Ethical Control of Unmanned Systems

Mission Design and Semantic Web Exemplars for Human Supervision of Lethal/Lifesaving Autonomy

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U.S. Semantic Technologies Symposium (US2TS)
Panel session: Hybrid AI for Context Understanding
North Carolina State University, Raleigh, NC

9-11 March 2020

US Semantic Technologies Symposium (US2TS)
Session: Hybrid AI for Context Understanding

What is nature of context that described hybrid AI system is trying to understand?

- Validate human orders to remote unmanned systems with capacity for lethal/lifesaving force.
- Ethics for Rules of Engagement (ROE), Laws of Armed Conflict (LOAC), operational constraints.

What specific methods and technologies does this hybrid AI system use, and how?

- Validatable XML mission syntax using controlled vocabularies with corresponding ontology.
- Perform SPARQL queries of RDF/OWL to check complex relationships, requirements, violations.
- Conversions for declarative orders, language implementations, Turtle triples with Protégé, ARQ.

What are current limitations in presented solution, what is plan for future work?

- Representative test cases are being tested in simulation to build out verification framework.
- Supports maritime operations with tractable Identification Friend Foe Neutral Unknown (IFFNU).
- Expand scope with larger mission sets for diverse operations by unmanned systems in real world.
- Bridge command and control (C2) with modeling and simulation (M&S) virtual environments, for
- Domain-expert qualification of hardware/software systems using tactical scenarios as unit tests.

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.

https://savage.nps.edu/EthicalControl

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

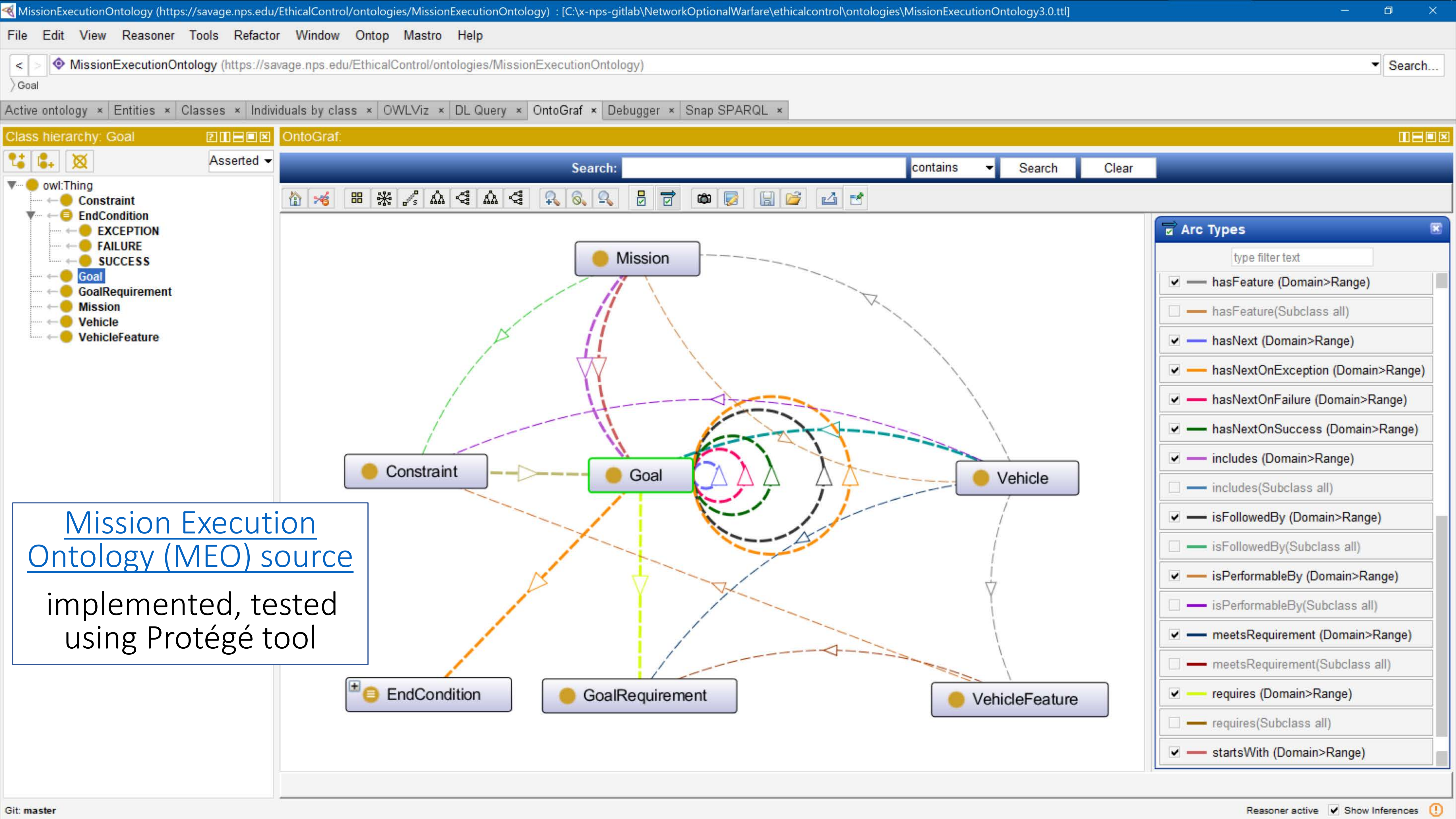
Example AVCL mission agenda, as pseudo-code XML

```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



[Mission Execution Ontology (MEO) source]()

implemented, tested using Protégé tool

