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TOWARD MORE RIGOR IN ONTOLOGICAL ANALYSES

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Abstract

Ontological analyses have been used in numerous publications to compare existing modelling grammars with an ontology. However, a sound theoretical research framework is still missing. Consequently, working with the results of such ontological analyses is theoretically questionable. The aim of the paper is threefold. Firstly, we want to contribute to such a theoretical research framework by formalising the ontological analyses approach. Secondly, we derive four formal requirements each ontological analyses must comply with. Lastly, we analyse whether current state of the art ontological analyses comply with our findings. While the formalisation demonstrates the strengths of the approach we conclude that current ontological analyses have theoretical deficiencies, which lead to serious limitations in their application.

Keywords: Ontological analysis, BWW Ontology

1 BACKGROUND

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 (Wand & Weber, 1990a, 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) for example, 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 (Schütte & Rotthowe, 1998, 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. Weber identifies the philosophical discipline 'Ontology' as a possible theoretical foundation for conceptual modelling grammars (Weber, 2003, p. viii). The basis for this theoretical foundation is the understanding of Ontology as categorical system of the world (Grossmann, 1992, p. 1) and the assumption that these categories exists in the real world.[1]

Weber, his colleague 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 (Shanks et al., 2003, p. 86). Additionally, it provides a method for a systematic comparison of an ontology with a modelling grammar and, therefore, minimises its subjectivity.

The 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 an equivalence, similarity or difference relation between ontological and grammatical constructs.

In this paper, however, we will disregard any epistemological discussion about the appropriateness of ontologies in the IS field. Instead we understand ontologies and modelling grammars as sets of constructs only and develop a formalism based on this understanding. All questions of the interpretation of these constructs as well as their relation to reality cannot be discussed here.

The paper proceeds as follows: In the next section we introduce and formalise the ontological analysis technique and, thereby, provide the theoretical basis of this paper. This formalisation leads to four prerequisites, all ontological analyses must comply with. These prerequisites are used to review existing ontological analyses. As a result we show in section 3 that these analyses do not comply with all requirements raised. In the last section we summarise our results and draw conclusions about possible future research areas.

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[1]This position has ever since been criticised. Bunge for instance accused Wand and Weber to hold a naive realist position (Bunge, 1990). Wyssusek argued against any ontological commitment (Wyssusek, 2004). However, since the paper will focus on a formalisation of ontological analyses 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." (Guarino, 1997, p. 298)

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 compared 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 ($equiv(x,x,C)$), symmetric ($equiv(x,y,C) \Leftrightarrow equiv(y,x,C)$) and transitive ($equiv(x,y,C) \wedge equiv(y,z,C) \Rightarrow$ $equiv(x,z,C)$ (Janich & Kambartel, 1974, 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 $\tilde{C} = \{c_0,...,c_{n-1}\}$ but differ in the criteria $\bar{C} = \{c_n,...c_{n+m}\}$ ($n,m \in N; n,m > 0; C = \tilde{C} \cup \bar{C}; \tilde{C} \cap \bar{C} = \varnothing$). 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 (Do & Rahm, 2002, p. 614). 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, transitivity exists only, if there is a non empty common subset $\tilde{C} \cap \tilde{C}' \neq \varnothing$ between both similarity criteria sets.
- Difference: If two things x and y are neither equivalent nor transitive, they are different. Difference is symmetric, but neither reflexive nor transitive.

Subsequently, we apply this knowledge to the domain of ontological analysis. The ontological analysis technique was described in detail by Weber (Weber1997, p. 92). This method has been used by several authors (for instance Fettke & Loos, 2003a; Fettke & Loos, 2003b; Green & Rosemann, 2000; Greiffenberg, 2004; Opdahl & Henderson-Sellers, 2002). Methodologically an **ontological analysis** compares a finite set of modelling grammar constructs $G = \{g_1,...,g_n\}$ with a finite set of ontological constructs $O = \{o_1,...,o_m\}$ ($n,m \in \mathrm{N}; n,m > 0$). 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 (Milton et al., 2001).

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. To classify these deficits, the comparison is divided into two mapping. The interpretation mapping is the comparison of the modelling grammar with the ontology. The representation mapping is the opposite comparison (see figure 1).

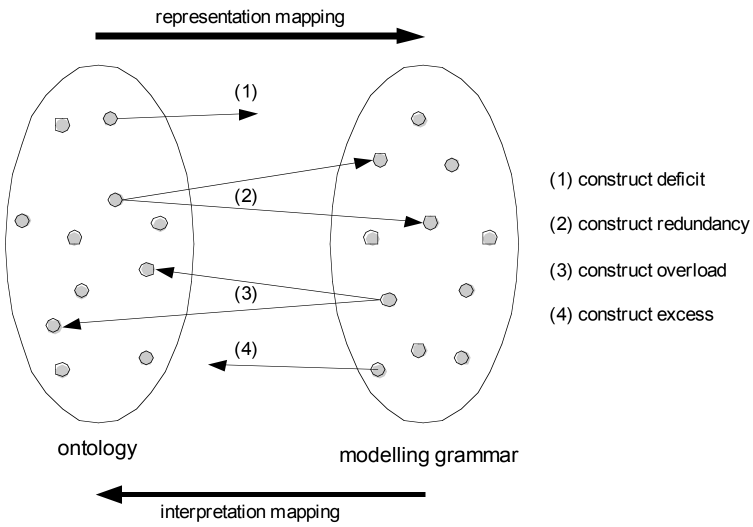

Figure 1. Ontological analysis according to Weber (Weber, 1997)

