Satellite Parts Ontology Development in DLR

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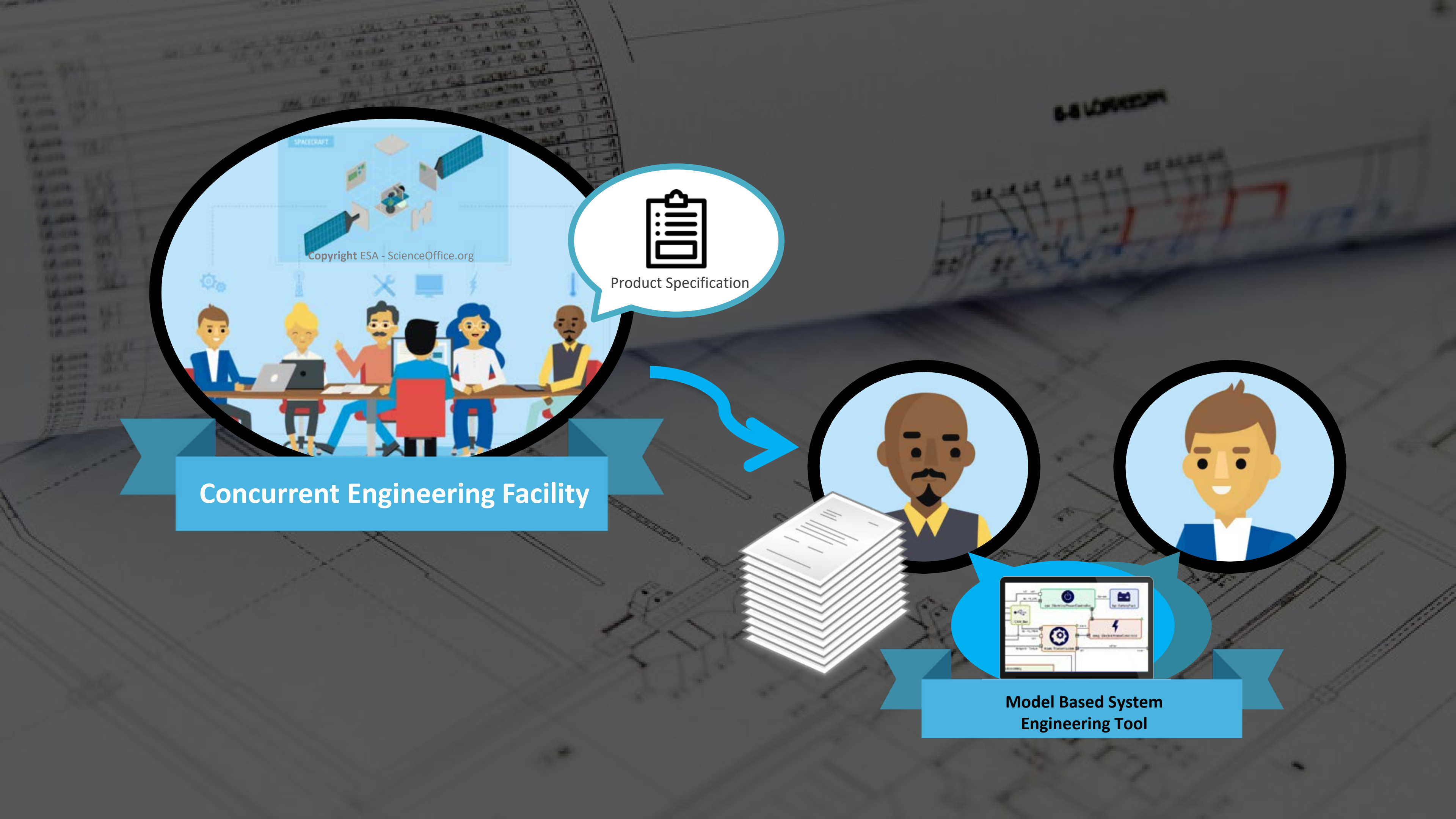
Knowledge for Tomorrow

Agenda

- Motivation
- Satellite Parts Ontology
- Lessons Learned
- Outlook



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Product Specification
Concurrent Engineering Facility
Model Based System Engineering Tool

Heterogeneous Formats

OVERVIEW

Under a grant from the Defense Production Act Title III, Ball is developing a new line of affordable, fully-domestic star trackers: CT-2020.

Domestically-sourced, secure solution

Utilizing all U.S. trusted suppliers, secure systems and flight software, the CT-2020 is an assured, fully U.S.-sourced solution for the nation's most important missions.

Low cost, high performance

Blending medium and high accuracy star tracker heritage in a compact, fully-integrated package, CT-2020 offers high performance and operational flexibility at a competitive price point.

CT-2020 integrates the latest high-efficiency Complementary Metal Oxide Semiconductor (CMOS) detector technology developed in the U.S. specifically for star trackers, enabling the CT-2020's cost-effective small mass and volume design.

