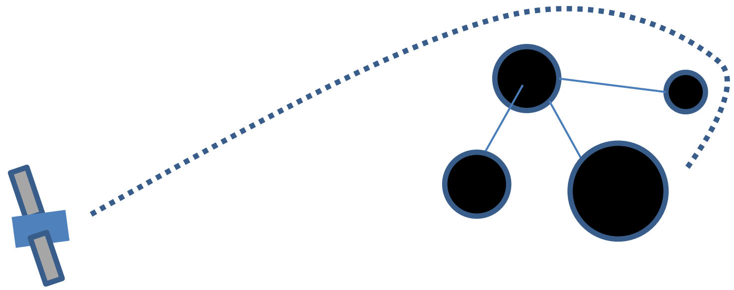

Space Situational Awareness Ontology

Robert John Rovetto*
T.S. Kelso**
*Corresponding author. Space Ontologist, Formal Ontologist,
rrovetto@terpalum.umd.edu; ontologos@yahoo.com
**Senior Research Astrodynamicist, AGI Inc.
tskelso@centerforspace.com

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Presentation Summary

- Presenter background
- Paper synopsis
- The Domain: SSA; space objects
- Ontology
- The Idea
- Conclusion

Presenter Bio

- Robert John Rovetto
  - *Education*
    - *MS coursework*: space studies, e.g., fund. orbital mechanics
    - *MA* – ontology focus (2011)
    - *BA* – philosophy w/business minor, IT focus (2007)
    - Misc. maritime operations training & education
  - Relevant Efforts
    - *Publications* (approx. 11, mostly independent work): human spaceflight, space ontology, biomedical ontology, shape ontology, philosophy
    - Ideation & championing space ontology since 2011
  - Current Status
    - Seeking space opportunities (educational and employment); seeking funding or collaboration to realize space domain ontology paper & project ideas. Ideal world: astronaut.

Full CV/experiences available upon request

Paper Synopsis

- Title: “Preliminaries of a Space Situational Awareness Ontology” by:
  - Robert J. Rovetto, Space Ontologist, Formal Ontologist, NY USA. (corresponding author)
  - T.S. Kelso, Senior Research Astrodynamicist, Center for Space Standards and Innovation
- Presents desiderata and objectives for the SSA Ontology (or any Space Domain Ontology)
- Draws upon and generalizes ideas introduced in: “An Ontological Architecture for Orbital Debris Data” Robert J. Rovetto, *Earth Science Informatics,* (2015).