```
@prefix :     <https://www.nps.edu/ontologies/MissionExecutionOntology> .
@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> .

<https://www.nps.edu/ontologies/MissionExecutionOntology> rdf:type owl:Ontology .

#################################################################
#    Object Properties
#################################################################

###  https://www.nps.edu/ontologies/MissionExecutionOntology#appliesTo
meo:appliesTo rdf:type owl:ObjectProperty ;
  rdfs:domain meo:Constraint ;
  rdfs:range [ rdf:type owl:Class ;
               owl:unionOf ( meo:Goal meo:Mission ) ] ;
  owl:propertyChainAxiom ( meo:appliesTo meo:includes ) ;
  rdfs:comment "A Constraint applies to one or more Missions and/or one or more Goals." .
[ rdf:type owl:Axiom ;
  owl:annotatedSource meo:appliesTo ;
  owl:annotatedProperty rdfs:range ;
  owl:annotatedTarget [ rdf:type owl:Class ; owl:unionOf ( meo:Goal meo:Mission ) ] ;
  rdfs:comment "A Constraint can apply to a Mission or a Goal (and nothing else)." ;
  rdfs:label "C1" ] .
[ rdf:type owl:Axiom ;
  owl:annotatedSource meo:appliesTo ;
  owl:annotatedProperty owl:propertyChainAxiom ;
