Ontology as a System

Technical Report · October 2019

DOI: 10.13140/RG.2.2.19493.45281

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Technical Report, SC-TR-00031
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System Concepts LLC, October 2, 2019

I. INTRODUCTION

Human beings use the term 'ontology' in a wide variety of contexts and applications. This document addresses ontology definitions, concepts and semantics. The discussion, evaluation and presentation of these ontological aspects is guided by the frameworks and system analysis depicted in Figure 1 that are associated with the General System Cube [Simpson and Simpson, Feb, 2019].

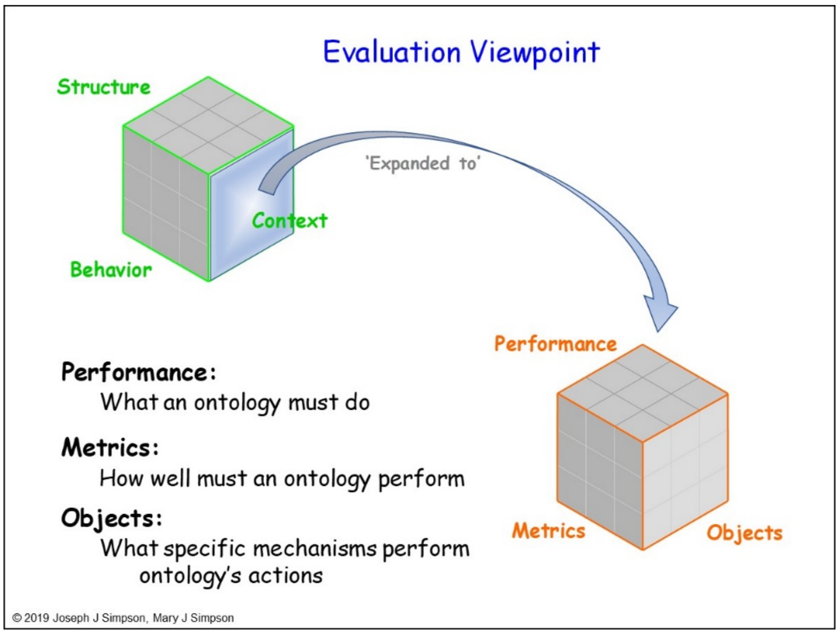

Figure 1. Evaluation Viewpoint

The subject of the system analysis, in this case an ontology, is evaluated to determine

- what the ontology must do,
- how well the ontology must do it, and
- the specific mechanisms used to perform what the ontology must do.

What an ontology must do is used as a starting point in this evaluation. The evaluation moves on to consider how well the ontology performs – ontological performance metrics. Finally, an overview of those objects and architectures used to satisfy ontological performance is provided to complete the 'ontology as a system' evaluation.

Given this approach, Section II, What an Ontology Must Do, discusses the functions and performance of an ontology. Section III, How Well an Ontology Must Perform, discusses the performance metrics associated with any specific ontology. Section IV, What Objects Create an Ontology, discusses the objects and components associated with a specific ontology. Section V, Ontology Contextual Integration, discusses a range of components needed to create an operational ontology framework. Section VI, Summary and Conclusions, presents a summary and short discussion of the document's content.

II. WHAT AN ONTOLOGY MUST DO

The following definitions for an ontology are used as foundational bases upon which a more detailed discussion is presented.