The Space Situational Awareness Domain

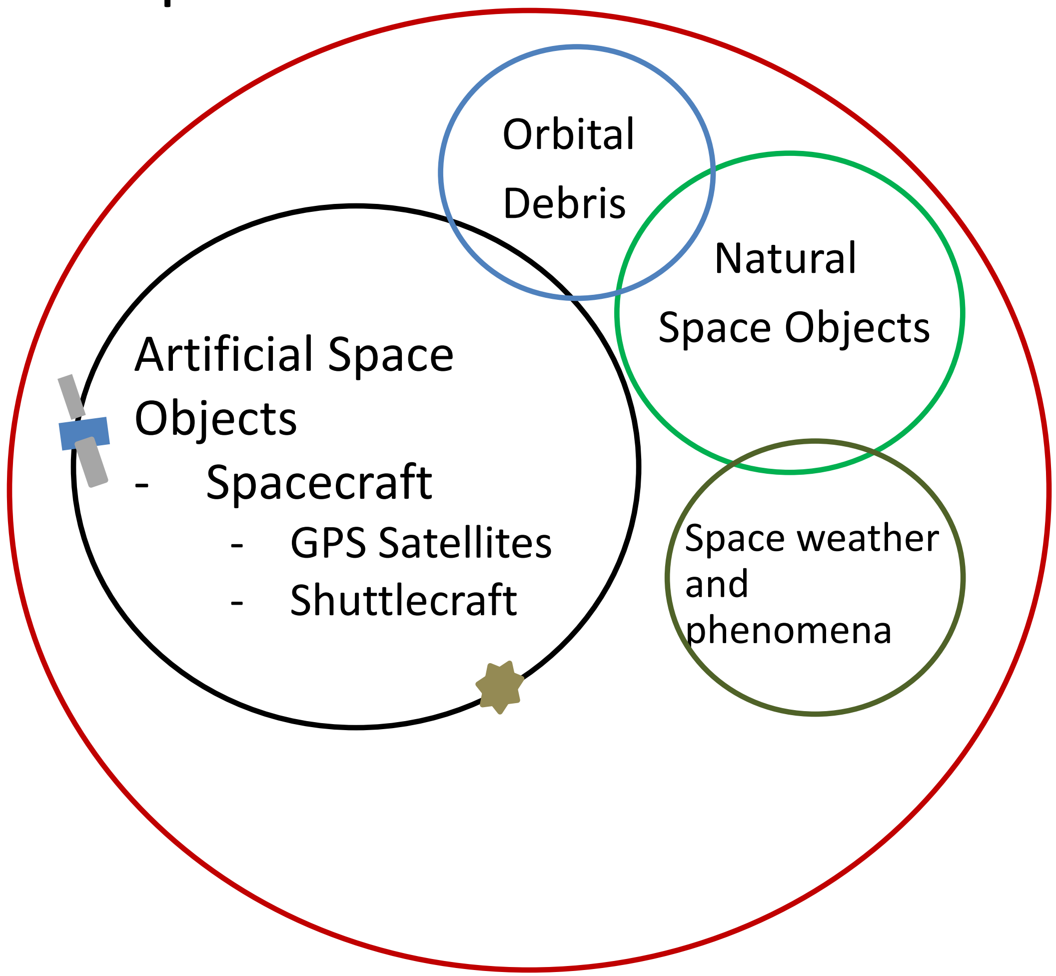
- SSA considerations
  - Definition
  - Its objects
  - Problems & Critical Areas of Importance
    - Orbital Debris
    - Spaceflight Safety, Safe space navigation
    - Spaceflight security, Space surveillance
    - Securing the future of human spaceflight

SSA includes…

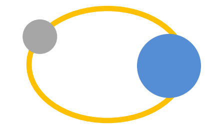
- **Observation** of the space environment
- **Identification** and **Tracking** of **space objects**
- **Accumulation of Data**
- **Knowledge discovery** (ideally is actionable)

SSA Domain Objects

Space Situational Awareness



Space Objects: Types and Distinctions



- Spacecraft
  - GPS satellites, Space Telescopes, Space Shuttles
- Orbital Debris
  - Spacecraft Fragments, Mission-oriented Orbital Debris, Non-functional spacecraft
- Natural vs. Artificial
  - Satellites (orbiting space objects)
  - Comets, Asteroid, Interplanetary spacecraft (Non-orbiting space objects)
- Functional vs. Non-Functional

SSA and Astronomical Data

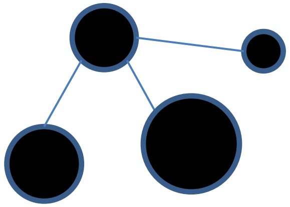
- Data gathered about objects in orbit and beyond
- Data Sources:
  - *Sensors*: space and ground-based sensors
  - *SSA actors*: NASA, ESA, Russian Federation, China, USAF, DoD, Private sectors, etc.
- Data Repositories:
  - Space object catalogs, Databases, e.g. DoD, Airforce; Private Sector, CSSI, Celestrak; Russian catalogs, ESA
  - May use different: classification schemes, data formats(problem)
  - Lack of standard terminology (potential problem)?

Data and more Data

Analyze and Reason over it…but structure and explicate it!

- Increasing volumes of space data! (problem)
  - Astronomy
  - Astronautics
  - Astrodynamics
  - Earth observation data, Geosciences
- Informatics (& ontology = solution)
  - ***Astroinformatics*** [see Kirk Borne]
  - Bioinformatics
  - Geoinformatics

Ontology



- Types
  - Philosophical
  - Formal
  - Applied
    - Computational Ontology
    - Ontology Development and Engineering

- Asks:
  - What are the *objects* in the given domain (the space environment)?
  - What are their distinguishing properties?
  - How are they *related*, and what *patterns* exist?
  - How can they be categorized (if at all) and described?

