Ontological Analyses Reconsidered - A Formal Approach

Andreas Gehlert and Werner Esswein

Dresden University of Technology, Helmhlotzstr. 10, 01069 Dresden, Germany
Email: {gehlert | esswein}@wise.wiwi.tu-dresden.de;
phone: ++49 351 463 36304, fax: ++49 351 463 37203

Abstract. Ontological analyses have been used in numerous publications to compare existing modelling grammars with an Ontology. Each analysis showed certain deficits of the modelling grammar. Consequently, improvements to these modelling grammars have been proposed. Most ontological analyses, however, are not based on a sound theoretical framework. This theoretical lack renders the results of these analyses incomparable. Thus, working with these results in practise is theoretically questionable. Therefore, in this paper we formalise the ontological analysis approach. This theoretical background allows us to formulate a set of prerequisites an ontological analysis must comply with. This new understanding leads to sound results, which are pairwise comparable. We sketch out intended applications, which are based on our theoretical framework. These applications include combining modelling grammars for a conceptual modelling project and translating models between different grammars. The paper is well embedded into current research as we use existing ontological analyses to show the application of our theoretical findings.

1 Introduction

Conceptual modelling is used to gain insights into a semantic problem domain. The resulting model is a language artefact with some relation to that problem domain ([1], p. 124). The grammar used to express this model is called modelling grammar. It allows the modeller to access the problem domain and at the same time divides the problem domain into different categories. If the modeller uses the Entity Relationship Model (ERM), he or she perceives reality as things and relations between things; if the Unified Modelling Language (UML) is used, reality is perceived as communicating objects. The degree of correspondence between reality and the modelling grammar has an important impact on the quality of the resulting models ([2], p. 246) and, thus, on the quality of the subsequent artefacts derived from these models.

Because of the importance of the modelling grammar for its artefacts, we need to develop a deeper understanding of these types of grammars. Ron Weber identifies the philosophical discipline 'Ontology' as a possible theoretical foundation for conceptual modelling grammars ([3], p. viii). The basis for this theoretical foundation is the understanding of Ontology as categorical system of the world (see [4], p. 1) and the assumption that these categories exists in the real world.[1]

Ron Weber, his colleague Yair Wand as well as other researchers compared different modelling grammars with different Ontologies. This process is called *ontological analysis*. The results of such an ontological analysis allow an assessment of the modelling grammar with regard to its appropriateness for conceptual modelling ([8], p. 86). Additionally, it provides a method for a systematic comparison and, therefore, minimises its subjectivity.

The very idea of such an ontological analysis is the harmonization of the real world view described by the Ontology and the view offered by the modelling grammar. The underlying premise is that the modelling grammar is suitable for conceptual modelling if it fits well with the Ontology. Hence, an ontological analysis is a comparison between a modelling grammar and an Ontology. The result of this comparison is a equivalence, similarity or difference relation between ontological and grammatical constructs. These results can be used to select and combine modelling grammars for a specific IS project as well as to translate models between different grammars.

By formalising the ontological analysis technique we are able to provide a set of prerequisites that all ontological analyses must satisfy to get sound results. This formalisation is not bound to a concrete Ontology so that it is generally applicable to all ontological analyses. We use this set of prerequisites to evaluate current ontological analyses and show that each of these works in focus has certain deficits that make their results incomparable. Eliminating these deficits enables a comparability of these results as well as applications based on them.

The article proceeds as follows: In the next section we introduce and formalise the ontological analysis technique and, thereby, provide the theoretical basis of this article. In section 3 we show the intended applications that would benefit from these theoretical findings. Afterwards, we review existing analyses on this theoretical basis and show that these analyses do not comply with all theoretical prerequisites discussed here (section 4). In the last section we summarise our results and draw conclusions about future ontological analyses.

