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MODELING STRUCTURAL CHANGE OVER TIME – REQUIREMENTS AND FIRST METHODS

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1 INTRODUCTION

Products are the subject of a continuous optimization process in order to be adapted to the fast changing market conditions and customer requirements. Product development grows more and more complex to match the increasing market complexity. Even small, apparently unimportant product changes may lead to far reaching impacts on the product structure or product development process. These dynamic changes in product structure have to be modeled in order to allow for a thorough system analysis and deriving predictions concerning further changes.
Matrix based methods like the Design Structure Matrix (DSM) [1] or the Domain Mapping Matrix (DMM) [2] are often used to describe those structures. Both matrices have been combined to form the Multiple-Domain Matrix (MDM) [3]. The MDM enables the depiction of a system from different perspectives, i.e. domains.
A model of changes in DSMs can be obtained by using the ΔDSM [4]. This allows for the analysis of a system's alterations between two time steps. Currently no methods have been introduced to depict a system structure evolving over time.
This paper presents the requirements for a method to model structural change over time. Subsequently those will be used to assess the ΔDSM. Finally, a MDM approach combining the ΔDSM with an additional mapping matrix will be introduced and assessed.

2 REQUIREMENTS FOR MODELING STRUCTURAL CHANGE OVER TIME

There are two main classes of requirements for depicting structures evolving over time. Firstly there are some basic requirements. If they are fulfilled a method can be applied for time modeling. Secondly there are supplementary requirements. They allow for further analyses and reasoning about the evolving structure. Supplementary requirements mainly address the logic behind the changes.
The basic requirements are:
- Nodes can be created or removed.
- Edges can be created or removed.

The supplementary requirements comprise:
- Nodes can be split or merged. The new nodes are directly linked to the previous nodes.
- Edges which replace a single edge can be linked to this edge.
- A node and its adjacent edges, introduced to replace an edge, can be linked to this edge and vice versa.

The requirements described above will be used to evaluate the ΔDSM as well as the extended approach described in section 4.

3 VALIDATION EXAMPLE FOR THE REQUIREMENTS

Based on the requirements a test case was developed. It spans one instance of each requirement. The structure of the first time step comprises n nodes; the second structure comprises m nodes.
The node changes between the two depicted states are the removal and adding of one node, as well as the merging of two nodes and the splitting of one node.
Between the time steps several edges adjacent to one node are removed. Respectively several edges linked to a different node are added.
Additionally there are several combined changes. An edge is replaced by an indirect path between the linked nodes. Additionally an edge is replaced by a node and two edges maintaining the link between the original nodes.

This test serves to evaluate different methods for modeling structural changes over time. The minimum requirement is to model all the effects e.g. that node 2 and node 3 vanish and a node 23 appears. The optimum is to model the logic behind the changes e.g. that the node 23 comprises node 2 and node 3.

4 EXEMPLARY ASSESSMENT OF SEVERAL TIME MODELING APPROACHES

4.1 The ΔDSM

The ΔDSM depicts the deviation from one DSM to another (equation 1), which enables the analysis of differences between the matrices. Both matrices may describe the same system at different points in time. Thus the changes carried out in the meantime become clear.

$$DSM(new) = DSM(old) + \Delta DSM \quad (1)$$

The basic claim of modeling the difference between two time steps is fulfilled. Changes of nodes are only partly included, their merging or splitting cannot be shown. This information is conveyed in a semantic way. Furthermore the changes concerning edges cannot be considered in a ΔDSM.

		node 1	node 23	node 3	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
		1	2	3	4	5	6	7	8	9	10	11	12
node 1	1	-1		-1	-1								
node 23	2					1				1	1		
node 3	3			-1		-1				-1			
node 4a	4						-1						
node 5	5						1	-1					
node 6	6			-1				1					
node 7	7												
node 8	8									-1	1		1
node 9	9												
node 4b	10						1				1		
node 10	11				1				1			1	
node 11	12												1

Figure 1: ΔDSM of the test case

Finally, in order to include every possible case the system has to consist of all elements which might be of interest at an arbitrary time step. Consequently a unnecessary large matrix results, which aggravates further analysis steps.