  owl:annotatedTarget ( meo:appliesTo meo:includes ) ;
  rdfs:comment "A Constraint that applies to a Mission must also apply to all of the Goals that Mission includes." ;
  rdfs:label "C3" ] .
```

[Mission Execution Ontology (MEO) source](https://www.nps.edu/ontologies/MissionExecutionOntology)

implemented, tested using Protégé tool

Turtle (.ttl) syntax

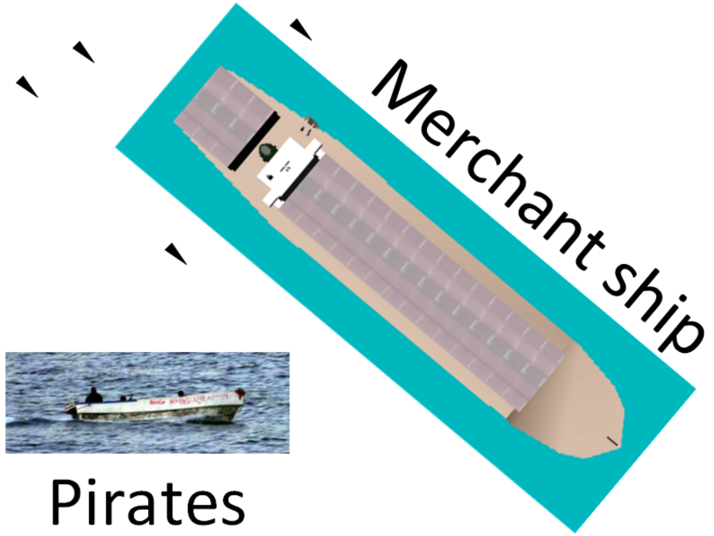
Life boat

Life-saving force: locate, track, communicate, beacon

Ethical control of unmanned systems is required for both lethal and lifesaving force if remote robots communicate intermittently, operating across lengthy time and distance.

Response dilemma for U.S. Navy ship

Lethal force: locate, warn, defend, threaten, attack



Respond to one or both scenarios with USV/UAV assets to establish on-scene visibility and presence

Pirates

Sailor Overboard Mission: Description

Purpose

- Life saving: single unmanned air/surface vehicle actions to complement human responses when performing *“SAILOR OVERBOARD”* operations.
- Carried out in direct concert with formal *shipboard emergency procedures*.