2 Theoretical Basis

As pointed out in the introduction an ontological analysis is a comparison. Each *comparison* includes at least three elements, the two things x and y to be com-

[1] This position has ever since been criticised. Bunge for instance accused Wand and Weber to hold a naive realist position ([5]). Wyssusek argued against any ontological commitment ([6]). However, since the paper will focus on a formalisation of ontological analysis it is not necessary to share the ontological and epistemological positions of the authors of the underlying Ontology. Constructivist and Computer Science readers may understand Ontology in the sense of Guarino: "An Ontology is an explicit, partial account for a conceptualisation." ([7], p. 298)

pared and the set of criteria C, which is used for this comparison. The result of a comparison is generally threefold:

- Equivalence: Two things x and y are said to be equivalent ($equiv(x, y, C)$), if both things cannot be distinguished by *all* criteria C used for their comparison. These things are pairwise replaceable. The equivalence relation is reflexive ($equiv(x, y, C)$), symmetric ($equiv(x, y, C) \Leftrightarrow equiv(y, x, C)$) and transitive ($equiv(x, y, C) \wedge equiv(x, y, C) \Rightarrow equiv(x, z, C)$; [9], p. 80).
- Similarity: Two things x and y are said to be similar ($sim(x, y, \tilde{C})$), if x and y cannot be distinguished by the criteria $\tilde{C} = \{c_0, \ldots, c_{n-1}\}$ but differ in the criteria $\bar{C} = \{c_n, \ldots c_{n+m}\}$ ($n, m \in \mathbb{N}; n, m > 0; C = \tilde{C} \cup \bar{C}; \tilde{C} \cap \bar{C} = \emptyset$). The similarity relation is symmetric $sim(x, y, \tilde{C}) \Leftrightarrow sim(y, x, \tilde{C})$, not reflexive (since each thing is equivalent to itself) and generally *not* transitive ([10]). The transitivity only applies to $sim(x, y, \tilde{C}) \wedge sim(y, z, \tilde{C}') \rightarrow sim(x, z, \tilde{C} \cap \tilde{C}')$. In other words, a transitivity exists only, if there is a non empty common subset $\tilde{C} \cap \tilde{C}' \neq \emptyset$ between both comparison criteria.
- Difference: If two things x and y are neither equivalent nor transitive, they are different. Difference is symmetric, but neither reflexive nor transitive.

The similarity criteria can be further described as a set of properties of the things x and y in which these things are indistinguishable. If x is compared to y, each property of x is compared to properties of y to find a correspondence. On the contrary, if y is compared to x each property of y is mapped to properties of x. Both comparison processes have the same result. However, in the comparison $x - y$ only the properties of x and, hence, the similarity criteria according to x are explicit. Consequently, the *full* set of dissimilarity criteria is implicit, because this set includes also all properties of y not used in this comparison.

Let $\tilde{C}$ ($\bar{C}$) be the criteria where x and y cannot (can) be distinguished and $\tilde{C}'$ ($\bar{C}'$) the criteria with which y and z cannot (can) be distinguished ($\tilde{C} \cap \bar{C} = \emptyset; \tilde{C}' \cap \bar{C}' = \emptyset$). There are four possible situations that might occur (see also figure 1):

1. In the first case x and z are similar according to the criteria $\tilde{C} \cap \tilde{C}'$. Consequently, the similarity relation is transitive if $\tilde{C} \cap \tilde{C}' \neq \emptyset$.
2. If $\tilde{C} \cap \tilde{C}' = \emptyset$ and furthermore $\bar{C} \cap \bar{C}' = \emptyset$ the things x and z are different. This difference, however, cannot be inferred transitively since only the criteria $\tilde{C}$ and $\tilde{C}'$ used in the pairwise comparisons of $x - y$ and $y - z$ are explicit.
3. In the case that $\tilde{C} \cap \tilde{C}' = \emptyset$ and $\bar{C} \cap \bar{C}' \neq \emptyset$ the things x and z are similar. This similarity, however, cannot be derived transitively since it is based on the dissimilarity criteria $\bar{C}$ and $\bar{C}'$ not used in the pairwise comparisons $x - y$ and $y - z$.
4. If $\tilde{C} = \tilde{C}'$ and $\bar{C} = \bar{C}'$ the things x and z are similar. This similarity can be determined transitively. x and z are, additionally, equivalent. This equivalence, however, cannot be derived from the pairwise comparisons $x - y$ and $y - z$.