Operational flexibility, on-orbit upgrades

Featuring operational flexibility, CT-2020 provides customers two modes of operation: fully autonomous attitude and directed search, in which the user can select certain regions of interest. In autonomous attitude mode, the tracker can achieve single head accuracies in the realm of 1 arcsec, with even higher accuracies in directed search mode.

CT-2020's robust software features an on-orbit environment simulator, allowing the tracker to emulate mission-specific integration and operations for risk reduction. In addition, the tracker's software can be upgraded while on-orbit, allowing updates to the star catalog, spatial/intensity calibration and software algorithms.

HERITAGE

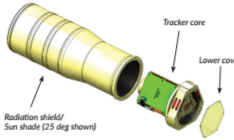
For more than 40 years, Ball has delivered the highest-reliability, highest-performance star trackers available to support civil, commercial and defense missions. We are leveraging this heritage to optimize the CT-2020 for cost and performance to bring an affordable, domestic star tracker solution to the U.S. market.

Expected availability of the CT-2020 is fourth quarter of 2019.

SPECIFICATIONS

- 1 arcsec performance stand-alone unit
- Provides full three-axis <1.0 arcsec performance with typical two-units on a spacecraft
- Full performance with a 15 deg sun angle
- Tracks with moon in field of view
- High rate capable (up to 8 deg/sec) with reduced performance to enable track-through-slew
- 1553, RS-422 command and data interfaces, SpaceWire option
- Simultaneous attitude output and full frame image output at 10 Hz over high speed LVDS
- On-orbit upgradeable software, star catalog, algorithms and spatial re-calibration
- TEC provides efficient, stable detector temp control, on-orbit adjustable
- Hardware-in-the-loop testing with built-in focal plane simulator enables end-to-end mission simulations
- Integrated LED polarity tester
- Two modes of operation: fully autonomous or directed search
- Mass: 3 kg
- Power: <8 W
- Modular options:
  - Nominal +28 V power, +120 V, +5 V options
  - Three sun shade options (15, 20, 30 deg)
  - Q or V-Level parts with full EEE parts traceability
- Radiation-hardened-by-design CMOS and ASIC
- Meets all relevant MIL-STD and SMC requirements
- Complete set of documentation and analysis available with production

SYSTEM COMPONENTS



µSTAR Tracker

Applications

- Satellite Attitude and Rate Determination
- GEO and LEO Satellite Orbits
- Long Duration/High Reliability Missions

Software Features

- Star Identification Based on Pyramid Code
- Integrated Systematic Error Correction Allows for High Accuracy
- Real-Time On-orbit Calibration Accounts for Degradation
- Extended Kalman Filter Produces Attitude and Rate Estimates
- Less Sensitive to Spurious Signals and Upsets

Configuration Options

Feature	MIST	uStar-100M	uStar-200M	uStar-200H	uStar-400M
FPA	Ruby	HAS2	HAS2	HAS2	HAS2
Accuracy (1σ)	30 arcsec	5-20 arcsec	1-20 arcsec	< 1 arcsec	1-5 arcsec
Average Power	<3W	< 5 W	8-10 W	< 10 W	< 18 W
Update Rate	10 Hz	1 Hz	10 Hz	10 Hz	100 Hz
DPE Mass (kg)	0.5 (Integrated Unit)	0.9	1.2	1.2	1.2
CHU Mass (kg)		0.9	0.9	1.5	2.1
Total (kg)	0.5	1.8	2.1	2.7	3.3

*Contact Warehouse for availability

Radiation Tolerance

Total Ionizing Dose (TID)	> 100 and 300 krad (option)
Single Event Latchup (SEL)	> 80 MeV/mg/cm^2
Single Event Upset (SEU)	< 10^{-3} errors/system-day
Neutrons	> $2x10^{12}$ n/cm^2

Supporting Electronics

The µSTAR™ features proven, high-performance, radiation hardened supporting electronics to ensure accurate, reliable functionality in the harsh space environment.

Proton 200K™ Radiation Hardened Space Computer

The Proton200k™ space computer is flight-proven, high speed, and radiation hardened to provide extraordinary performance benefits by removing the barriers associated with commercial processor offerings. It is a qualified space computer for onboard data processing with 1.8 GFLOPS @ 200 MHz Floating Point, 900 MFLOPS @ 200 MHz with SEU mitigated to 1E-4 errors/day