4.2 ΔDSM extended by mapping DMM

In the following an approach augmenting the ΔDSM will be presented. A mapping matrix (MAP) is introduced, which maps the old system with the new system. It is used to model the changes of the nodes. It is possible to model the logic behind the changes. It can be seen from the matrix in which way nodes are added or deleted.
The ΔDSM serves to implement the changes in edges.

$$DSM(new) = MAP^T \cdot DSM(old) \cdot MAP - \Delta DSM \quad (2)$$

The mapping enables limiting the system size. The gained DSM contains only elements momentarily necessary; the main focus can remain on the current system state.
Within this approach not only the basic requirement of depicting changes between different time steps is fulfilled but also part of the supplementary requirement by the implementing the logic behind the node changes. It is possible to grasp implicit knowledge as well as semantic knowledge. Though the logic behind node changes can be modeled explicitly the approach cannot model the logic behind edge and combined node and edge changes.

a)

		node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
		2	4	5	6	7	8	9	10	11	12
node 1	1										
node 2	2	1									
node 3	3	1									
node 4	4		1						1		
node 5	5			1							
node 6	6				1						
node 7	7					1					
node 8	8						1				
node 9	9							1			

b)

		2	4	5	6	7	8	9	10	11	12
node 23	2										
node 4a	4				-1						
node 5	5				1	-1					
node 6	6					1					
node 7	7										
node 8	8							-1			1
node 9	9										
node 4b	10				1						
node 10	11		1				1				
node 11	12							1			

Figure 2. a) Mapping DMM of the test case, and b) the corresponding ΔDSM

5 CONCLUSION AND OUTLOOK

In this paper requirements for structural change over time were presented. These requirements can be applied to evaluate any method for modeling structural change. There are basic requirements which every method must fulfill. Further there are supplementary requirements which mainly comprise the logic behind the changes.

Then a test case based on these requirements was introduced and applied to two time modeling methods. Although both fulfilled the basic requirements, only the second approach can model the logic behind the node changes. The logic behind edge changes and combined node and edge changes cannot be depicted by both methods. To solve this problem is still an open task. The here presented requirements and test case allow for comparing any time modeling method. Gaps in the possibilities of new approaches can be identified and their potential can be assessed.

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Index

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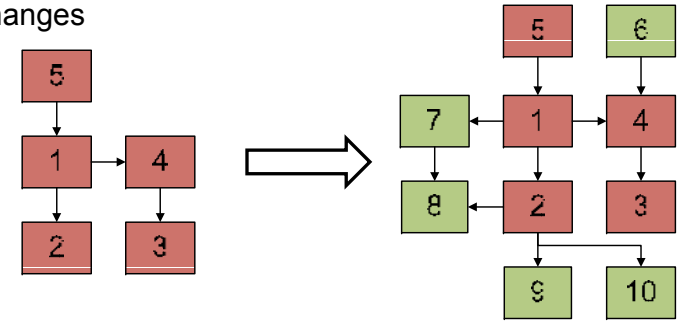
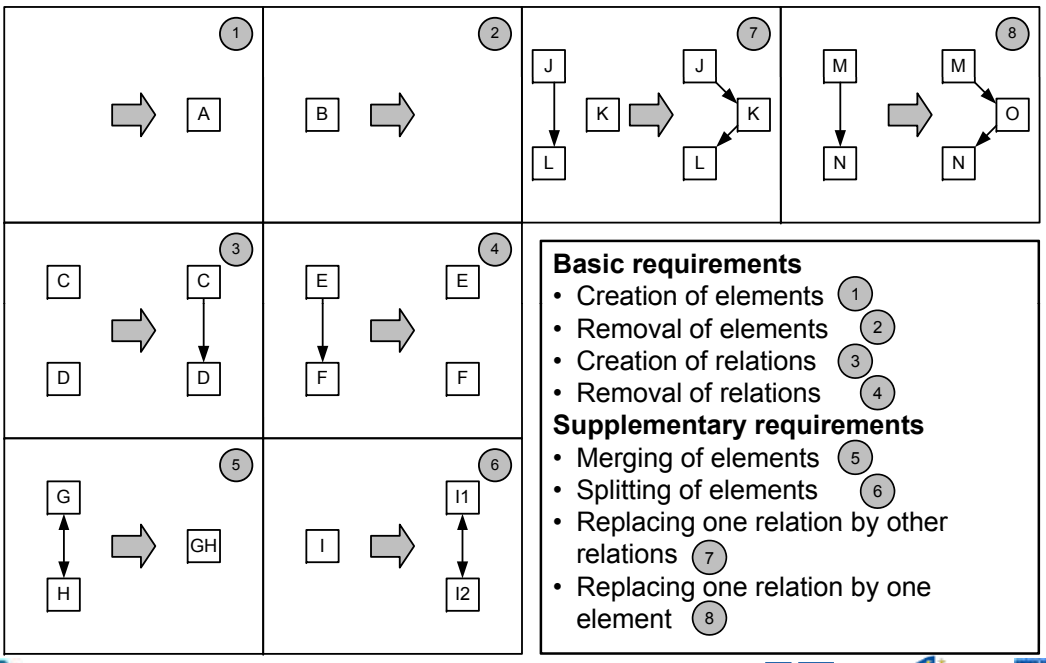
Motivation