An ontology is defined as:

- "1. a branch of metaphysics concerned with the nature and relations of being
  Ontology deals with abstract entities.
  2. a particular theory about the nature of being or the kinds of things that have existence" [Merriam-Webster, 2019]

- "Ontology is the philosophical study of being. More broadly, it studies concepts that directly relate to being, in particular becoming, existence, reality, as well as the basic categories of being and their relations. Traditionally listed as a part of the major branch of philosophy known as metaphysics, ontology often deals with questions concerning what entities exist or may be said to exist and how such entities may be grouped, related within a hierarchy, and subdivided according to similarities and differences." [Wikipedia, Sept. 2019]

- "An ontology is a specification of a conceptualization." [KSL.Stanford.Edu, 2019]

- "... an ontology is a catalog of the types of things that are assumed to exist in a domain of interest (D) from the perspective of a person who uses language (L) for the purpose of talking about D. The types in the ontology represent the predicates, word senses, or concept and relation types of the language (L) when used to discuss topics in the domain (D)." [Sowa, 2000, p. 492]

- "In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. The representational primitives are typically classes (or sets), attributes (or properties), and relationships (or relations among class members). The definitions of the representational primitives include information about their meaning and constraints on their logically consistent application. In the context of database systems, ontology can be viewed as a level of abstraction of data models, analogous to hierarchical and relational models, but intended for modeling knowledge about individuals, their attributes, and their relationships to other individuals. Ontologies are typically specified in languages that allow abstraction away from data structures and implementation strategies; in practice, the languages of ontologies are closer in expressive power to first-order logic than languages used to model databases" [Gruber, 2007]

- "An ontology is a formal description of knowledge as a set of concepts within a domain and the relationships that hold between them. To enable such a description, we need to formally specify components such as individuals (instances of objects), classes, attributes and relations as well as restrictions, rules and axioms. As a result, ontologies do not only introduce a sharable and reusable knowledge representation but can also add new knowledge about the domain." [Ontotext USA, Web Home Page, Sept, 2019]

Based on the given ontology definitions, an ontology must:

1. **Organize**,
2. **Relate**, and
3. **Present**

the things, structures and relationships (organized as knowledge) that exist in a specific domain. The domain may be foundational in the sense that it is a general domain that applies to all other domains. Or the domain may be constrained to a specific area of interest. The scope of the domain of interest is a constraining design factor associated with a specific ontology. The ontology language is another constraining ontology design factor. The intended audience or consumer of the ontology further shapes the ontology's purpose, structure and form. In every case, an ontology must present an organized model of the concepts and knowledge associated with the domain on interest.

A wide range of relationships may be used to organize an ontology. Typical relationships include, is-a-subclass-of, is-a-superclass-of, is-a and is-part-of. Ontology relationships may address the relationship between and among specific items, specific categories of items or between item categories and single items. Further, collections of items and categories may be addressed using the appropriate relationships. The type of relationship is strongly associated with a type of item organization. If an ontology includes discrete items, classes of items, and collections of both classes and items, then the ontology must be organized in a manner that supports the ontology performance goals as well as the ontology communication objects and media.

While there is a strong connection between an ontology's organization and its relationships, the target audience for an ontology also impacts the manner in which an ontology is constructed and communicated. The subjects of an ontology are abstract entities. However, a useful ontology is encoded into a range of concrete forms and distributed in a number of communication channels. An ontology that is available in a computer executable form will need to consider the types of network graphs created by the ontology relationships. The speed, usability and acceptance of an ontology may strongly depend on types of graphs and data structures that are used in the ontology application.

An ontology may be created to support a wide range goals and mission objectives. Some typical goals and mission objectives associated with ontology creation and development are:

- Support domain knowledge analysis,
- Clearly identify and categorize domain knowledge,
- Document domain assumptions and context,
- Share common domain knowledge structures, and
- Support reuse of domain knowledge.

The ontology's intended audience (human or software agent) has a strong impact on the ontology's configuration, language, and structure. In the final analysis an ontology must effectively communicate domain knowledge, at the proper level of abstraction, to the intended audience.

