Introducing GSO: A General Systemist Ontology

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Abstract. An important function of any information system is to represent an application domain. A general or foundational ontology provides a basis from which research on representational issues can be conducted. However, most efforts that develop general ontologies, have not taken a systems view. In this paper, we propose a General Systemist Ontology (GSO) for which we develop and apply a set of postulates. The intent of the ontology is to serve as a foundation for developing information technologies where the application could benefit from a systems perspective.

Keywords: Upper Ontology · General Systemist Ontology · Conceptual Modeling

1 Introduction

Information technologies (IT) continue to be ingrained into every facet of human experience. This has become increasingly obvious during the current COVID-19 pandemic where more and more physical contact is rapidly being enabled by IT. Examples include the rush to online learning, reliance on text messages for contact tracing, and delivery of goods and services that reduce human interaction. In the ever-expanding digital world, strong foundations for IT are needed more than ever before [1]–[3]. One of the most important, but difficult, functions of IT is to faithfully represent an application domain [4]–[6], which requires continued investigation into approaches to domain representation that rest upon strong theoretical foundations.

Ontology is a branch of philosophy which studies what exists [7]. It has been used widely as a foundation for research on representational issues. Various ontologies have been adopted or developed within the IT research community, including DOLCE [8], Unified Foundational Ontology (UFO) [9], social ontology of Searle [10], General Formal Ontology [11], and the Bunge-Wand-Weber (BWW) [12], [13]. The latter, BWW is based on ideas of a prominent philosopher and physicist Mario Bunge (1919-2020) and synthesized and adapted to information systems research. The BWW ontology contributes to both theory and practice of IT, with specific emphasis on representational issues in conceptual modeling [10], [14]–[18].

However, BWW captures a rather narrow, and relatively early, subset of Bunge`s work (i.e., 1977 and 1979 volumes [19], [20])[21]. Thus, expanding these foundations could prove valuable. Indeed, in the 40 years since the publication of the two primary sources of BWW [19], [20], Bunge published over 400 additional papers [22], in which his ideas were further expanded, refined, and sometimes, altered. A recent study [21] compares BWW to the later and expanded works by Bunge and shows the need to revise BWW by adapting and incorporating Bunge's work on systems. Thus, the objective of this research is to propose the development of a new ontology, which we call the *General Systemist Ontology* (GSO). The contribution is to propose the development of the General Systemist Ontology with a corresponding set of postulates and to articulate the core and periphery of the new ontology, as well as how the ontology can be used to support representational issues in conceptual modeling

2 Background: Bunge-Wand-Weber

The Bunge Wand Weber ontology is based on two seminal manuscripts which are part of Bunge`s eight volume *Treatise on Basic Philosophy* [19], [20]. A contribution in its own right [23], BWW has also been used in the development of the theory of ontological expressiveness and the representation and good-decomposition models [17]. Following the philosophy of Bunge, BWW [11], [12] postulated that the world is made of things – substantial individuals – which possess properties. Things change due to the loss or acquisition of new properties. Things which share their properties can be grouped into classes or kinds see Table 1, p. 222 [6] and [24]. The BWW ontology, and the models and theories derived from it, have been applied in various areas of IT, such as conceptual modeling, ontology engineering, data collection design, and data quality [25]–[29]. At the same time, BWW has been criticized for its physicalist focus, lack of attention to social and psychological phenomena and other issues (e.g., [10], [18], [23]).

The basis for BWW is based on two manuscripts from Bunge's 1977 and 1979 volumes. However, as Bunge frequently noted, ontology is inseparable from other beliefs, such as on how to obtain knowledge in the world [30]. Furthermore, since the publication of the 1979 volume, Bunge published over 400 manuscripts, further developing his ideas. Lukyanenko [21] details examples of the evolution of Bunge's writings since 1979, proposing the need for a new ontology. That analysis was limited to those constructs which BWW and the most recent work of Bunge had in common. In this paper, we outline the architecture for the new ontology based on more recent work of Bunge.

3 General Systemist Ontology - GSO

The main challenge in creating the new ontology is to distill and synthesize Bunge`s beliefs published in numerous different sources [21]. This new ontology is not derived from volumes of the *Treatise* which presented ideas systematically and with strong internal consistency. Rather, is has its foundation on the ideas spanning the last 40 years of Bunge's work.

The following are a proposed set of postulates which comprise the core of the General Systemist Ontology – GSO. They are derived from the work of Bunge and additional insights [21]. This is an upper-level ontology in that it is intended to take a systems approach that is applicable to many applications.

