The selection of modeling grammars

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Abstract: Information systems developers such as business process engineers use Conceptual Modeling to understand the information system's application domain and to derive such a system's requirements. For Conceptual Modeling an appropriate modeling grammar needs to be selected. Approaches have been identified to evaluate and select a modeling grammar. It is supposed that theory-based approaches contribute to a more effective selection of modeling grammars than non-theory-based approaches. However, only two approaches that are theory-based identified lead to a single modeling grammar: Cognitive Fit and Ontology. Using both approaches as complements results more effective to solve a specific (conceptual) modeling task than the individual approaches do. Therefore, we combine both approaches to a procedure that facilitates a theory-based approach to select a modeling grammar.

1 Introduction

The information system's (IS) purpose to manage information about its application domain can only be fulfilled if such a system appropriately reflects this information ([JMSV92]). IS developers use Conceptual Modeling to represent this information by composing the modeling grammar's constructs to a conceptual model ([WW02]). Depending on which type of information they intend to represent, IS developers solve a specific modeling task. To solve this task, a conceptual modeling grammar needs to be selected. However, a variety of grammars has emerged ([AF06]; [MKK02]). Some of these grammars, such as Business Process Modeling Language (BPML), claim to be advantageous to model processes. Other modeling grammars, such as the Unified Modeling Language (UML) do not specialize but propose to be advantageous to model every phenomenon of an application domain ([ES07]). [SR98] have identified in [RB96] seven approaches to evaluate and select a modeling grammar: *Feature Comparison, Metamodeling, Metrics, Contingency Identification, Paradigmatic Analyses, Ontology* and *Cognitive Fit.*

Each of the seven approaches contributes to the selection of a modeling grammar, but also reveals certain disadvantages. For Feature Comparison metrics have to be developed and applied. Both activities are very subjective ([RB96]). Metamodeling allows a less subjective evaluation of modeling grammars, but is limited to a pair wise comparison of a modeling grammar's constructs ([RB96]). Paradigmatic Analysis enables IS developers to reduce the number of applicable modeling grammars, but not to select a single one. To apply metrics or heuristics of Contingency Identification much empirical work is needed ([RB96]). Selecting a modeling grammar with Ontology is characterized by two gaps. Firstly, evaluations of modeling grammars with Ontology do not base on the same ontological constructs. Selecting a modeling grammar requires to compare these evaluations. However, if evaluations are not based on the same ontological constructs, they can't be compared ([GE07]). Secondly, IS development and consequently conceptual modeling are activities to solve problems ([VG98]). Therefore, the selection of a modeling grammar needs to be based on a modeling problem. The problem, however, is not yet considered in prior research of Ontology. Cognitive Fit allows combining the selection of a modeling grammar with the problem the modeling grammar is intended to solve. Cognitive Fit, though, lacks empirical evaluations of modeling grammars that can be used to select a modeling grammar.

Prior research supposes that theory-based approaches contribute to a more effective selection of modeling grammars than non-theory-based approaches ([Wa95]). Paradigmatic Analyses, Ontology and Cognitive Fit are theory-based. Yet, Paradigmatic Analysis does not allow selecting a single modeling grammar. Therefore, we base our procedure on Ontology and Cognitive Fit, using both approaches as complements to facilitate a more effective solution of a specific conceptual modeling task than the individual approaches do.

This study contributes to theory and practice. To theory, this study relates two different fields of research to facilitate a theory-based selection of a single modeling grammar. To practice the approach contributes a mechanism to select a modeling grammar to solve a specific modeling task, whose application does not require practitioners to be confident with Ontology or Cognitive Fit. Once this framework is established, practitioners just need to consider their modeling task to be given a hierarchy of modeling grammars.

This paper is organized as follows. We first introduce the theoretical background of the framework. The second section, will give an overview about Cognitive Fit and Ontology. In the third section, we explain the framework in detail and derive tasks to operationalize the approach. The results of an exemplary operationalization are presented in section four. Section five summarises the research contributions.

2 Theory

Our approach bases on the theory of Cognitive Fit and is operationalized through Ontology. We first explain how to apply Cognitive Fit to Conceptual Modeling and will continue how to use Ontology to operationalize the approach.