- Increasing requirements on products
- Fast changing markets
- Product, process and organization changes
- Structural changes



→ Focus of the DSM methods on one particular point of time
→ Some methods for modeling differences between structures
→ So far no methods specifically designed for time modeling

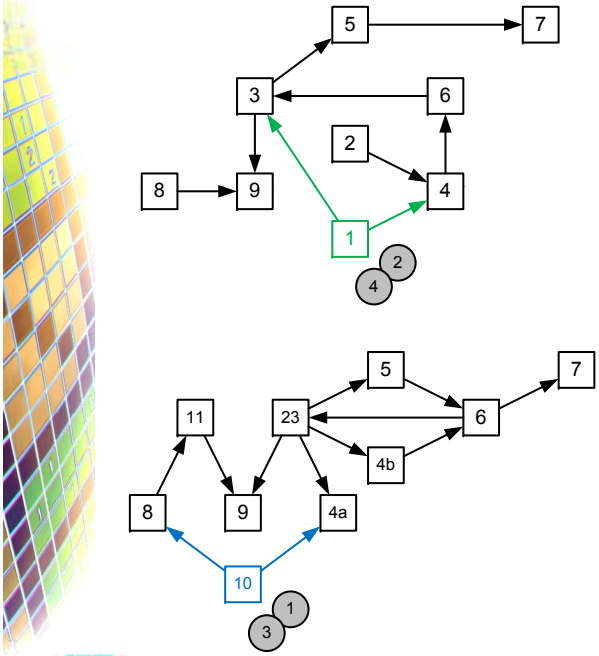
Requirements for modeling structural change over time



Basic requirements
- Creation of elements (1)
- Removal of elements (2)
- Creation of relations (3)
- Removal of relations (4)

Supplementary requirements
- Merging of elements (5)
- Splitting of elements (6)
- Replacing one relation by other relations (7)
- Replacing one relation by one element (8)

Validation example



- Removal of element 1 and its relations
- Creation of element 10 and its relations

Basic requirements
- Creation of elements 1
- Removal of elements 1
- Creation of relations 3
- Removal of relations 4

Supplementary requirements
- Merging of elements
- Splitting of elements
- Replacing one relation by other relations
- Replacing one relation by one element

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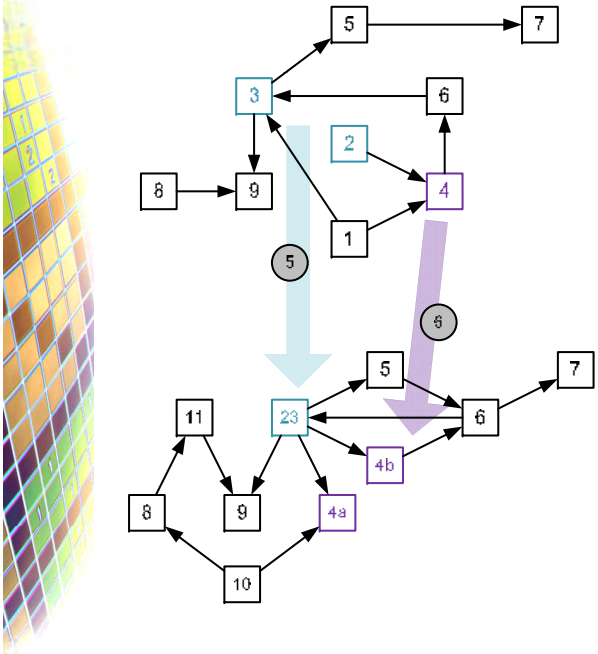
Validation example

