

Challenges in Requirements Engineering: A Research Agenda for Conceptual Modeling

Salvatore T. March
Vanderbilt University

Gove N. Allen
Tulane University

0. Abstract

Domains for which information systems are developed deal primarily with social constructions—conceptual objects and attributes created by human intentions and for human purposes. Information systems play an active role in these domains. They document the creation of new conceptual objects, record and ascribe values to their attributes, initiate actions within the domain, track activities performed, and infer conclusions based on the application of rules that govern how the domain is affected when socially-defined and identified *causal events* occur. Emerging applications of information technologies evaluate such business rules, learn from experience, and adapt to changes in the domain. Conceptual modeling grammars aimed at representing their system requirements must include conceptual objects, socially-defined events, and the rules pertaining to them. We identify challenges to conceptual modeling research and pose an ontology of the artificial as a step toward meeting them.

1. Introduction

The fundamental question in conceptual modeling research is, "How can we model the world to better facilitate our developing, implementing, using, and maintaining more valuable information systems?" (Wand and Weber 2002, p. 363). It is a design science research question (Hevner, et al. 2004). To address it researchers must build and evaluate artifacts: conceptual modeling grammars (constructs and rules), methods (guideline or procedures), and scripts (resultant representation).

Prior research has used ontology as a foundation for the development and evaluation of conceptual-modeling grammars (Wand and Weber 1995, Wand et al. 1999). It has conceptualized an information system as a state-tracking mechanism for concrete objects (things), which are the sole constituents of the referent "world." It has defined an event as a change in the state of a thing—the change occurring as a result of natural processes and subject to the immutable laws of nature (Bunge 1977). However, the domains for which information systems are developed are largely artificial. They deal primarily with social constructions—conceptual objects and attributes created by human intentions and for human purposes (Searle 1995, 2006).

Information systems play an active and purposeful role in these domains (March and Allen 2007). They document the creation of new conceptual objects, record and ascribe values to their attributes, make decisions and initiate actions within the domain, track activities performed, and infer conclusions based on the application of rules that govern how the domain is affected when socially-defined events occur. Emerging applications of information technologies are taking an even more active role in business domains. They are expected to evaluate business-dependent rules, learn from experience, and adapt to changes in the environment (Chen and Wong 2005). Conceptual modeling grammars must be capable of representing the conceptual objects, socially-defined events, and rules that characterize their design requirements. Furthermore, they must be capable of representing the purpose of an information system within

its organizational context, including goals, decision alternatives, constraints, and evaluation criteria (Simon 1996).

2. Background

The ontological work most frequently cited in the conceptual modeling literature is that of Mario Bunge. Bunge (1977) proposed a scientific ontology that distinguishes two types of objects: concrete and conceptual. The existence of concrete objects is observer-independent. They exist and possess substantial properties “even if we are ignorant of this fact” (p. 58). Conversely, the existence of conceptual objects depends solely upon human invention. They are “creations of the human mind” (p. 116) that “exist as long as there are rational beings capable of thinking them up.” Examples of concrete objects include people, buildings, machines, trees, minerals, animals, and electrons. Examples of conceptual objects include numbers, mathematical theories, intellectual property, legally created corporations, contracts and agreements, and the legal institution of a marriage. Bunge’s ontology specifically focuses on concrete objects, yet conceptual objects form the heart of business domains. If conceptual modeling is to have an ontological foundation, it must be an “*ontology of the artificial*.” One that is intended to represent the objects and attributes created by human intention, for human purposes, and imbued with meaning that is shared among participants.

Existing work in natural ontology should not be ignored in the development of an ontology of the artificial. Specifically, Bunge (1977) provides a sound representation of concrete objects and their properties. However, conceptual objects are “lawless.” It may be *agreed* that they will follow *invented* rules within a specific context; however those rules can be changed as purposes within the context change (Brooks 1987). Furthermore, such rules are enforced within different contexts. Some are enforced within a governmental context, others within the organizational context. In either case they are outside of Bunge’s ontology but they are fundamental to many business domains.

3. Premises

Business organizations use concrete objects such as people, machines, and buildings to accomplish their goals. However, they are concerned primarily with the meaning and purpose ascribed to concrete and conceptual objects and with invented rules that *form the basis of social intercourse*. A person is important to a business primarily because of the meaning and purpose ascribed to them (e.g., customer, employee).

