Ethical Control of Unmanned Systems

Repeatable Mission Evaluation through Unmanned Systems Data Strategy

Project Update for CRUSER
Consortium for Robotics Unmanned Systems Education and Research

Don Brutzman, Curtis Blais, Terry Norbraten, and Kristen Fletcher
Naval Postgraduate School (NPS)

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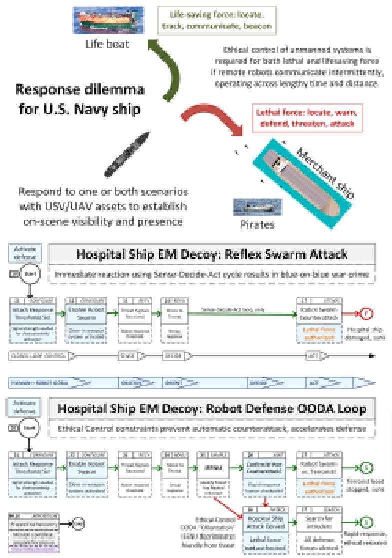
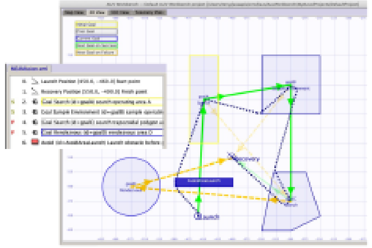
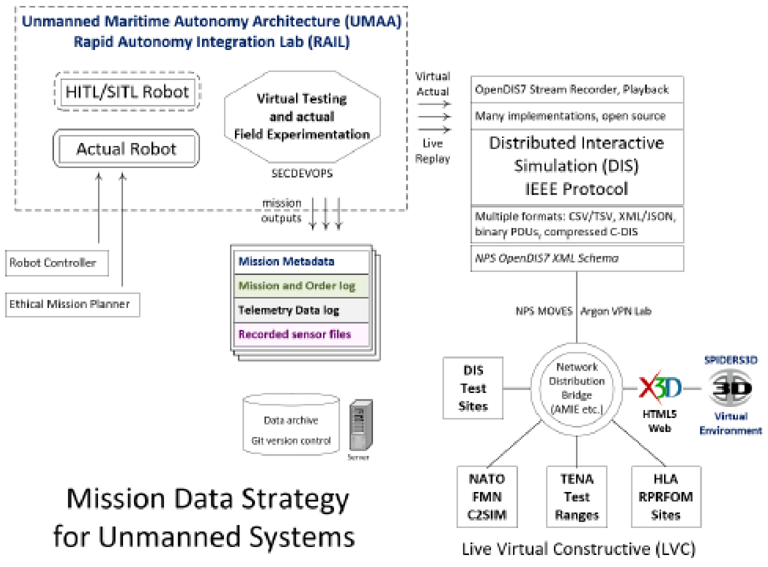




Mission Execution Ontology (MEO) evolving



Why / Objectives

- Ethical control of unmanned systems can be accomplished through structured mission definitions that are trusted, consistently readable, validatable, repeatable and understandable by humans and robots.
- Orders must be lawful. Unmanned systems must behave ethically and comprehensibly if they are to support manned military units effectively.
- Well-structured mission orders can be tested and trusted to give human commanders confidence that offboard systems *will do what they are told to do*, and further *will not do what they are forbidden to do*.
- Demonstrate that no technological limitations exist that prevent applying the same kind of ethical constraints on robots and unmanned vehicles that already apply to humans, in lethal and life-saving scenarios.

https://savage.nps.edu/EthicalControl

What / Deliverables

- Unmanned Systems Data Strategy is fundamental need for progress, otherwise all experiments (real or virtual) are unrepeatable, transient.
- Mission orders, metadata, track telemetry and sensor records together provide repeatable archiving of robot system testing for live-virtual-constructive (LVC) reuse, for replay live or rehearsal analysis.
- Update Mission Execution Ontology (MEO) concepts demonstrated in tests and simulation, building to perform field experimentation (FX).
- Define, simulate, and test combination of real-world goals and ethical constraints to robot mission tasking across set of canonical scenarios.
- Illustrate how human-robot teams meet moral and legal requirements if deploying unmanned systems with potential for lethal, life-saving force.

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Co-Investigator: Curtis Blais clblais@nps.edu 1.831.656.3215

Team Members and Focus-Area Presentations

Curtis Blais, Co-PI

- Data modeling and formal ontology development
- Mission Execution Ontology (MEO) and C2SIM standard with NATO

Kristen Fletcher

- Legal and ethical policies, ramifications

Terry Norbraten

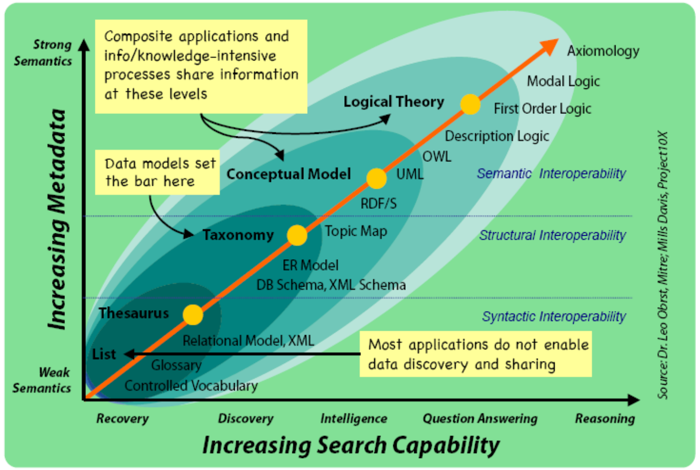
- Software design, development, and testing
- Data conversion using Data Format Description Language (DFDL)

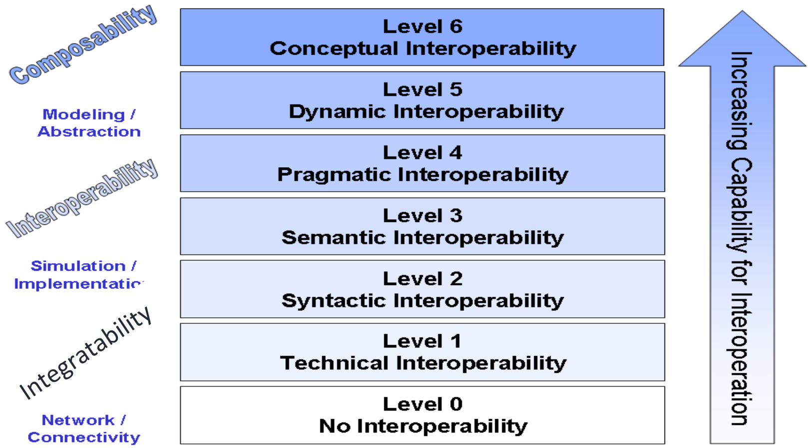
Don Brutzman, PI

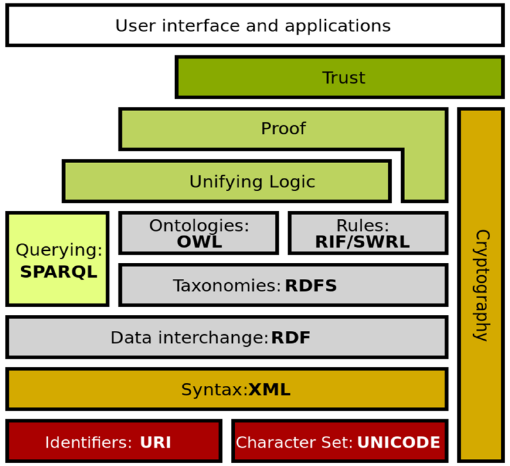
- Ethically constrained control of unmanned systems and robot missions by human supervisors and warfighters
- Unmanned systems data strategy and LVC interoperability architecture

Curtis Blais, Co-PI

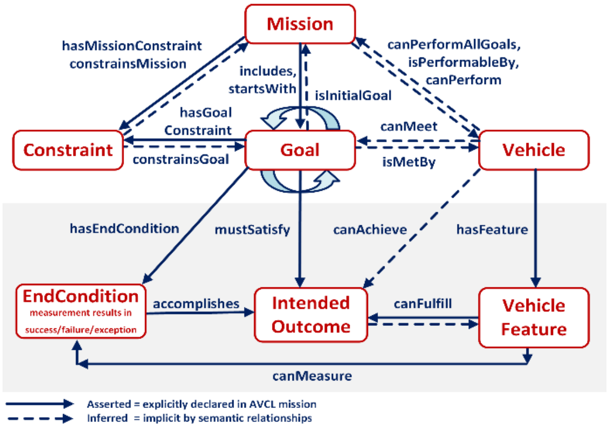
Data Modeling and Formal Ontology Development

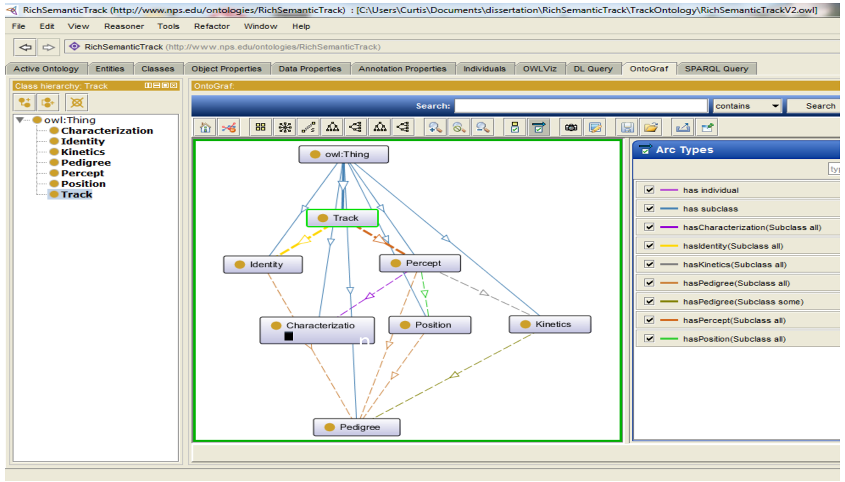




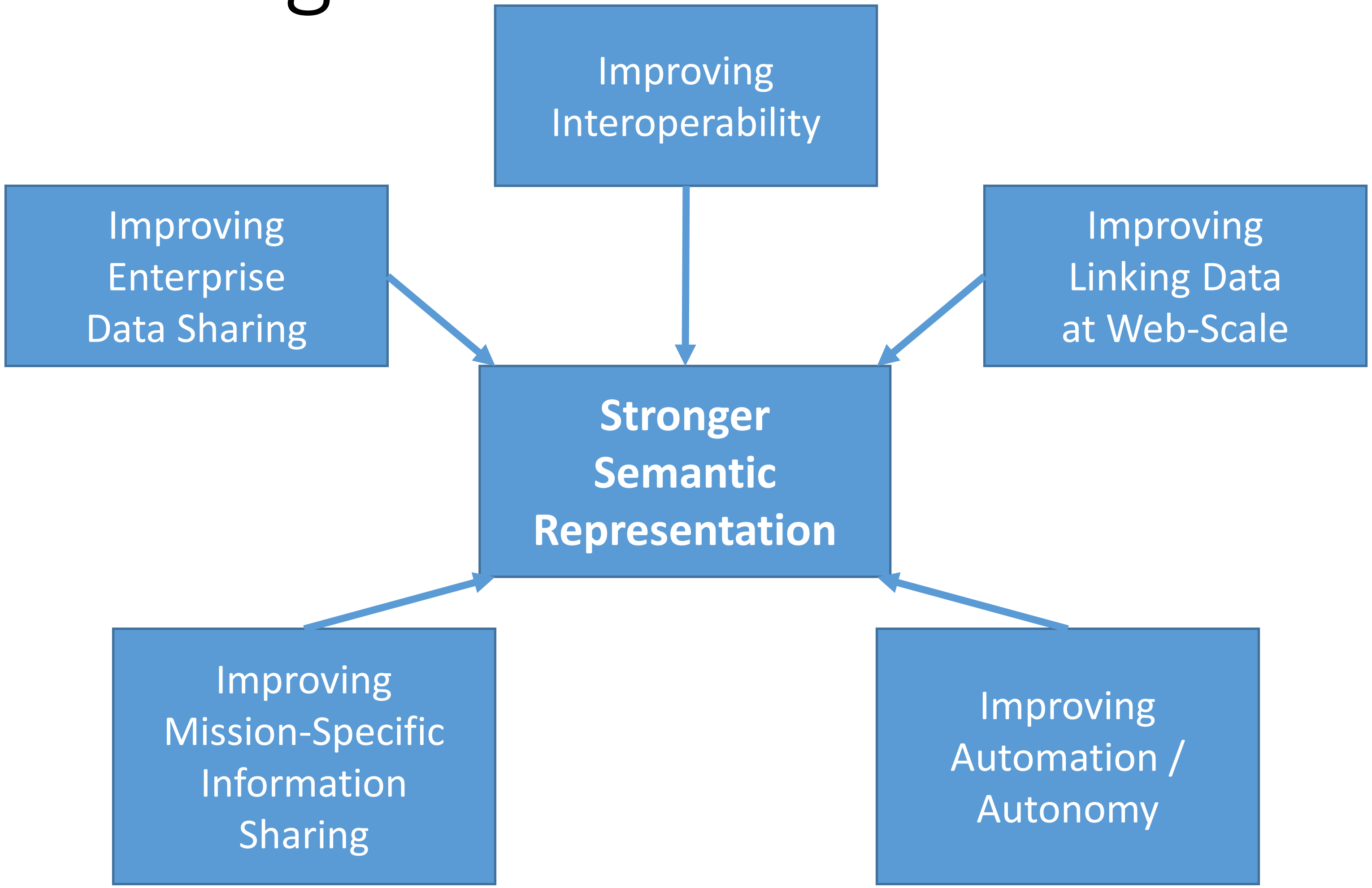


Mission Execution Ontology (MEO) 3.0





Motivation: Need for Stronger Semantics in Data Modeling

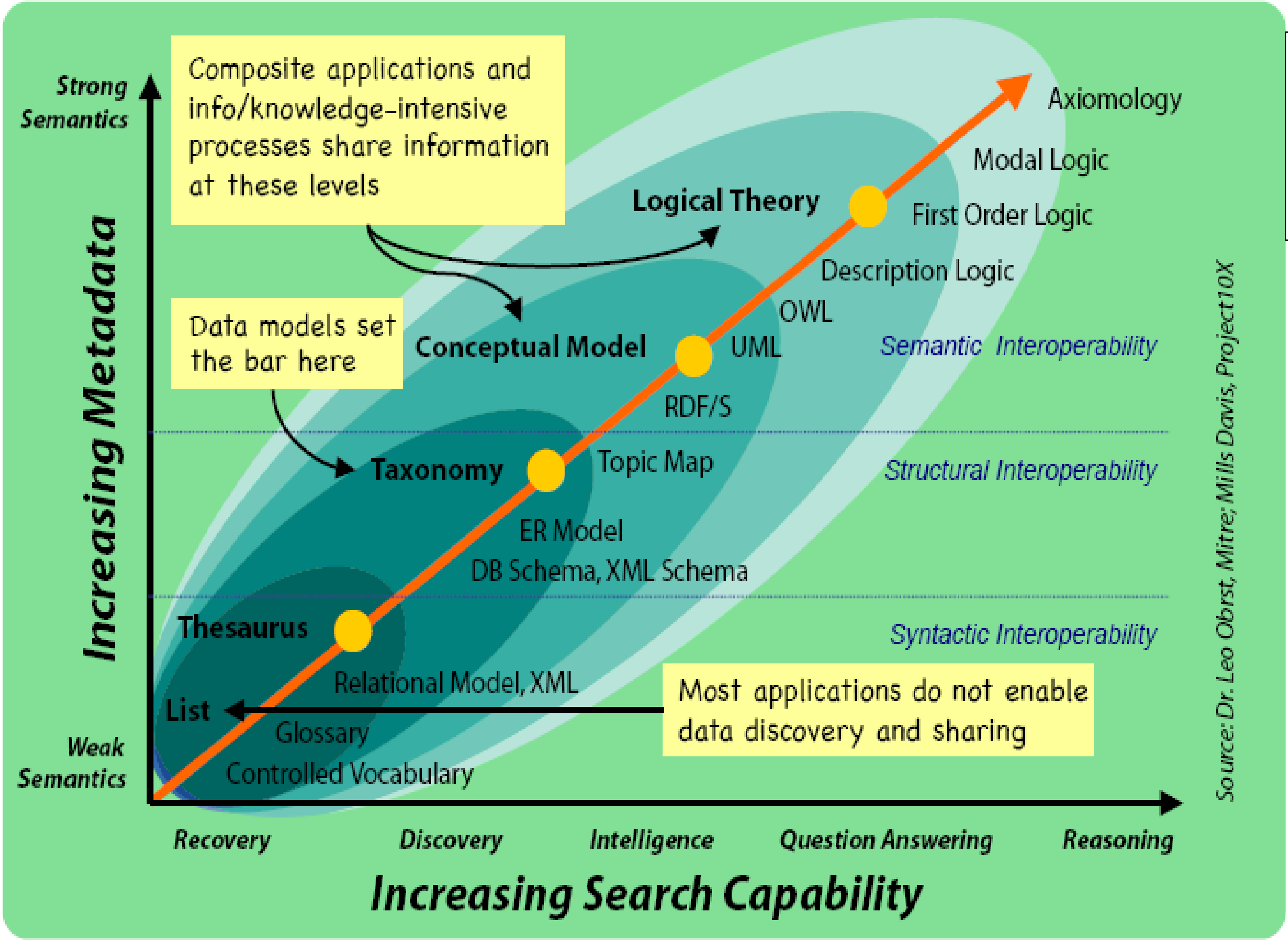


Improving Semantic Representation

- Knowledge Representation (KR) is an area of artificial intelligence (AI) research and practice focused on encoding meaning into data.
- Academia and industry now have a detailed path toward higher levels of machine understanding corresponding to human understanding.
- Refer to the Ontology Spectrum on the next slide (source: Obrst, Leo, and Mills Davis. 2006. *SICoP White Paper Series Module 2: Semantic Wave 2006 - Executive Guide to the Business Value of Semantic Technologies*, Project 10X, May 2015).