Bunge claims *Reality* is all that we know to exist and is distinguished into five "levels" of *reality*, which are physical, chemical, biological, social and technical [31, p. 25]. These levels may have different actual or perceptible to human properties or events, but all are ultimately grounded in the underlying physical level.

Postulate 1: *There are different levels of reality all based in physical reality*.

GSO adopts a new position that the world is made of *systems:* "everything is a system or a component of a system" [32, p. 23]. Bunge [33] explains (p. 174, emphasis added):

> The word 'system' is more neutral than 'thing', which, in most cases, denotes a system endowed with mass and perhaps tactually perceptible. We find it natural to speak of a force or field as a system but would be reluctant to call it a thing. By calling all existents "concrete systems" we tacitly commit ourselves *in tune with a growing suspicion in all scientific quarters* -- that there are no simple, structureless entities.

Consequently, we propose:

Postulate 2: *Reality is made of systems*.

Bunge asserts that systems are always composed of components or parts [32, p. 23], which are in themselves systems [21]. The systems in GSO are new ontological primitives; their composition and relationship with other systems are elaborated in a subcomponent of GSO. This CESM model conceptualizes systems in terms of four elements: *composition*, *environment*, *structure* and *mechanism* [34]. Bunge provides this example of a traditional nuclear family [30, p. 127]:

> Its components are the parents and the children; the relevant environment is the immediate physical environment, the neighborhood, and the workplace; the structure is made up of such biological and psychological bonds as love, sharing, and relations with others; and the mechanism consists essentially of domestic chores, marital encounters of various kinds, and child rearing. If the central mechanism breaks down, so does the system as a whole.

The possibility of the lack of "simple, structureless entities" [33, p. 174] leads to a controversial conclusion of an infinite recursion of systems. We do not take a stand on this (although note it is consistent with some recent thinking in string theory and astrophysics), and importantly point out that for the levels of reality of interest to IT (i.e., those beyond atoms), all systems *are formed from other systems*. While there could be no end per Bunge, we put a lower bound in GSO by stipulating that the reality of most interest to modern IT deals with systems which are composed of systems (e.g., atoms, molecules, social, technological systems, etc). Following the CESM model and our pragmatic focus on IT, we propose:

Postulate 3: *Systems of interest to IT are composed of systems*.

Postulate 4. *Systems exist in the environment of other systems.*

Postulate 5. The components of systems (sub-systems) *are related to one another through various types of bonds.*

Postulate 6. *Each system has its own mechanisms which define the behaviors of its sub-subsystems and the system as a whole.*

Systems have properties. There are properties of the components of systems. That is, there are sub-systems and the properties of the system as a whole – i.e., emergent properties.

Postulate 7. *Each system has properties: both of its sub-systems and of itself.*

The Postulate 1 of reality, being made of levels, is understood as composition of systems. We can thus postulate:

Postulate 8. *Each level of reality is defined by a set of systems at that level (and their emergent properties).*

Systems with "one or more" common properties in GSO [31, p. 111], form *classes* and those with properties which are interrelated, form *kinds* [30, p. 13].

Postulate 9. *A system with common properties can be grouped into classes and kinds.*

Some, but not, all systems undergo change, resulting in emergence (addition of new) or submergence (loss of old) of properties. A *state* is the list of the properties of the system at a given moment in time.

Postulate 10. *A state is the list of the properties of the system at a given moment in time.*

Notably, in GSO only concrete systems have states, as only concrete systems undergo change. GSO distinguishes two kinds of system: *conceptual* and *concrete*. A *conceptual* system is a system all the components of which are conceptual (e.g., propositions, ideas, theories). A *concrete* (or *material*) system in contrast are made of concrete subsystems, such as atoms, organisms, and societies.

Concrete systems are mutable; that is, they change in the virtue of energy transfer. For Bunge, [30, p. 12], "energy is not just a property among many. Energy is the universal property, the universal par excellence".

Postulate 11. *A concrete system is a system that has energy.*

When energy is transferred from one systems to another, an event occurs [30, p. 91]:

> Event C in thing A causes event E in thing B if and only if the occurrence of C generates an energy transfer from A to B resulting in the occurrence of E.

Multiple events form *processes.* A process is defined as "a sequence, ordered in time, of events and such that every member of the sequence takes part in the determination of the succeeding member" [33, p. 172].

Postulate 12. *A concrete system has events and processes.*

Laws, which are applicable to concrete systems only, are stable patterns which hold "independently of human knowledge or will" [31, p. 27]. Laws are thus the patterns of events and processes.

Postulate 13. *A law is a stable pattern of events and processes.*

First, because systems can be concrete or conceptual, a deep specification of each of these systems is needed. Bunge [30] discusses at length how systems interact. This introduces notions of *causality*, *trigger* and *chance* as different considerations for understanding useful patterns of interactions.