Formally, the **interpretation mapping** is the function $map: G \rightarrow 2^O$, which relates a set of modelling grammar constructs to the power set of ontological constructs so that $map(g) = \hat{O}$ with $g \in G$ and $\hat{O} \in 2^O$. *Construct excess* arises if there is a grammatical construct with no corresponding ontological equivalent ($\exists g \in G : map(g) = \varnothing$). *Ontological overload* is the situation in which there is more than one ontological construct for one modelling grammar construct ($\exists g \in G :| map(g) |> 1$).

The opposite comparison is called **representation mapping**. The representation mapping is the inverse function and relates a set of ontological constructs to the power set of modelling grammar constructs $map^{-1}: O \rightarrow 2^G$ so that $map^{-1}(o) = \hat{G}$ with $o \in O$ and $\hat{G} \in 2^G$. A *construct deficit* arises if one ontological construct is not present in the modelling grammar ($\exists o \in O : map^{-1}(o) = \varnothing$). In the case of *construct redundancy* there is more than one grammatical construct for at least one ontological construct ($\exists o \in O :| map^{-1}(o) |> 1$).

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 (see table 1).

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	For each pair-wise mapping $G \times 2^O$ the mapping type ($equiv, sim$) must be expressed ($\forall G \times 2^O \in map : G \times 2^O \rightarrow \{equiv, sim\}$).
Re4	For each similarity mapping type the similarity criteria $\tilde{C}$ must be made explicit.

Table 1. Formal requirements of ontological analyses.

Requirement Re1 calls for a unique set of ontological constructs. If such a set is shared among researchers, the ontology becomes a reference point for ontological analyses. This reference point is the most important prerequisite to compare results of different ontological analyses. Since all modelling grammars evolve, requirement Re2 requests to make the version of the modelling grammar explicit. Requirement Re3 ensures that not only the mappings are specified but also their mapping types. In other words, the researcher should state if he or she finds the construct mapping to be equivalent or different. If similarity is involved the researcher should additionally state in which criteria the constructs are similar and in which they differ. This is especially important if we use the results of different ontological analyses in a transitive manner.

3 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 (BWW-Ontology; Soffer & Wand, 2004; Wand & Weber, 1990b; , 1995; Weber, 1997), derived from the ontology of Mario Bunge, the General Ontological Language (GOL; Degen et al., 2001; GOL; Degen & Herre, 2001; Guizzardi et al., 2002; Guizzardi et al., 2004) and, most recently, the Cisholm ontology (Milton & Kazmierczak, 1999; Milton et al., 2001).

To review existing ontological analyses we need at least two different analyses carried out by different research groups. As the GOL and the Cisholm Ontology are relatively new approaches only a small number of ontological analyses have been carried out so far (most notably for data modelling techniques as in Milton & Kazmierczak, 1999; Milton et al., 2001). In contrast to GOL and Cisholm the BWW Ontology is very well understood. Many ontological analyses such as the analysis of the NIAM grammar (Weber & Zhang, 1996), the ERM (Weber, 1997), the UML (Evermann & Wand, 2001; Opdahl & Henderson-Sellers, 2002), the Architecture of Integrated Information Systems (ARIS; Green & Rosemann, 2000) and the Semantic Object Model (SOM; Fettke & Loos, 2003a) have been carried out by different research teams around the globe.

To strengthen our argumentation, we restrict ourselves to the ontological analyses of ARIS by Green and Rosemann (Green & Rosemann, 2000), UML by Opdahl and Henderson-Sellers (Opdahl & Henderson-Sellers, 2002) and SOM by Fettke and Loos (Fettke & Loos, 2003a) with the BWW ontology. According to our methodological basis, we need to verify, 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).

Since the focus of this paper 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, we do not provide any description of the BWW ontology (for meta models see Rosemann & Green, 2002; for a comprehensive description see Wand & Weber, 1990b; for a full description see Weber, 1997). For the same reason we do not describe the modelling grammars.

3.1 Ontological and Modelling Grammar 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 (Milton et al., 2001, p. 307). Consequently, we expect different ontological analyses to include different ontological constructs. To evaluate whether the ontological analyses of ARIS, UML and SOM were conducted on a common set of ontological constructs, we use the set proposed in an early publication by Wand and Weber (Wand & Weber, 1995) as a reference point. Table 2 summarises our findings.

Reference (Wand &	ARIS	UML	SOM (Fettke &

Weber, 1995)	(Green & Rosemann, 2000)	(Opdahl & Henderson-Sellers, 2002)	Loos, 2003a)
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 DoC_2	27 / 36 = 0.75 27 / 29 = 0.93	26 / 49 = 0.53 26 / 36 = 0.72	28 / 28 = 1.0 28 / 28 = 1.0

Table 2. Correspondence of ontological constructs used in different analyses.