Acronyms: Database (DB) ; Extensible Markup Language (XML); Resource Description Language / Schema (RDF/S); Unified Modeling Language (UML); Web Ontology Language (OWL)

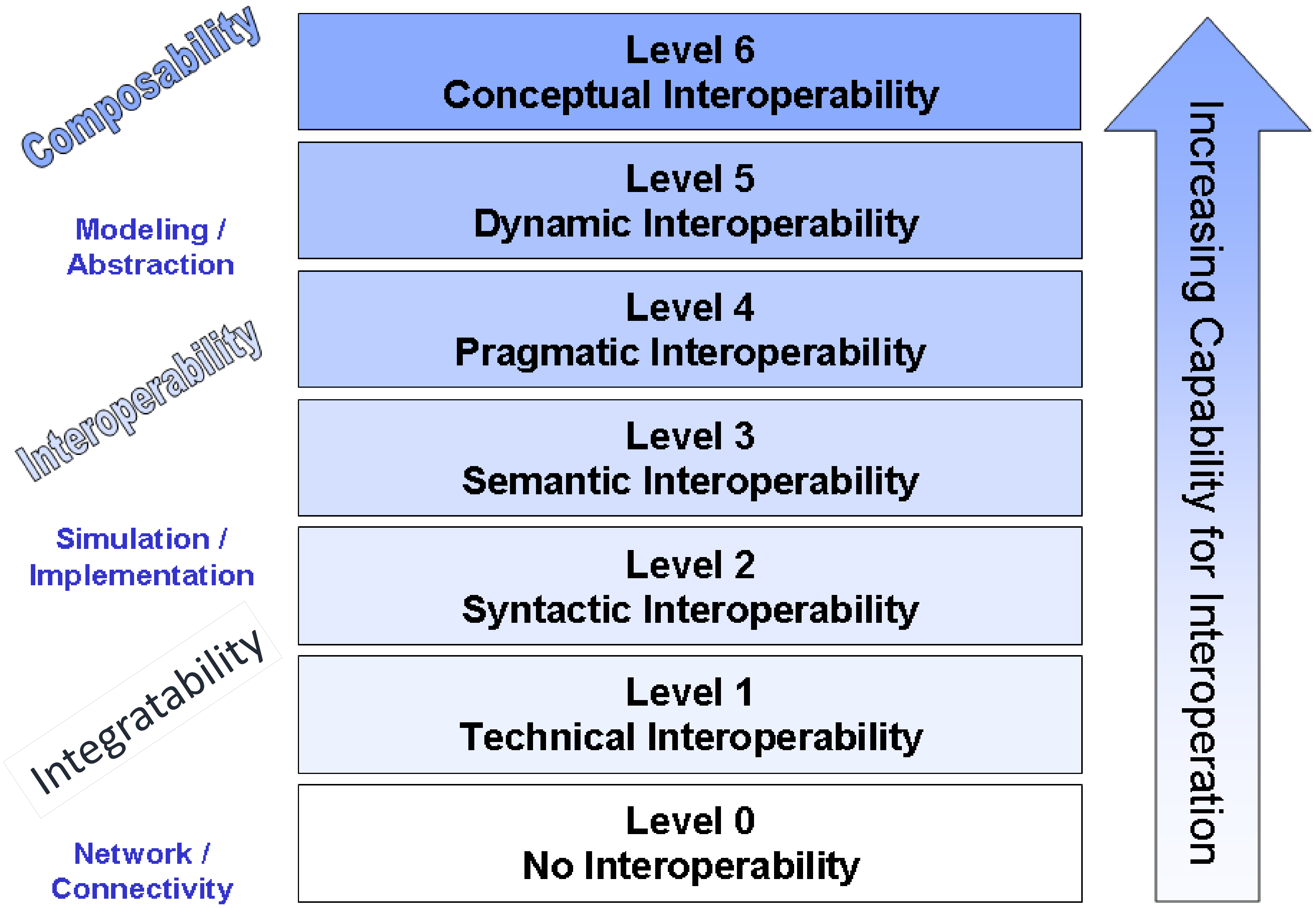
Improving Semantic Representation



Improving Interoperability

- Interoperability: “the capability of a system to automatically, without human intervention, provide services to and accept services from other systems, and to use the services so exchanged to enable the systems to work together to achieve a desired outcome” (Blais and Lacy 2004).
- Academia and industry have laid out a path toward higher levels of interoperability: refer to the Levels of Conceptual Interoperability Model (LCIM) on the next slide (source: Tolk, Andreas, Saikou Y. Diallo, Charles D. Turnitsa, and Leslie S. Winters. 2006. “Composable M&S Web Services for Net-centric Applications.” *Journal for Defense Modeling & Simulation (JDMS)*, 3:1:27-44. January.).
- Objective is to achieve conceptual and pragmatic interoperability.

Improving Interoperability: Levels of Conceptual Interoperability Model



Semantic Web: Knowledge Representation at Web Scale

- Architects of the World Wide Web have laid out a layered set of standards to achieve the Semantic Web vision: “not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation” (Berners-Lee et al. 2001)
- Ultimate goal: achieve a ***scalable trusted information infrastructure*** where humans and software interact meaningfully, in a repeatable environment where expectations of quality and integrity are met.
- Scalable approach indicates that single (ship + robot) solutions have potential to grow and encompass many simultaneous systems, thus improved data sharing, mission deconfliction, coordinated operations

Semantic Web Stack

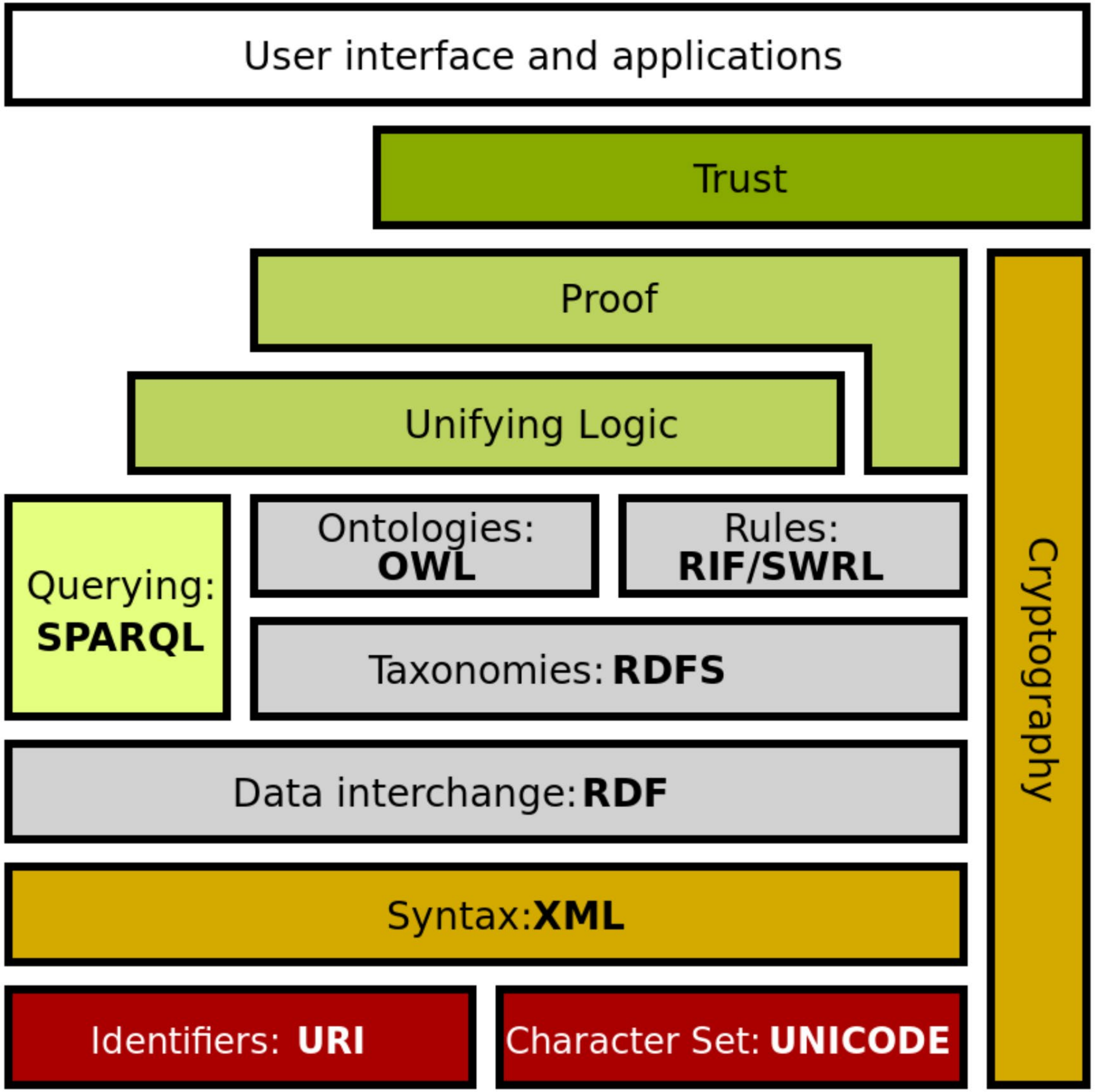
Extends larger Web architecture

- All of these data languages are approved W3C standards
- Proof and unifying logic are mathematically well defined

Trusting derived (composed) statements arises from

- Encryption + digital signature confirms trusted data sources
- Formal logic is basis for deriving new information
- Wikipedia: [Semantic Web Stack]

Of note: this project is exercising every layer of Semantic Web stack.



Autonomous Vehicle Command Language (AVCL)

Mission Tasking

- AVCL is a command and control language for humans supervising autonomous unmanned vehicles.
  - Clarity arises from close correspondence to human naval terminology.
- Structured vocabulary defining terms and relationships for mission planning, execution, conduct, recording and replay across diverse robot types.
- Common-ground XML representations for
  - Mission agenda plans, mission scripts, and post-mission recorded telemetry results.
  - ***Future work:*** defining unit tests and expected results for verification and validation.
- Operators have single archivable, validatable format for robot tasking, results
  - directly convertible to and from a wide variety of different robot command languages.

https://savage.nps.edu/Savage/AuvWorkbench/AVCL/AVCL.html

AVCL mission goals vocabulary (Davis 2015)

AVCL mission goals	Define	Used	Definition
Attack	partial	√	To conduct a type of offensive action characterized by employment of firepower and maneuver to close with and destroy an enemy.
Decontaminate	√		To provide purification making an area safe by absorbing, destroying, neutralizing, making harmless, or removing chemical, biological, or nuclear contamination.
Demolish	√		To destroy structures, facilities, or material by any available means.
IlluminateArea	√		To provide locale lighting by searchlight or pyrotechnics.
Jam	√		To deliberately radiate, re-radiate or reflect electromagnetic energy with the object of impairing the use of electronic devices or systems.
MarkTarget	√	√	To make visible (by the use of light, infrared, laser, smoke, etc.) of an object in order to allow its identification by another object.
MonitorTransmissions	√	√	To conduct electronic warfare support operations with a view to searching, locating, recording and analyzing radiated electromagnetic energy.
Patrol	√	√	To gather information or carry out a security mission.
Rendezvous	√	Partial	Achieve a meeting at a specified time and place.
Reposition	√	√	To change position from one location to another.
SampleEnvironment	Partial	√	Collect environmental samples for testing for chemical compounds, biological creatures, or nuclear hazards.
Search	√	√	To look for lost or unlocated objects or persons.

More Goal Types Foreseen

Example AVCL mission agenda, as pseudo-code XML

```xml
<?xml version="1.0" encoding="UTF-8"?>
<UUVMission>
  <GoalSet>
    <Goal area=”A” id=”goal1”>
      <Search nextOnSuccess=”goal2” nextOnFailure=”goal3”/>
    </Goal>
    <Goal area=”A” id=”goal2”>
      <SampleEnvironment nextOnSuccess=”goal3”
            nextOnFailure=”recover”/>
    </Goal>
    <Goal area=”B” id=”goal3”>
      <Search nextOnSuccess=”goal4” nextOnFailure=”goal4”/>
    </Goal>
    <Goal area=”C” id=”goal4”>
      <Rendezvous nextOnSuccess=”recover” nextOnFailure=”recover”/>
    </Goal>
    <Goal area=”recoveryPosition” id=”recover”>
      <Transit nextOnSuccess=”missionComplete”
            nextOnFailure=”missionAbort”/>
    </Goal>
  </GoalSet>
</UUVMission>
```

AVCL is readable by human or robot, captures logic of mission tasking

XML ensures syntactically correct, well-defined, numerically valid

Needed: semantic representation to check ethical, logical consistency

Motivating insights: converting data into logic

"The answer to your question is the response to the query."

- Jim Hendler and Dean Allemang
- Meaningfulness of an answer matches the precise meaning of a question.

"Trying to use the Semantic Web without SPARQL is like trying to use a relational database without SQL.“

- Tim Berners-Lee
- Language representations are needed for query as well as for information.

"The proof of the pudding is in the eating."

- Wiktionary
- Confidence in results requires testing.

Mission Execution Ontology (MEO) Development

- ✓Define MEO from concepts, properties, relationships using Protégé tool.
- ✓Create full set of canonical missions in AVCL (XML).
- ✓Determine exemplar mappings for AVCL primitives to Turtle for RDF/OWL.
- ✓Write conversion stylesheet AvclToMEO.xslt for full expressiveness.
- ✓Convert all AVCL missions to corresponding triples.
- ✓Confirm AVCL MEO, missions validate satisfactorily using Protégé, ARQ.
- ✓Automate build process as suite of repeatable unit-test queries (log).
- ✓SPARQL queries to test AVCL mission representations in Turtle.
- ✓Write SPARQL metaqueries to test, document MEO ontology relationships.
- ✓Continuing work: Adding Shapes Constraint Language (SHACL) statements for mission validation.
- ✓Continuing work: Ontology linking (mission specification, mission data stream, ethics, policies, provenance) for query and automated reasoning.

