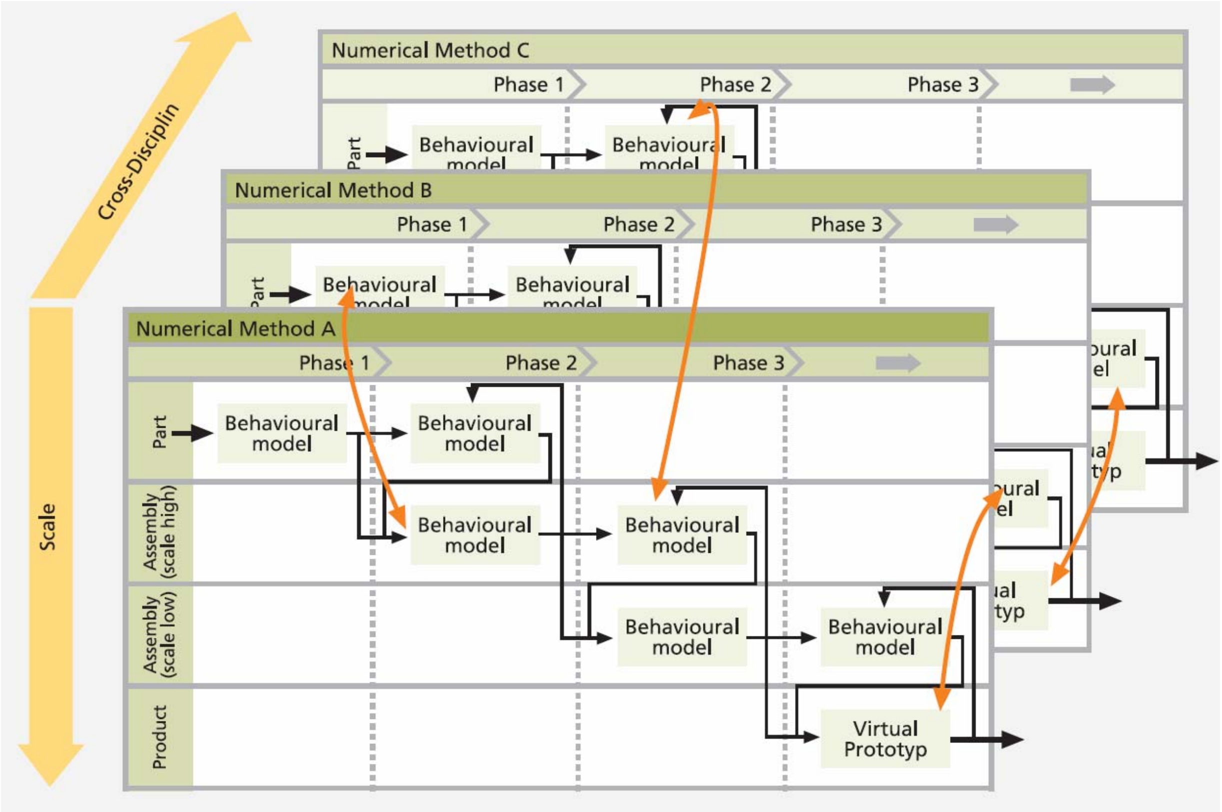

Fig. 4:CAE cube of processes.

behavior, function or form. This example is not domain dependent in that sense. A pure multi-domain integration, however, would analyze the behavior, where the function and the form are defined well. Similarly numerous other scenarios can be defined, which can include optimization loops, where e.g. the form would be variable.

The domain independent parts can be coupled on the basis of a common core model. For the domain dependent parts, scenarios are defined. They serve as process patterns for individual cases.

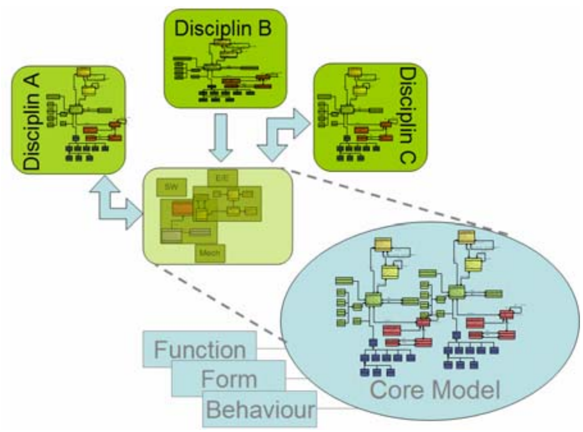

Fig. 5: Core model for CAE information mapping

7 Conclusion

The lifecycle approach has become an important issue of the product creation process in the last decade. As a result of the growing complexity and diffusion of CAE, engineering disciplines follow data management strategies to optimize the CAE workflows throughout the product lifecycle. Results of a study conducted by the Department of DiK to analyze the integration of HPC workflows revealed important conclusions concerning the CAE processes as well. The need for a multi-x CAE process management has emerged. The goal of this contribution is to define a requirements profile for a lifecycle approach concerning CAE processes.

Major points are the development of a strategy to represent the multi-dimensional dependencies; an architectural framework for different properties, which are involved in the CAE processes, such as organization, domain or discipline and ensuring the information integrity based on a core information model.

The Design Structure Matrix (DSM) approach is extended into the further dimensions to describe the multi-x CAE activities. It is aimed to externalize organizations' inherent process schemes and harmonized them with CAE workflows.

Next step is to build the solid concept based on the stated requirements and the framework presented. The capability of the concept is to be verified based on a complex, multi-disciplinary real life product.

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