An Overview of the BFO - Basic Formal Ontology - And Its Applicability to Satellite Systems

BRANDÃO, A. [1], **LOUREIRO, G.** [2]

[1] Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil
Aluno de Mestrado do curso de Engenharia e Gerenciamento de Sistemas Espaciais - CSE

[2]Instituto Nacional de Pesquisas Espaciais, São José dos Campos, SP, Brasil
Chefe do LIT - Laboratório de Integração e Testes

adolfo.brandao@gmail.com

geilson.loureiro@inpe.br

Abstract. *This work aims to present an overview of the top level ontology BFO - Basic Formal Ontology - and analyze its applicability to Satellite Systems. As a top level ontology, the BFO was designed to be extended, providing the basis for the specification of detailed representational artifacts about scientific and application information domains. These aspects and the challenges of satellite systems complexity and large size compose a suitable scenario for the creation of a specialized dialect to improve efficiency and accuracy when modeling such systems. By analyzing BFO based ontologies in other disciplines and existing satellite models it is possible to describe an application for satellite systems, which can provide a foundation for the creation of a concrete ontology to be applied on satellite modeling. As part of an ongoing work about satellite ontologies, it was found that BFO can be a powerful tool in the effort.*

Keywords: Ontology; Knowledge-based engineering; Complex systems; Model based systems engineering; Satellite systems.

1. Introduction

An ontology is a representational artifact composed of a taxonomy, concepts and relations between them, concerning an informational or scientific domain. Therefore, it formalizes knowledge about a specific subject and is studied nowadays by information systems, knowledge management and knowledge-based engineering disciplines, as opposed to philosophy, by the time of Aristotle [Rees 1954].

One purpose of ontologies is to allow consistent sharing, interchanging, collaboration, reuse and continued knowledge development among scientific communities regardless of location, language and sociocultural aspects, mainly by computational resources. This goal can only be achieved if knowledge is structured according to a formal, common computer based parley.

As observed by many scientists in many disciplines, as society evolves, also do the problems. Increasing demand for solving more complex problems require more advanced techniques and tools. According to [Warwick 2016],

> "It did not seem to matter as much in the heydays of the 1950's and 60's, when programs with technically unachievable goals were launched and canceled with astonishing regularity. But today shareholders and taxpayers, as well as customers, demand accountability, and program performance has become a crucial issue."

For those ever growing complexity problems, it is needed that computers are empowered with common means in order to share, reuse and expand knowledge. As stated by [Liu et al. 2005],

> "The task of computing is seamlessly carried out in a variety of physical embodiments. There is no single multi-purpose or dedicated machine that can manage to accomplish a job of this nature. The key to success ... lies in a large-scale deployment of computational agents capable of autonomously making their localized decisions and achieving their collective goals."

This is only achievable if disparate computers communicate efficiently among each other. This is one of the purposes of ontologies. One specific kind of ontology, upper level, or top level ontologies, allows two ontologies to be accurately related to one another. They do not specify an information domain, but rather lay down the common extensible structure needed to relate specific domain ontologies, being a tool for integrating and sharing knowledge.

On the satellite systems perspective, why is it needed an ontology? Letting aside the knowledge sharing and scientific development aspect, the very nature of complex systems is to be called to answer this question: Intricateness, size, variety, among others [Macau 2002]. According to [Skarka 2007],

> "Scientific literature shows that 80% of design engineers activities is related to repetitive, routine tasks, while the remaining 20% on innovative tasks."

A reason to use ontologies for product development is that it can encapsulate much information in a single concept, providing standard practices and reuse, enabling engineers to engineer more, instead of repeating manual, error prone work. When a problem is solved, or an error is corrected, it can be consistently propagated by the use of an ontology. This can reduce costs and improve quality, which is another very compelling reason.

At this point of our research there could not be found a single ontology related to designing and modeling satellites on the system level. This is why we think that creating such ontology would be an important contribution and is the subject of an ongoing work, mentioned in Section 5.