SPACE MICRO

jenaoptronik

Size & Mass		
Dimensions	154 mm x 154 mm x 237 mm	including baffle
Mass	approx. 2 kg	including baffle, GEO-shielding, DC/DC-converter, MIL1553
Imaging System Design		
Optics	refractive, focal length 43 mm, f/1.2	aspherical lens technology, rad-hard glass material
Detector Resolution	1024 x 1024 pixels	
Field of View	20 deg	circular
Detector Options	HAS2	APS CMOS radiation tolerant
	STAR1000	APS CMOS radiation hard
Temperature Range		
Operational	-30 °C ... +60 °C	typical cooler controller set point at TAPS=+30°C
Non-operational	-40 °C ... +70 °C	
Attitude Performance		
Random Error	< 1 arcsec [1σ], across boresight	includes LSFE, HSFE, TE
	< 8 arcsec [1σ], boresight	
Bias Error	< 5 arcsec, all axes	over full operational temperature range
Acquisition Time	< 10 sec, after switch-ON	
	< 5 sec, re-acquisition "lost in space"	direct entry to attitude tracking with apriori information
Slew Rate & Acceleration	< 0.3 deg/sec, ≤ 0.3 deg/sec²	full performance
	≤ 3.0 deg/sec, ≤ 2.0 deg/sec²	STAR1000 single head capability
	≤ 5.0 deg/sec, ≤ 7.0 deg/sec²	HAS2 single head capability
Sensitivity	6.0mi G0-reference star	end of life performance
Sampling Rate	10 Hz	
	16 Hz	others up to 32 Hz on demand
Stray Light	Sun: 26 deg exclusion angle	half cone
	Earth: < 20 deg	depending on orbit height and Earth illumination conditions
	Moon: accepted in field of view	
Interfaces		
Data	MIL-STD-1553B	optional selectable, others on demand
	RS422	
Power	28V nominal	optional selectable for either regulated or unregulated
	50V nominal	primary power s/c bus architectures
	100V nominal	other voltages on demand
Power Consumption		
MIL-STD-1553B	< 6 W, Peltier Cooler OFF	end of life
data interface	< 12 W, Peltier Cooler ON_{MAX}	
RS422	< 5 W, Peltier Cooler OFF	end of life
data interface	< 11 W, Peltier Cooler ON_{MAX}	
Operations		
Reliability	460 FIT, $T_{I/F}$=20°C	with Class 1 EEE parts
Operational Modes	Boot	fully autonomous mode switching from Power-ON to NAT
	Standby-Mode	by software parameter set-up possible
	Autonomous Attitude Determination (AAD)	
	Nominal Attitude Tracking (NAT)	
	Photo, Upload/Download, Self-Test	

EN 9100 certified AIRCERT Certification of Management Systems

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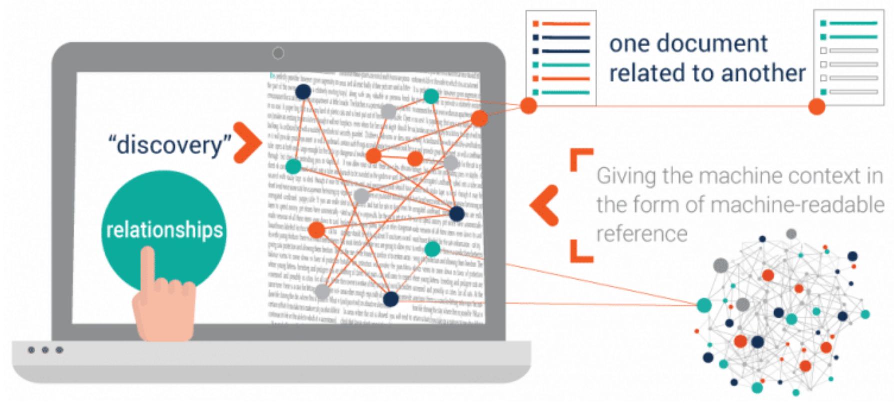
Machine-Interpretable Parts Description

