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APPROACH FOR A MODULARIZATION DRIVEN SYSTEM DEFINITION USING MULTIPLE DOMAINS

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ABSTRACT
Modularization of products or product families is common and frequently applied when designing product architecture and interfaces. Modularization is driven by various targets to face both, industry and customer needs, or to handle product specific problems. Due to this, a methodical and consistent system definition is crucial to match the set targets of modularization. In this paper possible aims for product architecture are introduced and a Multiple-Domain Matrix (MDM) based approach is presented to integrate relevant views and information needed for a targeted modularization. The main issue focuses the system modeling via domains and their dependencies within a MDM in a continuous iterative process to match all defined goals. The approach has been successfully applied in an industrial design project which dealt with the modularization for product family design of injection molding machines.

Keywords: Multiple-Domain Matrix, system definition, indirect dependencies, modularization, clustering

1 INTRODUCTION

Modular design at different levels of product concretization and detailing is nowadays widely applied by the industry in order to reach scale effects, reduce production cost, and development time and over all to enhance transparency and manage complexity. Platform components can be achieved through modular design of products or product families standardization of modules and sub-systems as well as the identification of appropriate platform components. Thereby, modularization is the process of decomposing product architecture into modules. These modules, as stated by Gershenson et al. (2003), can be seen as units, which provide a unique basic function necessary for the product to operate as desired. Product architecture is defined by Ulrich (1995) as the arrangement of functional elements, the mapping from functional elements to physical components and the specification of the interfaces among interacting physical components.

This paper introduces a structured approach to tackle the task of product architecture modularization. This approach is based on the methodology of Structural Complexity Management, as introduced by Lindemann et al. (2009). In the context of structural complexity management the main contribution of this research is the support and enhancement of the accuracy of the system's definition step in order to reduce iterations in the procedure when dealing with a modularization problem. The modularization target has to be considered as it has significant influence on the following procedure and methodology as modularization can be driven by a large number of influencing parameters and accomplished from different perspectives. In this paper a short excerpt of possible modularization targets and perspectives is provided based on a Multiple-Domain Matrix (MDM) approach and combined with the subsequent step of system definition. After introducing the approach in the next chapter, the approach is demonstrated through an actual case study.

2 APPROACH

The proposed approach describes the application of a Multiple-Domain Matrix (MDM) to integrate different appropriate perspectives for modularization of the product structure according to the set goals and the specific situation. Figure 1 shows the procedure of the approach:

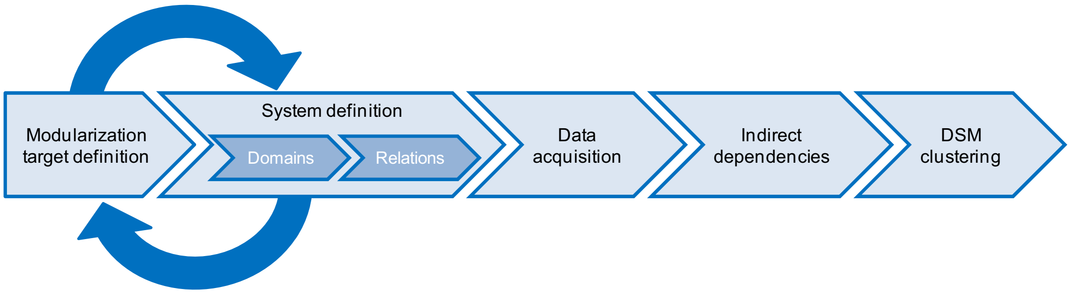

Figure 1. Procedure of the proposed target oriented modularization approach

Step one consists of defining the target concerning modularization and the according product architecture. This step has huge influence on the subsequent steps as the target outlines the modeling of the MDM. Targets concerning modularization strategies and purposes arise from the different internal (e.g. reusability) and external (e.g. market need) sources. All targets related to the product structure have to be considered previous and during the development phase even if the targets arise from later phases of the product life cycle.