III. HOW WELL AN ONTOLOGY MUST PERFORM

As discussed in the previous section, an ontology has three basic activities: (1) organize, (2) relate, and (3) present knowledge associated with the domain of interest. These activities are interrelated and any ontology design decision must consider the total integrated performance of the complete ontology. When considering ontology performance, it is helpful to distinguish between an ontology intended for human readers and an ontology intended for software agent execution and processing. The structure of a human readable ontology must address the limited memory and recall capabilities associated with human beings. Simple network knowledge graphs based on a single structuring relationship may be used to increase semantic understanding and communication with human beings. Machine executable ontology structures may be presented in graph types that have efficient searching and transform operations. The best knowledge graph structures would support both the human communication constraints and the computational complexity constraints.

The ontology domain and context also provide performance goals and objectives. No ontology stands alone. An ontology must be designed to work with a range of logic types, other domain ontologies, other domain information constructs (taxonomies) and communication channels. These performance issues may be addressed using standard interfaces that provide controlled access to the ontology structure.

How well an ontology must perform depends directly on the initial state of domain knowledge and the identified need for the final ontology. In a completely unstructured and open application area, the development of an ontology will begin to organize, structure and document the application area knowledge. The organization and structuring proceeds until the ontology performance objectives are achieved. In some cases, simple classification, documentation and communication of the fundamental knowledge in the domain may be all that is required. In other cases, complex concepts, knowledge structures, and relationships must be arranged in a manner that interfaces among humans, software agents and other ontology processes and software agents. The performance of any specific software and/or software component is directly dependent on the required ontology capability.

IV. WHAT OBJECTS CREATE AN ONTOLOGY

The objects that are used to create an ontology depend directly on the ontology audience, the language used to encode the ontology, and the degree to which an ontology must interact with other existing ontologies and information artifacts. At the most fundamental level, an ontology is a catalog of the types of things that exist in any specified domain. This catalog of types is developed using a specific view of the domain of interest. Using this description of an ontology, an ontology could be encoded in a wide range of artifacts, objects and configurations. The specific collection of objects used to create an ontology is based on the primary goals and objectives of the ontology. An ontology could be as simple as an abstract list of categories related in a simple manner. Or, an ontology could be constructed from a wide range of conceptual templates that are encoded in executable software that interact with an adaptable set of persistent data stores and objective rule sets. If an ontology is abstract and simple, then it has value in domains that are not well-defined and understood. The lack of understanding in the domain space can be associated with the ontology types, or the relationships between the types in the catalog.

Structural modeling, used to structure unknown or poorly defined systems, is a very simple type of an ontology. One structural relationship is selected to enable an evaluation of a collection of objects of the same category. Using a well-defined structural modeling approach, an ontology may be developed by integrating the result from one or more structural modeling activities. This type of ontology development is effective because of the clear, focused knowledge development performed at each interaction. Structural modeling also allows for the integration of other knowledge sources using the abstract relation type (ART) approach [Simpson and Simpson, April, 2009].

A formal, software-executable ontology has many more components (objects) than a simple, text-based, human-readable ontology. A more formal ontology may include: formal concept descriptions, classification templates, class attributes, class relationships, domain constraints, rules and axioms. Properly constructed, these more formal, software-executable objects create a knowledge representation that is interoperable and shareable. Many types of ontology objects are the subject of national and international standards. These standards help create an interoperable, dispersed ontology environment. The Object Management Group (OMG) Distributed Ontology, Model, and Specification Language (DOL) is an example of this type of standard [https://www.omg.org/spec/DOL/About-DOL/]. The OMG DOL standard addresses the following ontology objects: (1) semantics, (2) logic, (3) language, and (4) encoding types.

It is clear that there could be two or more ontologies associated with a specific domain of interest. Each ontology in the collection could have different knowledge models and/or structuring relationships. While it is possible in some cases to integrate a collection of ontologies into a single ontology, this is an area of active research and development.