2. Methodology

We executed an extensive, but not exhaustive literature examination on several published papers related to the subject matter in question, to determine whether this work is relevant in terms of scientific contribution. Material produced for an ongoing bibliometrics [McBurney and Novak 2002] work has been used, in which keyword searches followed by paper analysis were performed. This procedure is being carried on by executing a set of steps, described below and represented by Figure 1:

1. Mainly IEEE and Engineering Village were searched at this point of the research;
2. Objective keywords regarding ontologies, systems engineering, space systems and satellite engineering were searched for;
3. Time frame was set from beginning of all publications at each database;
4. Title and abstract were defined as the search attributes;
5. Papers were filtered according to most relevant titles;

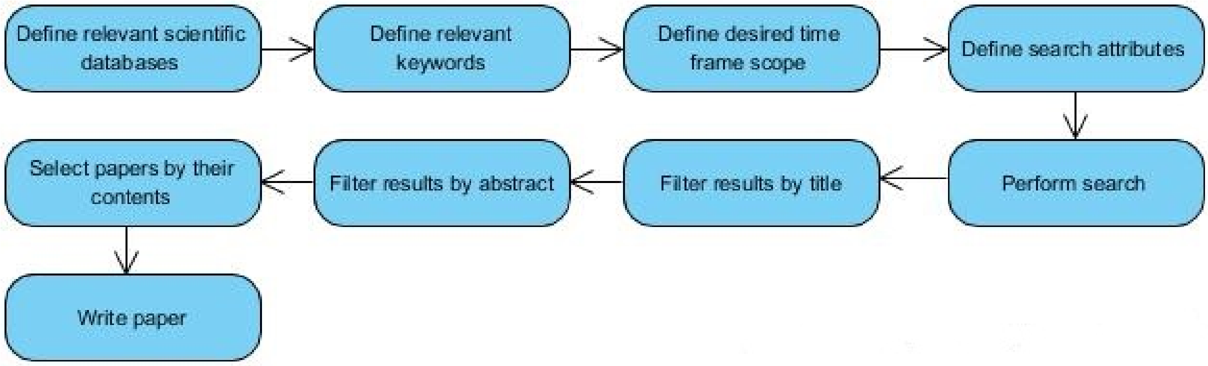

Figure 1. Research methodology steps.

6. Filtered papers were filtered again according to most relevant abstracts;
7. Filtered papers were selected based on the most relevant contents;
8. Article was written based on selected papers and author experience.

3. Results and Discussion

Some Considerations About Ontologies

Ontologies represent things that exist, things that are. In this prisma, they can be used to represent any physical thing in the world, any domain of information including complex systems, engineering systems and satellite systems. The most popular areas we could identify in which ontologies are vastly used are biology, medicine, pharmacology, chemistry and computer science. BFO was used in the design of a large list of industry ontologies, which can be found in [Arp et al. 2015]. In engineering in general and specifically in aerospace engineering, there are very few ontologies compared to other sciences.

After researching most popular scientific sources, very few ontology research works related to aerospace engineering and even less for satellite development were found. Among those works we can mention a few: [Arvor et al. 2019], a research which focuses on the capacity of ontologies to represent both symbolic and numeric knowledge, to reason based on cognitive semantics and to share knowledge on the interpretation of remote sensing images; [Cox et al. 2016], an ontology to characterize space objects according to a variety of parameters including their identifiers, design specifications, components, subsystems, capabilities, vulnerabilities, origins, missions, orbital elements, patterns of life, processes, operational statuses, and associated persons, organizations, or nations; [Malin and Throop 2007], a paper which paper describes a set of taxonomies for interpreting descriptions of aerospace entities, functions, properties and problems; [Blasch 2015], a work which explores the concepts of ontologies for applications to aerospace avionics as motivated by the NextGen and Single European Sky ATM Research (SESAR) standards and [Verhagen and Curran 2011], a paper about the development of an ontology for the aerospace composite manufacturing domain.

BFO Overview

BFO was created as a result of experience and practice. It has evolved from the Gene Ontology - GO [Ashburner et al. 2000], which has the purpose of representing the gene scientific domain. It was developed during years of research and practice, making it a very broad, general ontology, capable of representing all kinds of concepts. The most basic high level concepts of BFO are *Universals* and *Particulars*, reused from Aristotle [Rees 1954] which are applied to represent types and instances. Those can be easily understood by applying an analogy to computer

Table 1. BFO relations.

Universal-universal relations		
is_a	continuant_part_of	occurrent_part_of
Spatial and temporal relations		
adjacent_to	derives_from	preceded_by
has_participant	proper_continuant_part_of	proper_occurrent_part_of
has_continuant_part	integral_continuant_part	has_occurrent_part
integral_occurrent_part		

programming languages variables and its types. For example, a numeric variable with value 10 is of the type number. In this case, number is the *Universal* and 10 is the *Particular*. The development of a BFO based ontology must define specific concepts according to the desired information domain, or application domain, by extending those high level terms or, in other words, by adding new characteristics to them.