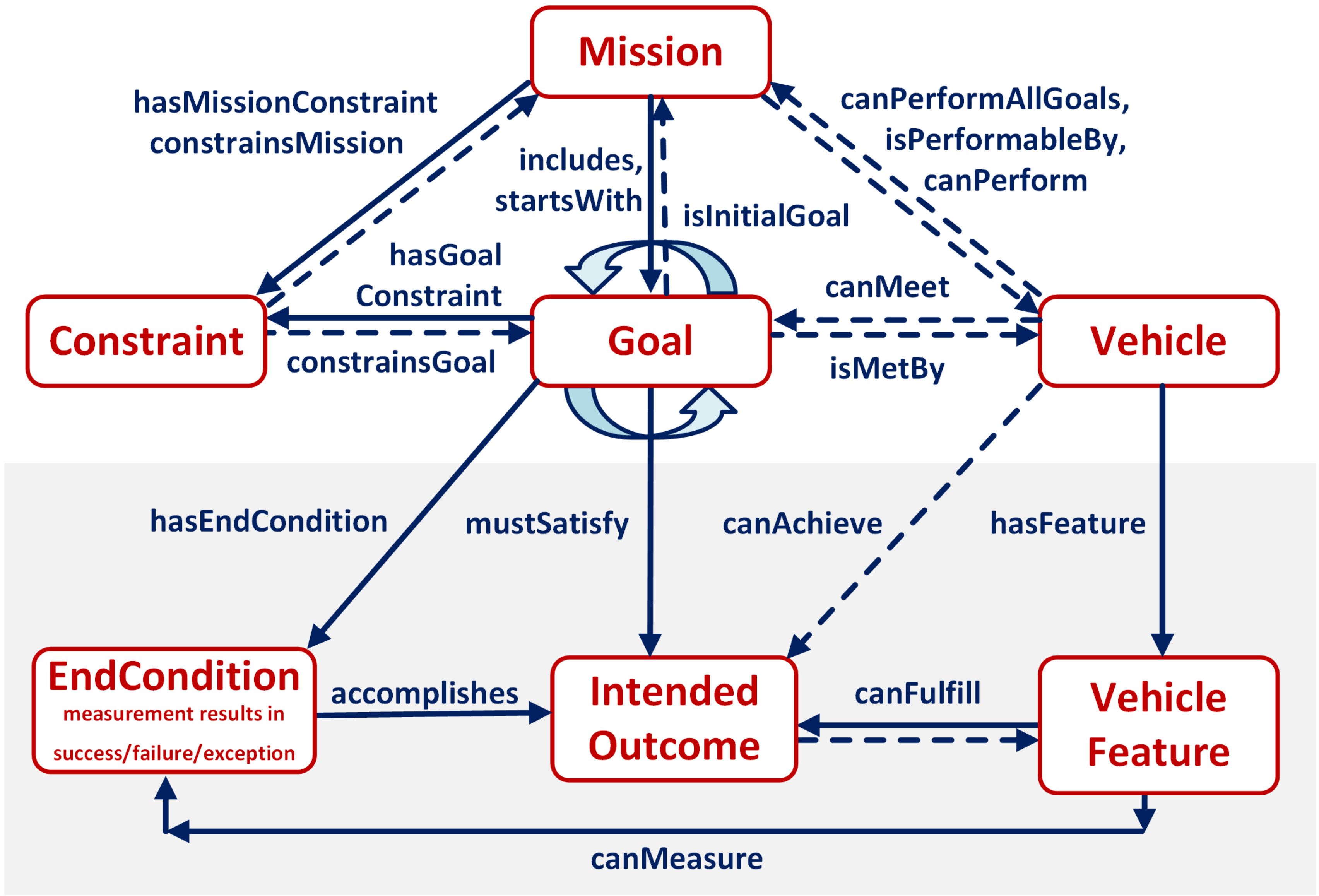
Description Logic (DL) Rules provide basis for Mission Execution Ontology (MEO)

Rules	Description Logic Equations	Plain-language description
M = Mission Rules		
M1	Mission $\sqsubseteq$ $\forall$startsWith.Goal $\sqcap$ =1startsWith.Goal	A Mission can only start with a Goal and must start with exactly one Goal
M2	Mission $\sqsubseteq$ $\forall$includes.Goal $\sqcap$ $\geq$1includes.Goal	A Mission can only include Goals and must include one of more Goals
M3	Mission $\sqsubseteq$ $\forall$hasConstraint.Constraint	A Mission can only be constrained by Constraints
M4	startsWith $\sqsubseteq$ includes	A Mission must include the Goal that it starts with
M5	Mission $\sqsubseteq$ $\forall$performableBy.Vehicle	A Mission can only be performed by a Vehicle
M6	Cannot be expressed in DL	A Mission cannot be performable by a Vehicle unless that Vehicle has the ability to identify all Constraints associated with that mission
M7	Cannot be expressed in DL	A Mission cannot be performable by a Vehicle unless that Vehicle has the capability to accomplish all Goals included in that Mission

Excerpted from full
Mission Execution Ontology
Decision Logic Tables

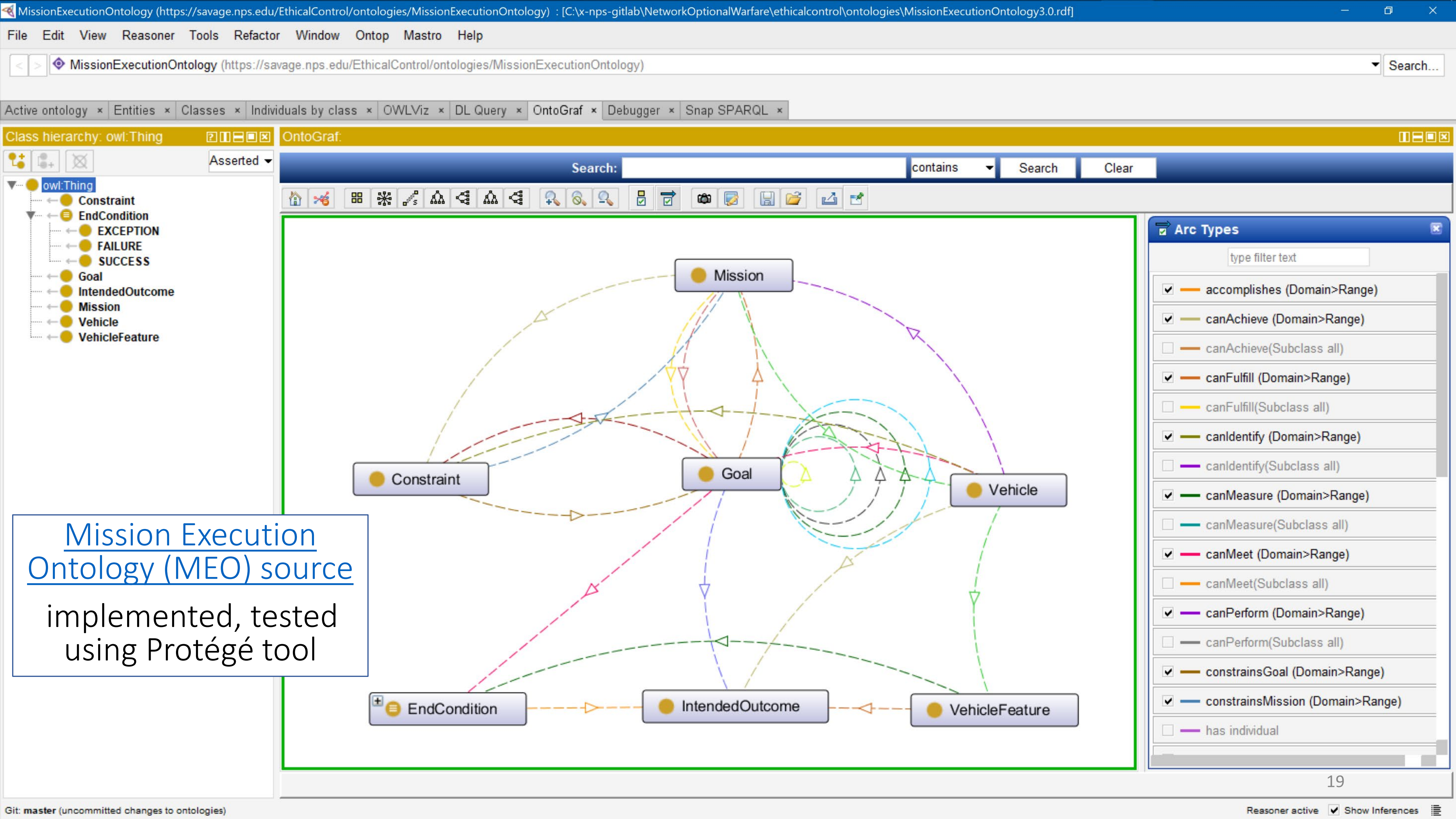
Original author: Duane Davis
Model updated by Curtis Blais in collaboration with Raytheon engineers through NPS-Raytheon CRADA

Mission Execution Ontology (MEO) 3.0



Asserted = explicitly declared in AVCL mission

Inferred = implicit by semantic relationships



[Mission Execution Ontology (MEO) source]

implemented, tested using Protégé tool

Mission Execution Ontology (MEO) for Ethical Control of Unmanned Systems in Surrogate Scenarios

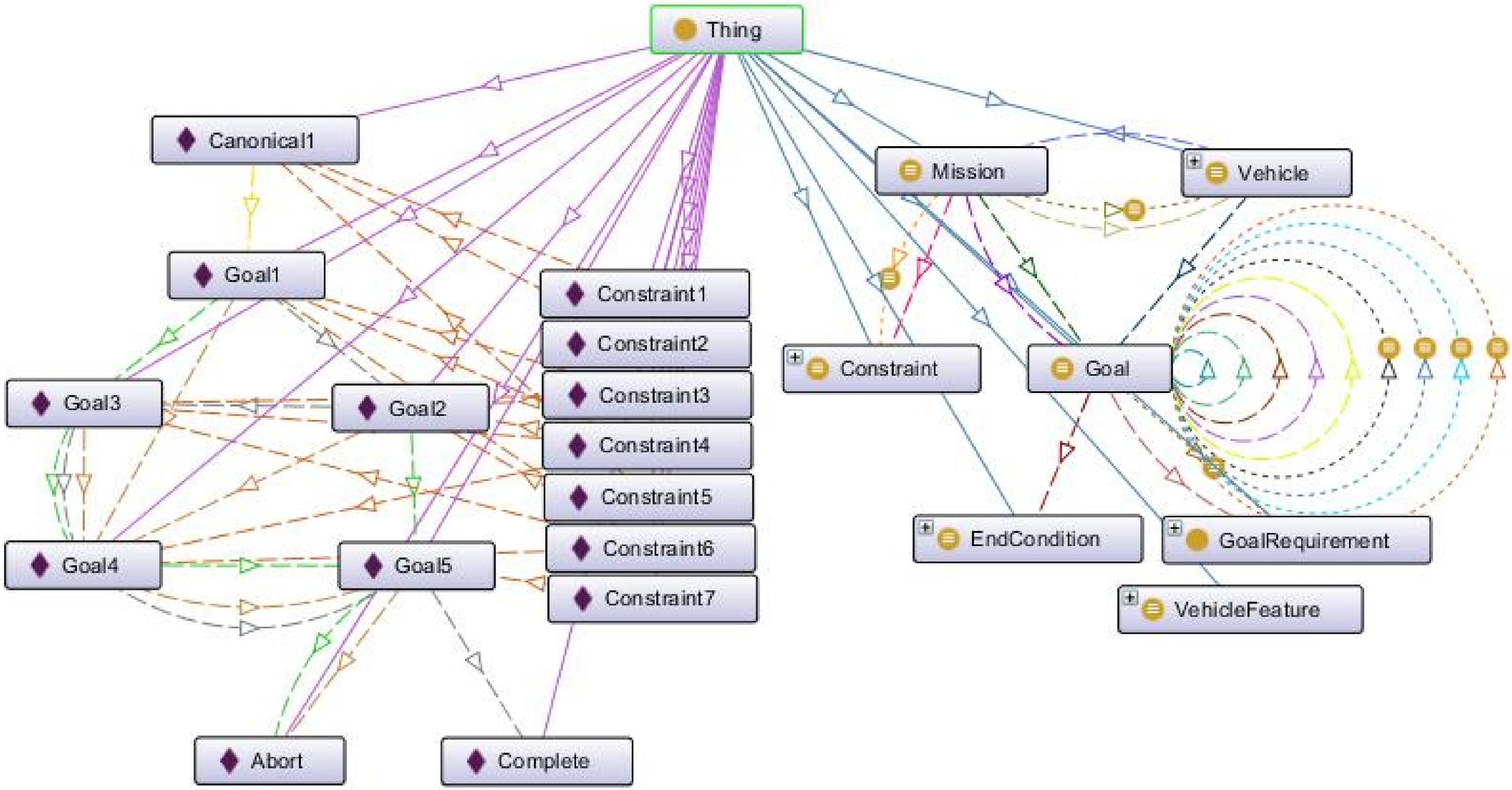
Summary of relationships

- **Autonomous Vehicle Command Language (AVCL) for Missions.**
  - Declarative XML, years of NPS research.
- **Multiple Mission Representations.**
  - Imperative commands (orders/waypoints/etc.).
  - Declarative commands (mission goals).
  - Mission results (order log, telemetry etc.).
  - Mission metadata for parameters, settings.
  - Lisp and Prolog examples (Bob McGhee, NPS).
- **Autonomous Unmanned Vehicle (AUV) Workbench Simulation and Visualization Support**
  - Recently restored, debug testing commenced.
  - AVCL 2.1 is prior published version, centered on *syntactic validation*, solo robot operations.
  - AVCL 3.0 is new working version for testing range of multi-participant missions.

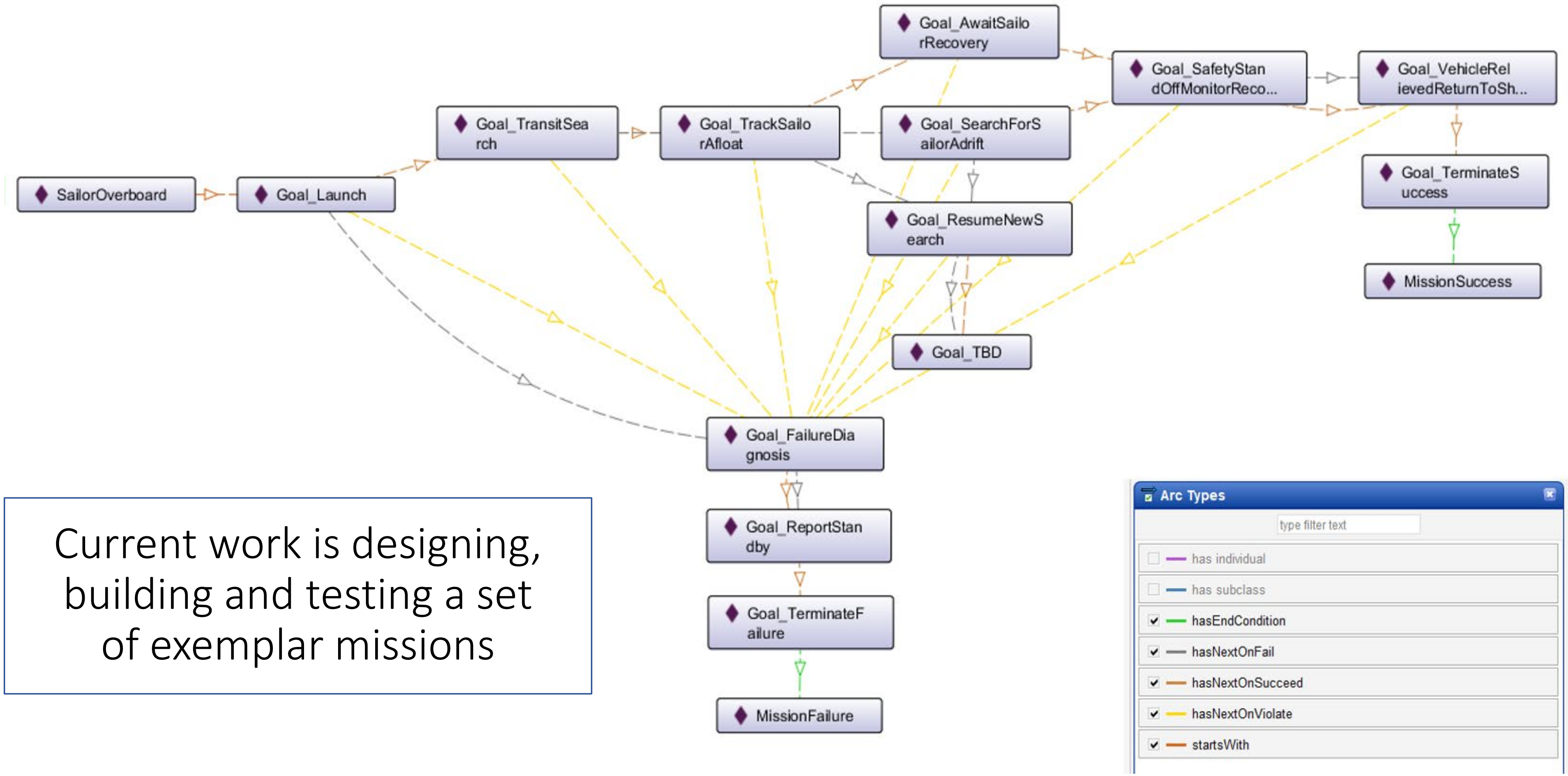
- **Mission Execution Ontology (MEO) for Semantic Validation**
  - Semantic Web framework of rules, relationships for *ethical validation.*
  - Initial examples in IEEE JOE paper.
  - Retested using current Protégé, Jena tools.