- Multiple UAVs/USVs might be employed in parallel with ships and aircraft, avoid mutual interference by each following deconflicted mission orders.

Phases

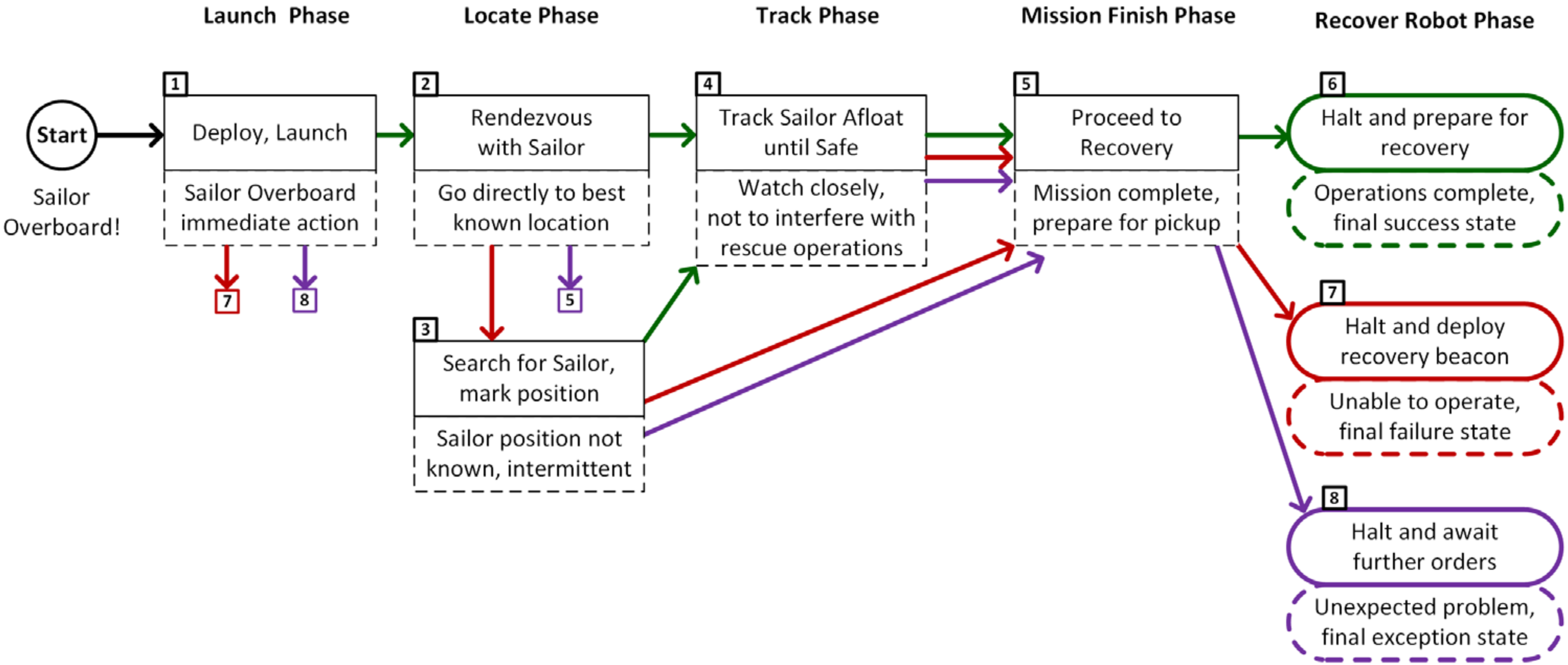
- Deploy/Launch, Rendezvous, Track Sailor until Safe, Return/Recovery.

Human Supervisory Role

- Order standoff if interfering, manual control is possible due to proximity, can communicate to sailor via loudspeaker or beacon light.

Sailor Overboard, 8 Phases – Mission Execution Automaton (MEA)

Single unmanned air/surface vehicle actions to complement human response when performing "**SAILOR OVERBOARD**" operations, carried out in concert with **shipboard emergency procedures**. Multiple UAVs/USVs can be employed in parallel with ships/aircraft, each following mission orders.



Legend

Don Brutzman and Bob McGhee
Mission upgrade 19 NOV 2019

SailorOverboard.xml in gitlab.nps.edu version control

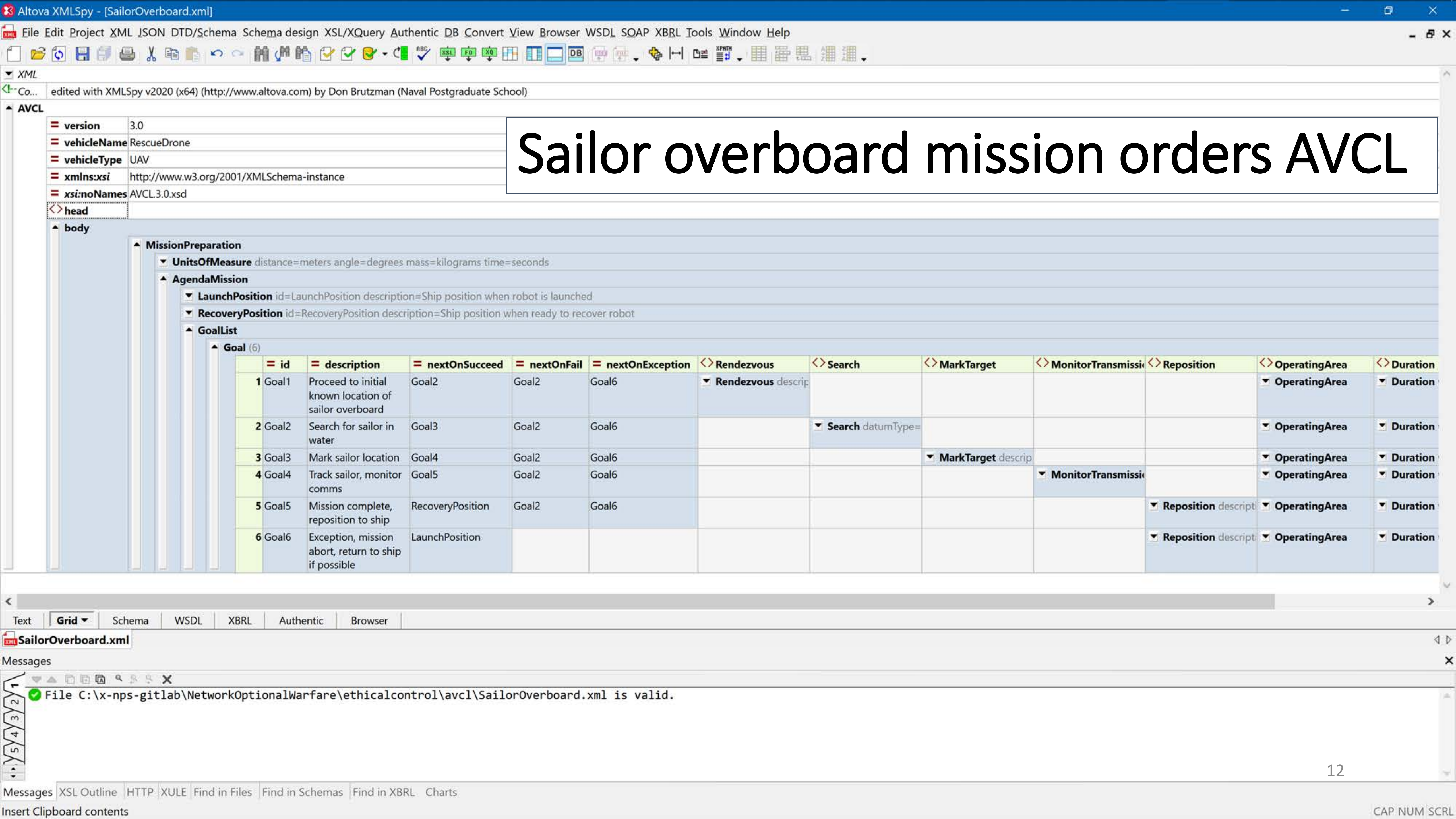
https://gitlab.nps.edu/Savage/EthicalControl/blob/master/missions/avcl/SailorOverboard.xml

GitLab   Projects   Groups   More   Search or jump to...

SailorOverboard.xml 5.63 KB   Edit   Web IDE   Replace   Delete