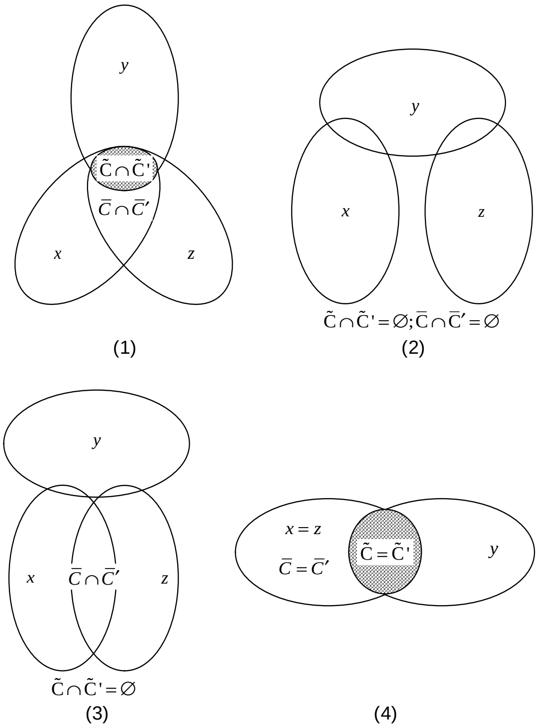

Fig. 1. Transitivity of similarity

If $equiv(x, y)$ and $sim(y, z)$ holds, it can be *generally* derived that x and z are similar ($sim(x, z)$). The comparison criteria for the similarity between y and z do not need to be explicit. If we do not know the criteria $\tilde{C}$ and $\tilde{C}'$ in the situation $sim(x, y); sim(y, z)$ nothing can be said about the relation of x and z. x and z can be equivalent, similar or different.

Subsequently we apply this knowledge to the domain of ontological analysis. Ontological analysis was described in detail by Weber ([11], p. 92). This method has been used by several authors (see for example [12], p. 69; [13], p. 2948; [14], p. 115; [15], p. 44; [16], p. 77). Methodologically an *ontological analysis* compares a finite set of modelling grammar constructs $G = \{g_1, \ldots, g_n\}$ with a finite set of ontological constructs $O = \{o_1, \ldots, o_n\}$ ($n \in \mathbb{N}, n > 0$). The researcher tries to find a correspondence between constructs with an equivalent, similar or different semantics ($sem(o) = sem(g)$, $sem(o) \approx sem(g)$, $sem(o) \neq sem(g)$ or shorter $equiv(o, g)$, $sim(o, g)$ and $diff(o, g)$). The Ontology is serving as a reference point in these comparison processes ([17], p. 305).

During the comparison commonalities and differences between the modelling grammar and the Ontology are examined. Any deviation of a $1:1$ mapping between the ontological and the grammatical constructs is called a deficit. In figure 2 these deficits are illustrated.

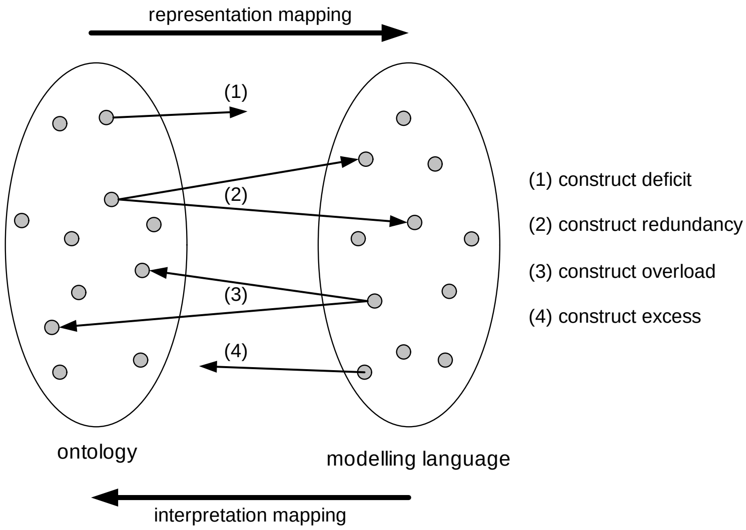

Fig. 2. Ontological analysis according to Weber ([11], p. 92)

The *representation mapping* MAP^r is a set of mappings map^r that relate one ontological construct o to a set of grammatical constructs $\hat{G}$ ($map^r : o \to \hat{G}$ with $o \in O$ and $\hat{G} \subset G \times G$). A *construct deficit* arises if one ontological construct is not present in the modelling grammar ($\exists o \in O : o \to \hat{G}$ so that $\hat{G} = \emptyset$). In the case of *construct redundancy* there is more than one grammatical construct for at least one ontological construct ($\exists o \in O : o \to \hat{G}$ with $|\hat{G}| > 1$).