- **Sailor Overboard and Other Missions**
  - Hand-crafted triples using Turtle syntax.
  - Beginning to build unit testing framework.
  - Confirming correlation of AVCL information model to existing MEO ontology.
  - Automatic conversion of AVCL missions to match, thus accelerating multiple-mission testing on diverse systems.
  - Visualization, reporting via AUV Workbench can aid understanding, mission planning and further progress.

Example Mission Validation using Protégé Tool



Ethical Control of Unmanned Systems in a Surrogate Scenario: Sailor Overboard Mission defined using the MEO Ontology



Current work is designing, building and testing a set of exemplar missions

SPARQL Protocol and RDF Query Language

- "SPARQL is an RDF query language — that is, a semantic query language for databases — able to retrieve and manipulate data stored in Resource Description Framework (RDF) format." -- Wikipedia
- Standardized as World Wide Web (W3C) Recommendation
  - Open-source implementations that we use include Apache ARQ and Protégé tool.
- We use SPARQL to express queries against AVCL missions in RDF/OWL (Turtle syntax) together with Mission Execution Ontology (MEO).
- Results reveal interesting properties about missions that are otherwise difficult to determine. Inferences can also be combined and correlated.
- Goal is to express in-depth mission-related queries that determine
  - Whether all logical mission prerequisites and constraints are satisfied, and
  - Whether tactical policies and Rules of Engagement (ROE) are met.

```
Perform Mission Execution Ontology metaquery MissionExecutionOntologyQuery_01.rq
to produce output file MissionExecutionOntologyQuery_01.rq.txt:

PREFIX :     <https://www.nps.edu/ontologies/MissionExecutionOntology/missions#>
PREFIX meo:  <https://www.nps.edu/ontologies/MissionExecutionOntology#>
PREFIX owl:  <http://www.w3.org/2002/07/owl#>
PREFIX rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xml:  <http://www.w3.org/XML/1998/namespace>
PREFIX xsd:  <http://www.w3.org/2001/XMLSchema#>

# @base <https://www.nps.edu/ontologies/MissionExecutionOntology/missions>

# MissionExecutionOntologyQuery_01.rq    Metaquery to list all properties
with corresponding domains and ranges in Mission Execution Ontology.

###############################################

SELECT distinct ?property ?domain ?range
WHERE
{
    ?property rdfs:range  ?range .
    ?property rdfs:domain ?domain .
}
ORDER by ASC(?property) # alphabetize

###############################################
```

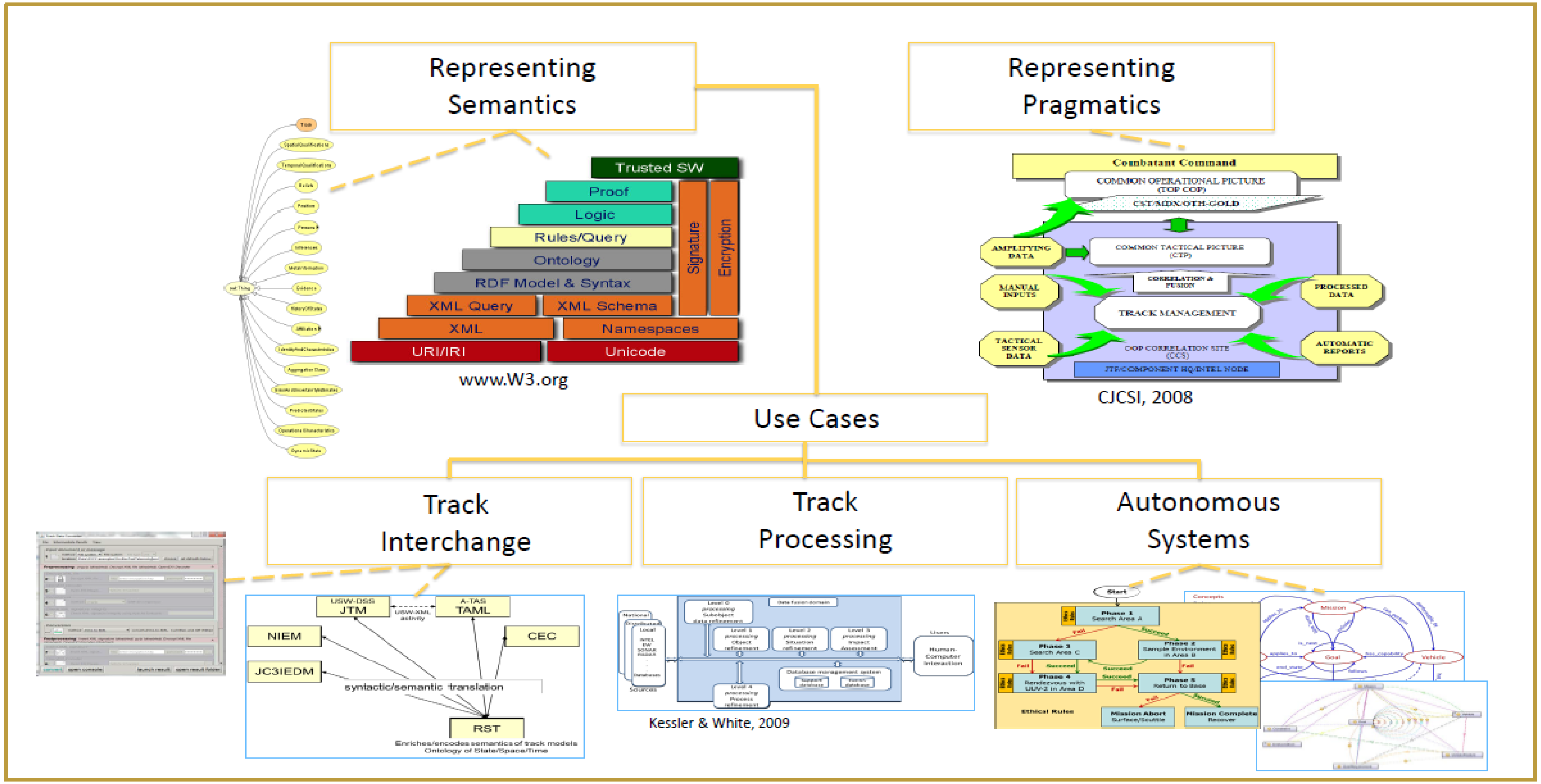
Confirm MEO via self-centered SPARQL *metaquery*
MissionExecutionOntologyQuery_01.rq

```
--------------------------------------------------------------------
| property              | domain                | range               |
====================================================================
| meo:appliesTo         | meo:Constraint        | _:b0                |
| meo:canFulfill        | meo:VehicleFeature    | meo:GoalRequirement |
| meo:canIdentify       | meo:Vehicle           | meo:Constraint      |
| meo:canMeet           | meo:Vehicle           | meo:Goal            |
| meo:canPerform        | meo:Vehicle           | meo:Mission         |
| meo:canTest           | meo:VehicleFeature    | meo:Constraint      |
| meo:hasConstraint     | meo:Mission           | meo:Constraint      |
| meo:hasEndCondition   | meo:Goal              | meo:EndCondition    |
| meo:hasFeature        | meo:Vehicle           | meo:VehicleFeature  |
| meo:hasNext           | meo:Goal              | meo:Goal            |
| meo:hasNextOnFail     | meo:Goal
| meo:hasNextOnSucceed  | meo:Goal
| meo:hasNextOnViolate  | meo:Goal
| meo:includes          | meo:Mission
| meo:isFollowedBy      | meo:Goal
| meo:isPerformableBy   | meo:Mission           | meo:Vehicle         |
| meo:meetsRequirement  | meo:Vehicle           | meo:GoalRequirement |
| meo:requires          | meo:Goal              | meo:GoalRequirement |
| meo:startsWith        | meo:Mission           | meo:Goal            |
--------------------------------------------------------------------
```

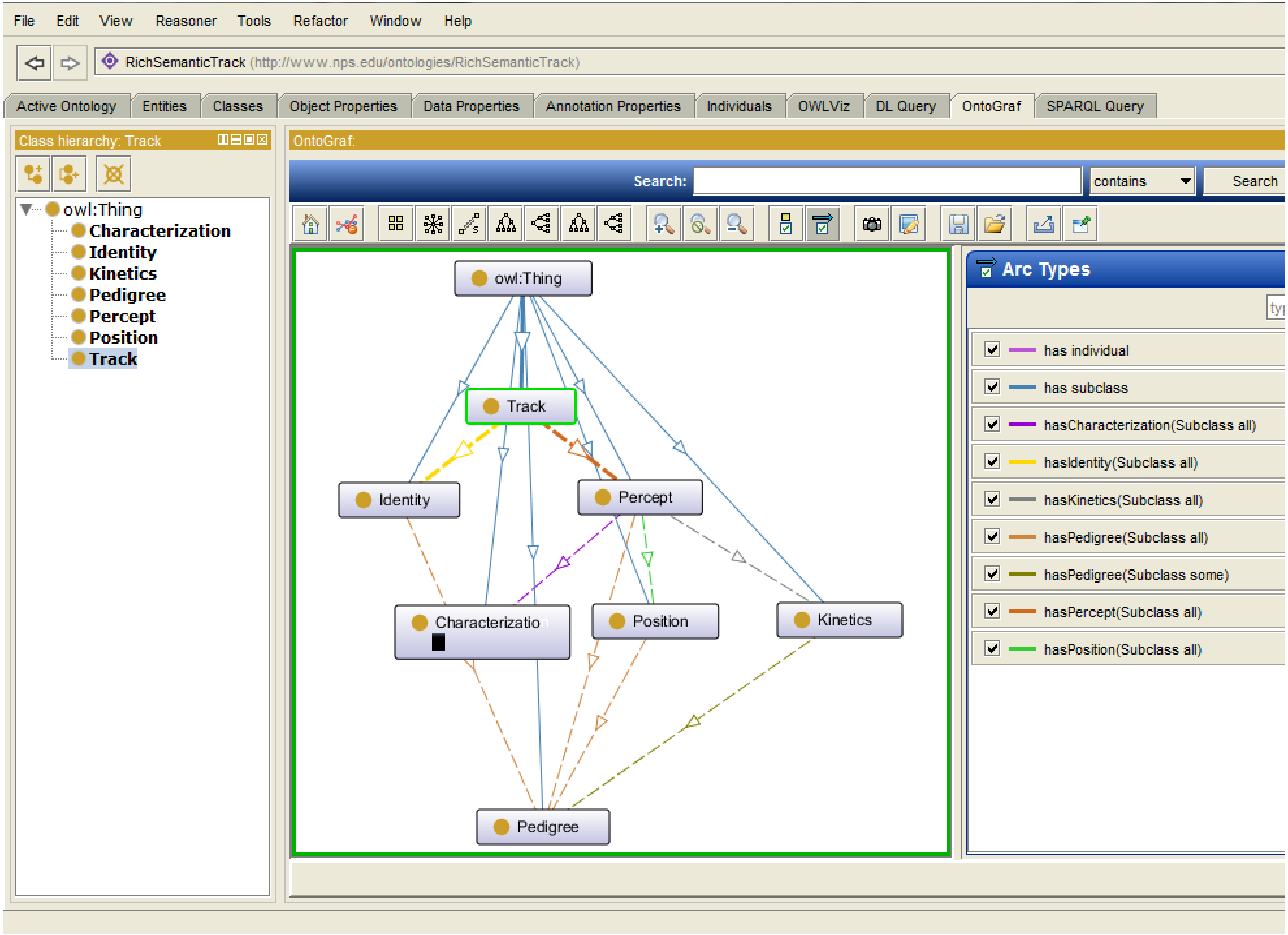
Confirm MEO via self-centered SPARQL *metaquery* response

[MissionExecutionOntologyQuery_01.rq.txt]()

Rich Semantic Track (RST) Ontology



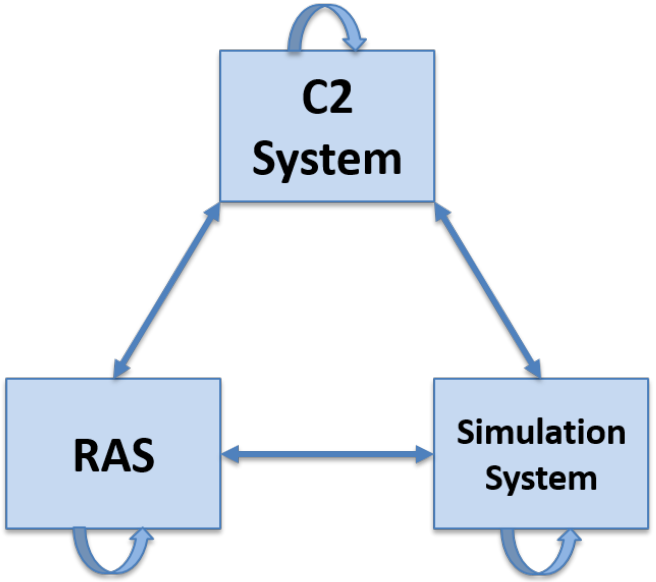
The Rich Semantic Track model formalizes the semantics and pragmatics of track data for broad application, including potential for improving data interchange and processing for unmanned systems.