Ontology: Types (1)

- **Philosophical Ontology**: a branch of metaphysics that concerns the nature of reality vis-à-vis categories of being and becoming
  - High-level (highly general)
  - Asserts classification systems with interrelations b/w categories to describe the world
  - Stems from the history of philosophy/thought

(*toward structuring and explicating the data!*)

Ontology: Philosophical Fundamental Distinctions & Concepts

- From philosophy…
  - Existence
  - Possibility & Modality
  - Persistence
  - Identity
  - Attribute-agreement (similarity)
  - Generality vs. Specificity
  - Universal vs. Particular
  - Causality
  - Dependence
  - Property vs. Property-Bearer
  - Composition vs. Constitution
  - Object—Process—Event
  - Category vs. Instance (of category)

Ontology: Types (2)

- **Formal Ontology**:
  - High-level (highly general)
  - Asserts classification systems with interrelations b/w categories to describe the world
  - Used formal logics to explicitly specify and describe the general (or specific) nature of the given domain
    - First-order Logic
    - Modal Logic
    - Higher-order Logics
    - Mereology (theory of parts and wholes)

Ontology: Types (3)

- **Applied Ontology**:
  - ‘applied ontology’ = Generic term for applying philosophical and/or formal ontology to specific applications, disciplines or domains.
  - Asserts classification systems with interrelations b/w categories to describe the domain
  - Used formal logics to explicitly specify and describe the general (or specific) nature of the given domain
    - First-order logic, Higher-order logics, Mereology
  - Develops ***computational ontologies =*** computable ontological theories
    - Computable artifacts consisting of classes, relations, knowledge representation statements/assertions
    - Uses knowledge representation, or ontology languages: *Common Logic*, OWL, etc.
    - Consider knowledge representation from AI: T-Box, A-Box.

Ontology Development (1)

(Can adopt software development process)

- Goals and Requirements
- Identify and delimit the domain
- Domain Research
  - Reference documents
  - Domain-professionals
  - Domain-specific vocabulary (→ ontology classes)
  - Domain knowledge (to be expressed/captured/ontologically characterized in the ontology)
- Philosophical analysis of key concepts

Ontology Development (2)

- Create list of terms to include in ontology
- Structure the terms = Taxonomy creation
  - Subsumption relation (*is a*), Partonomic relation (*part of*)
- Use Taxonomy or Ontology editor applications to form taxonomy/ontology file
- Translate domain knowledge (natural language statements) into ontology language
  - Helpful to start by hand (first-order or higher-order logic) BEFORE jumping to computable (ontology/knowledge representation) language. ***Take time to get it right before implementation! Save time and avoid ad hoc workarounds that compromise accuracy of representations***!
- Use editor applications to assert axioms, rules, etc. to capture domain knowledge

Ontology Development Questions

- For a given application or domain, we ask:
  - What are the objects, relationships and patterns in the domain, or subject matter of the application?
    - DOMAIN: Space
    - DOMAIN Objects: space objects, e.g. spacecraft satellites, orbital debris, etc.

  - What are application- or domain-specific terms that can be made into (computable) ontology classes?
    - ‘Planet’, ‘Moon’, ‘Orbital Debris’, ‘Satellite’, ‘Space sensor’, ‘Space Actor’, ‘Space Object’, ‘Orbital Parameter’, ‘Two-line Element’, ‘Orbit’

Ontology: Philosophy
General to Specific

- Object Categories (classes/types/universals)
- Relation Categories

Most general → Specific

Top-level (Domain-neutral)			Low-level (Domain-specific Level)
Endurant/Continuant	Physical Object	Space Object Astronomical Object	Orbital Debris
Perdurant/Occurrent	Physical Process, Event	Orbiting Process Orbital Decay	Astronomical Orbital Decay
Property/Dependent Entity	Physical Property	Space Object Property	Mass, Shape, Albedo