The opposite comparison is called *interpretation mapping* MAP^i. This set contains mappings map^i that compare one grammatical construct g to a set of ontological constructs $\tilde{O}$ ($map^i : g \to \tilde{O}$ with $g \in G$ and $\tilde{O} \subset O \times O$). *Construct excess* arises if there is a grammatical construct with no corresponding ontological equivalent ($\exists g \in G : g \to \tilde{O}$ with $\tilde{O} = \emptyset$). *Ontological overload* is the situation in which there is more than one ontological construct for one modelling grammar construct ($\exists g \in G : g \to \tilde{O}$ with $|\tilde{O}| > 1$).

The ontological analysis technique distinguishes interpretation from representation mapping. This is, however, only necessary for the constructs, which are not covered by any mapping. For all other constructs the representation mapping can be derived from the interpretation mapping and opposite (see the symmetry discussion at the beginning of this section). Assume the interpretation mapping $map^i : g \to \tilde{O}$ as given. To derive the representation mapping proceed as follows: Define the empty set $\hat{G}$. For each element $o \in \tilde{O}$ do: Add each g to $\hat{G}$ so that o is an element in the interpretation mapping of g ($map^r : o \to \hat{G}$ with $o \in \tilde{O}$ and $\hat{G} = \bigcup g : o \in map^i(g)$). Consequently, the representation mappings as provided for instance in ([15] p. 48 and [16] p. 81) are necessary and sufficient to analyse construct redundancy and construct overload. The modelling grammar (ontological) constructs g (o) not present in any mapping belong to the construct excess (deficit).

To sum up so far, an ontological analysis seeks to find a $1:1$ semantic correspondence between modelling constructs g and ontological constructs o with the mapping types $equiv$, sim and $diff$. Each deviation from this $1:1$ correspondence causes a deficit. To get sound results from an ontological analysis and to be able to use these results in subsequent operations we can formulate the following formal requirements each ontological analyses must comply with:

Re1 All ontological analyses must be based on the same set of ontological constructs.
Re2 The ontological analysis must specify the constructs of the modelling grammar used, for instance by specifying a meta-model of that grammar.
Re3 Each pair-wise mapping $G \times O$ must be expressed as a function $G \times O \rightarrow \{equiv, sim, diff\}$.
Re4 For each similarity mapping type the similarity criteria C must be made explicit.

Additionally, we need to understand the semantics of the ontological and modelling grammar constructs correctly.

3 Intended Applications

Each theory must have a set of intended applications. In this section we sketch two possible applications that need the rigor and the theoretical foundations of ontological analyses presented in the previous section:

1. combining modelling grammars for a conceptual modelling project and
2. translating conceptual models between different grammars.

The first application was sketched out by Weber. Within a conceptual modelling project the analyst might need to choose a set of conceptual modelling grammars in a way that they have a maximum ontological coverage and a minimal ontological overlap. A *maximum ontological coverage* asks for a low number of construct deficits of both modelling grammars ([11], p 101). A *minimal ontological overlap* arises if grammar combinations have few constructs that represent the same ontological construct ([18], p. 167). Thus, when combining two modelling grammars G and G' we seek to find at best $MAP^i(G) \cup MAP^i(G') = O$ and $MAP^i(G) \cap MAP^i(G') = \emptyset$.[2]

To translate a model from one modelling grammar to another we need to know the semantically equivalent constructs in these modelling grammars. These

[2] The ontological overlap can only be evaluated with regard to the Ontology. Any overlap of the modelling grammars caused by modelling grammar constructs which do not have an ontological equivalent cannot be determined on the basis of the results of ontological analyses (see again figure 1 and the related discussion in the previous section).

corresponding constructs can be determined on the basis of the results of ontological analyses. We use the transitivity feature of the equivalence and the similarity relation as pointed out in section 2. Having defined the interpretation and/or representation mapping(s) for two modelling grammars G and G' ($G \neq G'$) with the Ontology O, a comparison of grammatical constructs g with g' can be achieved by composing the mapping functions $map^i_G * map^r_{G'}$ ([19], p. 791). To translate a construct g to g', we firstly determine the set of ontological constructs via the interpretation mapping of G. Then we take each ontological construct and use the representation mapping of G' to derive the set of destination constructs ($G' = \bigcup_{o_n \in map^i_G(g)} map^r_{G'}(o_n)$).

4 Review of Existing Ontological Analyses

The method described in section 2 can be applied to any ontological analysis and, hence, to any Ontology. Three ontologies have proven to be useful including the Bunge Wand Weber Ontology ([20], [21], [11], [22]), derived from the Ontology of Mario Bunge, the General Ontological Language (GOL, [23], [24], [25], [26]) and, most recently, the Cisholm Ontology ([27], [17]).