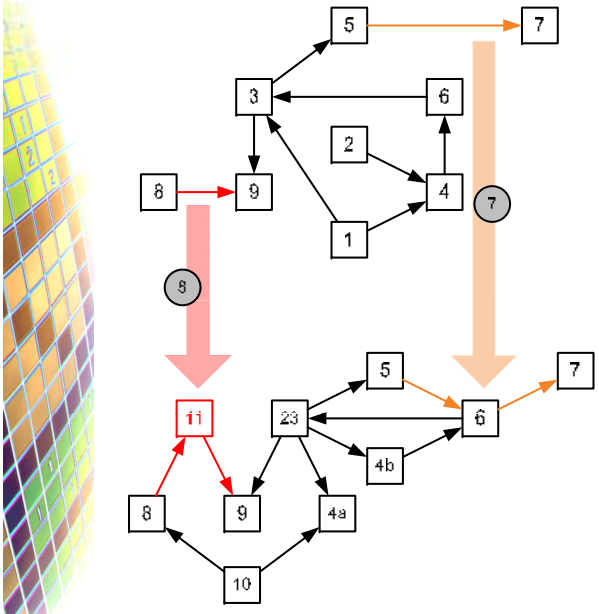


- Merging of element 2 and 3 into element 23
- Splitting of element 4 into elements 4a and 4b

Basic requirements
- Creation of elements
- Removal of elements
- Creation of relations
- Removal of relations

Supplementary requirements
- Merging of elements 5
- Splitting of elements 6
- Replacing one relation by other relations
- Replacing one relation by one element

Validation example



- Replacement of relation between elements 5 and 6 with the relations 5-6 and 6-7
- Replacement of relation between elements 8 and 9 with element 11

Basic requirements
- Creation of elements
- Removal of elements
- Creation of relations
- Removal of relations

Supplementary requirements
- Merging of elements
- Splitting of elements
- Replacing one relation by other relations (7)
- Replacing one relation by one element (8)

The ΔDSM and time modeling

ΔDSM=DSM(old) - DSM(new)

DSM(old)

	node 1	node 2	node 3	node 4	node 5	node 6	node 7	node 8	node 9			
node 1			1	1								
node 2				1								
node 3					1				1			
node 4						1						
node 5							1					
node 6			1									
node 7												
node 8									1			
node 9												

DSM(new)

	node 23		node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 23			1	1				1	1		
node 4a											
node 5					1						
node 6	1					1					
node 7											
node 8											1
node 9											
node 4b					1						
node 10			1				1				
node 11								1			

First time step

Second time step

ΔDSM

	node 1	node 23	node 3	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 1	-1		-1	-1								
node 23					+1				+1	+1		
node 3			-1		-1				-1			
node 4a						-1						
node 5						+1	-1					
node 6			-1				+1					
node 7												
node 8									-1	+1		+1
node 9												
node 4b						+1				+1		
node 10				+1				+1			+1	
node 11												+1

Removal of element 1

Removal of relation between element 6 and element 3

Creation of relation between element 23 and element 4b

Creation of element 10

Assessment of the ΔDSM

ΔDSM

	node 1	node 23	node 3	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 1	-1		-1	-1								
node 23					+1				+1	+1		
node 3			-1		-1				-1			
node 4a						-1						
node 5						+1	-1					
node 6			-1				+1					
node 7												
node 8									-1	+1		+1
node 9												
node 4b						+1				+1		
node 10				+1				+1			+1	
node 11												+1

ΔDSM=DSM(old) - DSM(new)