Here, some possible modularization targets are presented:

- Manufacturing
- Maintenance
- Reusability
- Variant Management
- Process (development, manufacturing,…)
- Designed space
- Distribution
- Testability
- Assembly
- Functional replacement
- Organization
- Communication within the product

After the target has been defined, the MDM as a Meta-Model is built. The MDM defines the system boundaries and therefore the scope as well as the specific views on the system. The MDM must be modeled carefully and in an iterative way with a steady matching to the goals. All matrices (Design Structure Matrix, DSM; Domain Mapping Matrices, DMM) and their specific interpretation must fit to the problem to be solved.

To build the MDM, the domains are chosen first. The determination of the considered aspects is essential to meet the goals according to the specific situation. The definition of the domains must be done in a methodical way to consider only the relevant ones for obtaining the right framework for the exact views on the system. Aspects irrelevant to the question must be neglected as the modeling, analyses and interpretation of the system is getting unnecessary complicated (Lindemann et al., 2009). The level of detail of the domains and their containing elements must be considered in an appropriate manner.

Possible domains for a MDM are:

- Physical components (parts)
- Processes
- (Stakeholder) requirements (internal/external)
- Parameters/Attributes/Features
- Documents
- Functions
- Departments/Persons
- Boundary conditions
- Milestones

The next step is to define the relation between the domains that are suitable for the project goal. This task is very important for the problem to be solved as the views and the interpretation of the DSMs and DMMs are assessed in this step. A steady match to the targets of modularization must be performed.

The chosen domains are interconnected via relations to get DSMs and DMMs with a specific meaning within the MDM. The challenge consists of finding the relevant relations between the right domains to get a targeted content within the matrices. One question which always must be considered is how the defined matrix can contribute to the defined modularization target and what the interpretation is within this matrix. Hence, the information and interpretation of the MDM must be compared to the modularization target. To fulfill the set targets, the system definition has to be readjust in an iterative way.

In case of the component DSM, the answer to defining relations is rather simple. Different types of relations can be found between two components, such as spatial adjacency, energy transfer, information exchange, and materials exchange according to Pimmler and Eppinger (1994). Helmer et al. (2008) combine these relations to a combined one. Further possible relations between parts can be "change" or more detailed spatial relations (e.g. tolerances, congruent, contact, assembly space, relative movement, chain dimensioning, minimum/maximum distance, clearance, etc.).

The DMMs have a special impact on integrating relevant information concerning the modularization target in the target DSM because the target DSM (mostly the component DSM) can be calculated via indirect dependencies from DMMs (Lindemann et al., 2009). Further DSM information can be induced through the cross-linking of parts because they are indirectly connected via other domains. For example, a DMM which links parts to functions (e.g. part serves function), can be multiplied with the transformed DMM DMM^T resulting in a DSM of parts connected because they serve the same function. With this, a functional view can be integrated by applying modularization algorithms to this DSM for matching a functional modularization goal.

Moreover, other DSMs not containing parts can contribute to an indirect calculation of the target DSM. The formula for this purpose is defined as following: $DSM_{Target} = DMM^* \; DSM_2 \; {}^*DMM^T$ (Lindemann et al., 2009). For example, components are linked (in DSM_{Target}) because one component serves a requirement that is further connected to another requirement (in DSM_2) which is served by the other component.

Special attention has to be paid applying this method of indirect calculation because the meaning and the interpretation of the information in the target matrix must be kept in mind and matched to the previous set target. Only by doing that, meaningful additional information can be integrated in the DSM.

As already mentioned, the defined target(s) according to modularization must be compared to the interpretation of the MDM while identifying and assessing the domain and their relation. The effort in data acquisition can be decreased to a minimum for a targeted process.