V. ONTOLOGY CONTEXTUAL INTEGRATION

As discussed in the previous section, the integration of two or more ontologies is a challenging task and has the capability to add great value if properly performed. Knowledge reuse is a primary source of value created when multiple individual ontologies are integrated within a given context. As a practical matter, knowledge identification, development and structuring are challenging and costly activities. Formulating specific components of domain knowledge into reusable, integrable modules creates great value for individuals who wish to develop one or more domain ontologies. As shown in Figure 2, 'Abstract Relation Type,' and Figure 3, 'Abstract Relation Type Integration,' ART forms may be constructed in a manner that allows a collection of ART forms to be effectively integrated. Each ART configuration has the capability to represent an independent model of the domain knowledge.

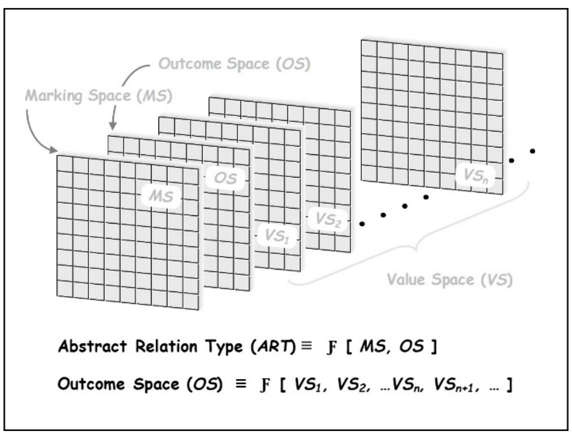

Figure 2. Abstract Relation Type (ART).

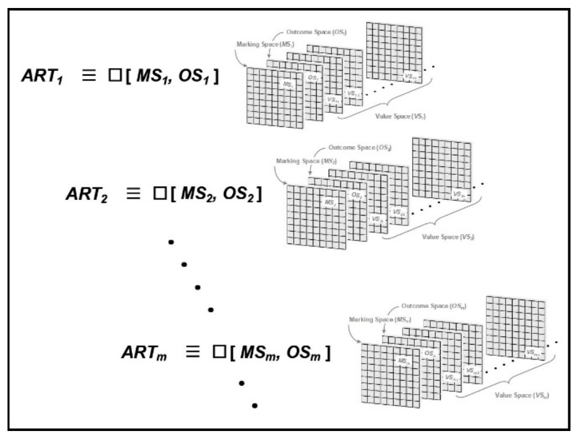

Figure 3. Abstract Relation Type Integration.

The ART form is based on the work of John N. Warfield and Charles Sanders Pierce. [Warfield, 1994] work in the area of the 'science of generic design' used binary matrices to encode domain knowledge. Charles Sanders Pierce's work in the area of the logic of relatives can be represented using binary matrices as shown by Jon Awbrey:

[https://oeis.org/wiki/Peirce%27s_1870_Logic_Of_Relatives_%E2%80%A2_Part_1].

The ART form provides a straightforward mechanism to encode domain structural knowledge and integrate this structural knowledge with the other key types of specific domain knowledge (behavior and context) through the use of binary matrices. A range of logic approaches (i.e., description logic, predicate logic, propositional logic, …) may be used to insert and retrieve knowledge from an ART form. The adaptive nature of the ART form makes it an excellent candidate for ontology integration activities.

VI. SUMMARY AND CONCLUSIONS

An ontology is a very loosely defined term. The range of ontology definitions currently in use are sufficient to allow confusion and contradictions in the application of the term. Using the evaluation perspective construct to detail the performance, metrics and objects associated with a given class of ontology constructs helps to address the confusion and minimize contradictions. At the most basic level, a distinction must be made between an ontology associated with metaphysical discourse and an ontology that is encoded in software and intended for use by software agents.

When an ontology development task is applied in a new domain, the processes and activities associated with structural modeling may be put to use in an effective and efficient manner. Further, the ART form may be used to encode knowledge and information in a manner that is structured, modular and integrable. More work is required to demonstrate specific ART forms associated with the logic of relatives, and how these forms may be integrated with the standard structural modeling ART forms.

