On the Foundation of the Ontological Foundation of Conceptual Modeling Grammars: The Construction of the Bunge–Wand–Weber Ontology

Boris Wyssusek and Helmut Klaus

Queensland University of Technology
Faculty of Information Technology
Centre for Information Technology Innovation (CITI)
GPO Box 2434, Brisbane Qld 4001, Australia
b.wyssusek@qut.edu.au
h.klaus@uqconnect.net

Abstract. In response to constant criticism that methods for conceptual modeling in information systems lack theoretical foundations, several approaches have been proposed. Among these, ontological approaches have recently received considerable attention. Though MCCARTHY and HAYES already in 1969 had called for "metaphysically adequate modeling," it was not before 1986 that WAND and WEBER commenced working out an ontological foundation of conceptual modeling, drawing on an ontology by BUNGE; thus later named Bunge–Wand–Weber (BWW) ontology. Nonetheless, its application triggered questions regarding its grounding, which remain open yet. Addressing some of these, a first review of the BWW ontology is being offered—putting it in the context of ontological foundations of conceptual modeling––as a bid for increased rigor in theory development. The emergence of conceptual modeling, BUNGE's ontology, and its adaptation by WAND and WEBER are summarized, concluding with questions regarding the overall project of ontological foundations of conceptual modeling.

1 Introduction

In developing information systems, conceptual models are the most fundamental means. Used in requirements engineering, they fulfill multiple purposes: design, documentation, and communication. These purposes, together with the issue of representation, have given rise to a wide range of methods of modeling that in turn have been subjected to criticism for their lack of theoretical foundation. The final response to the quest for theoretically grounded model development in information systems appears to be the reference to ontology, that holds the promise of foundational knowledge and hence of being a panacea for all problems that beseech systems development, and eventually organizational information systems at large. This line of argument is premised on the unquestioned pursuit of scientism that had been identified as the "orthodoxy" of information systems by KLEIN and LYYTINEN [16].

The most prominent and most developed of diverse approaches to ontology-driven conceptual modeling is the so-called Bunge–Wand–Weber (BWW) ontology. On the one hand, the claims made for this ontology are not trivial. On the other hand, any scrutiny of ontological approaches in general and of the BWW ontology is missing. Scholarly propriety demands careful reconsideration whether the ontological approach to foundations of conceptual modeling is feasible and defensible. The following essay will attempt to open up this debate. It is structured as follows:

First, we follow up the emergence of conceptual modeling and trace the quest for its theoretical foundation. The currently strongest theoretical impact is being attributed to ontological approaches, with the BWW ontology singled out. Second, to investigate the transposition from a scientific ontology into one for conceptual modeling, we present the salient assumptions underlying BUNGE's ontology, the source of the BWW ontology. Third, we recount the adaptation of BUNGE's ontology by WAND and WEBER, and conclude by questioning the overall project of ontological foundations of conceptual modeling.

2 The Emergence of Conceptual Modeling and the Quest for its Theoretical Foundation

Methodical information systems development is a process consisting of successive phases, and various methods are being used throughout the process. It has been shown that the costs of fixing errors increase exponentially over the time between making an error and fixing it (e.g., [1]), hence an economic motivation is given for scrutinizing especially methods used in requirements engineering—the first phase in the information systems development process. This focus is also justified by the fact that errors in requirements engineering are often only to be recognized when the system is put in use, since requirements are mostly concerned with behavioral aspects of information systems.

One category of methods used in requirements engineering is concerned with capturing requirements by means of conceptual models. Understanding information systems development as a process of successive translations—from requirements documentation to the final implementation of the system (e.g., [12])—, the impact of the quality of conceptual models of requirements on the outcome of information systems development becomes evident.