After the definition of a targeted MDM, the data acquisition and calculation of indirect dependencies based on DMMs and other DSMs are performed. The modularization can be performed via graphs or via clustering within the target matrix. Therefore, different existing clustering algorithms – based for example on minimum description length, generic algorithms, or distance penalty function (Hartigan, 1975; Pimmler and Eppinger, 1994; Kusiak, 1999; Browning, 2001; Yu et al., 2003; Yu et al., 2007) – can be applied.

One the one hand, all existing views and interpretations in the target component DSM can be clustered. The most important one concerning the modularization aim can be used as reference and the other sights can be shown in the clustered matrix to see in what kind the minor targets are also matched.

On the other hand, all different views can be stored in the target component matrix by superponing. The superponement is achieved by adding up the different matrices in the target matrix. Deduced and direct dependencies as well as the different meanings of the different types of relations, the crosses in the target matrix can be colored. The different views can be threatened in an equal way or weighted according their contribution to the target. This matrix can be clustered with or without respect to the weighting of the views to get a modular product architecture.

In both cases, the feasibility of the resulting clusters respectively modules must be checked and ensured by experts.

3 CASE STUDY

In this section, the presented approach is applied to an industrial design project. This project dealt with the modularization for product family design of injection molding machines.

The superior target was the identification of modules across a product family of injection molding machines. The modules should be checked according their scalability to be integrated within the product family.

First, proper domains were collected, namely components (26 elements), functional requirements (32 elements) and parameters (61 elements). Then, the dependencies between the domains were defined according the target of scalable modules. The initial dependencies outlined following matrices:

- DSM Components: component is geometrically related to component
- DSM Functional Requirements: functional requirement is related to functional requirement
- DMM Parameters – Components: parameter is performed by component
- DMM Component – Functional requirement: component fulfills functional requirement

After defining the initial DMM, the interpretations of the non-target matrices were identified and their meanings for the integration in the target DSM as well as their contribution to the set goals were analyzed. Therefore, the DSM Functional Requirement was deleted because of no target contribution. Moreover, a further geometrical view was defined by a hydraulic relation between the components. This view is essential as a lot of components interact through hydraulic activities. According to the target of scalability, the DSM Parameters was integrated into the MDM to gain more detailed information about the parameter interaction. With this, the view of the connection of components due to the dependency to parameters can be added into the target DSM by indirect calculation. This sight is an important one concerning the scalability as the identified modules can be analyzed if they can still perform the required function when changing parameters that enable an up or down scalability of the acquired machine. The DMM Components – Parameters was also added to the MDM as different directions of the relations between these domains exist in the system. After this iteration, a MDM was at hand in which all information was available needed to match the set targets. The final MDM is shown in Figure 2.

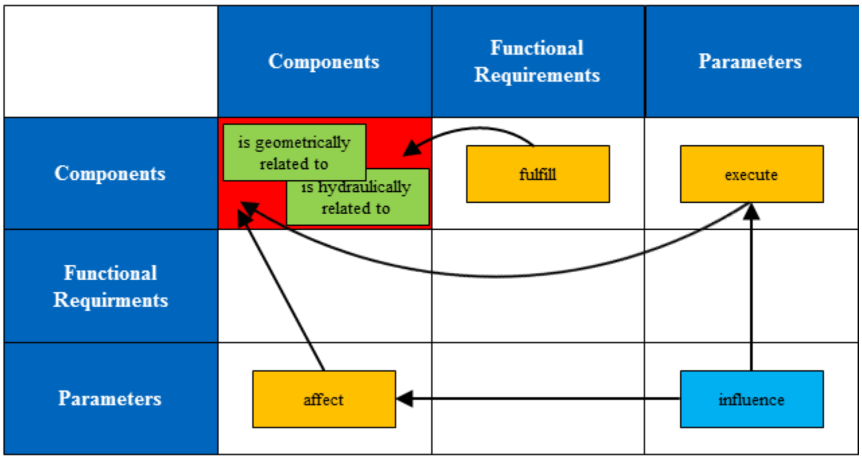

Figure 2. Meta-Model as MDM applied in the case study

The data for the presented matrices in the MDM were acquired according to the procedure of the Structural Complexity Management (Lindemann et al., 2009). Then additional views for the target DSM (red colored box in Figure 2) were calculated via indirect dependencies from the DMM Components – Functional Requirements, the DMM Parameters – Components, the DMM Components – Parameters as well as the DSM of Parameters. The way of the executed calculation is indicated by the arrows in Figure 2. The interpretations of the resulting views for the target DSM again were checked according their interpretation and contribution to the target achievement.