2.1 Cognitive Fit

System development is a problem solving activity ([VG98]). These activities are researched in Cognitive Psychology. [NS72] have developed a theory, in which humans are considered to be information-processing systems. Yet, people's information-processing capacity is limited. Therefore people seek to reduce the effort that is necessary to solve a problem. One way to reduce this effort is to simplify the problem-solving process. This process is simplified if the problem corresponds to the task that is intended to be solved, a state that Vessey calls Cognitive Fit. Within the problem-solving process the problem solver develops a mental representation of a possible problem solution. This representation is then transformed into a real problem solution. As shown within the basic model of figure 1 the degree of how information of the problem representation and of the problem-solving task corresponds, determines how efficient the problem solver can develop a mental representation, and thus can solve the problem ([VG98]).

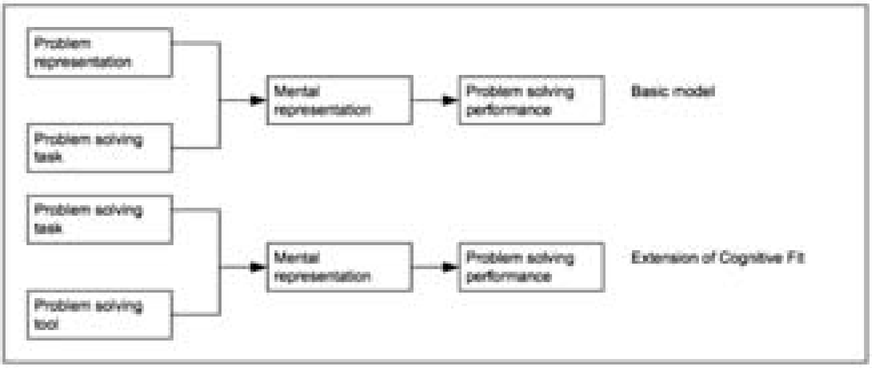

Figure 1: Basis model and extension of Cognitive Fit

[AS96] have extended the basic model for the problem-solving tool. The effort to solve a task is reduced if a Cognitive Fit occurs between the task and the method used to solve the task. We apply the extension of [AS96] to Conceptual Modeling. Correspondingly, the problem-solving task is specified to a modeling task and the problem-solving tool to a conceptual modeling grammar as shown in figure 2.

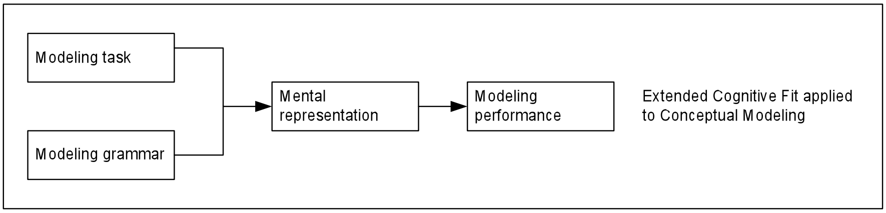

Figure 2: Extended Cognitive Fit applied to Conceptual Modeling

We use the extension of the Cognitive Fit of [AS96] applied to Conceptual Modeling as a theoretical basis for the framework. The framework will be operationalized through Ontology.

2.2 Ontology

Like conceptual modeling grammars, Ontology provides constructs and rules to describe real world phenomena ([MKK02]). Yet, Ontology and conceptual modeling grammars differ in intensity of prior research. Scientists have studied Ontology since Aristotle's time while research on Conceptual Modeling is comparably young. Prior research has used experience of Ontology for Conceptual Modeling by relating grammatical to ontological constructs. We use the evaluations of modeling grammars with the ontology of Bunge for our framework. This ontology is selected because a wide range of conceptual modeling grammars has already been evaluated with this ontology ([DGR04]) while other ontologies such as the ontology of Chisholm are only used to derive rules for Conceptual Modeling but not to evaluate its grammars.