BFO Entities

BFO presents many concrete elements (entities and relations) which allow to define a precise communication language and semantic for any domain, including satellite systems, which comprise our object of study. BFO, as all ontologies, is composed of a hierarchy of concepts, but following the single inheritance rule, where the elements are described from top down, increasing the level of detail and decreasing the level of generality, inheriting the characteristics of only one upper element. Lower elements are specializations of upper elements. Except by the top-most element, all elements in BFO have one more general concrete type. This hierarchical inheritance principle is fundamental to ontological languages based on a top level ontology because they are designed by extending the definition and characterization of the base concepts and defining possible relations between the new extension concepts. Figure 2 summarizes the entities defined by BFO 2.0 in [Ruttenberg 2019], and the element hierarchy.

BFO Relations

BFO defines two main kinds of relations: 1) Universal-Universal relations: relations between two universals and 2) Spatial and Temporal relations: treatment of location and adjacency and temporal aspects of relations. Table 1 provides the BFO relations defined by [Arp et al. 2015].

BFO Applicability to Satellite Systems

According to [Arp et al. 2015], BFO is an upper-level ontology developed to support integration of data obtained through scientific research. In this sense, it can support the integration of the disparate disciplines involved in a satellite design project, because diverse teams and sets of knowledge are required in order to be composed as a whole. For that to be achieved, models of different nature must have a mechanism of vocabulary synchronism and integration. This BFO integration feature is made clear by [Arp et al. 2015]:

> "BFO is deliberately designed to be very small, in order that it should be able to represent in consistent fashion those upper-level categories common to domain ontologies developed by scientists in different fields ... BFO assists domain ontologists by providing a common top-level structure to support the interoperability of the multiple domain ontologies created in its terms."

It can be noticed in Figure 2 and Table 1 the diversity and generality of the terms comprising the BFO entities and relations. This makes possible to reach the objective of being a tool to