The contact, the hydraulic, as well as the indirect calculated parameter view were superponed in the target DSM for clustering. The different types of relations in the target DSM were not rated as no priority of a specific view was outlined. Figure 3 presents the result from clustering this DSM. The identified modules are framed. One interesting aspect in the clustered matrix is the element "COMP11" which serves as a platform element for a highly interconnected cluster (blue dashed frame in Figure 3). The block of elements (at the left bottom of the matrix) that links the red with the blue module are mostly hydraulic and parameter driven interfaces. These interfaces would not be recognized if only contact relations were considered. Superponing of different views – both direct acquired and indirect calculated ones – could improve the level of detail as well as the resulting information of the machine for a holistic and target-oriented modularization. Afterwards, the relevant parameters which must be adapted for an up or down scalability were selected and their connection to components were extracted. The influence of selected parameters on the identified modules via the connected components was analyzed. This analysis comprised if the modules can be scaled in the actual configuration or if they have to be changed to still fulfill the requirements. If they have to be changed, the components to be adapted and components connected to them were identified and the interfaces from the according modules were checked and outlined according geometrical and hydraulic aspects.

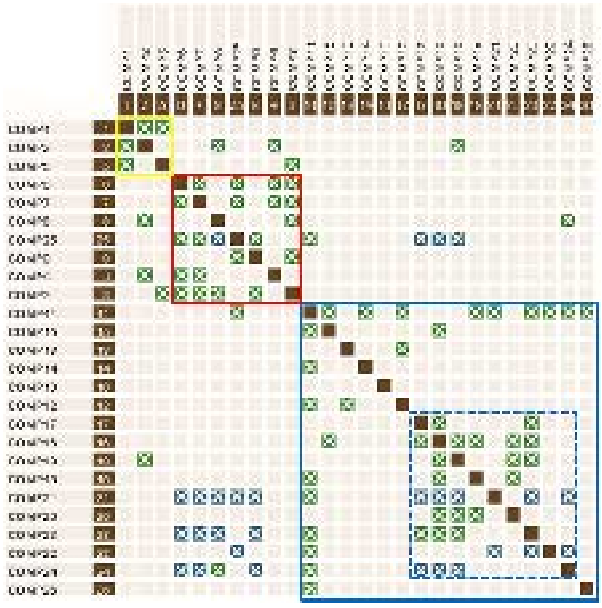

Figure 3. Clustered target DSM

3 DISCUSSION

As presented in the case study, the project aim of a modular product architecture among a product family with respect to scalability were matched applying the presented approach. The approach mostly supported the definition of the right and targeted DMM by an iterative way of steady comparison of the set target with the domains and their dependencies. Moreover, the constant examination of the interpretation of the contained MDM information led to the correct matrices regarding the target achievement.

Due to this systematic and iterative process the probability of acquiring wrong or unnecessary data were decreased. This resulted in less effort for data acquisition because not every possible matrix in the MDM was filled out in a time consuming procedure.

Furthermore, the approach and the case study confirmed that the main effort must be put into the system modeling to targeted increase the information content with respect to the modularization goals. More views can be implemented in the target DSM because of the use of DMM and their related indirect dependency calculation. Additional information in the target matrix supports and improves the modular system design from different points of view. Thus many different modularization targets can be achieved with a MDM based approach.

As modularization and the according architecture always are for the arrangement of physical components, the method offers information of multiple kinds of interfaces between and within physical modules because of the implemented views on the product.