- Natural Language Processing

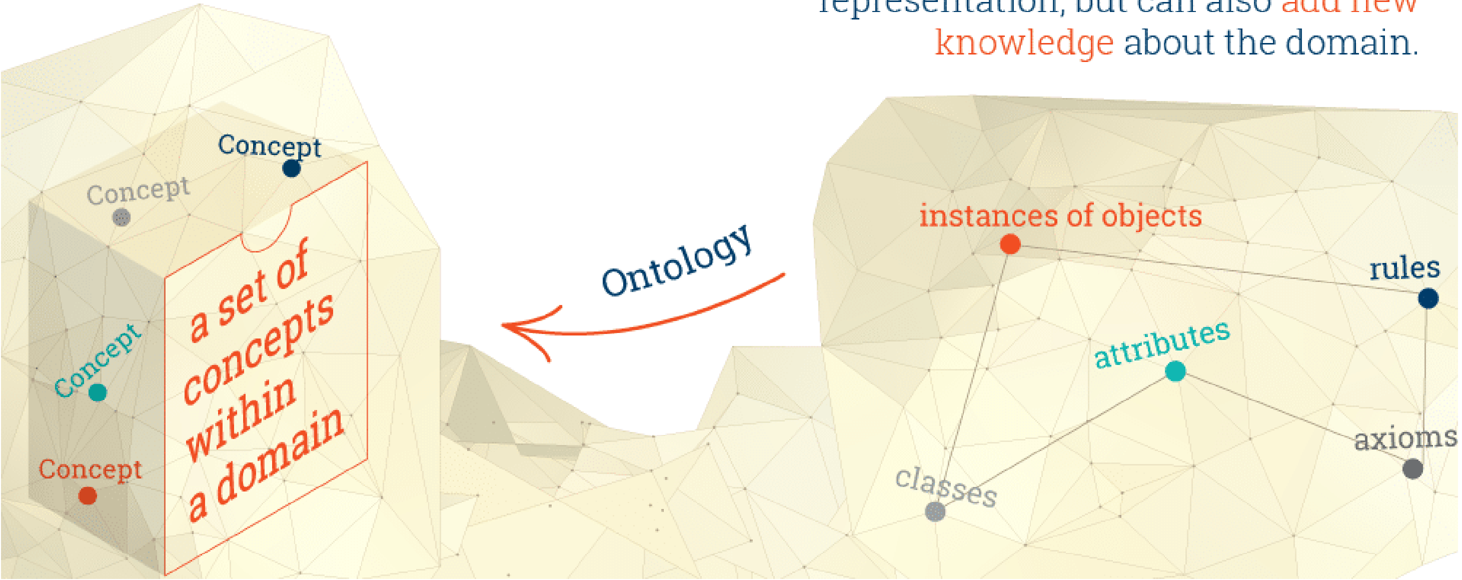
- Semantic Knowledge



https://www.ontotext.com/knowledgehub/fundamentals/what-is-machine-learning/

Ontology

Ontologies do not only introduce a sharable and reusable knowledge representation, but can also add new knowledge about the domain.



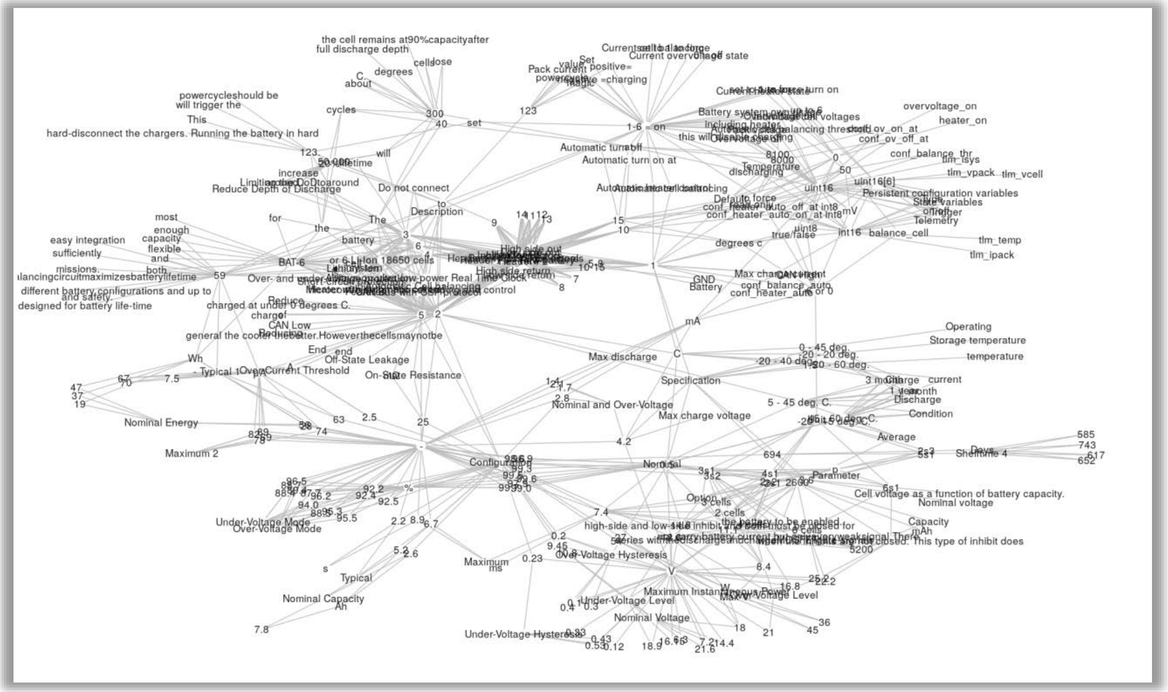
https://www.ontotext.com/knowledgehub/fundamentals/what-are-ontologies/

Spacecraft Parts Ontology: Usages

- Knowledge graph
  - Information retrieval
  - In cooperation with university of Leipzig