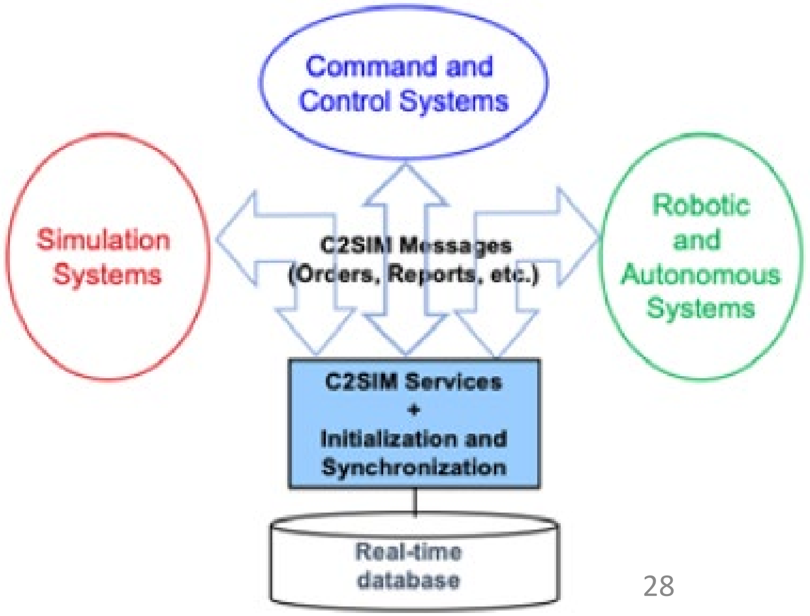
File Edit View Reasoner Tools Refactor Window Help
RichSemanticTrack (http://www.nps.edu/ontologies/RichSemanticTrack)
Active Ontology
Entities
Classes
Object Properties
Data Properties
Annotation Properties
Individuals
OWLViz
DL Query
OntoGraf
SPARQL Query
Class hierarchy: Track
owl:Thing
Characterization
Identity
Kinetics
Pedigree
Percept
Position
Track
OntoGraf:
Search:
contains
Search
owl:Thing
Track
Identity
Percept
Characterizatio
Position
Kinetics
Pedigree
Arc Types
has individual
has subclass
hasCharacterization(Subclass all)
hasIdentity(Subclass all)
hasKinetics(Subclass all)
hasPedigree(Subclass all)
hasPedigree(Subclass some)
hasPercept(Subclass all)
hasPosition(Subclass all)

Coalition Interoperability: C2SIM Standard

- Only international standard for information interchange across C2 systems, simulation systems, and robotic and autonomous systems (RAS)
  - Plans, orders, and reports
  - Being adopted as NATO Standardization Agreement (STANAG)
  - Identified standard for the NATO Federated Mission Networking initiative
- Published April 2020 by the Simulation Interoperability Standards Organization (SISO)
  - C2SIM Core Ontology and Standard Military Extension
  - C2SIM Land Operations Extension
  - C2SIM Guide



Nine-way interactions
(inter-system and extra-system)

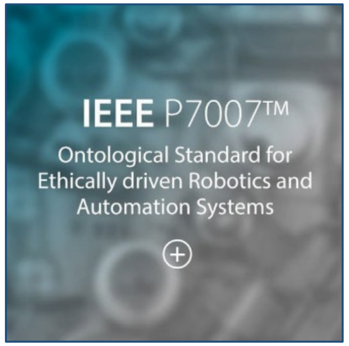


IEEE P7000-series Standards Projects

https://ethicsinaction.ieee.org

- P7000 Model Process for Addressing Ethical Concerns during System Design
- P7001 Transparency of Autonomous Systems
- P7002 Data Privacy Process
- P7003 Algorithmic Bias Considerations
- P7004 Standard on Child and Student Data Governance
- P7005 Standard on Employee Data Governance
- P7006 Standard on Personal Data AI Agent Working Group
- P7007 Ontological Standard for Ethically driven Robotics and Automation Systems
- P7008 Standard for Ethically Driven Nudging for Robotic, Intelligent and Autonomous Systems
- P7009 Standard for Fail-Safe Design of Autonomous, Semi-Autonomous Systems
- P7010 Well-being metrics Standard for Ethical Artificial Intelligence and Autonomous Systems
- P7011 Stadard for the Porcess of Identifying and Rating the Trustworthiness of News Sources
- P7012 Standard for Machine Readable Personal Privacy Terms
- P7014 Standard for Ethical Considerations in Emulated Empathy in Autonomous and Intelligent Systems

IEEE Standards Project P7007 for Ontological Standard for Ethically driven Robotics and Automation Systems



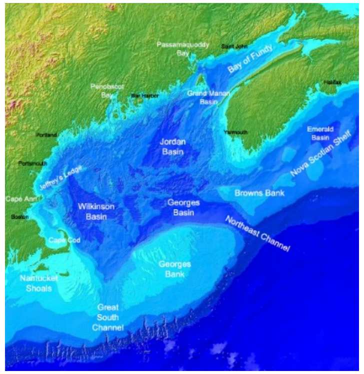
Published November 2021!

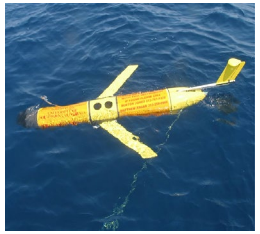
- IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems.
  - https://ethicsinaction.ieee.org includes large document providing broad rationale.
  - Includes 15 separate working groups in IEEE Standards Association (IEEE-SA).
- Relevant group: P7007, Ethically driven Robotics and Automation Systems.
  - "IEEE P7007 Standards Project for Ontological Standard for Ethically driven Robotics and Automation Systems establishes a set of ontologies with different abstraction levels that contain concepts, definitions and axioms that are necessary to establish ethically driven methodologies for the design of Robots and Automation Systems."
  - http://standards.ieee.org/develop/project/7007.html
  - Must be IEEE member, observe patent-policy requirements to participate in working group.
  - "Not the intent to specify required ethical behaviors, but rather to formalize a vocabulary of terms, concepts, and relationships that can be used to enable unambiguous discussion among [...] communities regarding what it means for autonomous systems to exhibit ethical behaviors."
  - Excellent forum with rich references, worth observation and participation.
- ***Active work:*** align several Ethical Control terms, concepts, use cases with P7007.

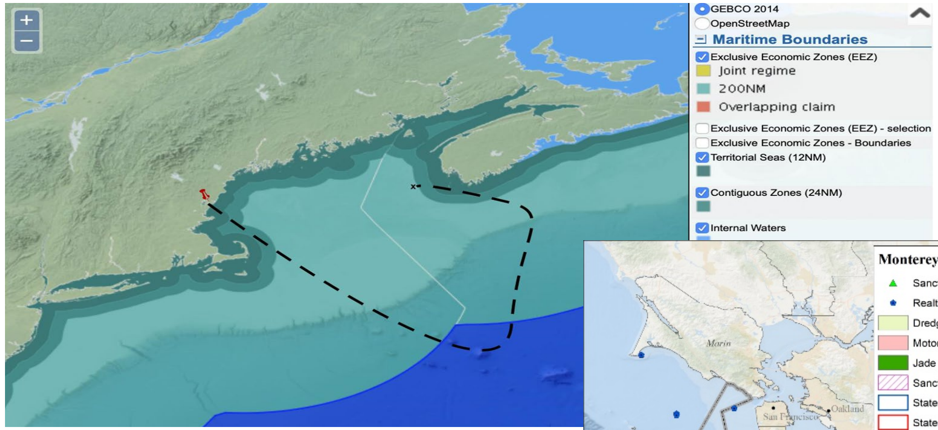
Kristen Fletcher
Legal and Ethical Policies

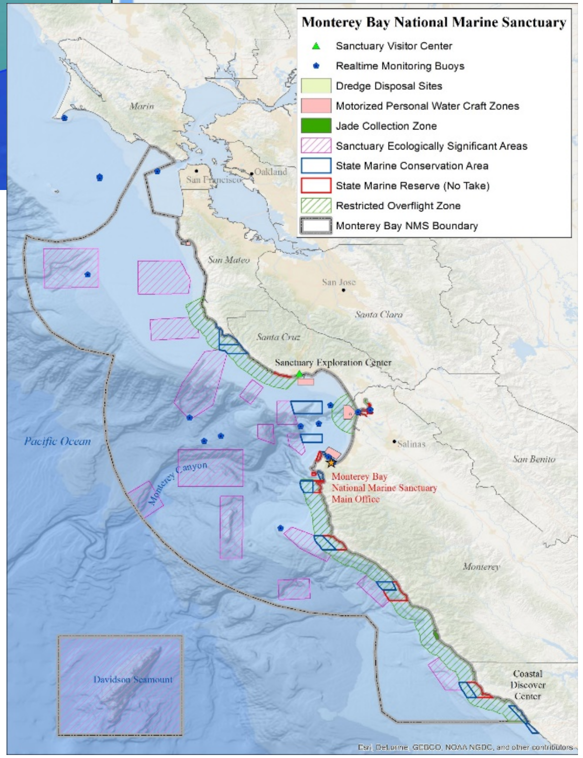
PROJECTS

SCENARIOS









THE PROJECTS

2021:

Ethical Control of Unmanned Systems: Repeatable Mission Evaluation Through Unmanned Systems Data Strategy for UMAA/RAIL
Brutzman, Blais, Fletcher / CRUSER

Priority Legal and Policy Issues of Unmanned Systems
Fletcher, Hahn, Lesse, DeCocco / CRUSER

Formation, Implementation, and Verification of Requirements for Human-Autonomy Teaming
Van Bossuyt, Weger, Semmens, Fletcher, Mesmer, Tenhundfeld, Jones / CRUSER

TTCP AI Strategic Challenge: Law/Ethics Theme Team
Fletcher, Choinski, Palmer, international partners / OSD OUSD R-E

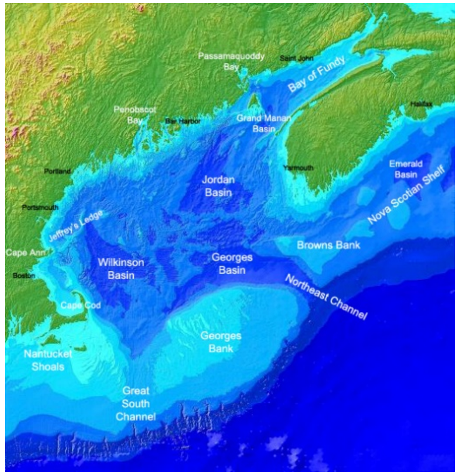
2022:

Advancing Clarity: Analysis of UxS Legal Questions
Fletcher, Hahn, Lesse / CRUSER

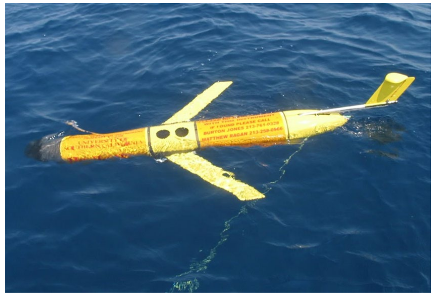
Interactive Synthetic Environment (ISE) to Evaluate Zero-Carbon UAS Launch Platforms in the Arctic
Dew, Balogh, Fitzpatrick, Fletcher, Lesse / CRUSER

TTCP AI Strategic Challenge: Law/Ethics Theme Team
Fletcher, Palmer, international partners / OSD OUSD R-E

SCENARIOS



Luke

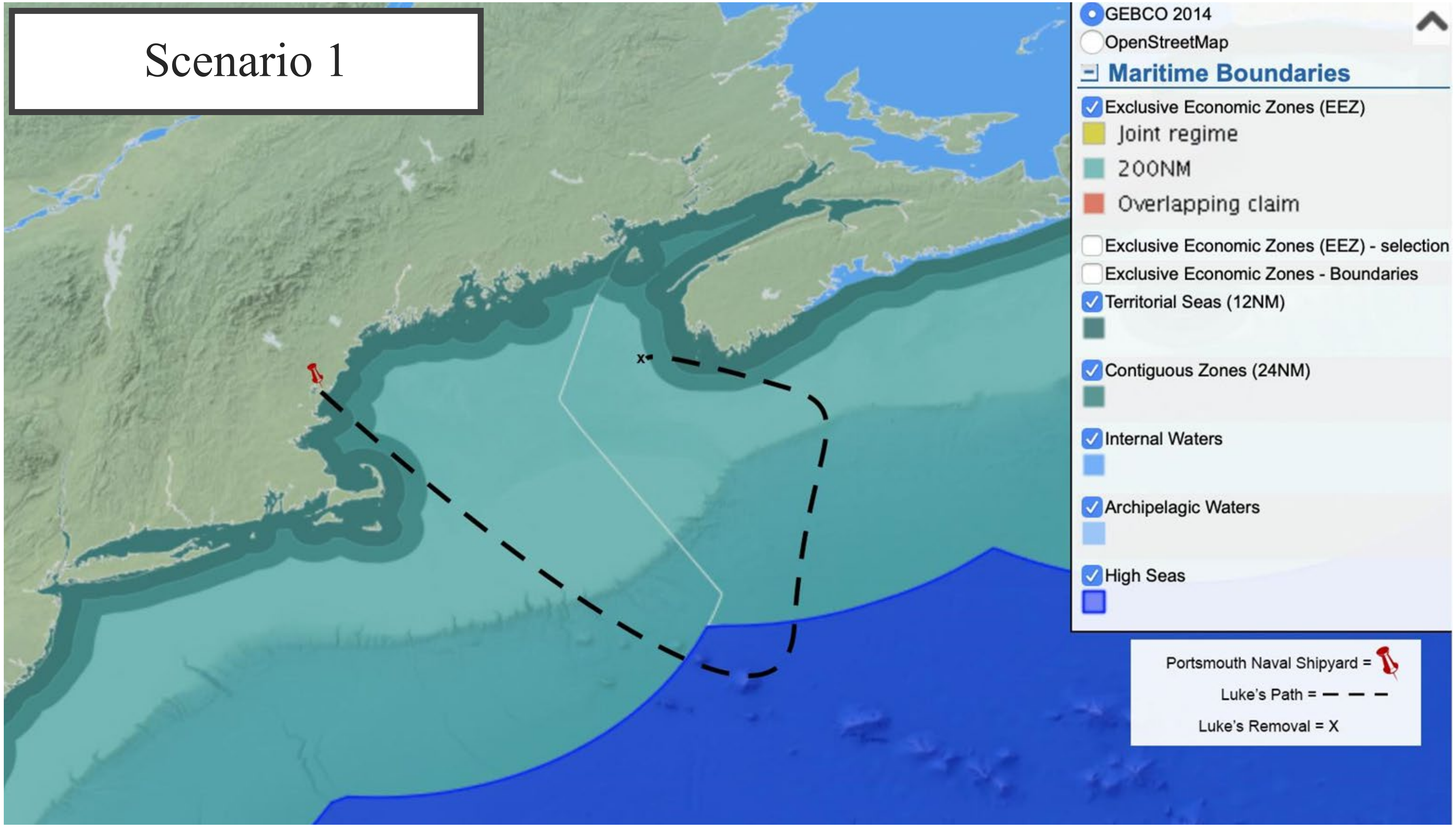


USNI News

WHAT ARE THE LEGAL REQUIREMENTS FOR AS/UxS TO OPERATE IN INTERNATIONAL WATERS AND EEZS?

WHAT ARE THE LEGAL CONSIDERATIONS FOR AS/UxS IN THE U.S. IN AREAS OF OVERLAPPING JURISDICTIONS?

Scenario 1

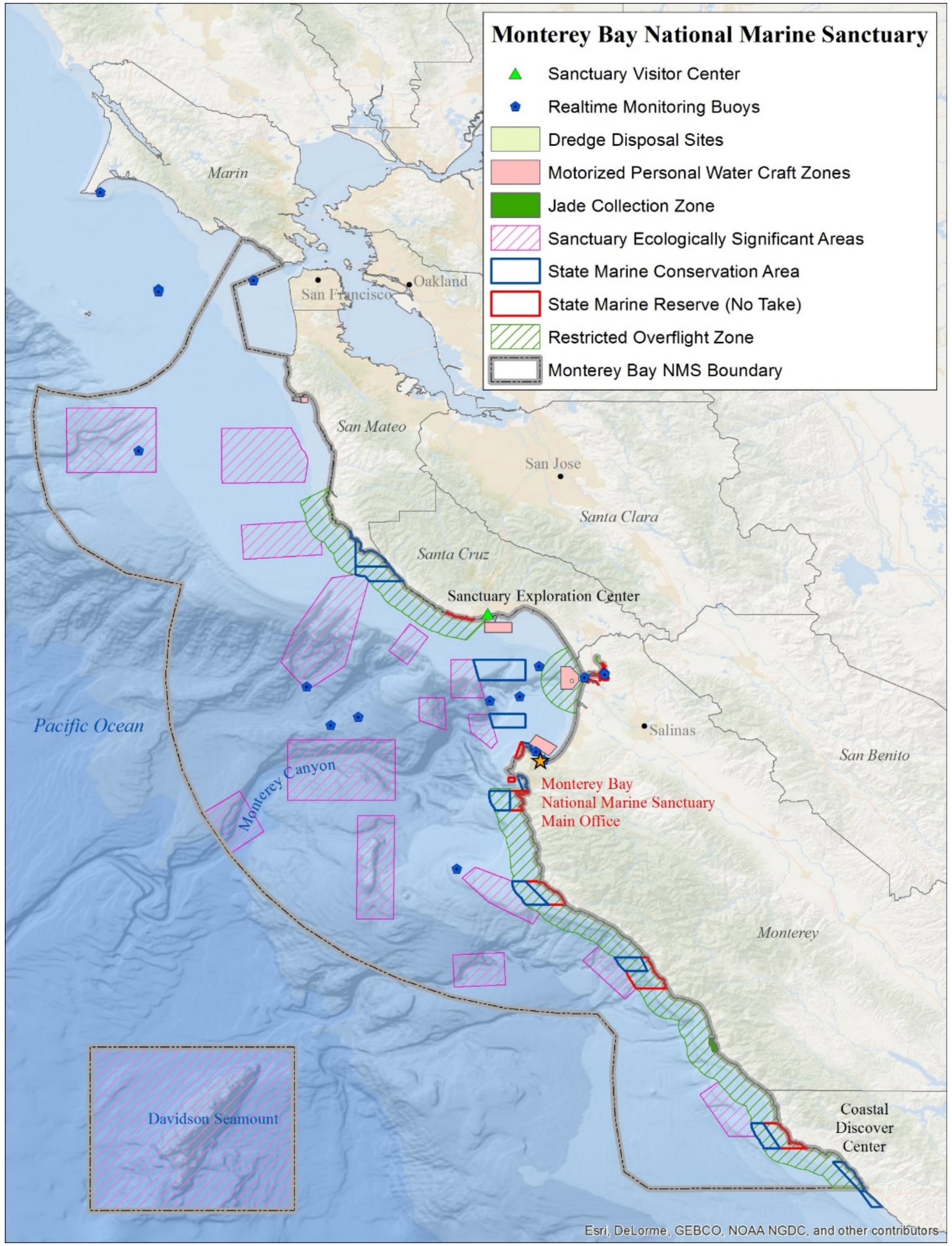


GEBCO 2014
OpenStreetMap
Maritime Boundaries
Exclusive Economic Zones (EEZ)
Joint regime
200NM
Overlapping claim
Exclusive Economic Zones (EEZ) - selection
Exclusive Economic Zones - Boundaries
Territorial Seas (12NM)
Contiguous Zones (24NM)
Internal Waters
Archipelagic Waters
High Seas
Portsmouth Naval Shipyard =
Luke's Path =
Luke's Removal = X
x

Scenario 2

- Protected Areas:
  - National Marine Sanctuary
  - State Marine Conservation Areas
  - State Marine Reserves

- Federal Laws
  - Clean Water Act
  - Laws related to:
    - Discharges
    - Marine Debris
    - Hazardous Waste



KEY FINDINGS

- Rapidly-evolving technology challenges the law: law and policy will often lag behind.

