Orbital Space Environment and Space Situational Awareness Domain Ontology

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1. Introduction

As the population of satellites and other orbital objects in the space environment increases, the potential for collisions and orbital debris formation does as well. Existing sensors observe much of the night sky, gathering various sorts of data, but no space actor has full coverage of the orbital space environment. Although some nations have data-sharing agreements, not all exchanged data is raw/unmediated, and not all space actors share data. In toto, this spotlights the need for more precise and complete space situational awareness (SSA) for the global community.

Achieving this requires exchanging data and analyzing it to generate knowledge that can be used to ensure the safety of persons and infrastructure in space and on Earth's surface. This data must be updated dynamically in real-time and actionable in order to protect lives and space assets. Following [1],[2], this project formally studies and ontologically represents the orbital space and space situational awareness domain. The domain is that of the orbital and near-Earth space environments; the objects and phenomena therein; their orbits and orbital properties, motion, causal interrelations; spacecraft operations; sensor data; observation, detection, prediction and modeling activities; and scientific disciplines such as astrodynamics.

Varieties of data include orbital parameters, spacecraft telemetry, and different sorts of observational sensor data (infrared, optical, etc.). .Existing data sources that have overlapping data include space debris catalogs, space object catalogs, and other SSA databases of: space-faring nations, such as the European Space Agency[3], and NASA (e.g. Orbital Debris Office); private-sector space organizations, such as Space Data Association; individual sensor and satellite operators; and academia (e.g., university observatories).

In conjunction with additional sensors, space data-exchange will help reduce the coverage gaps individual space actors may presently have while improving global SSA. Orbital trajectories, future positions and potential collisions (orbital conjunctions) can be more accurately determined if more data is made available. Just as with meteorological forecasts, predictive capabilities become more precise, and we stand to advance our scientific knowledge about the orbital environment.

Barriers to sharing SSA data include legal and security concerns, e.g., anonymity, proprietary information, data related to national security space assets, and international relations. Additional barriers include the different data formats, and data silos.

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2. Research, Questions and Methodology

I conceived the orbital debris ontology [1] as part of a potential joint space ontology to solve space domain problems in 2011. This was further explained and generalized in [2]. Over time I have accumulated a mass of orbital debris and SSA domain research to serve as reference and study material. However, given the relative novelty of applying ontology to this domain, there are limited literature/efforts. Other work includes: the International Virtual Observatory Alliance and University of Maryland Astronomical Object Ontology[4], and the NASA SWEET ontologies [5].

Selected research questions include the following. What are scientifically accurate formal representations of the domain? Are classical and contemporary ontological concepts and ontology languages sufficient to faithfully represent the domain? What ontology architecture and approach/method will best address domain problems? What domain queries can an ontology answer? Some questions include those of the source of some orbital debris object, and the type of orbital object. How can dynamic ontologies benefit the domain? Is the current state of applied ontology able to handle the physics-intensive aspects of the domain, and if not, what advancements are necessary to do so? Finally, predictive capability, causal models, astrodynamic models, and probability are important aspects to taken into account.

A minimal set of methodological steps includes: domain research; review of accessible data-sources; identifying domain scenarios, case-studies and problems to address; assessment of ontology methodologies and designs; whether to reuse existing ontologies; identify key concepts, terms and domain objects; assert corresponding ontology classes and interrelations; develop definitions; taxonomy creation; domain formalization; annotation of one or more data sources; production of an analytics and software package; validating the ontology by performing queries over data source; and revision as necessary.

3. Project Goals

The goals of the project are to create an ontology or ontology suite to formally and computationally represent the orbital space environment, its objects, relationships, and the processes that establish and maintain situational awareness of that environment. I seek a scientifically accurate representation that can annotate domain data and foster interoperability. This involves creating one or more space terminologies and taxonomies. A specific practical goal is data-sharing between data sources, as well as stimulating cooperation among space actors in the development process. I also seek to make theoretical and philosophical contributions to the domain. An overarching purpose of the project is to improve SSA and space safety.

[1] R.J.Rovetto, An Ontological Architecture of Orbital Debris Data, *Earth Science Informatics* 9(1) (2015), 67-82.

[2] R.J. Rovetto, and T.S. Kelso, Preliminaries of a Space Situational Awareness Ontology, AIAA/AAS Space Flight Mechanics meeting, Napa, CA, USA, (2016) forthcoming in *Advances in Astronautics*, Univelt.

[3] European Space Agency (ESA) "Space_Situational_Awareness" URL= http://www.esa.int/Our_Activities/Operations/Space_Situational_Awareness

[4] International Virtual Observatory Alliance (IVOA). Ontology of Astronomical Object Types. URL= http://www.ivoa.net/documents/Notes/AstrObjectOntology/

[5] NASA Semantic Web for Earth and Environmental Terminology URL= https://sweet.jpl.nasa.gov/