Conceptual modeling has its roots in AI and database research. In AI researchers faced the problem of representing knowledge in order to be able to simulate reasoning processes. Informed by cognitive science they understood knowledge as interrelated concepts, which in turn were understood as models of the world. The need for knowledge representations led to the development of modeling methods that were able to produce models of concepts, i.e., of knowledge (e.g., [20]). In database research the problem was different. Databases were already a well-established technology and the development of conceptual modeling methods started ex post. On the one hand, databases researchers faced the problem that extant representations were largely dependent on the DBMS. In order to enable the exchange of models (and data) between different DBMS, researchers were looking for modeling methods that would allow a de-coupling of models from the specificities of the DBMS. On the other hand, with extant representations dependent on the DBMS, only people with sufficient knowledge of the DBMS were able to create and understand data models. Hence, the need arose to develop methods that would enable people unfamiliar with the the DBMS to create and to understand data models. Conceptual modeling eventually provided the means for representations independent from DBMS (e.g., [24]).

Both AI and database research share the quest for representations of conceptual structure (e.g., [23; 2]). Yet there is one major difference: researchers in AI do not only 'posses' the conceptual structure they want to represent; they also have theories of the respective structures. Scripts, frames, semantic networks, etc. are all rooted in theories of cognitive science. In contrast, researchers in databases have a given form of representation, determined by the DBMS, and look for other forms of representation, but do not know on which conceptual structure to base this representation. They lack theories of the conceptual structures they want to represent.

In the phase of requirements engineering for information systems development we are confronted with the same situation as the database researchers. Neither do we 'posses' the conceptual structures on which to base the representation of requirements, nor do we have theories that provide us with such structures. The criticism has always been the lack of theoretical foundation of the respective modeling approaches, since most of them have been developed on the basis of practical wisdom and not on a scientific theory. Over time, various approaches towards the development of theoretical foundations have been proposed, drawing on disciplines such as psychology, cognitive science, linguistics, and, more recently, ontology. Yet a closer look reveals that the approaches proposed have mostly been used for the evaluation and comparison of extant conceptual modeling methods or conceptual models (e.g., [26; 22]).

In this paper we are concerned with ontological approaches towards the development of theoretical foundations of conceptual modeling that are based on philosophical ontology (e.g., [21]). We are especially concerned with the so-called Bunge–Wand–Weber (BWW) ontology as such a foundation (e.g., [29]).

The BWW ontology is based on the ontology of MARIO BUNGE [5; 6]. The development of the BWW ontology began in 1986, with the first publication to appear in 1988. During the last decade it gained increasing attention, documented by well over 100 publications drawing on this ontology in contexts such as comparison of ISAD grammars (e.g., [14]), ontological evaluation of modeling grammars (e.g., [25]) and of reference models (e.g., [13]), information systems interoperability (e.g., [15]), development of theoretical foundations for data quality (e.g., [30]), for modeling languages (e.g., [29]), and for method engineering (e.g., [28]) as well as requirements engineering for COTS software (e.g., [27]).

Both the history of the BWW ontology of almost 20 years and its wide scope of application justify and ask for an investigation into the foundation of this foundation. Such an appraisal is overdue, since questions regarding the foundation and justification of the BWW ontology have been raised frequently (e.g., [26]), yet have remained unanswered yet.

3 The Ontology of MARIO BUNGE

The goal of this section is neither a commentary nor a criticism of BUNGE's ontology—the peculiarities of the worldview underlying and depicted by it shall remain in the eye of the beholder. Rather, BUNGE's worldview and ontology are being referred to, (1) since his works are not widely known, and (2) to strengthen the awareness among users of the BWW ontology of what they are actually dealing with. The latter goal is motivated by our observation that a naïve practice with the BWW ontology is quite common.

The following expands the principal assumptions of BUNGE's "Ontology"—part of his eight volume "Treatise", in which he sought to cover comprehensively all 'traditional' fields of philosophical investigation, such as Semantics, Ontology, Epistemology, and Ethics—, with a view on its epistemological implications, and its explicit concept of science and philosophy at large. This will help to demonstrate that these assumptions are not lofty speculations that can be safely cast aside in the practice of conceptual modeling. They rather determine the claims that are being made for the validity and significance of conceptual modeling, consequently also how conceptual modeling is methodically organized and eventually how it is performed.