According to the ontology of BUNGE, the world is made of Things. Things exist individually or in Composition. Things possess Properties. While intrinsic Properties characterize one Thing, mutual Properties characterize a Composition. Things and Properties are the bases to derive further static and dynamic constructs ([Wa95]). Static constructs such as Kind and Class can be defined by mutual Properties. While Classes are defined by one mutual Property, Kinds need at least two Mutual Properties. Dynamic constructs are, for example, State, Event and Interaction. The State is determined by the values of all Properties. The change of a Property of a Thing, and thus the change of a State, is called Event. An Event is ruled by Laws, which are specialized Properties of a Thing. Presented constructs of the ontology of BUNGE are summarized in a metamodel by ([GRIR06]).

[WW02] identified interfaces between the ontology of Bunge and Conceptual Modeling. Their achievements are now referenced with the Bunge-Wand-Weber model (hereafter BWW model). The BWW model consists of three models: The State Tracking-, the Representation-, and the Good Decomposition Model (GDM). In more than 25 studies the BWW model is used to evaluate and to improve modeling grammars ([RRI06]). However, most of these studies have focused on the Representation Model and so far only little attention has been paid to the GDM and the State Tracking Model ([GP07]). Due to the strong focus on the Representation Model this study is limited to this model, too. This model relates ontological to grammatical constructs through ontological analysis.

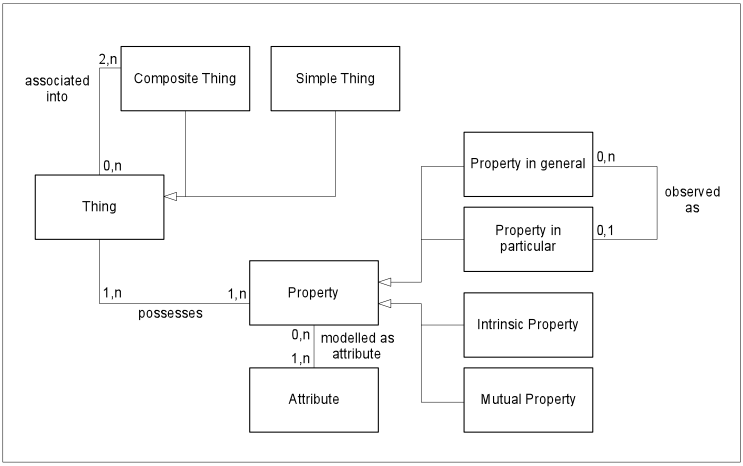

Figure 3: Extract from the Bunge-Metamodel (vgl. [GRIR06])

Ontological analysis focuses on revealing ontological deficits of conceptual modeling grammars. Four ontological deficits can be found ([We97]):

1. Ontological Incompleteness exists if at least one ontological construct does not have a grammatical equivalent.
2. Construct Redundancy exists if at least two grammatical constructs have one or more mutual ontological equivalents.
3. Construct Overload exists if at least one grammatical construct has more than one ontological equivalent.
4. Construct Excess exists if at least one grammatical construct does not have an ontological equivalent.

If ontological incompleteness is identified, the modeling grammar does not have sufficient constructs to model every possible phenomenon of an domain. If constructs of a modeling grammar are overloaded, redundant or do not have an ontological equivalent, the grammar's ability to create comprehensive models is affected. In this case, the modeling grammar is not ontologically clear ([GRIR06]). We use eight ontological analyses to operationalize our framework. Of these analyses, one focuses on the Architecture of integrated Information Systems (ARIS) ([GR00]) three on the Entity Relationship Diagram (ERD) ([We97]; [WSW99]; [Sh03]), one on the Open Modeling Language (OML) ([OH01]) and three on the Unified Modeling Language (UML) ([WSW99]; [IT05]; [OH02]).

3 Framework

Our framework bases on the theory of Cognitive Fit and is operationalized through Ontology. For its operationalization required grammatical constructs to solve the modeling task (operationalized from the modeling objective) and those provided by the modeling grammars are mapped on BWW constructs. Mapping provided and required constructs on BWW constructs allows determining their intersection. Constructs of the intersection will be assessed according to two criteria:

1. Maximum number of provided and needed constructs within the intersection.
2. Maximum degree of ontological clarity of the constructs within the intersection.