Premise 1. Conceptual modeling is primarily concerned with representing social phenomena.

Natural phenomena (Bunge 1977) result from processes that are governed by immutable laws. It is the role of science to discover and understand such laws. Social phenomena (Searle 1995, Davidson 1980) result from intentional human actions. When deemed important to do so, it is the role of a society, by collective agreement, to invent and enforce rules that govern social phenomena. Such rules frequently result in the creation of conceptual objects (e.g., social contracts and legal entities) that must be documented and validated by social means—there are no corresponding concrete (physical) objects. A major purpose of an information system is to provide such documentation and validation. A sales order, for example, is a conceptual object created when a buyer and a seller agree upon the terms of the sale. It follows the rules of

commerce established by governments, regulatory agencies, and specific business organizations. Its existence is documented in an information system (manual or automated).

Another purpose of an information system is to execute the rules invented to accommodate the occurrences of defined social phenomena. We term such social phenomena *conceptual events*.

Premise 2. Defined social phenomena, termed *conceptual events*, have rules that specify the actions to be taken when they occur.

Conceptual events are conceptual objects. The rules associated with them are invented and changeable. The specified actions frequently involve the creation of conceptual objects and the ascription of attributes to conceptual and concrete objects. A “sale,” for example, is a conceptual event resulting in the creation of a sales order. The recognition of a “sale” event is by a social agreement between the buyer and the seller governed by regulations imposed within a larger social system. Such conceptual events and the rules governing them are an integral part of a conceptual model.

We must differentiate this notion of *conceptual event* from the event construct defined by Bunge (1977) and used in prior conceptual modeling research (e.g., Wand and Weber 1995). In that work an *event* is defined as a change in the *state* of a concrete object, the change being affected by a law, which describes the natural processes affecting the change. Neither the occurrence that initiated the change nor the purpose (meaning) of the change is considered. A *conceptual event* includes elements of purpose, intention, and rules governing the commitments and obligations (conceptual objects) created by the participants when it occurs (Geerts and McCarthy 2002). An important role of information systems is to process conceptual events, documenting the agreed upon commitments and obligations incurred.

Premise 3. An information system is primarily an event-processing mechanism utilizing event rules to make decisions, create conceptual objects, and ascribe attributes to concrete and conceptual objects.

A business may declare, for example, that a “person becomes a customer” when that person initiates a “registers at web site” event. The person becomes a customer when he or she fills out the registration form and presses “submit.” The rules may specify that the person who initiated the event is to be ascribed: (1) the attribute “authorized for sales transactions” and (2) the set of attributes common to all customers. This set of attributes may include those associated with the data entered, e.g., name and address as well as attributes whose values are generated according to the event’s rules, e.g., customer number, customer status (initialized at “provisionary”), and credit limit (initialized to \$1000). Furthermore the “registers at web site” event, a conceptual object, is related to the customer object. The values of its attributes do not change even if the values of the customer’s attributes are changed by subsequent events (March and Allen 2007).

We term such event-processing information systems “active” because they actively participate in the business domain rather than passively record facts from it. The rules for some events may be unknown or outside the scope of the information system. For such events the modeler may choose not to represent the event in the conceptual model but only to represent

attributes of the affected objects. The role of the information system is said to be “passive” with respect to that event, being limited to recording attribute values and histories.

Premise 4. The *scope* of a conceptual event rule is the set of social institutions with the authority to change and enforce it.

The scope of a conceptual event rule represents the degree of control an organization has over its definition, enforcement, and modification. Some of the rules that must be represented in business domains are constraints within their legal environment. These are enforced by governmental agencies. Their violation can result in legal action, fines, and even termination of the business. Such rules include fair trade practices, Sarbanes Oxley, and minimum wage. Changing them requires the act of a socially authorized governing body (e.g., a legislative or judicial act). Other rules represent policies of the business. They are defined, enforced, and changed by the organization itself. Their violation may have financial consequences but are discretionary within the broader social context in which the business operates. Such rules include policies for product pricing, warranties and returns, employee compensation and incentives, quality control, vendor selection, and technology use. Organizations frequently define event rules to assure compliance with rules imposed by the environment. Policies defining separation of accounting duties with respect to authorization, recording, and custody over organizational assets, for example, assure compliance with the control requirements of Sarbanes-Oxley.