BUNGE is commited to dialectical materialism [5, p. 5], which is an offspring of the materialism of the 19th century and a philosophical doctrine developed by ENGELS [11], and later by LENIN [17] (for an overview see, e.g., [18]). Its sibling is logical positivism, and despite major differences, many similarities between the two are extant (see for example, [10]). Materialism explains world as being determined ultimately by matter. In our era its ontological correlate is realism and its epistemological is objectivism. Dialectics refers to the overall dynamics of matter, which is conceived of as akin to a debate in ancient Greece: antagonistic forces (thesis and antithesis) are in contention, out of which emerges a higher force (synthesis) that overcomes the contradictory state of the former. Thus, BUNGE's philosophy is rooted in the scientific worldview as it has emerged since the Enlightenment.

According to that, BUNGE claims that the real world, i.e., the material world, exists independent from our knowledge [8, p. 229]. His scientific worldview also holds that objective human knowledge is possible, since—as far as it is based on scientific methods—it represents the real world [8, p. 233]. Hence, truth is possible, but only by means of science, as the scientific method is the only way to obtain truth [8, p. 231].

From that follows that truth must find its expression in the language of science, which is mathematics. Statements, to be valid, need to be transformed into symbols ruled by logic. Thus he claims: "Unless a construct is assigned a definite mathematical status […] it is not exact and may be a fake, i.e. a *flatus vocis* rather than a genuine concept" [5, pp. 8–9].

BUNGE stresses the incompatibility of his concept of science with other theories of cognition, such as empiricism and phenomenalism. He holds that science is non-phenomenological, i.e., it "attempts to account for reality behind appearance" [6, p. 147], and that although "phenomena […] are experientially immediate, [...] they are neither ontologically or scientifically primary" [6, p. 147].

The position of the human being within this worldview implies that there is only one way left to come to fundamental statements about world. Materialism means that "*res cogitans* is a *res extensa*" [6, p. 146]. In other words, since matter is all that is, and this is accessible to science directed towards that matter, including the human being, all other attempts at knowledge are void, including so-called non-scientific philosophical knowledge. From that follows the determination of ontology as "general science" and that its task is to "stake out the main traits of the real world as known through science" [5, p. 5]. BUNGE thus emphasizes: "[I]t is not true that ontology has become impossible after the birth of modern science. What has become impossible *de jure* – though unfortunately not *de facto* – is nonscientific ontology" [5, p. 7]. The historically primal domain of philosophy in this way becomes a secondary domain of scientific activity. In BUNGE's terms, ontology is an *a posteriori science* [5, p. 8], and thus nothing external to science. It draws together the diverse disciplines and their projections of world into a coherent whole: "A complete ontology should include both universal and regional ontological theories. The former serve as frameworks for the latter, which will in turn illustrate and in a way test the former" [5, p. 11].

The coherent whole is being constituted by means of formal logic. "Formal science, or at least some of it, constitutes both the language and the formal skeleton of scientific ontology. In particular, scientific ontology presupposes abstract mathematics, including deductive logic" [5, p. 13]. This unifying view is ontological theory that "is a theory that contains and interrelates ontological categories, or generic concepts representing components or features of the world" and that "[…] is a [hypothetical deductive] system, not just a set, of interrelated ontological categories" [5, p. 11]. To put it overtly simply, BUNGE's ontology is formal science. Being thus imbued with abstractions and formal logic, suggests its proximity to modeling. Both, ontology and formal science deal with models of the world: "Theoretical science and ontology handle not concrete things but concepts of such, in particular conceptual schemata sometimes called *model things*" [5, p. 119].

In sharp contrast to BUNGE's claims to a scientific ontology only obliged to reason and logic is his rather disquieting polemic against any other conceptions of philosophy and science. For example, for BUNGE, opposing philosophical schools must be based on irrational motives: Subjectivists are not able to differentiate between a model and what the model is about, hence subjectivists suffer from "a form of mental derangement" [5, p. 121]. This implies that any deviation from BUNGE's doctrine, especially from realism and objectivism, is unworthy of any serious consideration; even more, anything else cannot be simply erroneous, it can only be explained out of a person's mental insanity.