- Conversion to part database schema https://gitlab.com/dlr-dw/ontocode

- Part data exchange interface
  - Web API

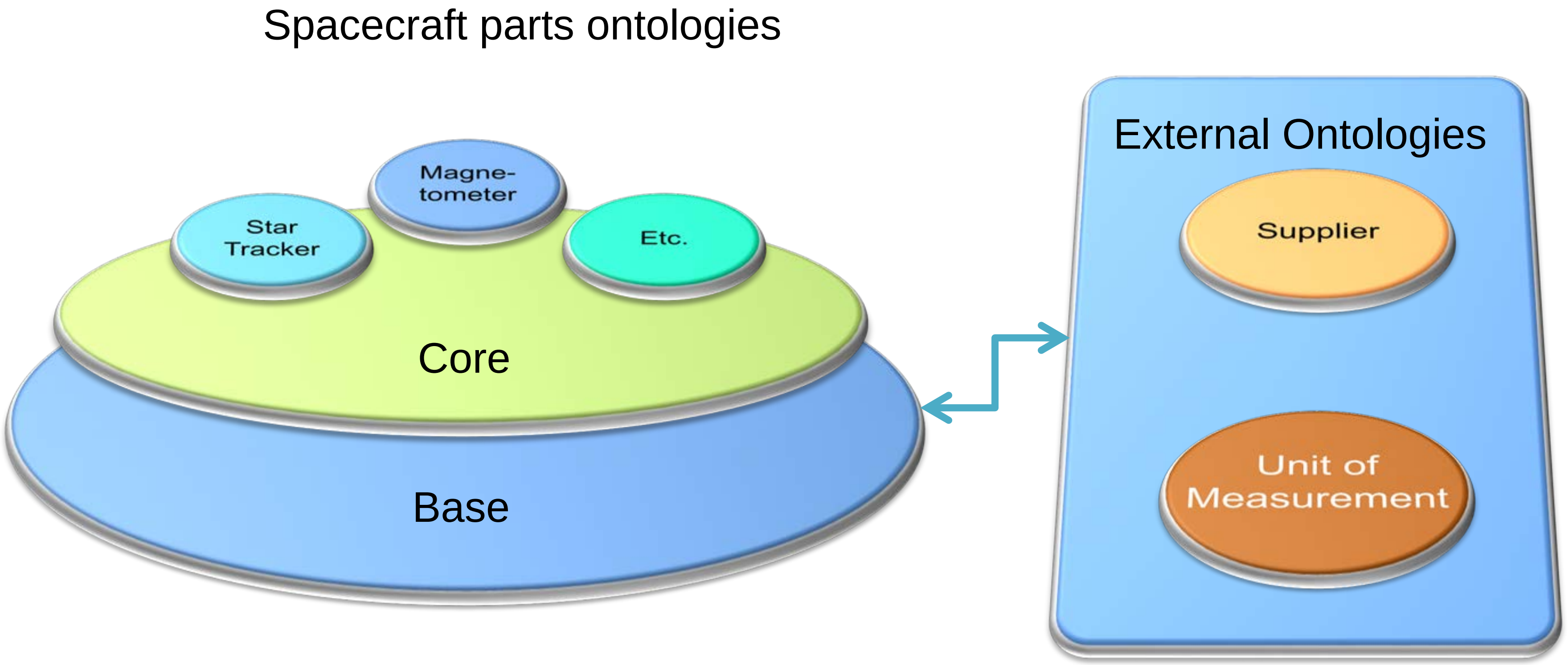


Spacecraft Parts Ontology: Implementation

- Data models developed by DLR's in-house MBSE tool
  - Virtual Satellite

    https://github.com/virtualsatellite
- Existing product description standards
  - ECSS-E-ST-60-20C - Star Sensor Terminology and Performances
- Actual product data sheets
- Interview with system engineers and manufacturers
- https://zenodo.org/record/2616374