4 CONCLUSION AND OUTLOOK

This paper introduced a methodology to integrate different relevant sights on a MDM-based system modeling to arrange a targeted product modularization. The main focus includes the modeling of the domains and their dependencies with in this MDM in a continuous iterative process to match all defined goals. Moreover, a way is presented to incorporate DMMs into the target DSM for different point of views on the specific situation via the deduction of indirect dependencies. A more detailed and targeted modularization can be executed via clustering in matrices or graphs.

The same approach is current applied in another project. The modularization target is to define modules that can be manufactured and assembled at different development sites. The modules have to be testable in a stand-alone environment before delivery. In this project, an appropriate MDM was set up to match these goals and the approach will be evaluated during this project.

Subsequent research to this approach will be done concerning the deduction of system models in a MDM-based manner to match various modularization targets (as presented above) in a generic way first. Afterwards, these models have to be evaluated in appropriate case studies.

Moreover, the development for a high-quality clustering algorithm should be performed. Requirements that arise from this paper are e.g. the appropriate clustering of a matrix with various types of dependencies whereat the possible weighting of the different matrices contained should be regarded. Thus, the manual effort in re-clustering clustered matrix could be decreased whereas the quality of the clustering result according to the goal achievement could be increased.

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INVEST ON VISUALIZATION

Approach for a Modularization Driven System Definition Using Multiple Domains

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INVEST ON VISUALIZATION

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- Target Oriented Modularization Approach
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  - System Definition
  - Deduction of Indirect Dependencies
  - Modularization of the Target Matrices
- Conclusion

Technische Universität München

Problem Description and Motivation

- Increasing and rapidly changing customer needs
- Increasing product range and external variety

➔ Increasing internal variety and complexity

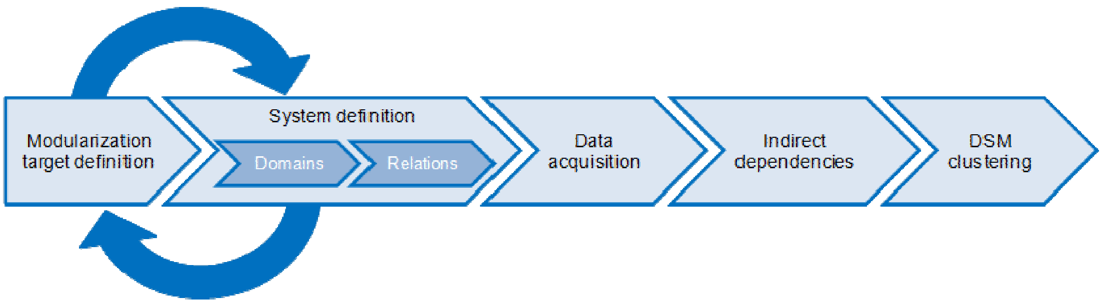
Modular design constitutes a strategy to manage and reduce internal complexity through standardization on several product concretization and aggregation levels

- Structural complexity management as methodology for modularization
- Modularization can be carried out from several different perspectives