The modeling grammar that best fulfills both criteria is most likely to allow modeling relevant real world phenomena in a comprehensive way. Figure 4 provides an overview of the framework and derives three tasks to its development.

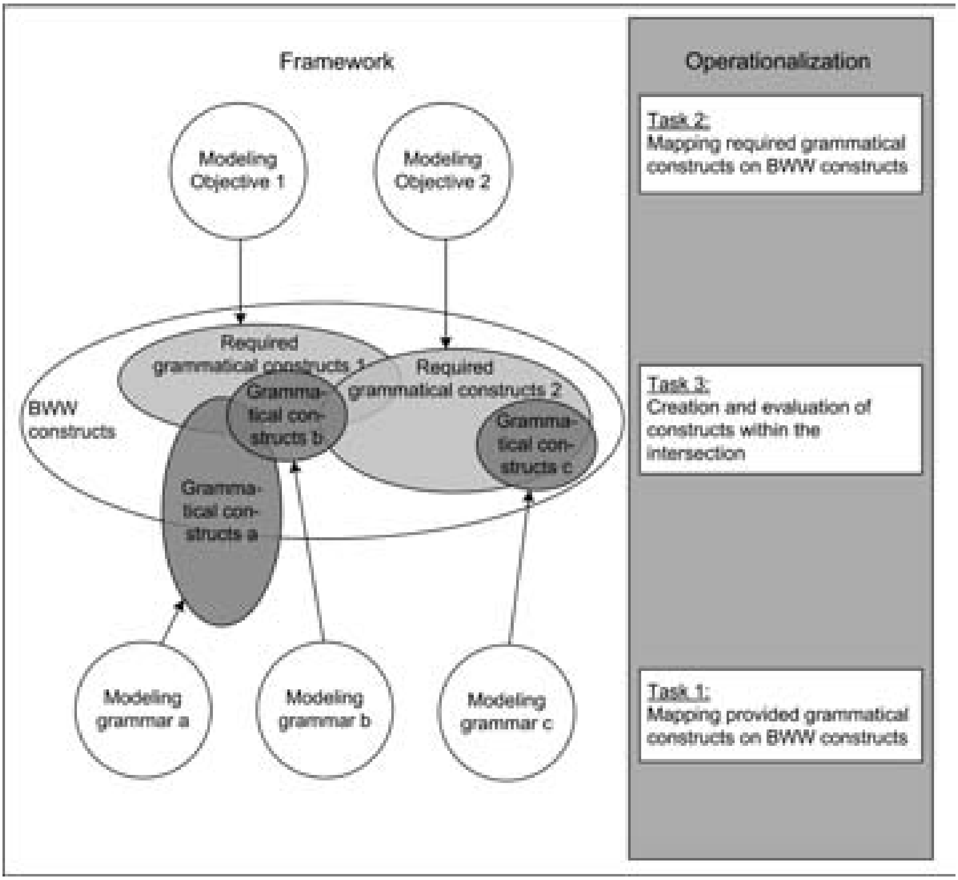

Figure 4: Framework and derivation of tasks to create the framework

Firstly, provided and required grammatical constructs are mapped on BWW constructs. Therefore, ontological analyses will be used, as they already provide relations between grammatical and ontological constructs. For that reason, this study is limited to modeling grammars presented in section 2. Secondly, required constructs to solve a modeling goal are extracted. Thereto, modeling tasks will be researched within a content analysis using the framework of ([Kr04]). The sample is limited to the IS-world magazines, since latest research primarily used this medium to publish research results. Having researched modeling tasks, these tasks will be accumulated to a more comprehensive framework of tasks. As not every modeling task might be relevant, their practice relevance will be assessed. Therefore, the classification of reference models by ([FL03]) is used. Reference models accelerate conceptual modeling by serving as a pattern to create specific models ([RA07]). Correspondingly, a modeling task is relevant if this task is performed as many times, that the creation of a reference model is useful. After limiting modeling tasks to relevant modeling tasks, reference models classified by [FL03] are used to derive grammatical constructs necessary to solve the modeling task. These constructs are then mapped on BWW constructs. Thirdly, the intersection of provided and required ontological constructs is created. The intersection of these constructs indicates to which degree modeling grammars offer constructs to solve the modeling tasks. These constructs will be assessed towards ontological clarity. The degree to which modeling constructs are available and ontologically clear indicates how appropriate a modeling grammar is for a task. Since the appropriateness of several modeling grammars is assessed a hierarchy will be established. For the subsequent exemplification of the framework for modeling grammars are used. These grammars include Elements of the ARIS-Framework [Sch94], ERD [Ch76], UML [RJB04] and OML [FHG98] and are selected as they are considered in available ontological analyses that serve as a basis for this exemplary operationalisation.