The following should not be understood as an attempt at explaining BUNGE's vehement delimitation and denial of dialogue. However, it has to be pointed out that ultimately BUNGE's ontology fails to match its own claims. This can be illustrated by his Existence criteria that are based on a circular proposition. Here the following assumptions are made: (1) Humans exist, because things exist, otherwise we could not act upon things. (2) We cannot prove the existence of things independently from any other thing whose existence we do not question at the moment. We have to assume our own existence in order to prove the existence of something else. BUNGE thus rightfully concludes "This is a criterion of relative existence. Absolute existence cannot be established even though it need not be excluded. In order to show that *x* exists we must exhibit its connections with some thing *y* whose existence is not questioned in the given investigation. In particular, but not necessarily, this second object can be a human observer" [5, p. 161]. Yet this means nothing but a canceling out of the fundamental claim of realism, the reality of world independently of the human being. "The reality of an object consists in its being a part of the world. And the conjecture of the reality of an object must be *tested* through its immediate or remote perceptible effects but it does not *consist* in the latter" [5, p. 161]. This then implies that reality of something transcends what can be established by scientific methods and formal logic. By that, the realist assertion recedes into speculative thought that it had sought to surmount.

4 The Adaptation of BUNGE's Ontology by WAND and WEBER

In 1986 WEBER spent his sabbatical at University of British Columbia, where WAND held a position at the same time. WAND and WEBER shared a common interest in some fundamental issues of information systems development. Understanding an information system as a representational system, they came up with the following fundamental question that would guide their joint work for many years: "Given a user's or a group's conception of the real world, under what conditions would an information system provide a good or a poor representation of this conception?" [37, p. xi].

It happened that WEBER had an office next to MATTESSICH, a renown accounting researcher and philosopher of science (e.g., [19]). Once, WEBER asked MATTESSICH the following question: "[W]hat were the set of generic constructs that people employ to structure their conceptions of the world?" MATTESSICH handed WEBER the Treatise by BUNGE [37, p. 73]. Subsequently WEBER skimmed some of the books and "discovered theoretical foundations that excited [WEBER] in terms of their implications for information systems. When [WEBER] showed the contents of Volume 3 [i.e., [5]] to [WAND], [WAND] too concluded they had important implications for theory in the information systems discipline" [37, p. xi]. They realized "that a number of researchers within the information systems and computer science fields unknowingly had been working on ontological questions. These researchers had been working in the area that is usually called 'conceptual modeling' or 'semantic data modeling' […]" [37, p. 73]. In later accounts WAND and WEBER describe the appeal and their motivation for their use of BUNGE's ontology as follows:

- "We turned […] to MARIO BUNGE's *Ontology* in order to obtain the formal foundation for modelling information systems" [34, p. 124].
- BUNGE's "*Ontology* was used for three purposes: first, as a point of view, and as a source of some fundamental propositions; second, as a source for basic constructs to be applied to modelling information systems; and third, as a source of notation for the model" [34, p. 146).

- BUNGE's "Ontology was chosen because its objective is to describe the structure of the real world" [31, p. 214].
- "BUNGE's ontology attracted us because many concepts he examines are directly applicable to the information-systems and computer-science domains" [33, p. 63).
- "We chose to employ, adapt and extend BUNGE's ontology for several reasons. First, in our view his ontology is better developed and better formalized than any we have encountered so far. […] Second, BUNGE models the world as a world of systems. Thus, he is concerned with concepts that are fundamental to the computer science and information system domains. […] Third, we believe we have been able to use BUNGE's ontology to obtain useful theoretical and practical results" [35, pp. 220–221].
- "We have chosen to work with BUNGE's ontology because it deals directly with concepts relevant to the information systems and computer science domains (e.g. systems, subsystems and couplings). Moreover, BUNGE's ontology is better developed and better formalized than any others we have encountered" [36, p. 209].
- "I have chosen BUNGE's work to explicate the notion of a system for two reasons. First, while I am not a philosopher, in my view it is the best formulated and most complete theory of ontology that I have been able to find […].BUNGE has strived to make his theory clear and exact by articulating his constructs via mathematics. Second, BUNGE [5, p. 24] [claims]: 'Metaphysics can render service by analyzing fashionable but obscure notions such as those of system, hierarchy, structure, event, information, …' [5, p. 24)]" [37, p. 33].
- We chose [BUNGE's] work for several reasons. First, it is oriented towards systems. Second, it is intended to deal with a wide range of systems, from physical to social. Third, it is well formalized, both in defining the concepts and outlining the premises and in providing a consistent notation. Finally, it draws upon an extensive body of prior work related to ontology" [29, p. 287].