Postulate 14. *Concrete systems change states due to interaction with other systems.*

Furthermore, each interaction happens via different types of energy transfer (e.g., mechanical, thermal, kinetic, potential, electric, magnetic, gravitational, chemical). This affects the outcomes of the interaction, including the change in properties of systems. For example, thermal energy transfer can lead to change in chemical composition of a system.

Postulate 15. *The change of state of systems depends on the type of energy transfer which occurs.*

Bunge views ontology and epistemology as inseparable and an important expansion of GSO is into Bunge`s epistemology. GSO connections with epistemology are numerous and multilayered. Thus, *phenomenon* [33, p. 173] is an occurrence registered by the sensory apparatus of humans or other animals triggered by a change or a serious of changes in the state of a concrete system.

Postulate 16. *Phenomenon is a change in the human system due to change in another concrete system.*

Furthermore, events, processes, phenomena, and concrete systems are *facts* – mental objects of human thought about systems [33, p. 174]. Facts are observed and subjected to "purposeful and enlightened perception" [33, p. 181]. Observations can be *direct* when the object of observation is perceptible and *indirect* – "a hypothetical inference employing both observational data and hypotheses" [33, p. 181]. As most observations are indirect, the theories and human background knowledge become central themes in Bunge`s epistemology. Humans theorize about unobserved properties of systems, as well as the unobserved elements of the system based on the CESM model.

We summarize these ideas in the following postulates:

Postulate 17. *Facts are objects of observation.*

Postulate 18. O*bservations can be direct and indirect.*

Postulate 19. *Indirect observations are required to reason about unobservable facts.*

Postulate 20. *Indirect observations are made with the help of mental theories about properties of concrete systems.*

GSO is based on the core architecture around systems formalized as Postulates 1-20. These postulates, then, form the foundation of an upper-level ontology of GSO.

4 Discussion and Conclusions

The work of the philosopher Mario Bunge has been an important influence on ontology research in IT, including in conceptual modeling. Although prior work on conceptual modeling were based on BWW, we have proposed a new ontology. The General Systemist Ontology provides a new, systems perspective for conceptual modeling, based on the more recent writings of Bunge. GSO puts systems at the center of reality and builds other ideas around this fundamental notion. This results in a set of postulates and constructs that can serve as a basis for representations that seek to capture the way the real-world is and how it functions. Based on GSO, ontology-based conceptual modeling could consider greater support of systems and ensure that systemic properties, such as emergent properties and elements of the CESM model are embedded in conceptual modeling constructs. While some of these ideas exist in conceptual modeling research (e.g., the aggregation construct of UML), the extent to which existing models, or any extensions, align with GSO, could be useful for modeling real world phenomena.

The GSO is significantly nuanced in representing the change of (concrete) systems. Specifically, the new notion of energy is a key construct, because energy transfer allows systems to acquire or lose properties. There are different forms of energy in the world. Despite its importance, the notion of energy has so far escaped the theoretical toolbox of conceptual modeling. The question remains as to whether this notion could advance conceptual modeling practice. GSO also introduces phenomenological considerations, including the notion of phenomena, as well as the path from phenomena to human theories and mental models about the world. This is a notable departure from BWW, which focuses on the physical composition of reality (with the exception of the notions of classes and attributes, which are also part of GSO). GSO, therefore, contributes to the new area of phenomenological ontology although the synergy between GSO and other phenomenological ontologies [35] should be investigated.

Typical use cases for GSO include modeling of phenomena where the systemic aspects are especially essential for emphasizing and capturing. For example, if the goal is to capture observations of individual birds in a region, BWW has been shown as suitable in an application [36]. If the goal is to depict how, due to climate change, birds engage with their environment (which is composed of systems, such as fish, ocean currents, tides, winds, cliffs, predators), and how different sub-systems of birds factor into these interactions (i.e., their digestive system), GSO may provide greater expressiveness and support. Further research is needed to identify typical use cases for GSO, and to provide guidance for when to adopt this ontology.

As any ontology, GSO may have limitations for some conceptual modeling applications due, for example, to its endurantist view, of denial of existence of properties of properties. Some of these have been shown limiting for certain conceptual modeling uses [37], so further development of GSO is needed to better assess the boundaries of GSO and overcome these limitations.

This description of BSO features the essential ideas of the more recent thinking of Mario Bunge and should provide the necessary basis to motivate continued work on GSO, including formalization of the elements of the ontology, comparison of GSO to other major ontologies (e.g., DOLCE [8], UFO [9], GFO [11] and others) and developing applications of GSO for conceptual modeling and other areas of IT.

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