Premise 5. The *range* of a conceptual event rule is the set of objects that are affected by the rule.

The range of a conceptual event rule represents the breadth of the rule’s influence. The range of a policy implemented by a corporation about hourly compensation is the set of hourly employees of the company; the range of a state law on minimum wage is the state’s set of minimum wage workers and the companies for which they work.

Premise 6. Identification of objects (conceptual and concrete) is fundamental to the conceptual modeling of business domains.

Distinguishing objects is fundamental to language (Davidson 1980) and hence to communication and exchange within business domains. Business organizations must often differentiate individual objects such as employees, customers, contracts, sales, sales orders, and shipments as well as types of objects such as raw material and product categories (e.g., at the stock keeping unit (SKU) level rather than the individual (serialized) level. They frequently rely on artificial means such as ascribed identifier attributes to distinguish such objects. The representation of such ascribed attributes is fundamental to the purpose of a conceptual model—conveying a shared understanding of the phenomena within the domain (Kent 1978).

4. Ontology of the Artificial for Conceptual Modeling

One implication of the above premises is that information system requirements are *designed* not *discovered*. While a conceptual modeler must analyze the domain to identify the important objects and rules, these must be understood in the context of design—design of the information system, design of the business, and design of the social context in which they operate. All are artificial systems (Simon 1996) upon which the organization can exert varying degrees of

influence. Based on the above premises we propose the following as a rudimentary ontology of the artificial.

1. There are two types of objects—concrete and conceptual.
 - 1a. *Concrete objects* exist physically.
 - 1b. *Conceptual objects* exist by human invention and social agreement.
2. Attributes are ascribed to concrete and conceptual objects for human purposes. Attributes map functionally from objects to values.
3. There are two types of attributes: substantial and invented.
 - 3a. *Substantial attributes* are ascribed to concrete objects to represent human understanding of natural phenomena (substantial properties of concrete objects).
 - 3b. *Invented attributes* are ascribed to concrete and conceptual objects to enable social intercourse.
 - 3c. One purpose for the ascription of invented attributes to objects is their *identification* (individuation).
4. Objects may be grouped into *types* (classes, categories) based on the ascription of one or more common attributes.
 - 4a. An object may be grouped into multiple types.
 - 4b. Types may exist in hierarchical or networked relationships with other types. Subtypes inherit attributes from their supertypes.
 - 4c. *Optional attributes* may be included in the definition of a type.
5. The *status* of an object is the set of values of its attributes at a point in time. The *history* of an object is the chronology of its status.
6. There are two types of events, concrete and conceptual.
 - 6a. *Concrete events* affect changes to substantial properties of concrete objects. They follow immutable, natural, discoverable laws.
 - 6b. *Conceptual events* affect changes to invented attributes of concrete and conceptual objects. They have purpose (intention) and follow rules that are designed and defined by human agreement. These rules are mutable, of varying scopes and ranges, subject to evaluation, and can be intentionally violated.
 - 6c. Concrete events exist in a causal sequences (natural processes) and can be initiated by a conceptual event; however, concrete events do not have purpose or meaning. Purpose and meaning are associated only with conceptual events.
 - 6d. Objects that are affected by the same event are said to be in *relationship* with the event and, hence, in relationship to each other through the event.
7. Objects may *compose* and *decompose* to form other objects.
8. Events may *compose* and *decompose* to form other events.

While we recognize the above ontology is cursory we believe it is useful for the purpose of developing a research agenda in conceptual modeling—the construction and evaluation of an ontology suited to the representation of the social phenomena that characterize business domains and to the development of information systems that actively participate in their operation and management.

5. Research Challenges

A number of research challenges remain. These involve the development and evaluation of constructs, methods, and scripts by which this proposed ontology can be effectively applied in conceptual modeling. First, constructs are needed to conceptually represent conceptual events and their rules. We have proposed their representation as conceptual objects and attributes, respectively; however, this proposition must be assessed. Furthermore event rules are likely to be most appropriately represented at the “event-type” level. Therefore a mechanism for categorizing events may also be necessary. Second, the ontology must be demonstrated to be effective in enabling the conceptual modeling of business domains and must be demonstrated to lead to effective designs and implementations. The parsimony and understandability of conceptual models built using it must be assessed and methods to guide their construction and evaluation must be developed.