4 Results of exemplary operationalisation

Solving the first task relations between grammatical and ontological evaluations are extracted from ontological analyses. To solve the second task a content analysis was conducted. The content analysis reveals three different frameworks of modeling tasks. [JMSV92] distinguish four worlds of modeling task: Subject-, System-, Usage- and Development world modeling. Subject world modeling describes the information the IS maintains. How this information is implemented is described with System world modeling. The IS is implemented in the system's environment. This environment, such as agents, activities, and users is described in Usage world modeling. [JMSV92] do not only focus on the IS system and its environment but also on how it is developed. Therefore, they use Development World modeling.

[Ly87] distinguishes three main categories: IS-, IS environment- and IS context modeling. IS modeling describes the structure and behavior of an IS. As the second main category, IS environment modeling describes the interaction of an IS with its environment. IS environment modeling includes modeling IS architecture, information need from the organizational point of view, success factors of the IS project, Sociotecnical issues and an evaluation. Lyytinnen's third category, IS context modeling focuses on contingencies and their impact on the IS development strategy. [AAGS06] distinguish static and dynamic information modeling. Static information modeling describes structural information such as concepts, properties and constraints. They call this modeling declarative information modeling. Dynamic information modeling describes behavior. It includes strategic and tactical information modeling. While strategic information modeling describes problem-solving activities such as what is to do, and in what order, tactical information modeling focuses on describing how and when to include declarative information. To apply the modeling tasks of [JMSV92], [Ly87] and [AAGS06] to the framework, the modeling tasks are first aggregated and subsequently assessed regarding their relevance in practice. Relevance in practice of modeling tasks is indicated though the number of reference models allocated to the tasks.

Table 1: Modeling Task and allocation of reference models to these tasks

Modeling task [JMSV92]	Modeling task [Ly87] and [AAGS06]	Explanation	Reference Modeling Literature (author, pages)
Subject World Modeling	Static Information Modeling	Describing the structural information such as concepts, properties and constraints	[Me00], 31 [Sche94], 91, 163 [Jo92], 131, 209 [Lo97], 106 [GDV08], 7, 49, 52, 69
	Dynamic information modeling	Describing the behavior that takes place in the domain such as functionality, processes, inferences, calculations and action sequences	[BS96], 150 [Re97], 143, 183, 189 [Me00], 88, 129 [Jo92], 69, 131 [GDV08], 11, 12, 13, 45
System World Modeling	IS-Architecture Modeling	Describing the overall architecture for an organization by identifying major applications	
	Formalistic IS Modeling	Describing the static structure and IS dynamics. Static structure is expressing in terms of entities, properties, and relation-ships. IS dynamics is expressed as triggers and event that change the data	[BS96], 127, 192 [Me00], 20 [Sche94], 150 [Lo92], 121 [Ku99], 204 [Schw99], 193 [Lo97], 116 [We93], 102
	Functional IS Modeling	Describing IS in terms of connected activities that process, transform, store, access, and modify data. Functional IS models are therefore process orientated and originate from the design of the systems for processing	[BS96], 164 [Sche94], 160 [KT98], 300-302 [Schw99], 195

		documents presented in files of records	[Lo97], 112
Usage World Modeling	Socio-technical Modeling	Describing the work organization by incorporating features of the IS, user, and organizational environments	
Develop-ment World Modeling	Success Factor Modeling	Describing organizational characteristics such as computer experience to predict IS implementation risk	
	Evaluation Modeling	Describing technical and cost-efficiency criteria	
	Contingency Modeling	Describing contingencies and impact on the IS development strategy	
	Strategical Information Modeling	Describing problem-solving activities such as what to do, when, and in what order	[Sche94], 609
	Tactical Information Modeling	Describing how and when to include the new declarative information about the problem	[Sche94], 683, 684