In this paper, we focus on ontological analyses with the help of the BWW Ontology. Ontological analyses include for example the NIAM grammar ([18]), the ERM ([11]), the UML ([15], [28]), the Architecture of Integrated Information Systems (ARIS; [16]) and the Semantic Object Model (SOM; [14]).

Since in this paper the focus is on formal aspects only and since the authors of the before-mentioned ontological analyses already covered the semantic aspect of the modelling grammar and the Ontology respectively, it is not necessary to provide any description of the BWW Ontology (for a comprehensive description see [20]; for a full description see [11], for meta models see [29] and [30]). For the same reason we do not describe the modelling grammars.

To strengthen our argumentation, we restrict ourselves to the ontological analysis of ARIS by Rosemann and Green ([16]), UML by Opdahl and Henderson-Sellers ([15]) and SOM by Fettke and Loos ([14]). According to our methodological basis, we need to check, which ontological and grammatical constructs were used (Re1, Re2), whether all mapping types were given (Re3) and whether the similarity criteria were made explicit (Re4).

4.1 Ontological and Modelling Language Constructs

Extracting ontological constructs from an Ontology is generally difficult and subject to the researcher. Since this operation cannot be formalised, no algorithm can be constructed to reduce the subjectivity of the selection of ontological constructs ([17], p. 307). Consequently, we expect different ontological analyses to use different ontological constructs. As a reference point for these ontological constructs we use an early publication by Wand and Weber ([21]). Table 1 summarises our results:

Table 1. Correspondence of ontological constructs used in different analyses

Reference ([21])	ARIS ([16])	UML ([15])	SOM ([14])
Thing	x	x (further distinction in composite thing, and component ∼)	x
Properties	further distinction in property in particular, ∼ in general, intrinsic ∼, mutual ∼, emergent ∼, hereditary ∼, attributes	x (further distinction in intrinsic property, mutual ∼, complex ∼, law ∼, natural law ∼, human law ∼, characteristic ∼, resultant ∼, emergent ∼, ∼ in general, attribute)	x
State	x	x	x
Conceivable state space	x	x	x
State law	x	x	x
Lawful state space	x	x	x
Event	x	x	x
Event space	x (conceiveable event space)	x (conceiveable event space)	x
Transformation	x	x	x
Lawful transformation	x	x (transformation law with slightly different semantics)	x
Lawful event space	x	x	x
History	x	x	x
Coupling	x (additional synonym: binding mutual property)	x (synonym: acting on)	x
System	x	x	x
System composition	x	x	x
System environment	x	x	x
System structure	x	x	x
Subsystem	x	x	x
System decomposition	x	x	x
Level structure	x	x	x
Stable state	x	x	x
Unstable state	x	x	x
External event	x	x	x
Internal event	x	x	x
Well-defined event	x		x
Poorly defined event	x		x
Class	x	x	x
Kind	x	x (slightly different semantics); further distinction in subkind	x
no comparable construct	process, acts on	property function, codomain, subclass, kind-subkind relationship, process, possible state space, binding mutual property, direct acting on, coupled event, whole part relation	
DoC_1	27 / 36 = **0.75**	26 / 49 = **0.53**	28 / 28 = **1.0**
DoC_2	27 / 29 = **0.93**	26 / 36 = **0.72**	28 / 28 = **1.0**

To operationalise the correspondence between the ontological constructs proposed by Wand and Weber and the constructs used by other researchers we calculate a degree of correspondence. It is the ratio of the number of elements used by Wand and Weber *and* by the author of the ontological analysis to the number of all ontological constructs ($DoC = |O \cap O'|/|O \cup O'|$).

The authors of the analyses of ARIS and UML specialised some constructs of the BWW Ontology—most notably the properties construct. Furthermore, they used additional constructs not mentioned in [21]. The analysis from Opdahl and Henderson-Sellers is most critical since it uses many ontological constructs that are not defined by Wand and Weber. Additionally, the analysis is complicated because of the usage of composite ontological constructs (e. g. intrinsic complex property; intrinsic non-law property; [15], p. 49).

To reflect the specialisation of ontological constructs, we calculate the degree of correspondence twice. DoC_1 includes all constructs used by the authors. DoC_2 excludes all constructs that are specialisations of ontological constructs introduced by Wand and Weber in [21].