```xml
<?xml version="1.0" encoding="UTF-8"?>
<AVCL version="3.0" vehicleName="RescueDrone" vehicleType="UAV" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSchemaLocation="../../avcl/AVCL.3.0.xsd">
	<head>
		<meta name="title" content="SailorOverboard.xml"/>
		<meta name="created" content="19 November 2019"/>
		<meta name="modified" content="31 December 2019"/>
		<meta name="creator" content="Don Brutzman"/>
		<meta name="reference" content="https://wiki.nps.edu/display/NOW/Ethical+Control+of+Unmanned+Systems"/>
		<meta name="reference" content="https://gitlab.nps.edu/Savage/EthicalControl/raw/master/missions/SailorOverboard8PhaseMission.png"/>
		<meta name="identifier" content="https://gitlab.nps.edu/Savage/EthicalControl/tree/master/missions/avcl/SailorOverboard.xml"/>
		<meta name="generator" content="Altova XMLSpy, https://www.altova.com"/>
		<meta name="generator" content="Apache NetBeans, https://netbeans.apache.org"/>
		<meta name="generator" content="NPS Autonomous Unmanned Vehicle (AUV) Workbench, https://savage.nps.edu/AuvWorkbench"/>
		<meta name="license" content="../license.html"/>
	</head>
	<body>
		<MissionPreparation>
			<UnitsOfMeasure distance="meters" angle="degrees" mass="kilograms" time="seconds"/>