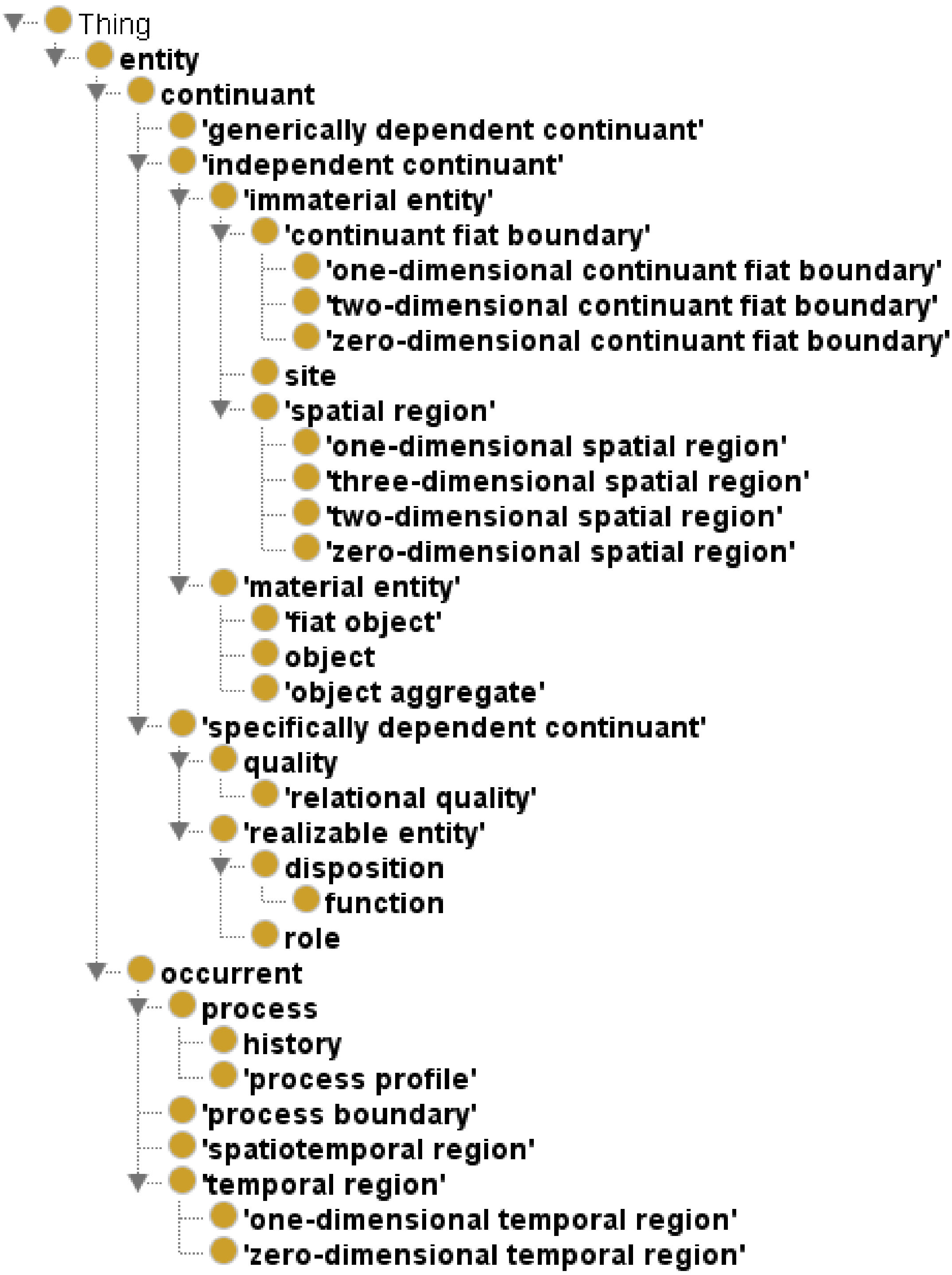

Figure 2. BFO 2.0 entities. [Source: https://github.com/bfo-ontology/BFO/wiki]

construct languages and representational artifacts to be applied in any field of science, including satellite systems modeling.

Structure and Behavior

A top level ontology, such as BFO, provides the base concepts, is very general and capable of scaling down to more specific areas while making it possible to maintain the structure and logic of all things to be represented. Also, it is by nature carefully designed to be extended. It brings concepts for things that are (*Continuants*), things that occur (*Occurrents*), going down to a certain level of generality, after which the concepts must be specific to the domain in question; By defining *Continuants* and *Occurrents*, it covers both static (structure) and dynamic (behavior) aspects of satellite design concepts such as its physical constituent parts and its behavior function flows.

Element Detailment

Many elements in BFO can be used to detail parts of a satellite system, including *Quality*, *Disposition*, *Function*, *Specifically Dependent Continuant*, *Generically Dependent Continuant*, among others. Those can provide a means to formalize fine grained details which can be further reused and shared among projects. Also, other information modeling ontologies can be applied to represent very precise modeling constructs, including standard and complex systems of engineering units. By formalizing qualities, or attributes, it becomes possible to ensure only pertinent qualifiable elements can be qualified with specific information.

Subsystems Interfaces

Many constructs from BFO target the relationship among parts which can be further refined. *Site*, *Spatial Region*, *Continuant Fiat Boundary* are entity examples. From the relations side, all the relations from BFO can be used directly or refined to represent interfaces at any level in a satellite system, such as *adjacent_to*, *has_participant*, and others. By designing semantic language rules, roles in an interface interaction can be validated in order to fulfill their responsibilities by providing only valid information, energy or matter, at a conceptual level.

Risks and Failures

Failure Modes and Effects Analysis is a very powerful tool do identify actions to mitigate possible failures and should be carried out for all aerospace systems, including satellite systems [Mozaffari et al. 2013]. [Ebrahimipour et al. 2010] proposes an approach to use an ontology to carry on FMEA activities in such a way its results can be shared and reused among projects. According to [Ebrahimipour et al. 2010],

> "The information stored in risk assessment tools is in the form of textual natural language descriptions that limit computer-based extraction of knowledge for the reuse of the FMEA analysis in other designs or during plant operation. To overcome the limitations of text-based descriptions, FMEA ontology has been proposed that provides a basic set of standard concepts and terms."

The FMEA ontology shows an example of application of an ontology for complex systems and can be a reference to develop risk management concepts in a BFO based satellite systems ontology. Aspects of a satellite project which can be modeled and designed in conformance to a formal ontology can be many more than those mentioned in this section. The ones covered by this work are part of a preliminary study to provide a starting point for a deeper research to be carried out in our ongoing work, mentioned in Section 5.

4. Conclusion

In our experience, disparate and informal notations and inconsistent sets of vocabulary are applied to create isolated and disintegrated models. Even when standard languages are used, modeling environments still lack syntactic and semantic verification throughout the miscellaneous models, which can cause misunderstandings, increasing the time needed for comprehension at each development stage and many issues can arise as consequence.

An ontology defines a standard clear semantic, language and vocabulary needed for a precise communication among teams involved in any scientific research or product development. A top level ontology helps to enforce the correctness and robustness of such artifacts and its constructs. Being based on the same top level ontology, different sets of terms can be integrated in a consistent fashion allowing more effective collaboration and reuse.