Table 1 shows that there is generally a good correspondence between the reference set of ontological constructs and the constructs used in different ontological analyses. The best correspondence was achieved by Fettke and Loos ($DoC_1 = DoC_2 = 1.0$) followed by the analysis of Rosemann and Green ($DoC_1 = 0.75$; $DoC_2 = 0.93$). As indicated above the analysis of the UML shows the lowest correspondence to the BWW Ontology ($DoC_1 = 0.53$; $DoC_2 = 0.72$). These numbers lead to the following thesis:

> **Thesis 1**: Researchers used different ontological constructs for their ontological analyses (violation of Re1).

Additionally, some researchers do not compare single constructs but construct combinations instead. In this comparison they point out, for example, that one ontological construct maps to (many) modelling grammar constructs in a way that only the combination of these grammatical constructs *together* represent the ontological construct (Green and Rosemann mapped BWW-internal event to ARIS event-type, function, type, event-type; [16], p. 81; Fettke and Loos mapped the BWW-properties to SOM attributes and relations; [14], p. 119). This situation must be carefully separated from construct redundancy. If a construct redundancy occurs, an ontological construct maps to more than one grammatical construct in the sense that these grammatical constructs are *separately* equivalent/similar to the ontological construct.

> **Thesis 2**: The structural comparison of the modelling grammar and the Ontology was not initially intended by Weber ([11], p. 92). More work needs to be done to evaluate the prerequisites and consequences of such structural comparison.

The determination of the grammatical constructs is much easier since they can be directly extracted from the modelling grammar's meta model. However, there are only two analyses for a single modelling grammar carried out by more than one research group. These are the analyses of the ERM conducted by Weber ([11]) and the ERM analysis as part of the analysis of ARIS by Rosemann and Green ([16]).[3] Because there are many versions of the ERM, we cannot compare the evaluation of the ERM by Weber with those conducted by Rosemann and Green. There is too little information whether or not researchers used the same set of modelling grammar constructs. Consequently, we cannot assess this aspect here.

4.2 Specification of Mapping Types and Similarity Criteria

Green and Rosemann do not distinguish between equivalent and similar mapping types. Instead they provide a mapping table in the representation mapping format ([16], p. 81) only. The text indicates that the authors see the corresponding ontological and grammatical constructs in that table as equivalent constructs. All other pairwise mappings from ontological to modelling grammar constructs are specified as different.

In the analysis of the UML from Opdahl and Henderson-Sellers the authors make a difference between equivalent and similar constructs. Four different situations can be identified in the text:

1. Subtype: The UML construct is classified as more specific than the ontological construct (e. g. the UML-property is more specific than a BWW-intrinsic property; [15], p. 49).
   Interpretation: This means that the UML construct includes the ontological construct and has additional properties. If these additional properties do not map to the Ontology, they must be regarded as non conceptual properties of that construct (see [15], p. 44). Consequently, these properties cannot be included into the ontological analysis at all. If so, these grammatical constructs must be classified as being equivalent with the respective ontological construct. The constructs cannot be distinguished by all criteria used in this comparison since these criteria are provided by the ontological construct only.
2. Element of: UML constructs are classified as being an element of a BWW construct that describes a set of elements ("UML-value represents an element in a BWW-codomain"; [15], p. 49).
   Interpretation: Both things regard aspects on a different abstraction level (set vs. element). Hence, both constructs must be classified as different.
3. Specification of additional constraints: The authors specify additional constraints of the modelling grammar or ontological constructs, e. g. "UML-property with a non-primitive type ..." or "... BWW-mutual property of two or more things." ([15], p. 49)

[3] Bodart et al. used the insights of the ontological analysis of the ERM within a laboratory experiment ([31]) but did not improve or criticise it. The same can be said about the UML. Evermann and Wand did not provide a full analysis of the UML but formulated important consequences for its use ([28]).

Interpretation: The authors classify the corresponding constructs as similar. Furthermore, they define the similarity criteria explicitly. These similarity criteria can not only include UML attributes but also association between UML constructs.

4. Specification of the position in the construct hierarchy: Because the authors span a hierarchy of ontological and grammatical constructs, they occasionally need to specify the general constructs: "BWW-intrinsic property [of a thing] that is not a law or whole-part relation" ([15], p. 48).
   Interpretation: The authors seem to use specialisation in the sense that each specific construct is at the same time a member of its more general constructs. This explains the need to describe the position within this specialisation hierarchy. In other words, this positioning only specifies the ontological/modelling grammar construct. The constructs themselves must be regarded as equivalent.