- Applicable laws may differ depending on the operating environment and level of autonomy.

- The need to understand the environmental and climate considerations for these systems is increasing. *(CRUSER Advancing Legal Clarity Project)*

Kristen Fletcher, Energy Academic Group: kristen.fletcher@nps.edu

(added) Observations: Ethics, Law and Data

- Conceptual Interoperability is straightforward for humans to measure: "does it make sense?"
- **We are not** asking robots to make ethical decisions – illegal, not possible. **We are** enabling systems support for ethical human decision making.
- "Answer to question" = "response to query" means we all have to get beyond curious syntax to shared terminology and understanding of results, otherwise (like it or not) your overall system design must be insufficient.
- Rules followed by warfighters, peace officer, responsible individuals are all based on **The Law**. Thus we can now strive for consistency with LOAC, etc.
- **TRUST** is the top of the semantic chain… bridging to next section:

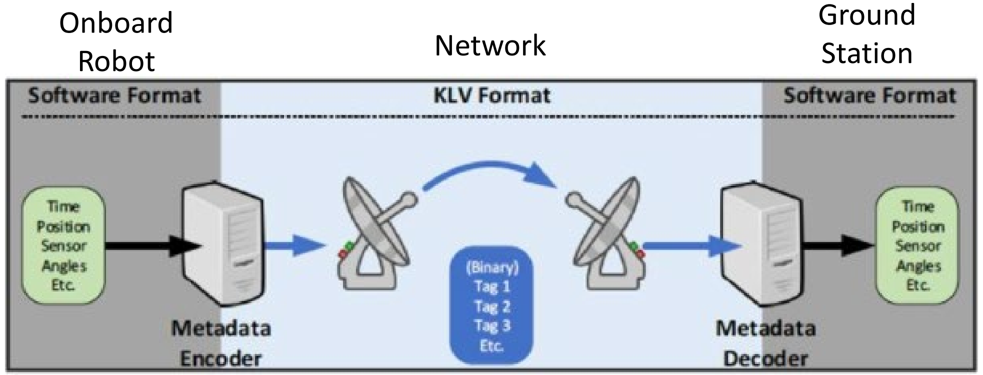
In God We Trust. All Others Bring Data! W. Edwards Deming

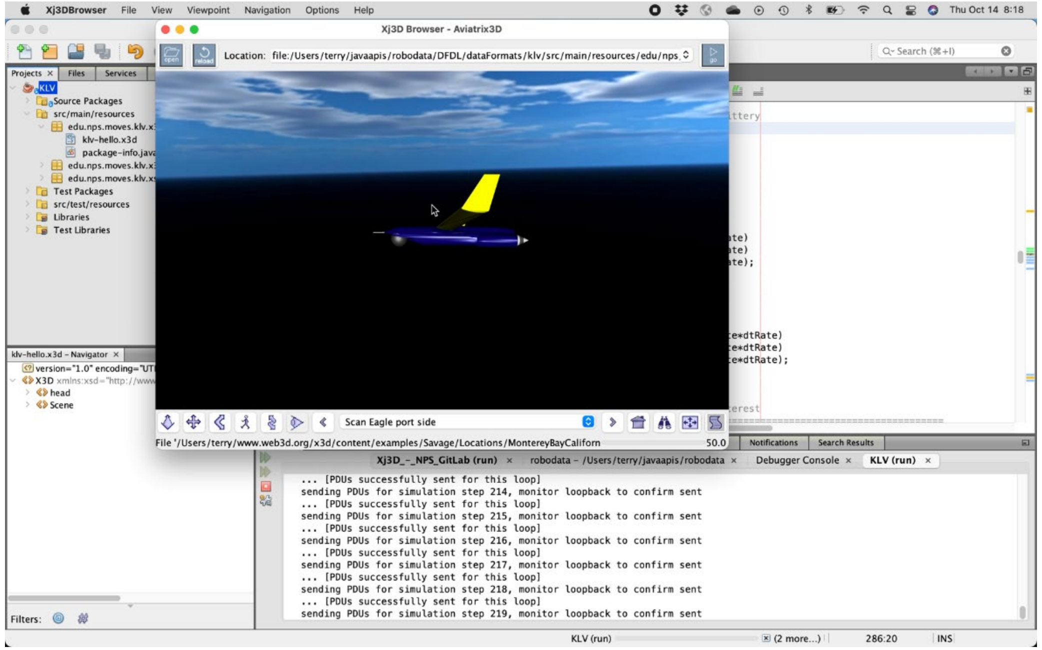
Terry Norbraten

Software Design, Development, and Testing

Real-World Mission Execution

Virtual-World Mission Playback

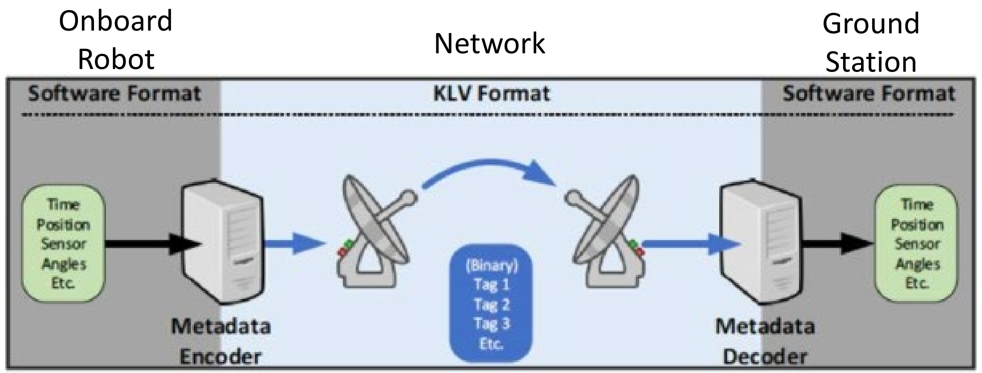




208000459F4A6AA4AA8050271C20602FD

KLV 2 3D

The process of capturing wirelessly networked KLV Local Set data transmitted from an unmanned aerial system (UAS) to visualizing that data in 3D using Open Source, Open Standards technology.



PCAPNG File
{Wireshark/tshark}

Filter for udp.port==4040
{Wireshark/tshark}

Marked up filtered PCAPNG (Hex Text) (Parse)
{pcapng.dfdl.xsd}

file

Extract KLV (UDP payload) (Hex Text)
{ExtractPcapng DataValues.xslt}

file

Parse, visualize KLV (Hex Text) as marked up XML
{klv.dfdl.xsd}

file

In-memory DOM objects

{DFDL extract KLV Hex}

Java parse KLV telemetry track into DIS

Decode KLV (Hex Binary)
{Harder KLV Java}

Decode KLV (Decimal)
{West Ridge Systems jMisb}

Generate DIS PDU Tracks
{OpenDIS7 Java}

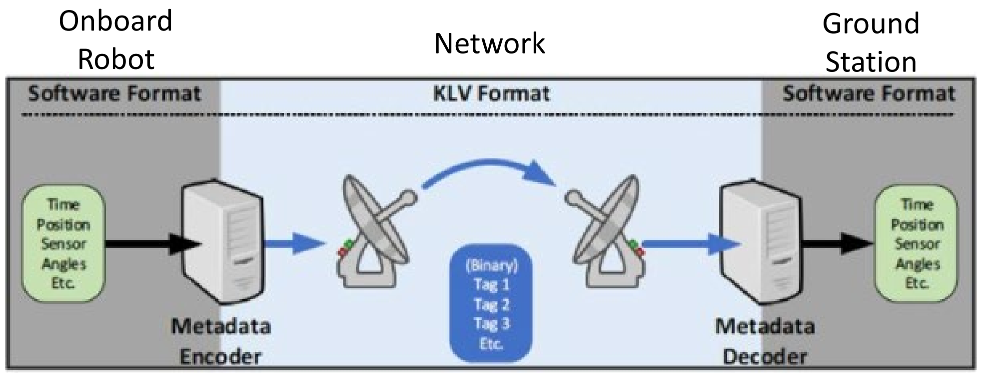
Save/Replay DIS PDU streams
{OpenDIS}

Visualize 3D Scene (Playback)
{X3D, Spiders3D}

LVC
{Plan, Analyze, Train, Archive}

The Blais approach would be KLV XML -> XSLT -> RST XML

The top right + lower left blocks might be replaced by DIS Schema with DFDL for KLV, as a general pattern for DIS DFDL parsing of any telemetry track values, leapfrog for future telemetry patterns. End result remains DIS XML in either case.



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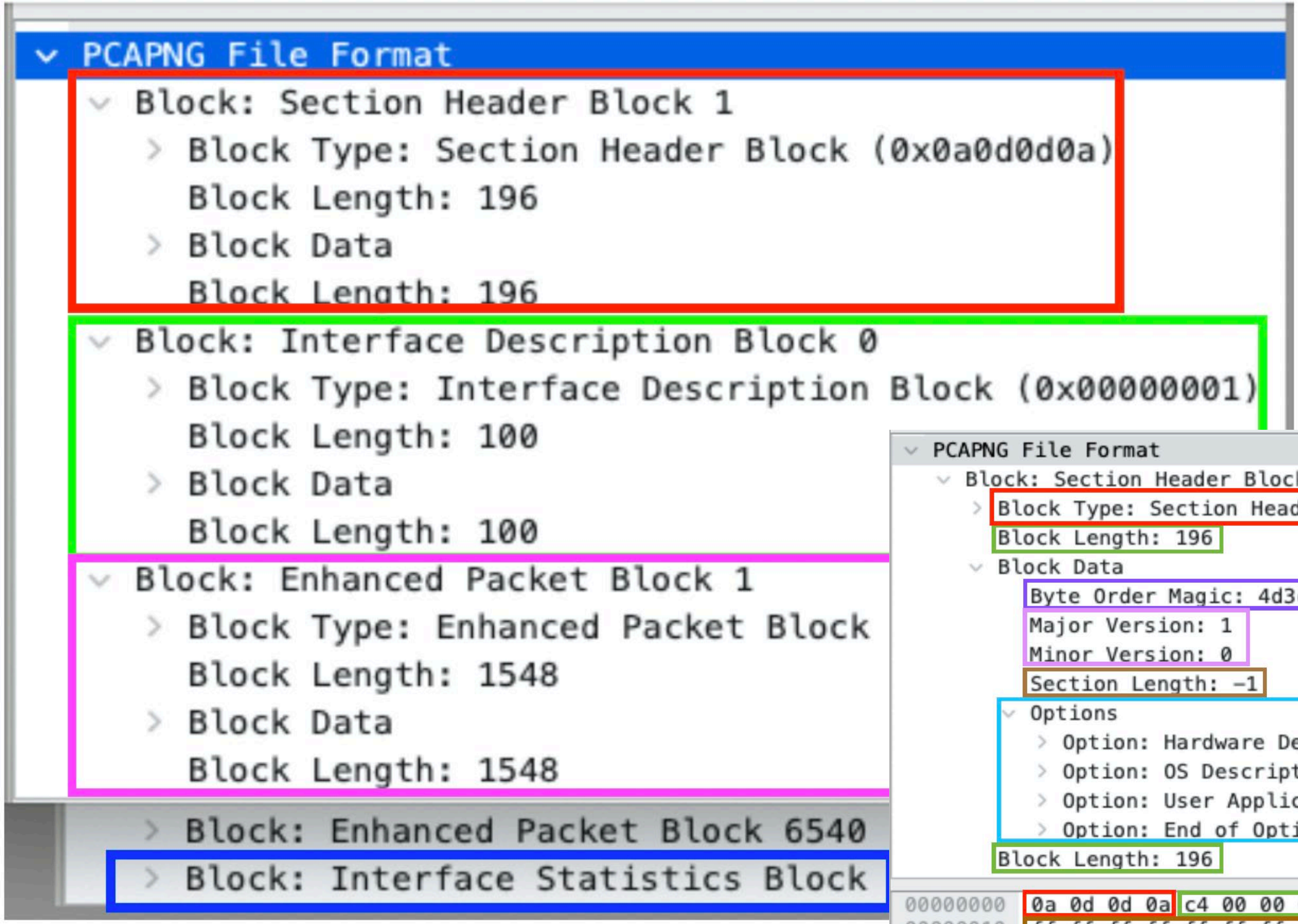
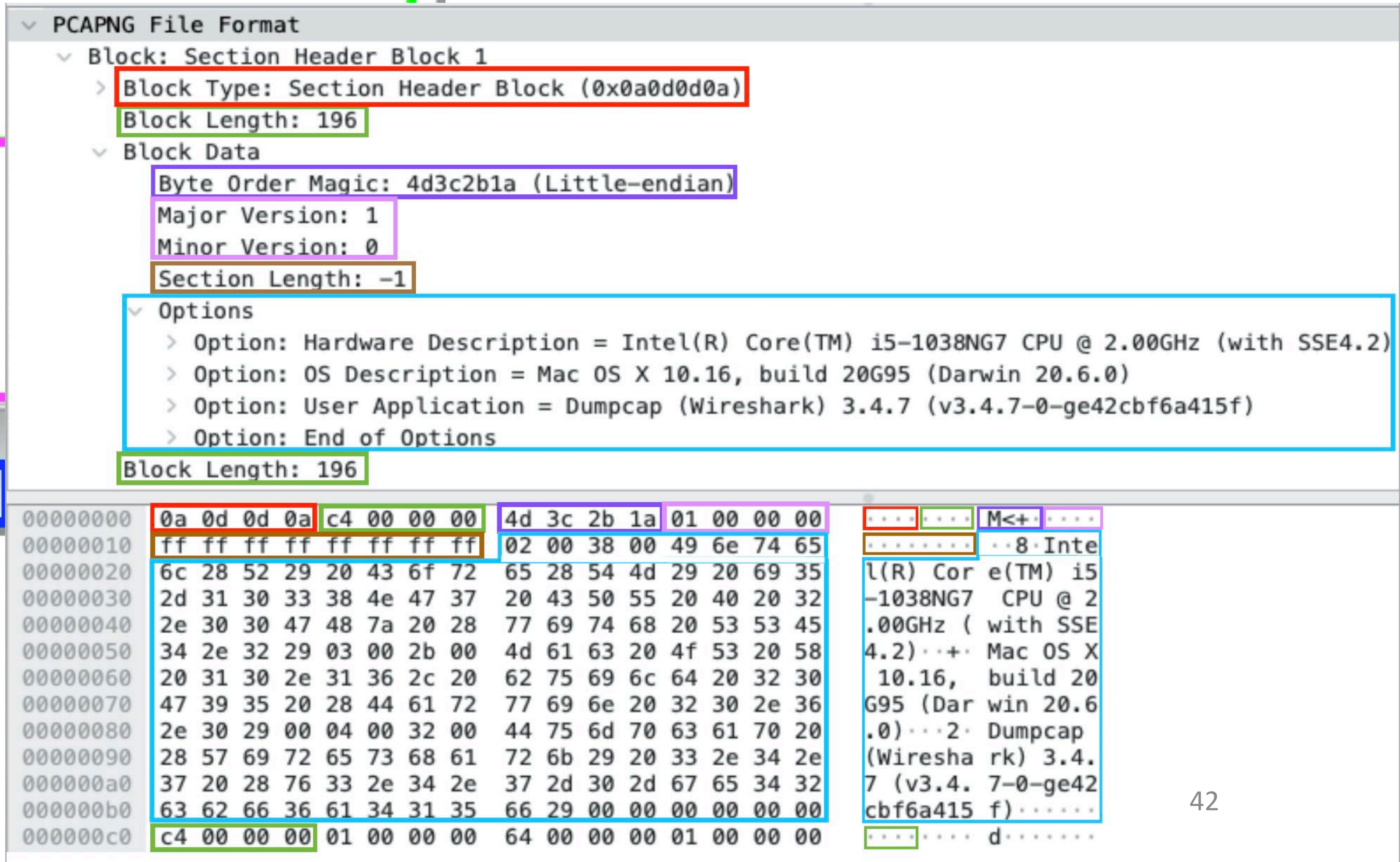
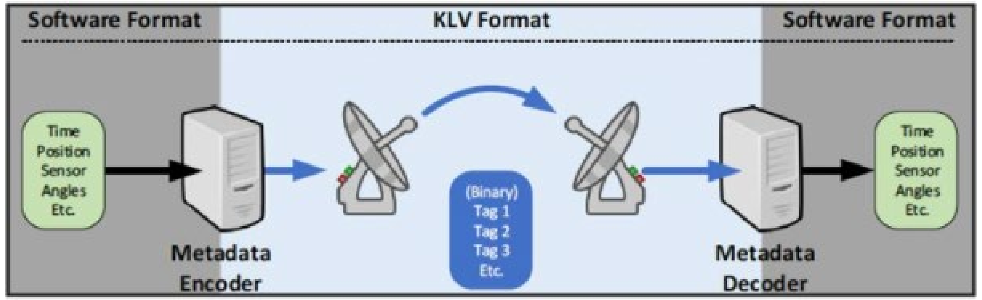