Summarizing the above statements, it can be said that BUNGE's ontology was 'chosen' by WAND and WEBER because (a) it uses a familiar terminology such as system, subsystem, and event, that can readily be applied to conceptual modeling in information systems (b) it is to a large extent formalized; (c) it provides a notation that can be re-used; (d) it seems to be a highly developed work in ontology.

Comparing the section on BUNGE's ontology with the paragraphs above, it becomes obvious that WAND and WEBER proceeded in a reductionistic fashion when they adapted BUNGE's ontology. First, they did not deal with the ontological commitment that is fundamental to BUNGE's ontology—the commitment to a scientific worldview and a dialectical-materialist understanding of world. Second, focusing on familiar terminology and formalization, WAND and WEBER transferred the *formalism* as well as the *terminology* from the domain of scientific ontology to the domain of conceptual modeling without actual ontological content. They persistently overlooked that terminology and constructs belong to two distinct domains (i.e., [3; 4]). Third, WAND and WEBER quite obviously understood BUNGE's ontology in terms of conceptual modeling—not vice versa. Hence, in their adaptation WAND and WEBER transferred *concepts* from the domain of conceptual modeling to the domain of ontology—not vice versa. This finds its expression in the following claims: conceptual modelers "unknowingly had been working on ontological questions" [37, p. 73] and "the conceptual modelers' insights were substantive, value-adding contributions to the ontologists' theories/models" [37, p. 74].

WAND and WEBER's understanding of BUNGE's ontology as an essentially formal theory, hence not as an ontological theory in the sense of BUNGE, contributed substantially to their ability to use BUNGE's 'ontology' for the 'ontological' foundation of conceptual modeling grammars. Having freed the formalism from every ontological commitment, WAND and WEBER proceeded to borrow freely but selectively. They adapted, among others, the following 'constructs': system, subsystem, thing, property, attribute (e.g., [37, pp. 33–54]). Yet without ontological commitment, those 'constructs' are just meaningless terms [5, p. 14]. This is the case, since a formalism does not provide ontological content: "[A] mathematical *formalism* is by itself neutral with respect to matters of fact. So, unless the formalism is 'read' in factual terms, it will 'say' nothing about reality" [3, p. 104]. Hence, without ontological commitment, WAND and WEBER conceptualize the creation of conceptual models in terms of the BWW 'ontology' as a translation from an observation language (i.e., the "user's view") to a theory language (i.e., the conceptual modeling language): "Whether a user's view of the real world reflects objective reality or socially constructed reality […] does not affect our model. We take the view as given, however it is formulated, and model it accordingly" [35, p. 218, footnote 1]. Yet, this understanding of conceptual modeling is clearly not based on a realist ontology such as BUNGE's. Rather it seems to be informed by logical positivism (e.g., [10]).

It becomes evident that WAND and WEBER implicitly showed that the idea of an ontological foundation of a modeling grammar is wrong from its inception. A conceptual modeling grammar is just a (semi-)formal language that can be used to create 'sentences.' A language does not say what the elements of the language actually refer to. Only if an ontological theory or any factual theory is being used for the interpretation of 'sentences,' the elements of a modeling language become meaningful with respect to the world. It is the very lack of ontological commitment of (modeling) languages that allows us to use, e.g., the entity-relationship modeling formalism to model about every aspect of the world, independent from any ontological commitment. Limitations regarding the expressiveness of a language are not an ontological concern, but a linguistic one—languages are ontologically neutral [4, pp. 189–190].

In the process of adaptation of BUNGE's ontology its ontological content got lost. Without ontological commitment, the BWW 'ontology' cannot be based on BUNGE's ontology that is dialectical materialism. Instead, WAND and WEBER seem to have followed presuppositions that are similar to those of logical positivism. Not distinguishing clearly between signs, concepts, reality and not clearly defining the relationships between those categories have contributed to the confusion of linguistic issues with issues of ontology (see also [7; 9]). BUNGE's thesis of the ontological neutrality of language contradicts the idea of an ontological foundation of conceptual modeling grammars.