Ontology: Levels & Categories

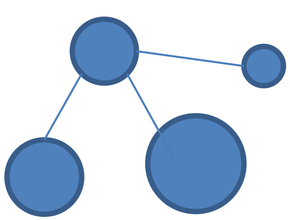
- Ontological Levels
  - A vague and controversial concept
  - may be arbitrary
  - may be domain-specific
  - may be based on scientific classifications
- “Top-level” = most general (domain-neutral)
  - Ex: Endurant/Continuant, Perdurant/Occurrent
- “Upper-level” = very general
- “Mid-level” = lower-lever (more specific) but more general than specific disciplines.
- “Low-level” = very specific, e.g., domain-specific
- Upper-level categories subsume lower-level
  - Combined with rules of inference, e.g., the conditional, their interrelationships allow for automated reasoning.
    - Given transitivity of is_a, If X is_a Y & Y is_a Z, then X is_a Z

The Idea (1)

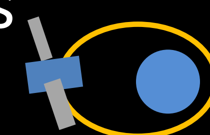
The Goal/Idea: improve space safety by improving SSA via space/SSA data-sharing as presented in *Rovetto (2015, ESI)*

<u>The Approach</u> *applied to* **<u>The Domain</u>**

Ontology



Space Situational Awareness



The Idea (2): SSAO Suite

- Distinct but overlapping scientific disciplines
  - Astrodynamics
  - Astronautics
  - Astronomy
  - Physics
- General knowledge captured in ontology
- Suite of modular ontologies, e.g. Astrodynamics Ontology.
- May (re)use terms from existing resources, e.g. NASA SWEET ontologies (incomplete by contemporary ontology standards), IVOA (UMD)

The Idea (3): Domain Class Terms

- Spacecraft / Space Vehicle
- Satellite
  - Artificial Satellite
  - Natural Satellite
- Orbital Debris
  - <Debris Classes>

- Orbit
- Orbital Parameter
  - Inclination
  - Epoch
  - Right Ascension
  - …

- Space Object
- Celestial Body
- Central Body
- Planet
- Moon
- Star

Indentation = class subsumption

The Idea (4)

- Data-sharing among Space Databases and Object catalogs
- Use ontology to assert common terminology and scientifically accurate theory of the domain
- Terms from an upper space ontology can annotate SSA data from disparate databases, thereby creating a connection between them