PCAPNG File Format
Block: Section Header Block 1
Block Type: Section Header Block (0x0a0d0d0a)
Block Length: 196
Block Data
Block Length: 196
Block: Interface Description Block 0
Block Type: Interface Description Block (0x00000001)
Block Length: 100
Block Data
Block Length: 100
Block: Enhanced Packet Block 1
Block Type: Enhanced Packet Block
Block Length: 1548
Block Data
Block Length: 1548
Block: Enhanced Packet Block 6540
Block: Interface Statistics Block


PCAPNG File Format
Block: Section Header Block 1
Block Type: Section Header Block (0x0a0d0d0a)
Block Length: 196
Block Data
Byte Order Magic: 4d3c2b1a (Little-endian)
Major Version: 1
Minor Version: 0
Section Length: -1
Options
Option: Hardware Description = Intel(R) Core(TM) i5-1038NG7 CPU @ 2.00GHz (with SSE4.2)
Option: OS Description = Mac OS X 10.16, build 20G95 (Darwin 20.6.0)
Option: User Application = Dumpcap (Wireshark) 3.4.7 (v3.4.7-0-ge42cbf6a415f)
Option: End of Options
Block Length: 196
00000000 0a 0d 0d 0a c4 00 00 00 4d 3c 2b 1a 01 00 00 00 ········M<+·····
00000010 ff ff ff ff ff ff ff ff 02 00 38 00 49 6e 74 65 ··········8·Inte
00000020 6c 28 52 29 20 43 6f 72 65 28 54 4d 29 20 69 35 l(R) Cor e(TM) i5
00000030 2d 31 30 33 38 4e 47 37 20 43 50 55 20 40 20 32 -1038NG7 CPU @ 2
00000040 2e 30 30 47 48 7a 20 28 77 69 74 68 20 53 53 45 .00GHz (with SSE
00000050 34 2e 32 29 03 00 2b 00 4d 61 63 20 4f 53 20 58 4.2)··+· Mac OS X
00000060 20 31 30 2e 31 36 2c 20 62 75 69 6c 64 20 32 30 10.16, build 20
00000070 47 39 35 20 28 44 61 72 77 69 6e 20 32 30 2e 36 G95 (Dar win 20.6
00000080 2e 30 29 00 04 00 32 00 44 75 6d 70 63 61 70 20 .0)···2· Dumpcap
00000090 28 57 69 72 65 73 68 61 72 6b 29 20 33 2e 34 2e (Wiresha rk) 3.4.
000000a0 37 20 28 76 33 2e 34 2e 37 2d 30 2d 67 65 34 32 7 (v3.4. 7-0-ge42
000000b0 63 62 66 36 61 34 31 35 66 29 00 00 00 00 00 00 cbf6a415 f)······
000000c0 c4 00 00 00 01 00 00 00 64 00 00 00 01 00 00 00 ········d·······

Onboard Robot

Network

Ground Station



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LVC

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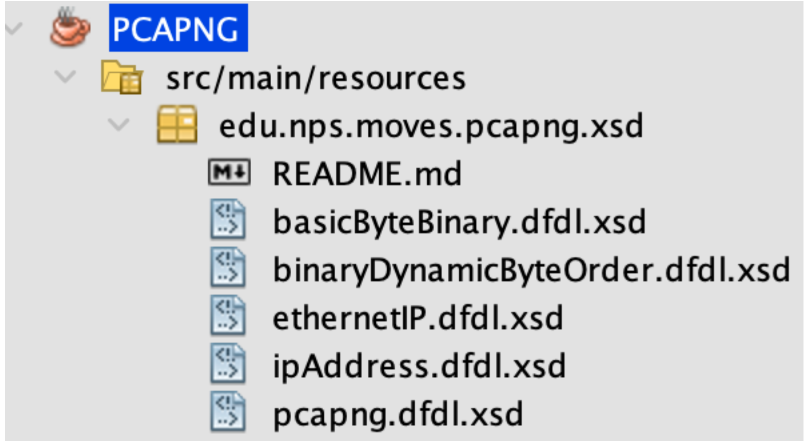
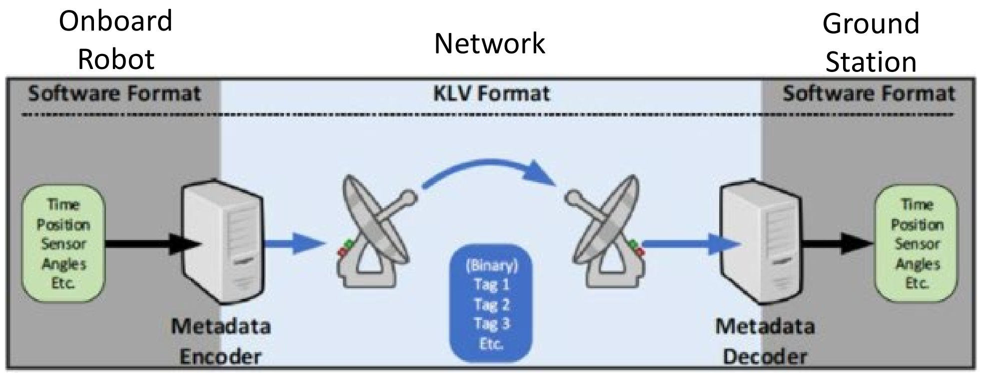
DFDL decorated XML Schema for PCAPNG




```xml
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema" version="1.1"
        xmlns:dfdl="http://www.ogf.org/dfdl/dfdl-1.0/"
        xmlns:fn="http://www.w3.org/2005/xpath-functions"
        xmlns:daf="urn:ogf:dfdl:2013:imp:daffodil.apache.org:2018:ext"
        xmlns:dfdlx="http://www.ogf.org/dfdl/dfdl-1.0/extensions"
        xmlns:eth="urn:ethernet"
        xmlns:db="urn:dynamicEndianBinary"
        xmlns:pcapng="urn:pcapng:1.0"
        xmlns:tns="urn:pcapng:1.0"
        targetNamespace="urn:pcapng:1.0">

    <xs:import namespace="urn:dynamicEndianBinary"
            schemaLocation="binaryDynamicByteOrder.dfdl.xsd"/>

    <xs:import namespace="urn:ethernet"
            schemaLocation="ethernetIP.dfdl.xsd"/>

    <xs:annotation>
        <xs:appinfo source="http://www.ogf.org/dfdl/">
            <dfdl:format ref="db:binaryDynamicByteOrder" byteOrder="littleEndian"/>
            <!--
            Used to eliminate common subexpression in outputValueCalc of CapturedPacketLength
            -->
            <dfdl:defineVariable name="valueLen" type="xs:int" dfdlx:direction="unparseOnly"/>
        </xs:appinfo>
    </xs:annotation>

    <!--
    Since this is a DFDL schema for a concrete file format, we have a root global element.
    All other elements are declared as local element declarations and so will have
    unqualified names
    -->

    <xs:element name="PCAPNG" type="tns:PCAPNG"/>

    <xs:complexType name="PCAPNG">
        <xs:sequence>

            <xs:element name="SectionHeader">
                <xs:complexType>
                    <xs:sequence>
                        <xs:element name="Block">
                            <xs:complexType>
                                <xs:sequence>
                                    <xs:element name="Type" type="xs:hexBinary" dfdl:lengthKind="explicit"
                                            dfdl:length="4" dfdl:lengthUnits="bytes">
                                        <xs:annotation>
                                            <!-- Diagnostic to see what BlockType # really is -->
                                            <xs:appinfo source="http://www.ogf.org/dfdl/">
                                                <dfdl:assert message="{ fn:concat('BlockType # was not 0x0A0D0D0A.
                                                        test="{ (. eq xs:hexBinary('0A0D0D0A')) }"/>
```



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DFDL Decorated XML Schema for KLV

```xml
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema" version="1.1"
           xmlns:dfdl="http://www.ogf.org/dfdl/dfdl-1.0/"
           xmlns:fn="http://www.w3.org/2005/xpath-functions"
           xmlns:daf="urn:ogf:dfdl:2013:imp:daffodil.apache.org:2018:ext"
           xmlns:dfdlx="http://www.ogf.org/dfdl/dfdl-1.0/extensions"
           xmlns:db="urn:dynamicEndianBinary"
           xmlns:klv="urn:klv:ST0601.14"
           xmlns:tns="urn:klv:ST0601.14"
           targetNamespace="urn:klv:ST0601.14">

    <xs:import namespace="urn:dynamicEndianBinary"
            schemaLocation="edu/nps/moves/pcapng/xsd/binaryDynamicByteOrder.dfdl.xsd"/>

    <xs:annotation>
        <xs:appinfo source="http://www.ogf.org/dfdl/">
            <dfdl:format ref="db:binaryDynamicByteOrder" outputNewLine="%LF;"/>
        </xs:appinfo>
    </xs:annotation>

    <xs:element name="UASDataLink" type="tns:KLV"/>

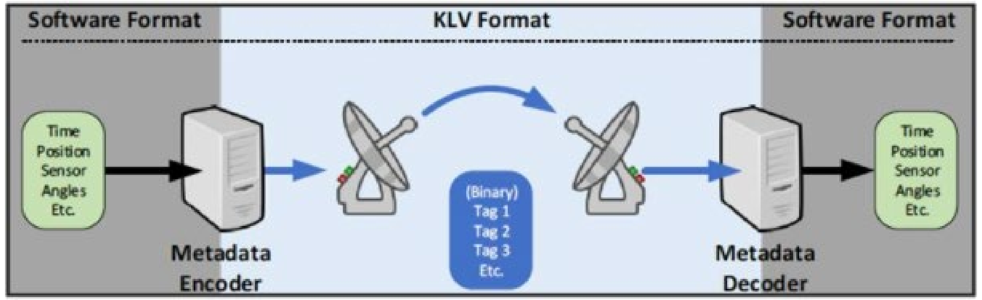
    <xs:complexType name="KLV">
        <xs:sequence>
            <xs:element name="Packet" maxOccurs="unbounded">
                <xs:complexType>
                    <xs:sequence dfdl:terminator="%NL;">
                        <xs:element name="ULKey" type="xs:string" dfdl:lengthKind="explicit"
                                    dfdl:lengthUnits="characters" dfdl:alignment="8" dfdl:length="32"/>
                        <xs:element name="Length" type="xs:string" dfdl:lengthKind="explicit"
                                    dfdl:lengthUnits="characters" dfdl:alignment="8" dfdl:length="2"/>
                        <xs:element name="Value" type="klv:localset"/>
                    </xs:sequence>
                </xs:complexType>
            </xs:element>
        </xs:sequence>
    </xs:complexType>

    <xs:complexType name="localset">
        <xs:sequence>
            <xs:element name="PrecisionTimeStamp" type="klv:timestamp"/> <!-- Required -->
            <xs:element name="Platform" type="klv:platform"/>
            <xs:element name="ImageSource" type="klv:isource"/>
            <xs:element name="Sensor" type="klv:sensor"/>
            <xs:element name="Target" type="klv:target"/>
            <xs:element name="Frame" type="klv:frame"/>
```

Onboard Robot

Network

Ground Station



PCAPNG File {Wireshark/tshark} → Filter for udp.port==4040 {Wireshark/tshark} → Marked up filtered PCAPNG (Hex Text) (Parse) {pcapng.dfdl.xsd} → file → Extract KLV (UDP payload) (Hex Text) {ExtractPcapng DataValues.xslt} → file → Parse, visualize KLV (Hex Text) as marked up XML {klv.dfdl.xsd} → file

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Decode KLV (Hex Binary) {Harder KLV Java} → Decode KLV (Decimal) {West Ridge Systems jMisb} → Generate DIS PDU Tracks {OpenDIS7 Java}

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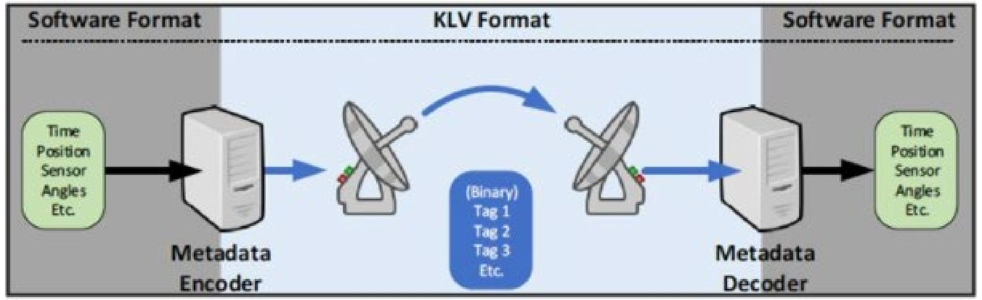