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 ($DoC = |O \cap O'| / |O \cup O'|$, (Tversky, 1977, p. 333)).

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 (Wand & Weber, 1995). The analysis from Opdahl and Henderson-Sellers is most critical since it uses many ontological constructs that were 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 Opdahl & Henderson-Sellers, 2002, 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 of the reference set.

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 Green and Rosemann ($DoC_1 = 0.75$; $DoC_2 = 0.93$). 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 conclusion:

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

Additionally, some researchers did 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 (for example, Fettke and Loos mapped the BWW-properties to SOM attributes and relations in Fettke & Loos, 2003a, p. 119; Green and Rosemann mapped BWW-internal event to ARIS event-type, function, type, event-type in Green & Rosemann, 2000, p. 81). 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.

> **Conclusion 2**: The structural comparison of the modelling grammar and the ontology was not initially intended by Weber (Weber, 1997, p. 92). More work need 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 (Weber, 1997) and the ERM analysis as part of the analysis of ARIS by Green and Rosemann (Green & Rosemann, 2000).[2] Because there are many versions of the ERM, we cannot compare the evaluation of the ERM by Weber with those conducted by Green and Rosemann. There is too little information whether or not researchers used the same set of modelling grammar constructs. Consequently, we cannot assess this aspect here.

3.2 Specification of Mapping Types and Similarity Criteria

Green and Rosemann did not distinguish between equivalent and similar mapping types. Instead they provide a mapping table only (Green & Rosemann, 2000, p. 81). The text indicates that the authors see the corresponding ontological and grammatical constructs in that table as equivalent constructs. All other pair-wise mappings from ontological to modelling grammar constructs can be seen as being 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:

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[2] Bodart et al. used the insights of the ontological analysis of the ERM within a laboratory experiment (Bodart et al., 2001) 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 (Evermann & Wand, 2001).

- *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 in Opdahl & Henderson-Sellers, 2002, 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 (Opdahl & Henderson-Sellers, 2002, 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.

- *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"; Opdahl & Henderson-Sellers, 2002, p. 49).

  Interpretation: Both things regard aspects on a different abstraction level (set vs. element). Hence, both constructs must be classified as different.

- *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; Opdahl & Henderson-Sellers, 2002, p. 49).

  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.

- *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" (Opdahl & Henderson-Sellers, 2002, 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. Consequently, we can conclude:

> **Conclusion 3**: Different mapping types are currently distinguished in ontological analyses (Re3).
>
> **Conclusion 4**: If researchers find a similarity between an ontological and a grammatical construct they rarely make the similarity criteria explicit (violation of Re4).

4 CONCLUSION, POTENTIAL AND FURTHER RESEARCH

The formalisation of the ontological analysis technique revealed the theoretical requirements of such an analysis. As we have shown the core requirement is the usage of a unique set of ontological constructs. In such a case the ontology becomes a reference point. This reference enables new applications, which can be conducted on the basis of the results of two or more ontological analyses.

As we have shown here, such a reference ontology does not exist yet in the BWW ontology field. This might be due to the formal focus of ontologies in general so that the specification of ontological constructs are less clear (Milton et al., 2001, p. 307). To enhance the expressiveness of ontological analyses and to enable them for subsequent operations, we propose to find a consensus about the BWW ontological constructs and to document it using a meta-model (Rosemann et al., 2004, p. 112). Especially all modifications to the ontology prior to the ontological analyses as suggested by Rosemann and Green under the label "focussing" should be generally avoided (Rosemann & Green, 2000, p. 622).

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 (Fettke & Loos, 2003a; Opdahl & Henderson-Sellers, 2002). 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 especially if this similarity feature is subsequently used in a transitivity situation.

More research needs to be done to extend the formalism provided here to cover the pattern matching approach. This powerful tool might be useful to extend the range of intended applications.

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APPENDIX: LIST OF MATHEMATICAL SYMBOLS

Symbol	Meaning
x, y, z	concrete things
$equiv$	equivalence relation (reflexive, symmetric, transitive)
sim	similarity relation (not reflexive, symmetric, not transitive)
$diff$	difference relation (not reflexive, symmetric, not transitive)
C, C'	sets of criteria used to compare things
$\tilde{C}, \tilde{C}'$	sets of similarity criteria
$\overline{C}, \overline{C}'$	set of dissimilarity criteria
m, n	natural number used as indices
G	set of modelling grammar constructs (grammatical constructs)
2^G	power set of G
$\hat{G}$	$\hat{G} \in 2^G$
g_m	a modelling grammar construct (grammatical construct)
O	set of ontological constructs
2^O	power set of O
$\hat{O}$	$\hat{O} \in 2^O$
o_m	an ontological construct
$sem()$	semantics of an element
map	mapping between a set and a power set (interpretation mapping)
map^{-1}	inverse mapping of map (representation mapping)