According to table 1 only four modeling task result as practice relevant: Static Information Modeling, Dynamic Information Modeling, Formalistic IS Modeling, and Functional IS Modeling. Of these modeling tasks constructs are extracted from the reference models allocated to the modeling tasks as seen in table 2. Therefore, grammatical constructs were first extracted and then translated to ontological constructs with the help of already established relations between grammatical and ontological constructs in existing ontological analyses. Figures in Table 2 stand for the number of reference models that include a certain BWW-Construct.

Table 2: Allocation of ontological constructs to modeling tasks

BWW Constructs	Static Information Modeling	Dynamic Information Modeling	Formalistic IS Modeling	Functional IS Modeling	Strategic Information Modeling	Tactical Information Modeling
Binding Mutual Property			4			
Class	6	1	6	1	1	
Coupling	2		6		1	
Event		4	1	4		

External Event	1	5	1	4		1
Internal Event		4	1	4		
Intrinsic Property	3		6		1	
Intrinsic State Law	2	1	1			
Kind	9	5	7	1		
Lawful State Space	1		4			
Level Structure	2	4		1		1
Mutual Property	3	2	6			
Natural Kind/Subkind Rel.		2	1			
Non-binding Mutual Property	2	2	1			
Process	2	10	1	5		1
Property	5	7	3	5		2
Property in General	3	2	5	1		
Stable State	1	5	1	4		1
State		4	1	4		1
State Law	3	2	8	4		1
Subkind			1			
Subsystem	2	3				1
System						1
System Environment		1				
Thing	3	4	5			2
Transformation	2	8	2	5		1
Well-defined Event		4	1	4		
Whole-Part Relationship	3		1			

Having extracted required and provided constructs the intersection of these constructs will be determined and evaluated. Therefore a scoring model is used with scores ranging from 0-5. If the required ontological construct has an ontologically clear equivalent within the grammar the correspondent grammatical construct is given a 0. Score 1 is given if the required ontological construct is characterized by construct overload or redundancy. If both, construct overload and redundancy occur, the correspondent construct is given a 2. Since the model is more affected if there is no grammatical equivalent for a required ontological construct, the modeling grammar is given a 5 in that case. Some ontological constructs are more important to solve a modeling task than others. That way, to solve a Static Information Modeling task it is more important that a modeling grammar has a grammatical equivalent for classes than for Lawful State Spaces or State Spaces. To solve this problem the points given to a certain construct is weighted by the number of how many time the construct was needed in the reference models.

Table 3: Scoring model

BWW-Construct	Static Information Modeling					Dynamic Information Modeling					Formalistic Information Modeling					Functional Information Modeling				
Modeling grammar	*WEIGHT*	ERD	ARIS	UML	OML	*WEIGHT*	ERD	ARIS	UML	OML	*WEIGHT*	ERD	ARIS	UML	OML	*WEIGHT*	ERD	ARIS	UML	OML
B. Mutual Property											4	2	5	1	2					
Class	6	2	1	2	5	1	2	1	2	5	6	2	1	2	5					
Coupling	2	2	0	0	5						6	2	2	0	5	1	2	0	0	5
Event						4	5	0	2	2	1	5	0	2	2	4	5	0	2	2
External Event	1	5	0	2	5	5	5	0	2	5	1	5	0	2	5	4	5	0	1	5
Internal Event						4	5	0	1	5	1	5	0	1	5	1	0	5	2	5
Intrinsic Property	3	2	1	1	2						6	2	1	1	2					
Intrinsic State Law	2	5	5	1	5	1	5	5	1	5	1	5	5	1	5					
Kind	9	0	5	2	5	5	0	5	2	5	7	0	5	2	5	1	0	5	2	5
Lawful State Space	1	2	5	5	5						4	2	5	5	5					
Level Structure	2	5	0	5	5	4	5	0	5	5						1	5	0	5	5
Mutual Property	3	2	2	2	2	2	2	2	2	2	6	2	2	2	2					
Natural K./Subk. R.						2	5	5	0	0	1	5	5	0	0					