Broad adoption in many domains has proven BFO to be a powerful tool to accomplish successfully effectiveness and accuracy in many projects. Its general terms and coverage of all base concepts and distinctive characteristic aspects about things that can exist in the real world are concluded to make BFO a relevant candidate for any domain.

It can be clearly perceived by reading the BFO overview in the discussion section, that it provides enough terms to represent all material things, processes, compositions, relations, and so on, required in all systems. Even more abstract concepts as boundaries, spaces, regions, among others, can be formally defined by using BFO as a top ontology.

As for satellite systems, the lack of ontologies at the system level is a clear opportunity for the proposition of such an artifact. Being BFO one of the most robust, mature and popular top level ontologies available, we conclude it has the characteristics which may be useful to bring to the satellite engineering teams environment a change game tool.

5. Ongoing Work

“An Ontology for Satellite Systems” is an ongoing work for my masters degree at INPE. It is being made of a deep research of ontologies in general, specific ontologies related to space and satellite systems, bibliometrics research and literature review and it is planned to be concluded by 2020.

Acknowledgments: *Dr. Geilson Loureiro, my dear mentor; Italo Rodrigues, for being a great supporter of space systems engineering research at INPE.*

References

Arp, R., Smith, B., and Spear, A. D. (2015). *Building Ontologies with Basic Formal Ontology*. The MIT Press.

Arvor, D., Belgiu, M., Falomir, Z., Mougenot, I., and Durieux, L. (2019). Ontologies to interpret remote sensing images: why do we need them? *GIScience & Remote Sensing*, 56(6):911–939.

Ashburner, M., Ball, C. A., Blake, J. A., Botstein, D., Butler, H., Cherry, J. M., Davis, A. P., Dolinski, K., Dwight, S. S., Eppig, J. T., Harris, M. A., Hill, D. P., Issel-Tarver, L., Kasarskis, A., Lewis, S., Matese, J. C., Richardson, J. E., Ringwald, M., Rubin, G. M., and Sherlock, G. (2000). Gene ontology: tool for the unification of biology. *Nature Genetics*, 25(1):25–29.

Blasch, E. (2015). Ontologies for nextgen avionics systems. In *2015 IEEE/AIAA 34th Digital Avionics Systems Conference (DASC)*, pages 3B5–1–3B5–13.

Cox, A. P., Nebelecky, C. K., Rudnicki, R., Tagliaferri, W. A., Crassidis, J. L., and Smith, B. (2016). The space object ontology. In *2016 19th International Conference on Information Fusion (FUSION)*, pages 146–153.

Ebrahimipour, V., Rezaie, K., and Shokravi, S. (2010). An ontology approach to support fmea studies. *Expert Syst. Appl.*, 37(1):671–677.

Liu, J., Jin, X., and Tsui, K. C. (2005). *Autonomy Oriented Computing - From Problem Solving to Complex Systems Modeling*. Springer.

Macau, E. E. N. (2002). Sistemas complexos e complexidade. In *Anais...* Congresso Temático de Dinâmica, Controle e Aplicações, 1. (DINCOM).

Malin, J. T. and Throop, D. R. (2007). Basic concepts and distinctions for an aerospace ontology of functions, entities and problems. In *2007 IEEE Aerospace Conference*, pages 1–18.

McBurney, M. K. and Novak, P. L. (2002). What is bibliometrics and why should you care? In *Proceedings. IEEE International Professional Communication Conference*, pages 108–114.

Mozaffari, F., Eidi, A., Mohammadi, L., and Alavi, Z. (2013). Implementation of fmea to improve the reliability of geo satellite payload. pages 1–6.

Rees, D. A. (1954). Aristotle's ontology. *The Classical Review*, 4(3/4):247–249.

Ruttenberg, A. (2019). Basic formal ontology (bfo). https://basic-formal-ontology.org/. accessed: 01.07.2019.

Skarka, W. (2007). Application of moka methodology in generative model creation using catia. *Engineering Applications of Artificial Intelligence*, 20(5):677 – 690. Soft Computing Applications.

Verhagen, W. J. C. and Curran, R. (2011). Ontological modelling of the aerospace composite manufacturing domain. In *ISPE CE*.

Warwick, G. (2016). Problems aerospace still has to solve. https://aviationweek.com/defense/problems-aerospace-still-has-solve. Aviation Week. accessed: 03.10.2017.