			<AgendaMission>
				<LaunchPosition id="LaunchPosition" description="Ship position when robot is launched">
					<LatitudeLongitude latitude="0" longitude="0"/>
				</LaunchPosition>
				<RecoveryPosition id="RecoveryPosition" description="Ship position when ready to recover robot">
					<LatitudeLongitude latitude="0" longitude="0"/>
				</RecoveryPosition>
				<GoalList>
					<Goal id="Goal1" title="Deploy, Launch" description="Sailor Overboard immediate Action" nextOnSucceed="Goal2" nextOnFail="Goal2" nextOnException="Goa
						<Rendezvous description="">
							<TargetVehicleID value="101" description="Sailor in water"/>
						</Rendezvous>
						<OperatingArea>
							<Point>
								<LatitudeLongitude latitude="36.62" longitude="121.506"/>
								<!--36°36´11˝N 121°53´37˝W-->
							</Point>
						</OperatingArea>
						<Duration value="300"/>
```

Sailor overboard mission orders AVCL



Ontology for Ethical Control of Unmanned Systems in a Surrogate Scenario: Example Relationship Definitions

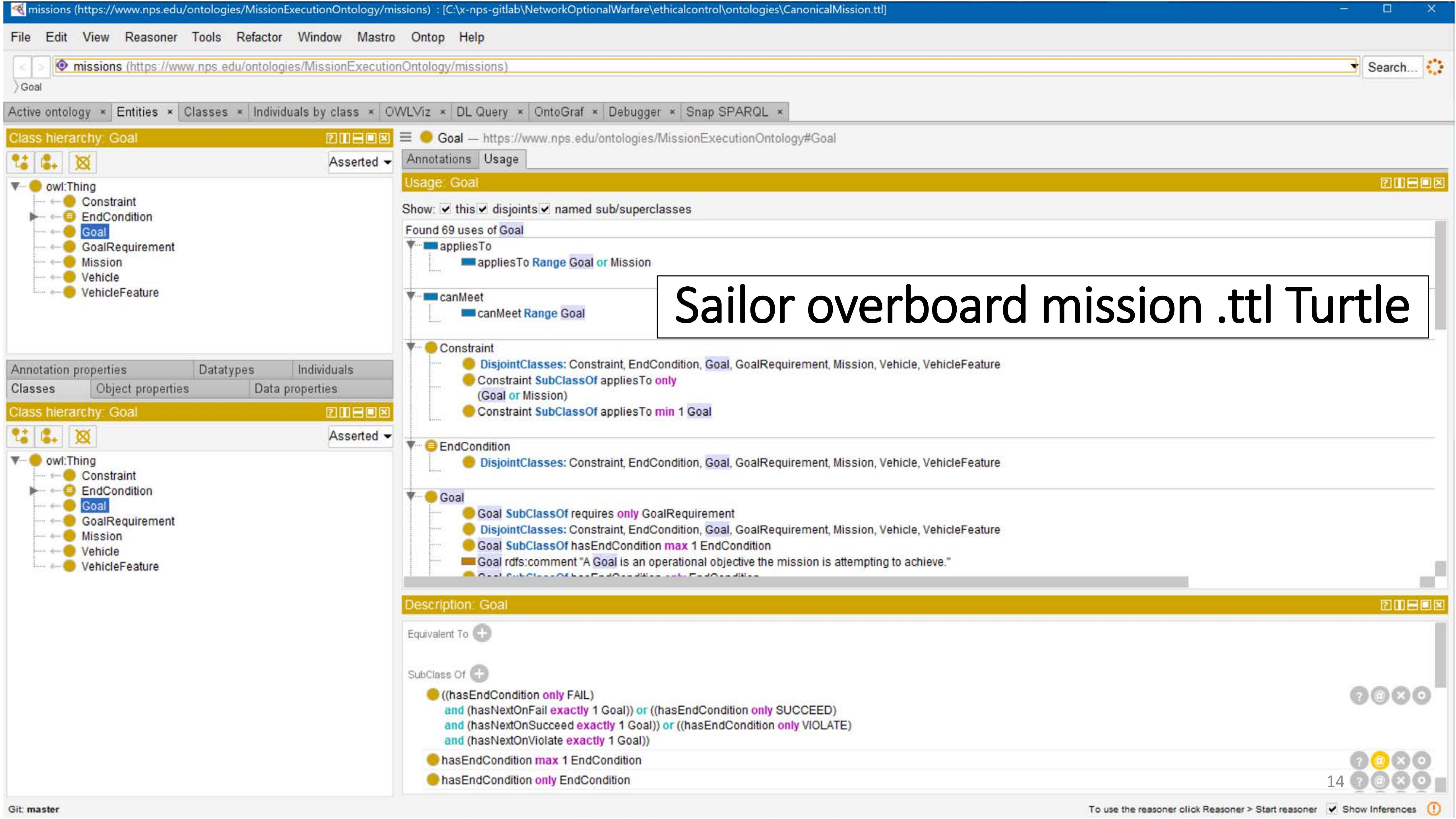
Mission Definition Expressed in Subject-Predicate-Object Triples Using Semantic Web Standards

Excerpt of Sailor Overboard Mission, expressed in Turtle Syntax:

```
###  https://www.nps.edu/ontologies/MissionExecutionOntology/missions#Goal_Launch
        :Goal_Launch rdf:type owl:NamedIndividual ;
                meo:hasNextOnFail :Goal_FailureDiagnosis ;
                meo:hasNextOnSucceed :Goal_TransitSearch ;
                meo:hasNextOnViolate :Goal_FailureDiagnosis .

###  https://www.nps.edu/ontologies/MissionExecutionOntology/missions#Goal_TransitSearch
        :Goal_TransitSearch rdf:type owl:NamedIndividual ;
               meo:hasNextOnFail :Goal_SearchForSailorAdrift ;
               meo:hasNextOnSucceed :Goal_TrackSailorAfloat ;
               meo:hasNextOnViolate :Goal_FailureDiagnosis .
```

Sailor overboard mission .ttl Turtle



first mission query MissionGoalsQuery_01 - hooray!

Brutzman, Don authored 1 hour ago

MissionGoalsQuery_01.rq 1.7 KB

```
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>

# MissionGoalsQuery_01.rq    Query to list all goals with corresponding description information and sequencing logic.

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

SELECT ?goal ?nextOnSucceed ?nextOnFail ?nextOnViolate ?isPartOfPhase ?description # ?GoalFound ?phase

WHERE
{
    ?goal   a meo:Goal ; # Shorthand expression: a = rdf:type
            meo:isPartOfPhase      ?isPartOfPhase ; # TODO what about when no value is provided
            meo:hasNextOnSucceed   ?nextOnSucceed ;
            meo:hasNextOnFail      ?nextOnFail ;
            meo:hasNextOnViolate   ?nextOnViolate ;# TODO rename as Exception
            rdfs:comment           ?description .