N.-b. Mut. Property	2	5	5	0	0	2	5	5	0	0	1	5	5	0	0					
Process	2	5	2	2	1	10	5	2	2	1	1	5	2	2	1	5	5	2	2	1
Property	5	2	1	2	2	7	2	1	2	2	3	2	1	2	2	5	2	1	2	2
Property in General	3	2	2	5	5	2	2	2	5	5	5	2	2	5	5	1	2	2	5	5
Stable State	1	5	0	0	5	5	5	0	0	5	1	5	0	0	5	4	5	0	0	5
State						4	5	0	1	0	1	5	0	1	0	4	5	0	1	0
State Law	3	2	1	0	2	2	2	1	0	1	8	2	1	0	2	4	2	1	0	2
Subkind											1	5	5	0	0					
Subsystem	2	5	1	5	5	3	5	1	5	5										
System Environment						1	5	0	1	2										
Thing	3	2	1	1	2	4	2	1	1	2	5	2	1	1	2					
Transformation	2	5	2	0	2	8	5	2	0	2	2	5	2	0	2	5	5	2	0	2
Well-defined Event						4	5	0	5	5	1	5	5	5	5	4	5	5	1	2
Whole-Part Relation	3	5	5	1	2						1	5	5	1	2					
Results	55	2.6	2.3	1.9	3.5	80	3.5	1.4	1.7	3.0	70	2.4	2.4	1.8	3.3	47	4.2	1.2	1.3	2.7

According to the Scoring Model, modeling grammars with lower scores offer more required construct that lead to more comprehensive models while modeling grammars that exhibit higher scores are characterized by a lack of constructs needed to solve the task and/or by an abundance of ontologically unclear constructs. The allocation of scores to the modeling grammars for each modeling task allows deriving a hierarchy of modeling grammars. The resulting hierarchy is presented in table 4.

Table 4: Hierarchy of modeling tasks

Modeling tasks / Hierarchy	Static Information Modeling	Dynamic Information Modeling	Formalistic IS Modeling	Functional IS Modeling
1.	UML	ARIS	UML	ARIS
2.	ARIS	UML	ERD	UML
3.	ERD	OML	ARIS	OML
4.	OML	ERD	OML	ERD

Except for one modeling task, Formalistic IS Modeling, the modeling grammars of the ARIS-Framework and UML alternate within the first two ranks of the hierarchy while ERD and OML alternate within rank three and four.

5 Conclusion

Prior research does not allow selecting a modeling grammar in a theory-based way. In this study a framework is developed that enables a theory-based selection of a modeling grammar. Cognitive Fit is used as a theoretical basis. If a Cognitive Fit occurs between a modeling grammar and a modeling task, the grammar allows creating the same type of information that the modeling task requires. This way, the modeling task can be solved efficiently. Using Cognitive Fit as a theoretical basis we benefited from relating Conceptual Modeling to a modeling task. We further benefited in that we did not need to compare ontological analyses directly but used them as a tool to combine required constructs of a modeling task with the provided constructs of a modeling grammar. Directly comparing ontological analyses so far has not been possible since each analysis bases on different constructs. For the operationalization of the framework Ontology is used. Using Ontology, we benefited from already existing ontological analyses, which provide relations between ontological and grammatical constructs. In addition, Ontology enabled us to assess modeling grammars for their capability to trace real world phenomena. By using Cognitive Fit as a theoretical basis and Ontology for its operationalization we could include benefits and avoid gaps inherent to each of the theory. The conception of the framework is only done exemplarily and we don’t claim it to be complete. Therefore, a content analysis was used to determine modeling task and reference models were used to assess their relevance in practice. According to the framework, modeling grammars were allocated to the modeling task and a hierarchy of these grammars could be established. Further research still need to be done to assess the concepts of the Bunge-Ontology to evaluate modeling grammars, since there are still concepts that are hardly possible to map onto this ontology. The operationalization of the framework serves as a basis to test the framework empirically with a laboratory experiment within future research.

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