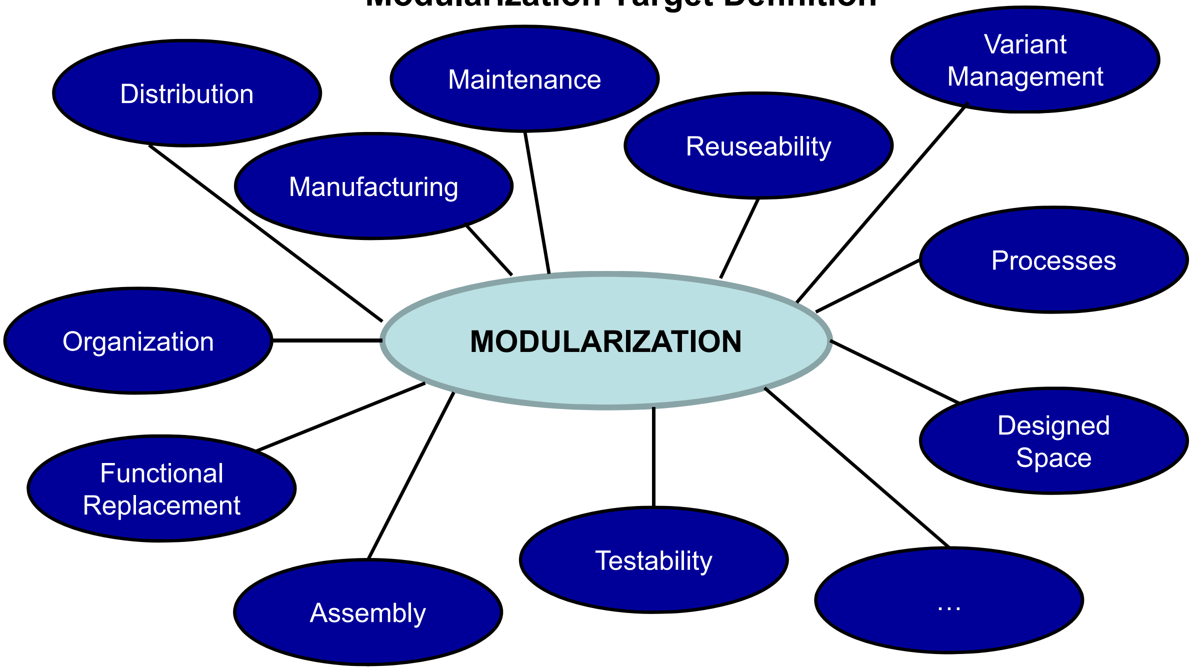
➔ Adequate goal definition and overview on modularization perspectives needed

➔ Deduction of a suitable analysis system according to the goal definition

Target Oriented Modularization Approach



Modularization Target Definition



Modularization Target of this Paper

Scalability across product families of injection moulding machines

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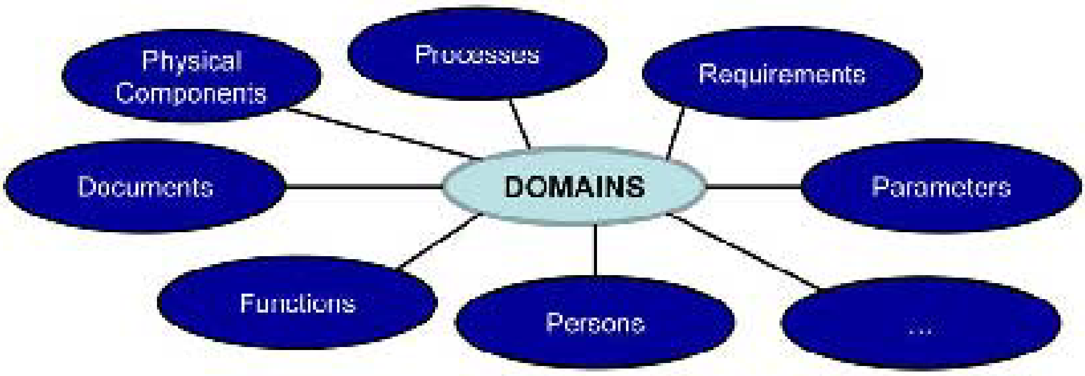
System Definition (I)

- System Definition based on the Multiple-Domain-Matrix (MDM), consisting of DSMs and DMMs