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Saved DIS PDU Capture

```
# Start, ENCODING_PLAINTEXT, 20211014_081738, DIS capture file, ./pduLog/PduCaptureLog96.dislog
[0,0,0,0,0,0,0,0],[7,1,1,1,-11,100,-82,45,0,-112,40,0,0,0,0,1,0,1,1,0,1,2,0,-31,50,25,0,0,0,0,0,-31,0,0,0,0,61,9,101,15,-69,74,-85,56,60,-91,18,39,0,0,0,0,0,0,0,0,0,0
[0,0,0,0,0,87,-68,94],[7,1,22,5,75,72,-87,-67,0,32,40,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,2,0,0,-81,-46,0,0,0,-16,91,101,100,117,46,110,112,115,46,109,111,118,101,1
[0,0,0,0,12,76,-25,39],[7,1,1,1,-11,100,-82,-11,0,-112,40,0,0,0,0,1,0,1,1,0,1,2,0,-31,50,25,0,0,0,0,0,-31,0,0,0,0,60,-84,1,-4,-69,-122,-113,-59,60,36,63,-27,0,0,0,0,0,0
[0,0,0,0,12,84,105,-80],[7,1,22,5,75,76,105,-61,0,32,40,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,2,0,0,-81,-46,0,0,0,-16,91,101,100,117,46,110,112,115,46,109,111,118,101
[0,0,0,0,24,93,11,60],[7,1,1,1,-11,100,-81,-66,0,-112,40,0,0,0,0,1,0,1,1,0,1,2,0,-31,50,25,0,0,0,0,0,-31,0,0,0,0,60,-54,76,104,59,9,118,-6,60,-92,63,-31,0,0,0,0,0,0,0,0
[0,0,0,0,24,100,-121,38],[7,1,22,5,75,80,27,-47,0,32,40,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,2,0,0,-81,-46,0,0,0,-16,91,101,100,117,46,110,112,115,46,109,111,118,101
[0,0,0,0,36,-123,-60,1],[7,1,1,1,-11,100,-80,-121,0,-112,40,0,0,0,0,1,0,1,1,0,1,2,0,-31,50,25,0,0,0,0,0,-31,0,0,0,0,60,-90,-35,-18,-69,-87,15,-24,60,50,-73,-70,0,0,0,0,0,
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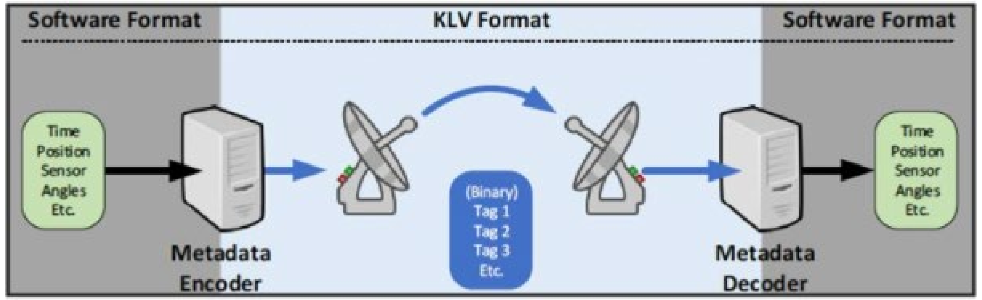


PCAPNG File
{Wireshark/tshark}

Filter for udp.port==4040
{Wireshark/tshark}

Marked up filtered PCAPNG (Hex Text) (Parse)
{pcapng.dfdl.xsd}

file

Extract KLV (UDP payload) (Hex Text)
{ExtractPcapng DataValues.xslt}

file

Parse, visualize KLV (Hex Text) as marked up XML
{klv.dfdl.xsd}

file

In-memory DOM objects

{DFDL extract KLV Hex}

Java parse KLV telemetry track into DIS

Decode KLV (Hex Binary)
{Harder KLV Java}

Generate DIS PDU Tracks
{OpenDIS7 Java}

Decode KLV (Decimal)
{West Ridge Systems jMisb}

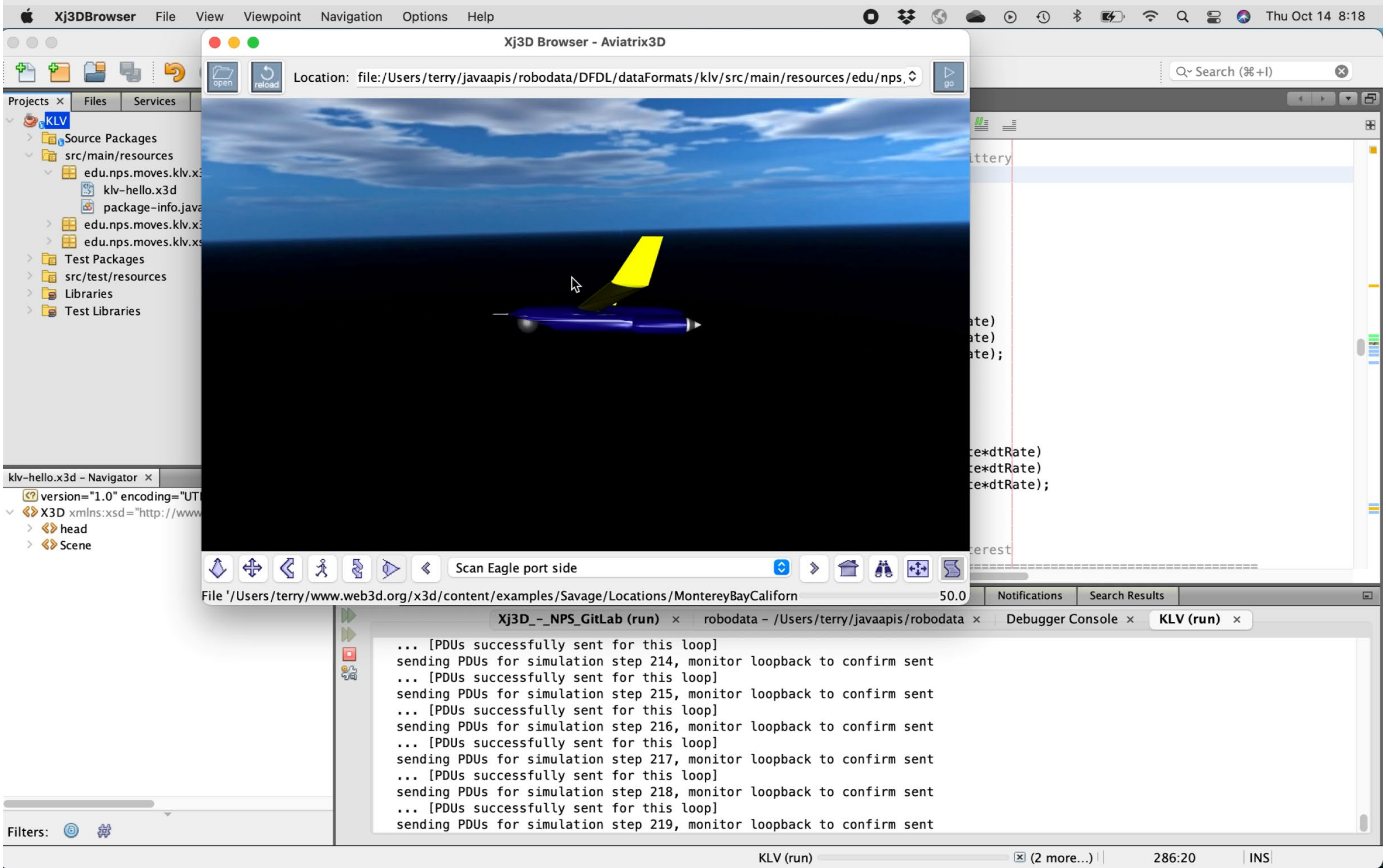
Save/Replay DIS PDU streams
{OpenDIS}

Visualize 3D Scene (Playback)
{X3D, Spiders3D}

LVC
{Plan, Analyze, Train, Archive}

The Blais approach would be KLV XML -> XSLT -> RST XML

The top right + lower left blocks might be replaced by DIS Schema with DFDL for KLV, as a general pattern for DIS DFDL parsing of any telemetry track values, leapfrog for future telemetry patterns. End result remains DIS XML in either case.



It works ☺

 online

Open-Source, Open-Standards Technology Used

- Wireshark
- PCAPNG
- ST 0601.17
- SMPTE ST 336
- Apache Daffodil
- OpenDIS7 Java
- Harder KLV
- West Ridge Systems jMisb
- X3D Graphics
- Xj3D
- XML (Schema, XSLT)
- OpenJDK
- Apache NetBeans IDE

Robodata & RobodataCUI Code Repositories

- Robodata including PCAPNG transformation: https://gitlab.nps.edu/Savage/robodata
- RobodataCUI including KLV transformation: https://gitlab.nps.edu/SavageDefense/robodatadefense

(added) Check Questions

- No prior knowledge of this robot? Standards, bits, go? YES
- Peeling computer-science onion: unlike other flow diagrams, your boxes aren't *programs* but rather refined *data*? YES
- You modified community's pcap Packet Capture mappings written for Data Format Description Language (DFDL), added next-generation PCAPng support and posted back? YES
- If you can handle this robot, are we ready for any other? YES

The Purpose of Computing is Insight, Not Numbers

[Richard W. Hamming]

Don Brutzman
Synopsis: Ethical Control of Unmanned Systems

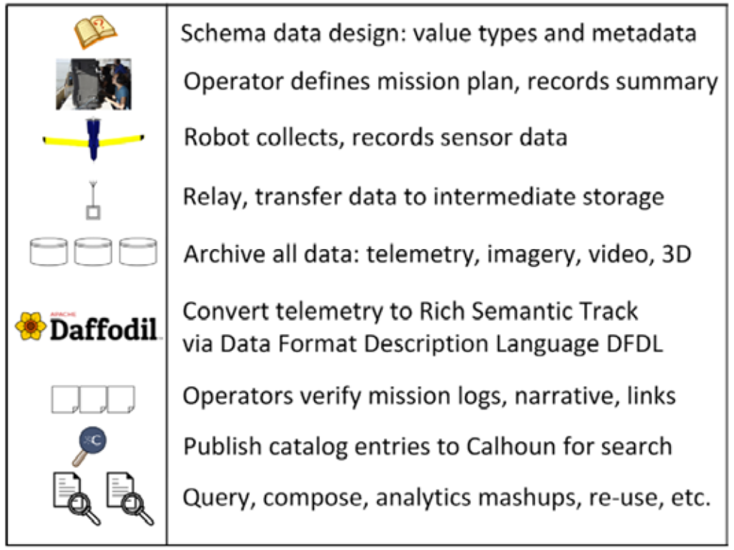
- **Project Motivation**: ethically constrained control of unmanned systems and robot missions by human supervisors and warfighters.
- **Precept:** well-structured mission orders can be syntactically and semantically validated to give human commanders confidence that offboard systems
  - *will **do** what they are told to **do***, and further
  - *will **not do** what they are **forbidden to do***.

Paraphrase: can qualified robots correctly follow human orders?

- **Project Goal:** apply Semantic Web ontology to scenario goals and constraints for logical validation that human-approved mission orders for robots are semantically coherent, precise, unambiguous, and without internal contradictions.
- **Long-term Objective:** demonstrate that no technological limitations exist that prevent applying the same kind of ethical constraints on robots and unmanned vehicles that already apply to human beings.

Data Strategy for Unmanned Systems

CRUSER Consortium for Robotics and Unmanned Systems Education and Research



Robodata Workflow: Collection and storage of data enables recording, replay, smoothing and visualization of robot tracks.

Problem Statement

- *What are you trying to do?* Continuing creation of Data Strategy for Unmanned Systems Field Experimentation, Simulation and Analysis.
- *What is your approach?* A data plus metadata pipeline for any robot mission definition and telemetry has been demonstrated for all technical components. This project will prepare end-to-end exemplars from CRUSER FX and produce a transition plan for mainstream adoption of best practices in NPS experimentation.

Exemplars Implemented and Ready to Scale Up

Impact

- *What contribution does this work make to your field?* Integrating multiple open-source libraries utilizing multiple open-data standards for comprehensive robot data collection.
- *What is the warfighting impact?* NPS FX is a microcosm matching test range capabilities at Fleet activities. Collaborative connections that are repeatable over time benefit all parties.
- *How will you measure success?* Reuse and adaptation of robot data for live-virtual-constructive (LVC) analysis.

Transition

- *Who cares?* This work directly reflects operational testing TESTDEVOPS and PMS 406 UMAA/RAIL. Multiple NPS collaboration partners include robot developers, armed services, and coalition forces. Mutual support for NPS/USNA research and education keeps all efforts grounded and relevant.
- *What are specific sources of continued support and collaboration?* Multiple candidates identified aligning NPS transformation with all key players, now and longitudinally into the future.

We Want All Your Data!

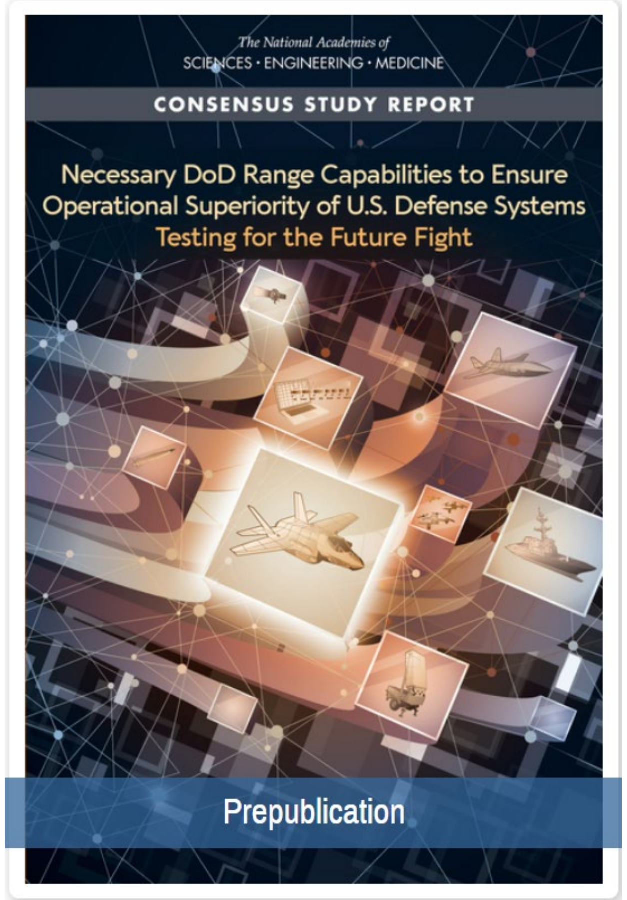
- Huge amounts of data gets collected by CRUSER experimenters
- Huge amounts of data gets saved and ignored, remaining unused
- This is not uncommon

- What if everything was saved, structured, annotated with metadata?
- What if analysis, replay, re-use, Live Virtual Constructive (LVC) were easy?
- What if all student/faculty/partner products were archivable?
- What if best practices influenced DoD and DTIC, all for the better?

NPS Field Experimentation (FX) as DoD Test Range

- JIFX at Camp Roberts quarterly
- New Sea Land Air Military Robotics (SLAMR) by NPS is possible even more frequently
- Connect via TENA infrastructure for Distributed Interactive Simulation (DIS) and NATO C2/SIM repeatability and mashups
- Open or CUI access

- Outcome: NPS "looks like" a DoD Test Range with best practices for TestDevOps
- Consider annual focus on Test + Evaluation with COTF and other testing commands



National Academies' report, November 2021

Necessary DoD Range Capabilities to Ensure Operational Superiority of U.S. Defense Systems: Testing for the Future Fight.

https://www.nap.edu/catalog/26181/necessary-dod-range-capabilities-to-ensure-operational-superiority-of-us-defense-systems

Where must we all go next

- Massive testing of unmanned hardware + software ability to follow both orders and constraints in physically realistic virtual environments: **TestDevOps** for learning-improvement cycles.
- **Influence and impact operations**: certify real-world capabilities via field experimentation (FX), confirmed by Big Data analysis, defense test range exercises, wargames and theses.
- Human warfighters and mission commanders (not just engineers) review and approve unmanned systems as… **qualified.**
- New normal will be **human + machine teaming** together; future must mainstream all capabilities in acquisition and deployment.
- **Welcome to the future** – the horizon is here!

Acknowledgements

- This work builds upon 3 decades of essential inquiry by NPS faculty, staff and graduate/doctoral students serving on active duty. We thank them all.
- Co-investigators Dr. Curtis Blais and Dr. Robert B. McGhee. CRADA leads RADM Jerry Ellis USN (Ret.) and Julie Leeman, Raytheon Technologies.
- Research support by Raytheon Missile Systems (RMS) and Raytheon BBN Technologies (Tucson Arizona and Arlington Virginia) has been instrumental in recent progress during 2019-2020.
- Significant contributions by Hsin-Fu "Sinker" Wu, Richard Markeloff and others at Raytheon, supporting current work under CRADA with NPS.
- Work with Dr. Jakub Flotyński on X3D Ontology for Semantic Web was an essential prerequisite to the capabilities demonstrated here.
- Collaborative design efforts with numerous skilled engineers and scientists is gratefully acknowledged. Further activity is welcome.

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