5 Conclusion

The preceding discussion, even when limited in scope, has demonstrated that the project of developing theoretical foundations of conceptual modeling on the basis of ontology is neither feasible nor defensible. Yet, this conclusion does not simply mean that WAND and WEBER's work has been erroneous. Rather the project of ontology-based conceptual modeling is impossible in principle. This has not only gone apparently unnoticed up until now, but rather ontology-based modeling is an expanding area of theoretical research and publication within the domain of systems analysis and design. Following KLEIN and LYYTINEN [16], this may be attributed to one of the traits of scientism, namely its inability to reflect on its own presuppositions and limitations; combined with the institutional bias and dominance of scientism, dysfunctional discourses are bound to prosper. The empirical analysis of how WAND and WEBER's foundational work became adopted and diffused remains a task to be addressed in a separate publication.

The impossibility of ontological foundations for conceptual modeling suggests moreover a reconsideration of the approach in general. This reflection should, in our view, stress the contextual and semantic problems of conceptual modeling. There have been already numerous attempts in this direction in the past. However, the tenet that conceptual modeling should not be guided primarily by abstract formalisms, but be practiced with the awareness of its object being socially and linguistically constituted needs to be evolved further. This correspondingly entails a reflective stance on part of the practitioners and theoreticians of conceptual modeling, including the question which knowledge and how knowledge is constituted by conceptual modeling. Ontologically driven conceptual modeling avoids this question, since ontology supposedly provides us with foundational knowledge of world. A socially and linguistically oriented perspective on conceptual modeling would consequently also have to keep in view the question of power in relation to knowledge. In contrast, this question has to remain opaque in scientistic modeling, since it assumes objective and neutral cognition with the ensuing imposition of methods and systems. One limitation of the preceding essay is not having touched on this issue either. For example, we have not discussed that ontological foundations of conceptual modeling may be an imposition of a *Weltanschauung* on the modeler and ultimately on the user.

References

1. Boehm, B. W.: Software Engineering Economics. Prentice-Hall, Upper Saddle River (1981)
2. Brodie, M. L.: On the development of data models. In Brodie, M. L., Mylopoulos, J., Schmidt, J. W. (Eds.): On Conceptual Modelling: Perspectives from Artificial Intelligence, Databases, and Programming Languages. Springer, New York (1984) 19–47
3. Bunge, M.: Treatise On Basic Philosophy: Volume 2: Semantics I: Sense and Reference. Reidel, Dordrecht (1974)