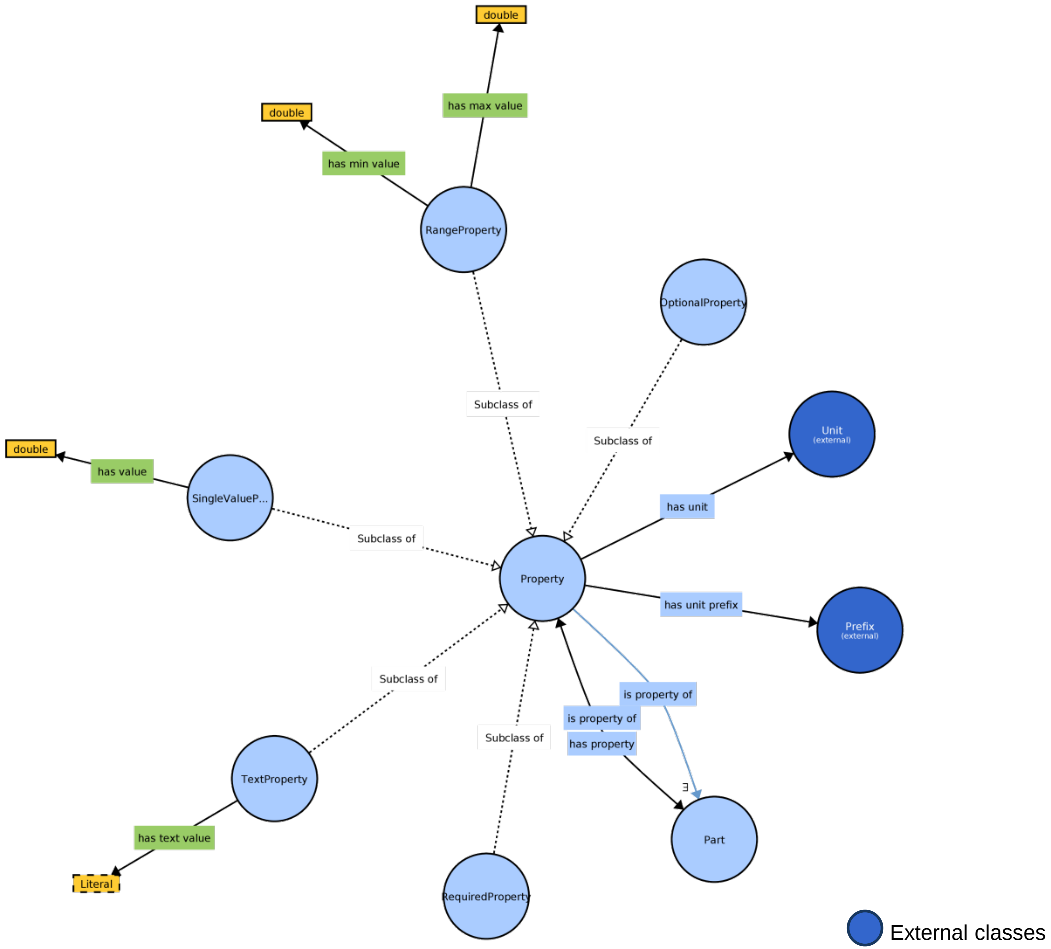
Spacecraft Parts Ontology: Hierarchical Structure



Spacecraft Parts Ontology: Base

- Primary classes
  - Part
  - Part's attribute
  - Type of attribute

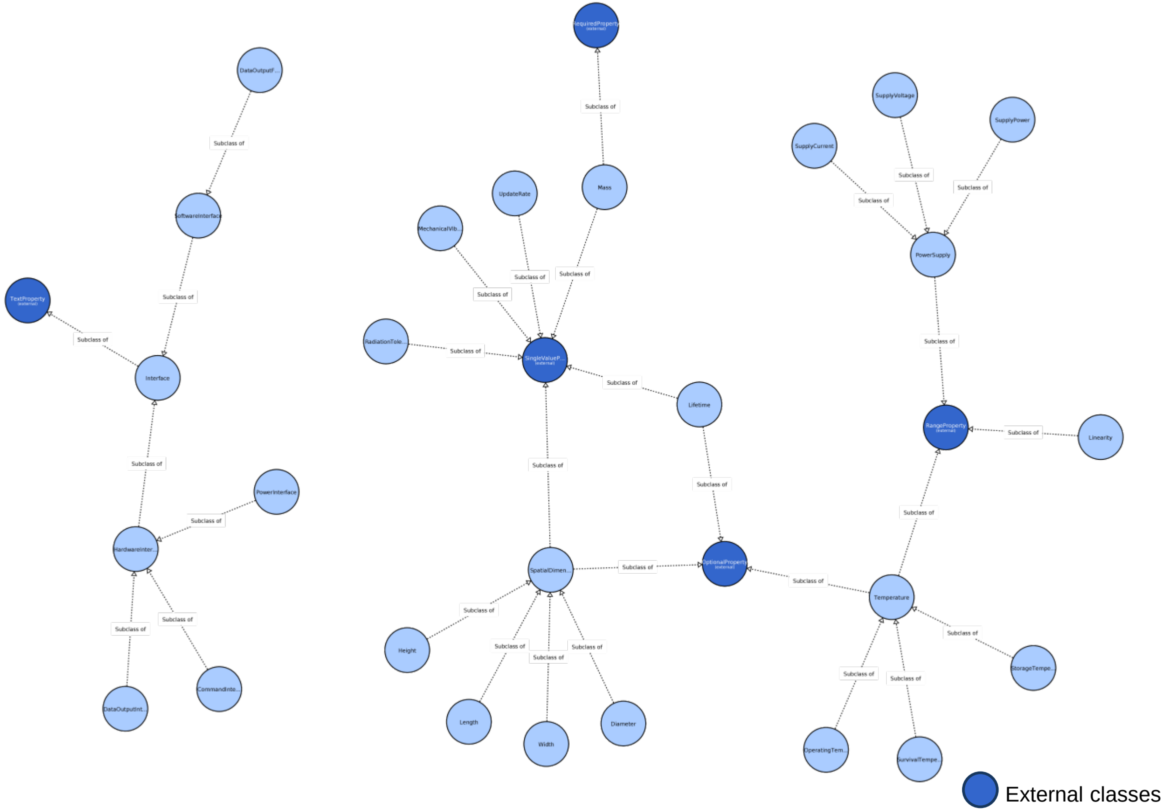
- Primary properties
  - "is property of"
  - "has property"
  - "has unit"