1. Define domains, e.g.:

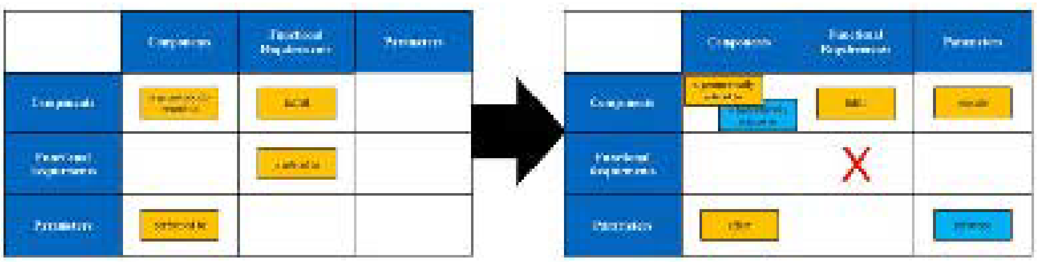


2. Define relations between domains

System Definition (II)

3. Check the specific meaning of every matrix within the MDM; consider the deduction of indirect dependencies via multiplication and their interpretation
4. Compare the informational content of the MDM with the defined modularization target
5. Repeat step 1-4 to readjust the system definition, if the informational content of the MDM does not fit to the set target

<u>Example of the iterative process of the system defintion:</u>



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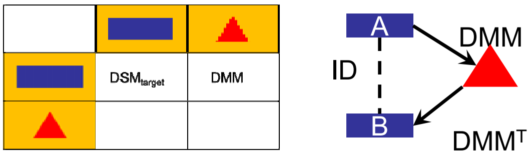
Deduction of Indirect Dependencies

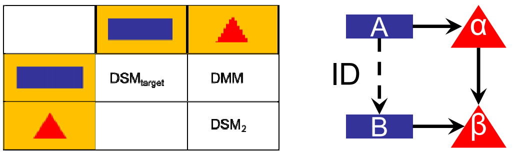
Applied ways of deduction of indirect dependencies and their interpretation:

- $DSM_{target} = DMM*DMM^T$



A is linked to B (indirekt: ID), because they are both connected to the same element of ▲

- $DSM_{target} = DMM*DSM_2*DMM^T$

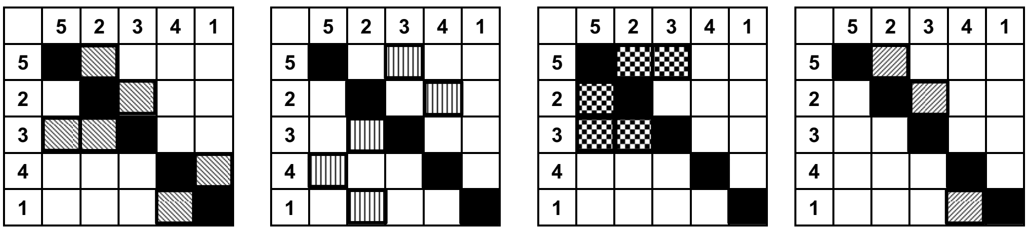


A links on B, because A is linked to α which links to β which is linked to B

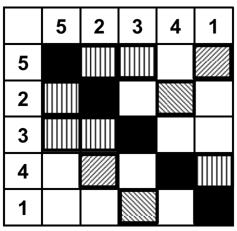
Further rules of the deduction of indirect dependencies, see Lindemann et al., 2009

Modularization of the Target Matrices Including Different Views

1. Cluster the target matrix according to the most important matrix view concerning the modularization target; arrage all other matrix views as the reference matrix (left matrix below):



2. Cluster the superponing of all target matrices:



direct dependency
indirect dependency
direct and indirect dependency
X number of superponed dependencies

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Conclusion

- Modularization of product architectures constitutes a strategy in order to enhance standardization, reduce development and manufacturing time, enhance quality and reach scale effects
- Major importance to define the target and the perspective of the modularization to be carried out
- According to the modularization target a suitable system definition can be deducted
- Through matrix operations and deduction of indirect dependencies target driven modularization can be applied

➡ Reduction of iterations during the procedure of structural complexity management

➡ Enhancement of the results quality

➡ Establishment of clarity for the modularization scope at the beginning of a structural optimization intention