- ΔDSM must contain all elements of all time steps → Matrix is oversized
- Modeling beyond basic requirements based on semantics

Basic requirements
- Creation of elements ✓
- Removal of elements ✓
- Creation of relations ✓
- Removal of relations ✓

Supplementary requirements
- Merging of elements ✗
- Splitting of elements ✗
- Replacing one relation by other relations ✗
- Replacing one relation by one element ✗

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Extension of the ΔDSM by mapping matrices (1)

$$DSM(intermediate) = MAP^T \cdot DSM(old) \cdot MAP$$

Creation

DSM(old)

	node 1	node 2	node 3	node 4	node 5	node 6	node 7	node 8	node 9
node 1			1	1					
node 2				1					
node 3					1				1
node 4						1			
node 5							1		
node 6			1						
node 7									
node 8									1
node 9									

MAP

	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 1										
node 2	1									
node 3	1									
node 4		1						1		
node 5			1							
node 6				1						
node 7					1					
node 8						1				
node 9							1			

Removal
Split
Merge

MAP^T

	node 1	node 2	node 3	node 4	node 5	node 6	node 7	node 8	node 9
node 23		1	1						
node 4a				1					
node 5					1				
node 6						1			
node 7							1		
node 8								1	
node 9									1
node 4b				1					
node 10									
node 11									

DSM (intermediate)

	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 23		1	1				1	1		
node 4a				1						
node 5					1					
node 6	1									
node 7										
node 8							1			
node 9										
node 4b				1						
node 10										
node 11										

Extension of the ΔDSM by mapping matrices (2)

$$DSM(new) = DSM(intermediate) + \Delta DSM = MAP^T \cdot DSM(old) \cdot MAP + \Delta DSM$$

DSM (intermediate)

	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 23		1	1				1	1		
node 4a				1						
node 5					1					
node 6	1									
node 7										
node 8							1			
node 9										
node 4b				1						
node 10										
node 11										

DSM(new)

	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 23		1	1				1	1		
node 4a										
node 5				1						
node 6	1				1					
node 7										
node 8										1
node 9										
node 4b				1						
node 10		1				1				
node 11							1			

ΔDSM

	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 23										
node 4a				-1						
node 5				+1	-1					
node 6					+1					
node 7										
node 8							-1			+1
node 9										
node 4b										
node 10		+1				+1				
node 11							+1			

Relation between element 8 and element 9 removed

Relation between element 8 and element 11 created

Assessment of the extended ΔDSM

MAP

	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 1										
node 2	1									
node 3	1									
node 4		1						1		
node 5			1							
node 6				1						
node 7					1					
node 8						1				
node 9							1			

ΔDSM

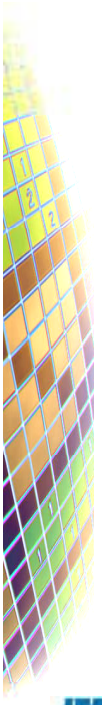
	node 23	node 4a	node 5	node 6	node 7	node 8	node 9	node 4b	node 10	node 11
node 23										
node 4a				-1						
node 5				+1	-1					
node 6					+1					
node 7										
node 8							-1			+1
node 9										
node 4b										
node 10		+1				+1				
node 11							+1			

$$DSM(new) = MAP^T \cdot DSM(old) \cdot MAP + \Delta DSM$$

Basic requirements
- Creation of elements ✓
- Removal of elements ✓
- Creation of relations ✓
- Removal of relations ✓

Supplementary requirements
- Merging of elements ✓
- Splitting of elements ✓
- Replacing one relation by other relations ✗
- Replacing one relation by one element ✗

Conclusion and Outlook



- Requirements for modeling structural change
  - 4 basic requirements → What are the changes?
  - 4 supplementary requirements → How are the changes?
- Validation example
  - At least one instance of each requirement
- Methods for change modeling
  - ΔDSM: only basic requirements fulfilled
  - Extended ΔDSM: basic and two supplementary requirements fulfilled
  - No method fulfilling all requirements

- Future work
  - Designing better modeling methods fulfilling all requirements
  - Studying structural evolution