Spacecraft Parts Ontology: Core

- Common attributes for all parts
  - Mass
  - Lifetime
  - Operating Temperature
  - Width, Height, Length

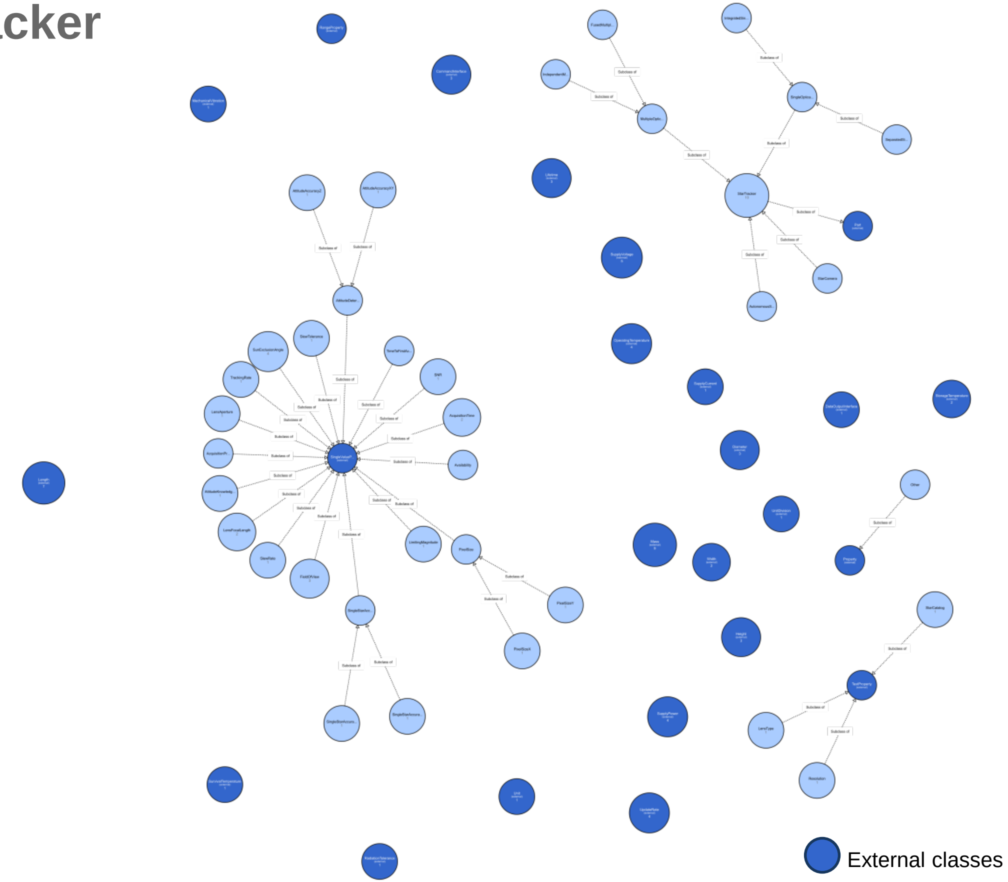
- 26 attributes



Spacecraft Parts Ontology: Star Tracker

- Specific attributes to star trackers
  - Attitude accuracy
  - Field of view
  - SNR
  - Etc.