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Appendix A: Definitions

Abduction generates theories, conjectures, hypotheses, and explanations not yet verified by induction or deduction [Simpson and Simpson, 2018, March].

Abstract (A) is pure information as distinguished from any particular encoding of the information in a physical medium. Formally, Abstract is a primitive that satisfies the following axioms:

- No abstraction has a location in space: $\sim(\exists x\text{:Abstract})(\exists y\text{:Place})\text{loc}(x,y)$.
- No abstraction occurs at a point in time: $\sim(\exists x\text{:Abstract})(\exists t\text{:Time})\text{pTim}(x,t)$.

As an example, the information you are now reading is encoded on a physical object in front of your eyes, but it is also encoded on paper, magnetic spots, and electrical currents at several other locations. Each physical encoding is said to *represent* the *same* abstract information [Sowa, 2000].

Augmented human intelligence is the proper alignment of computer-based resources focused on providing the information humans need, in a format that humans can process, to perform the value analysis tasks at which humans excel.

Boolean reasoning is based on Boolean equations, and not on the predicate calculus. Boolean reasoning is based on the Blake canonical form, and syllogistic reasoning. The Boolean reasoning used in this paper is similar to, but different than, switching theory or Boolean minimization approaches [Brown, 2003]. Warfield's use of a zero (0) to represent either the formal logical notion of false (mathematical concept) or the empirical real-world state of unknown (empirical knowledge), is a key operation that integrates the operations of the system 'metalanguage' (natural language relationships) and system 'object language' (mathematical relations).

Complexity is defined as the measure of the difficulty, effort and/or resources required for one system to effectively observe, communicate, and/or interoperate with another system [Simpson and Simpson, 2009, p. 2].

Deduction is a process of formal, mathematical reasoning that produces a conclusion based on a set of assumptions given as true [Simpson and Simpson, 2018, March].

Degenerative structural thread is defined as a malformed or degenerative structural thread that is composed of a single object. Given a single object there is no other object to support a relationship connection.

Degree of focus: A relationship's 'degree of focus' is a numerical value that indicates how many AMEI categories are associated with any given natural language structural relationship. The minimum dispersion value is two (2) and the maximum dispersion value is twenty-seven (27) [Simpson and Simpson, August, 2017].

Dispersed natural language structuring relationship attribute: A dispersed natural language structuring relationship is dispersed if it maps to more than one logical property group within the AMEI. The dispersed attribute's numerical values range from two (2) groups to twenty-seven (27) groups. This numerical value provides a dispersion metric that describes the 'degree of focus.' [Simpson and Simpson, August, 2017].

Global attribute of a system structuring relationship structures a system using a mediating artifact between and among the system objects [Simpson and Simpson, June, 2017, p. 10]

Identity matrix is a square matrix that has a one (1) in each cell on the matrix diagonal.

Induction generates conclusions based on observations of experimental data [Simpson and Simpson, 2018, March].

Inference reduces uncertainty and develops clear objective views of the world [Simpson and Simpson, 2018, March].

Local attribute of a system structuring relationship operates directly between and among the system objects without a mediating artifact [Simpson and Simpson, June, 2017, p. 10].

Mathematical model relations are the formal mathematical constructs used to represent the natural language structuring relationships in a well-defined formal manner.

Mathematical relations focus mainly on the relations of sets, and set members. Warfield built on Hilbert's 'language pair' concept of metalanguage and object language to view mathematical relations as the 'object language,' while viewing natural language relationships as the 'metalanguage' [Warfield, 1994:47].

Natural language relationship is a term used in human conversation and contextual discourse to indicate some type of order, structure or other manner in which two or more objects are associated between and among themselves. A natural language relationship conveys substantive real-world knowledge, and is an interpretive relationship. Warfield identified six categories of interpretive relationships: 1) definitive, 2) comparative, 3) influence, 4) temporal, 5) spatial, and 6) mathematical [Warfield, 1994:60-61].