Fettke and Loos also distinguish between equivalent and similar mapping types by indicating that one modelling grammar construct maps partially to an ontological construct. The mapping criteria are, however, not specified.

> **Thesis 3**: Different mapping types are currently distinguished in ontological analyses (Re3).

> **Thesis 4**: If researchers find a similarity between an ontological and a grammatical construct they rarely make the similarity criteria explicit (violation of Re4).

5 Conclusion, Potential and Further Research

The starting point of any ontological analysis is the modelling grammar and the Ontology. For a precise interpretation of the results, grammars and ontologies are compared on the construct level. To do so the researcher needs to know these constructs. Meta models have proven to be useful to document the constructs of the modelling grammar. Ontologies, however, are specified on a formal basis, so that the ontological constructs are less clear ([17], p. 307). In fact, researchers in the BWW community used different BWW constructs for their analysis as indicated in the previous section. However, if there is no consensus about the ontological constructs of the BWW Ontology its function as reference Ontology is reduced. Therefore, the results of the ontological analyses are incomparable.

Furthermore, researcher must specify the mapping types for each pairwise mapping of modelling grammar and ontological constructs. In some of the analyses this information is implicit ([15], [14]). If a similarity was found the comparison criteria were not always explicit. However, as stated above, a similarity relation can only be interpreted correctly if the criteria are known in which two constructs are similar.

Lastly, we did not investigate whether the researcher of different ontological analyses understood the modelling grammar as well as the Ontology in the same way. Rosemann et al. indicate that this might not always be the case ([32], p. 113). These differences in the interpretation can only be resolved in a reasonable discourse and in a logical reconstruction of the BWW and the modelling grammar (see [33] for such an approach).

These aspects lead to the conclusion that the existing ontological analyses provided an insight into the modelling grammar. The analyses are, however, pairwise incomparable. The usage of ontological analyses is reduced. Each operation on these results is theoretically questionable.

As pointed out in the paper the main prerequisite to enhance the power of ontological analyses in the BWW field is to stabilise the Ontology by defining its ontological constructs. Rosemann et al. point out that a meta model of the Ontology as well as a cooperative work of at least two researchers can minimise the effect of misinterpreting the Ontology ([32], p. 112). If forthcoming research follows this unified view provided by the meta model, the results of the ontological analysis will be more profound. The suggestion by Rosemann and Green to focus an Ontology e. g. to specialise and/or project it ([32], p. 119) should be generally avoided. Focussing an Ontology contradicts the idea of an Ontology being a reference point in comparison processes.

Further research is needed to address the problem of similarity. We have shown here that this includes criteria which are used in the comparison of the modelling grammar and the Ontology. These criteria must be explicit to be useful for the intended applications described in section 3. More work needs to be done to derive these comparison criteria generally.

Another research topic is the pattern matching approach. It is an extension to the ontological analysis described here such that not only single constructs are compared to each other but rather sets of constructs. We expect the ontological analysis being more difficult with this approach. It is beyond the scope of this paper to evaluate whether this pattern matching approach should be generally avoided.

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Mathematical Symbols

Symbol	Meaning
x, y, z	Concrete things
$equiv$	equivalence relation (reflexive, symmetric, transitive)
sim	similarity relation (non reflexive, symmetric, non transitive)
$diff$	difference relation (non reflexive, symmetric, non transitive
C, C'	sets of criteria used to compare things
$\tilde{C}, \tilde{C}'$	sets of similarity criteria
$\bar{C}, \bar{C}'$	set of dissimilarity criteria
m, n	natural number used as indices
G, G'	set of modelling grammar constructs (grammatical constructs)
$\hat{G}, \hat{G}'$	$\hat{G} \subset G \times G$, $\hat{G}' \subset G' \times G'$
g_m, g'_n	a modelling grammar construct (grammatical construct)
O, O'	set of ontological constructs
$\hat{O}, \hat{O}'$	$\hat{O} \subset O \times O$, $\hat{O}' \subset O' \times O'$
o_m	an ontological construct
$sem()$	semantics of an element
MAP^r	set of representation mappings
map^r	a representation mapping
MAP^i	set of interpretation mappings
map^i	a representation mapping