Third, the applicability and value of this ontology in active conceptual modeling must be assessed. Active conceptual modeling (Chen and Wong 2005) focuses on enhancing our understanding of how to model systems that learn from past experiences. It requires conceptualizations that facilitate the analysis and re-analysis of social phenomena to generate alternate or proposed histories and conclusions. The representation of events as conceptual objects and the conceptualization of an information system as an active, event-processing mechanism provide the basis for this understanding. They also provide a framework for the representation of stories and narrative (Robinson and Hawpe 1986) and for the representation of episodic and semantic memory (Tulving 1983), each a significant component of human information processing and sense-making. Future research should investigate how the proposed ontology can be used to develop intelligent learning-based applications in areas such as business intelligence, global situation monitoring, surveillance, reconnaissance, design, decision-making and decision-evaluation.

Finally we observe that an ontology is itself an artifact, developed by human intention for specific purposes. Within the scope of conceptual modeling the purpose of ontology is to enable the development of effective information systems. We have proposed the beginnings of an ontology of the artificial to address this problem.

6. References

- Allen, G. N. and March, S. T., "A Critical Assessment of the Bunge-Wand-Weber Ontology for Conceptual Modeling," *Proceedings of the Sixteenth Annual Workshop on Information Technologies and Systems*, December 9-10, 2006, Milwaukee WI, pp. 25-30.
- Brooks, F.P., Jr. "No Silver Bullet: Essence and Accidents of Software Engineering," *IEEE Computer* (20:4), April 1987, pp 10-19.
- Bunge, M. *Ontology I: the Furniture of the World*, volume 3 of *Treatise on Basic Philosophy*, D. Reidel Publishing Company, Boston, MA, 1977.
- Chen, P. P. S. and Wong, L., "A Proposed Preliminary Framework for Conceptual Modeling of Learning from Surprises," *International Conference on Artificial Intelligence*, Las Vegas, Nevada, June 27-30, 2005, pp. 905-910.
- Davidson, D., *Essays on Actions and Events*, Oxford University Press, USA, 1980.
- Geerts, G. L. and McCarthy, W. E. "An Ontological Analysis of the Economic Primitives of the Extended-REA Enterprise Information Architecture," *International Journal of Accounting Information Systems*, (3:1), March 2002, pp. 1-16.
- Hevner, A., March, S. T., Park, J. and Ram, S. "Design Science Research in Information Systems," *MIS Quarterly* (28:1) March 2004, pp. 75-105.

- Kent, W. *Data and Reality*, Elsevier Science Limited, North-Holland, 1978 (republished in 1998 and reprinted in 2000 by 1st Books).
- March, S. T. and Allen, G. N., "Ontological Foundations for Active Information Systems," *International Journal of Intelligent Information Technologies*, (3:1), January-March 2007, pp. 1-13.
- Robinson, J. A. and Hawpe, L. "Narrative Thinking as a Heuristic Process." In *Narrative Psychology: The Storied Nature of Human Conduct*, Sarbin, T. R. (ed.), Prager Publishers, New York, NY, 1986.
- Searle, J. R., "Social Ontology: Some Basic Principles," *Anthropological Theory* (6:1), 2006, pp. 12-29.
- Searle, J. R., *The Construction of Social Reality*, New York: Free Press, 1995.
- Simon, H.A. *The Sciences of the Artificial*, 3rd Edition, MIT Press, Cambridge, MA, 1996.
- Tulving, E. *Elements of Episodic Memory*, Oxford University Press, New York, NY, 1983.
- Wand, Y. and Weber, R. "On the Deep Structure of Information Systems," *Information Systems Journal* (5), 1995, pp. 203-233.
- Wand, Y. and Weber, R. "Research Commentary: Information Systems and Conceptual Modeling -- A Research Agenda," *Information Systems Research*, (13:4) December 2002, pp. 363-376.
- Wand, Y., Storey, V. C., and Weber, R. "An Ontological Analysis of the Relationship Construct in Conceptual Modeling," *ACM Transactions on Database Systems* (24:4), December 1999, pp. 494-528.