Order: If a binary relation, R, is reflexive and transitive, and R and the complement of R, are antisymmetric, then R is called an order [Simpson and Simpson, October, 2014].

Partial Order: If the complement of R is not antisymmetric and all other conditions are met, then R is called a partial order [Simpson and Simpson, October, 2014].

Physical (P) is an entity that has a location in space-time. Formally, Physical is a primitive that satisfies the following axiom:

- Anything physical is located in some place: $(\forall x\text{:Physical})(\exists y\text{:Place})\text{loc}(x,y)$.
- Anything physical occurs at some point in time: $(\forall x\text{:Physical})(\exists t\text{:Time})\text{pTim}(x,t)$.

  More detailed axioms that relate physical entities to space, time, matter, and energy would involve a great deal of physical theory, which is beyond the scope of this report [Sowa, 2000]].

Reachability matrix: A reachability matrix is a square, transitive, reflexive, binary matrix (M), which serves as a model matrix for a matrix model whose model relation is 'is antecedent to' [Warfield, 1976, p. 231].

Reflexivity: Reflexivity involves one individual object. The logical properties constituent to the Reflexivity grouping are the reflexive, irreflexive, and nonreflexive property. If a relation is reflexive, then an object bears this relation to itself ($x\text{R}x$). An irreflexive relation states that no object bears this relation to itself ($x \not{\text{R}} x$). The nonreflexive logical property is a composite property, which states that in a set of objects, some objects are reflexive and some objects are irreflexive [Simpson, Simpson, and Kercheval, Mar 2017].

Specific natural language structuring relationship attribute: A specific natural language structuring relationship is specific if it maps to only one logical property group within the AMEI [Simpson and Simpson, August, 2017].

Structural thread: Artifacts created on structural graphs when two or more objects are connected using a relationship link; a term used to identify a pattern of relationship connections in a structural graph. [Simpson and Simpson, June, 2017, p. 11]

Symmetry: Symmetry involves two individual objects. The symmetric, asymmetric and nonsymmetric logical properties belong to the Symmetry grouping. A symmetric relation requires that if object x bears a relation to object y, then object y also bears a relation to object x ((if $x\text{R}y$, then $y\underline{\text{R}}x$) *and* (x != y)). An asymmetric relation states that if object x bears a relation to object y, then object y does not bear a relation to object x ((if $x\text{R}y$, then $y \not{\text{R}} x$) and (x != y)). The nonsymmetric logical property is a composite property and can only exist when a set of objects have both symmetric and asymmetric relations mapped among them [Simpson, Simpson, and Kercheval, Mar 2017].

System may be defined in a number of ways.

- A ‘construction rule’ definition; that is, a system is a relationship mapped over a set of objects [Simpson and Simpson, Oct 2014].
- The ‘functional rule’ definition of a system is “a constraint on variety,” wherein constraint identifies and defines the system of interest [Heylighen, 1994].
- A ‘contextual’ definition: that is, a system is simply a whole that can be decomposed into its parts, and is a convenient means of facilitating the description and analysis of anything [Mar, 1994].

Transitivity: Transitivity involves three or more individual objects. Transitive, intransitive, and nontransitive relations all belong to the transitivity grouping. Transitive relations state that if object x bears a relation to object y and object y bears a relation to object z, then object x also bears a relation to object z ((if ($x\mathrm{R}y$ and $y\mathrm{R}z$), then $x\mathrm{R}z$) *and* (x != y != z)). Intransitive relations state that if object x bears a relation to object y and object y bears a relation to object z, then object x does not bear a relation to object z ((if ($x\mathrm{R}y$ and $y\mathrm{R}z$), then $x \not\mathrm{R} z$) *and* (x != y != z)). The nontransitive logical property is a composite property and may only exist where a set of objects have both transitive and intransitive relations mapped among them [Simpson, Simpson, and Kercheval, Mar 2017].