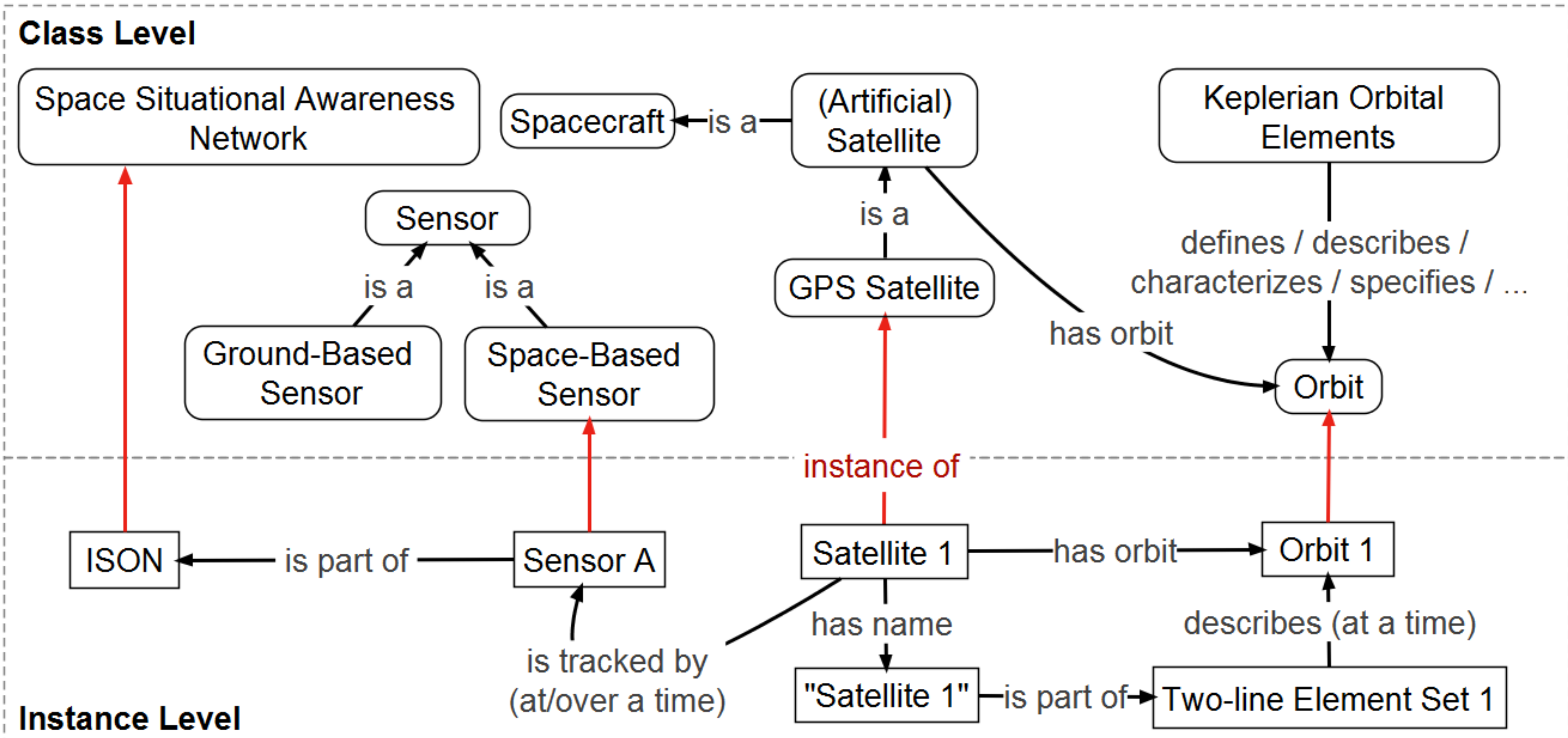
The Idea

- Disparate database may use different terms to reference the same particular object in the world outside the database, or may use different terms to refer to the same *type* of space object
- Ontology helps…
  - Distinction b/w type and individual
    - Class subsumption vs. Intantiation relation
  - Asserting a class term subsuming those of the databases (generalization)

Benefits of applying ontology

- Potential for:
  - Domain clarification, Data Explication
    - Philosophical, formal concept analysis
  - Taxonomy and Vocabulary creation
    - E.g., Space object taxonomy
  - Space object categorization
  - Data Annotation
  - Data-sharing
  - Knowledge discovery
  - Computability, Automated reasoning/inference (similar to informatics)
  - Astrodynamic Standards innovation?

SSA Ontology: Example scenario (1)



Example (2): Natural Language to FOL

All Space-based Sensors are types of Sensors.
(A1) $\forall x[\text{is\_a}(x, \text{Space-Based Sensor}) \longrightarrow \text{is\_a}(x, \text{Sensor})]$

All GPS Satellites are types of Satellites.
(A2) $\forall x[\text{is\_a}(x, \text{GPS Satellite}) \longrightarrow \text{is\_a}(x, \text{Satellite})]$

Sensor A is an instance of Space-Based Sensor.
(A3) Instance_of(Sensor A, Space-Based Sensor)

In computable KRR language, automated reasoner infers…

Sensor A is an (indirect) instance_of Sensor Sensor

Conclusion

- Apply philosophical and formal ontological rigor to space domain awareness
- Create computable model of the domain
  - Aims: conceptual clarity data annotation, data-sharing, semantic interoperability, KRR, and knowledge discovery
- Yields a space domain or SSA ontology
- Further work: domain research, formalizations, complete ontology file, misc.

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Acknowledgements

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- T.S. Kelso of Center for Space Standards and Innovation
- Thank *you* for listening

Questions, Comments, Suggestions?

Seeking…

- Space opportunities: educational, employment, apprenticeships, and funding to realize my space ontology paper/project ideas
- Training in astronautics and satellite operations, and
- colleagues for paper ideas

… so if you have interest in these or related space areas, please contact me. If I can be of service with other space-related areas, I'd be interested in exploring possibilities.

Thank you