- 36 Attributes



Spacecraft Parts Ontology: Different Parts

- Star Tracker
- Magnetometer
- Camera

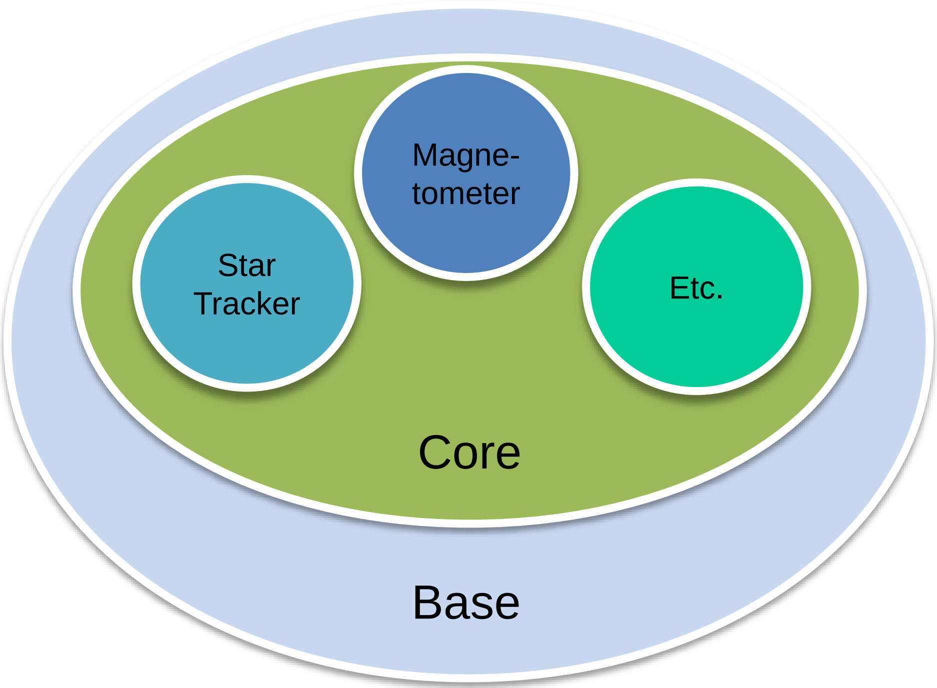
Reviewed

- Battery
- Magnetic torque
- Reaction wheel
- Solar panel
- Earth sensor
- Sun sensor
- Thruster

Implementing

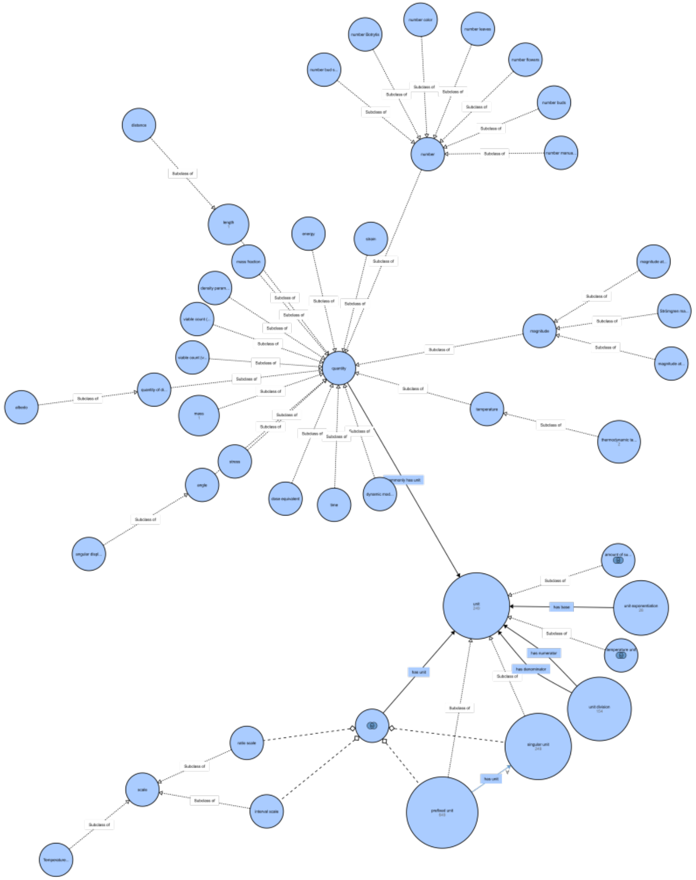
- Antenna
- AOCS
- OBC

Planned



Spacecraft Parts Ontology: External

- Supplier detail: company name, address, contact https://schema.org/Organization.ttl
- Unit of Measurement: https://github.com/HajoRijgersberg/OM



Languages & Tools

- Terse RDF Triple language (Turtle) syntax
  - Due to its readability and edit-ability.
  - A syntax for expressing data in the Resource Description Framework (RDF) data model
  - Recommended by World Wide Web Consortium (W3C).

```
###  http://ontology.dlr.de/spacecraft-parts/core#MechanicalVibration
:MechanicalVibration rdf:type owl:Class ;
                     rdfs:subClassOf base:SingleValueProperty .


###  http://ontology.dlr.de/spacecraft-parts/core#HardwareInterface
:HardwareInterface rdf:type owl:Class ;
                   rdfs:subClassOf :Interface .


###  http://ontology.dlr.de/spacecraft-parts/core#Height
:Height rdf:type owl:Class ;
        rdfs:subClassOf :SpatialDimension .
```

- Reasoner: Openllet

  https://github.com/Galigator/openllet

- Visualization:

  http://www.visualdataweb.de/webvowl/

Lesson Learned

- An ontology creation is an iterative process; it cannot be done in one-shot
- Domain experts (system engineers and manufacturers) must be involved
- There are numerous existing ontologies that can be reused
    - https://schema.org/
    - Units of measure ontology (OM) https://github.com/HajoRijgersberg/OM
- Ontologies should be loosely coupled
    - So that each ontology can be updated independently

Outlook

- Transfer and exchange knowledge between different phases of system lifecycle
  - During the testing phase, a test case can be tracked back to a requirement

- Current ontology is available at:
  - https://zenodo.org/record/2616374
  - Magnetometer, Star tracker, Camera
  - More categories are coming soon

Thank you for your attention!