4. Bunge, M.: Treatise On Basic Philosophy: Volume 2: Semantics II: Interpretation and Truth. Reidel, Dordrecht (1974)
5. Bunge, M.: Treatise On Basic Philosophy: Volume 3: Ontology I: The Furniture of the World. Reidel, Dordrecht (1977)
6. Bunge, M.: Treatise On Basic Philosophy: Volume 3: Ontology II: A World of Systems. Reidel, Dordrecht (1979)
7. Bunge, M.: Philosophical problems in linguistics. Erkenntnis 21 (1984) 107–173
8. Bunge, M.: Realism and antirealism in social sciences. Theory and Decision, 35 (1993) 207–235
9. Bunge, M.: Semiotic systems. In Altmann, G., Koch, W. A. (Eds.): Systems. New Paradigms for the Social Sciences. de Gruyter, Berlin (1998) 337–349
10. Carnap, R.: Philosophical Foundations of Physics. Basic Books, New York (1966) chapters 23–26
11. Engels, F.: Dialectics of Nature. Lawrence and Wishart, London (1940)
12. Feigenbaum, E. A.: How the "what" becomes the "how". Communications of the ACM 5 (1996) 97–104
13. Fettke, P., Loos, P.: Ontological evaluation of reference models using the Bunge-Wand-Weber model. In Proceedings of the Ninth Americas Conference on Information Systems (2003) 2944–2955
14. Green, P. F.: An Ontological Analysis of Information Systems Analysis and Design (ISAD) Grammars in Upper Case Tools. PhD thesis, University of Queensland, Australia (1996)
15. Green, P., Rosemann, M.: Usefulness of the BWW ontological models as a "core" theory of information systems. In Gregor, S. D., Hart, D. N. (Eds.): Information Systems Foundations: Building the Theoretical Base. Australian National University, Canberra (2002) 147–164
16. Klein, H. K., Lyytinen, K.: The poverty of scientism in information systems. In Mumford, E., Hirschheim, R. A., Fitzgerald, G., Wood-Harper, T. (Eds.): Research Methods In Information Systems. Elsevier, Amsterdam (1985) 131–161
17. Lenin, V. I.: Materialism and Empirio-Criticism: Critical Notes Concerning a Reactionary Philosophy. Lawrence and Wishart, London (1927)
18. Lichtheim, G.: Historical and dialectical materialism. In Wiener, P. P. (Ed.): Dictionary of the History of Ideas, Volume 2. Charles Scribner's Sons, New York (1973) 450–456
19. Mattessich, R.: Instrumental Reasoning and Systems Methodology: An Epistemology of the Applied and Social Sciences. Reidel, Boston (1978)
20. McCarthy, J., Hayes, P.: Some philosophical problems from the standpoint of AI. In Meltzer, B., Michie, D. (Eds.): Machine Intelligence 4. Edinburgh University Press, Edinburgh (1969) 463–502
21. Milton, S., Kazmierczak, E.: An ontology of data modelling languages: a study using a common-sense realistic ontology. Journal of Database Management 2 (2004) 19–38
22. Moody, D. L.: Theoretical and practical issues in evaluating the quality of conceptual models: current state and future directions. Data & Knowledge Engineering (2005) to appear
23. Mylopoulos, J., Levesque, H. J.: An overview of knowledge representation. In Brodie, M. L., Mylopoulos, J., Schmidt, J. W. (Eds.): On Conceptual Modelling: Perspectives from Artificial Intelligence, Databases, and Programming Languages. Springer, New York (1984) 3–17
24. Navathe, S.: Evolution of data modeling for databases. Communications of the ACM 9 (1992) 112–123
25. Rohde, F.: An ontological evaluation of JACKSON's system development model. Australian Journal of Information Systems 2 (1995) 77–87

26. Siau, K., Rossi, M.: Evaluation of information modeling methods – a review. In Proceedings of the Thirty-First Hawaii International Conference on System Sciences, Volume 5 (1998) 314–321
27. Soffer, P., Golany, B., Dori, D., Wand, Y.: Modelling off-the-shelf information systems requirements: an ontological approach. Requirements Engineering 3 (2001) 183–199
28. Wand, Y.: Ontology as a foundation for meta-modelling and method engineering. Information and Software Technology 4 (1996) 281–287
29. Wand, Y., Monarchi, D. E., Parsons, J., Woo, C. C.: Theoretical foundations for conceptual modeling in information systems development. Decision Support Systems 4 (1995) 285–304
30. Wand, Y., Wang, R. Y.: Anchoring data quality dimensions in ontological foundations. Communications of the ACM 11 (1996) 86–95
31. Wand, Y., Weber, R.: An ontological analysis of some fundamental information system concepts. In Proceedings of the Ninth International Conference on Information Systems (1988) 213–224
32. Wand, Y., Weber, R.: An ontological model of an information system. IEEE Transactions on Software Engineering 11 (1990) 1282–1292
33. Wand, Y., Weber, R.: Toward a theory of the deep structure of information systems. In Proceedings of the Eleventh International Conference on Information Systems (1990) 61–71
34. Wand, Y., Weber, R.: MARIO BUNGE's ontology as a formal foundation for information systems concepts. In Weingartner, P., Dorn, G. J. W. (Eds.): Studies on MARIO BUNGE's Treatise. Rodopi, Amsterdam (1990) 123–149
35. Wand, Y., Weber, R.: On the ontological expressiveness of information systems analysis and design grammars. Journal of Information Systems 4 (1993) 217–237
36. Wand, Y., Weber, R.: On the deep structure of information systems. Information Systems Journal 3 (1995) 203–223
37. Weber, R.: Ontological Foundations of Information Systems. Coopers & Lybrand Research Methodology Monograph No. 4, Coopers & Lybrand, Melbourne (1997)

Acknowledgements

BORIS WYSSUSEK's contribution to this paper was funded by SAP Research and an Australian Research Council (ARC) Linkage Grant – project number: LP0454094.