    # https://stackoverflow.com/questions/11234371/sparql-query-results-without-namespace
    BIND (strafter(xsd:string(?goal),"#")            AS ?GoalFound)
    BIND (strafter(xsd:string(?nextOnSucceed),"#")   AS ?GoalNextOnSucceed)
    BIND (strafter(xsd:string(?nextOnFail),"#")      AS ?GoalNextOnFail)
    BIND (strafter(xsd:string(?nextOnViolate),"#")   AS ?GoalNextOnViolate)
#   BIND (coalesce(?isPartOfPhase,"")                AS ?phase)
}
ORDER BY (?GoalFound) # alphanumeric order results in order given by each name
###############################################
```

SPARQL mission query
[MissionQuery_01_GoalBranches.rq]()

SPARQL query response

[SailorOverboardConverted. MissionQuery_01_GoalBranches.rq.txt]

goal	nextOnSuccess	nextOnFailure	nextOnException	isPartOfPhase	description
:Goal1	:Goal2	:Goal2	:Goal5	"Launch"	"Deploy, Launch: Sailor Overboard Immediate Action"
:Goal2	:Goal4	:Goal3	:Goal5	"Locate"	"Rendezvous with Sailor: Go directly to best known location"
:Goal3	:Goal4	:Goal5	:Goal5	"Locate"	"Search for Sailor: Sailor position not known, intermittent"
:Goal4	:Goal5	:Goal5	:Goal5	"Track"	"Track Sailor afloat until safe: Watch closely, not to interfere with rescue operations"
:Goal5	:Goal6	:Goal2	:Goal6	"Mission Finish"	"Proceed to Recovery: Mission complete, prepare for pickup"
:Goal6				"Recover Robot"	"Halt and prepare for recovery: Operations complete, final success state"
:Goal7				"Recover Robot"	"Halt and deploy recovery beacon: Unable to continue, final failure state"
:Goal8				"Recover Robot"	"Halt and await further orders: Unexpected problem, final exception state"

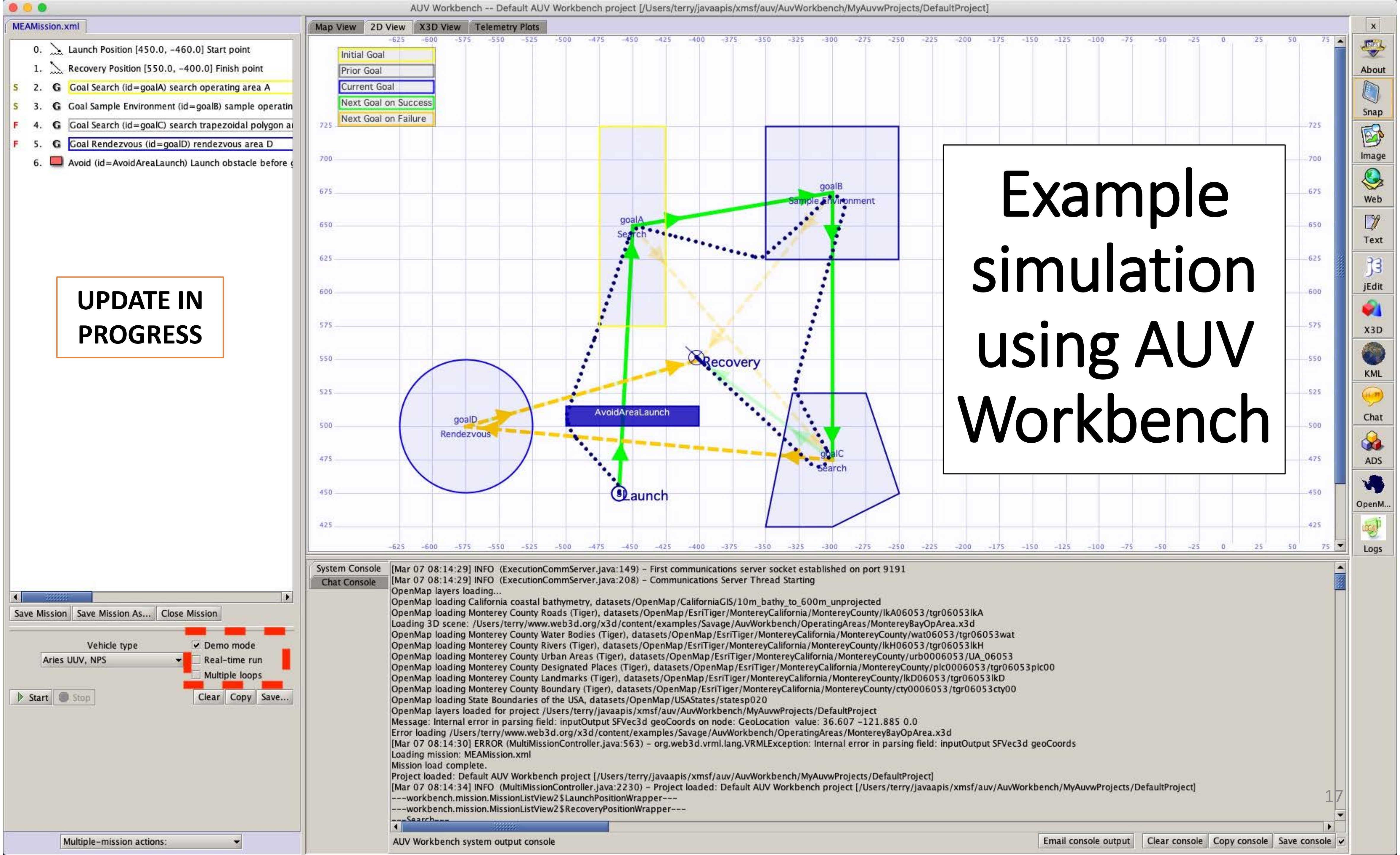
SPARQL query response

[SailorOverboardConverted. MissionQuery_02_InitialGoal.rq.txt]

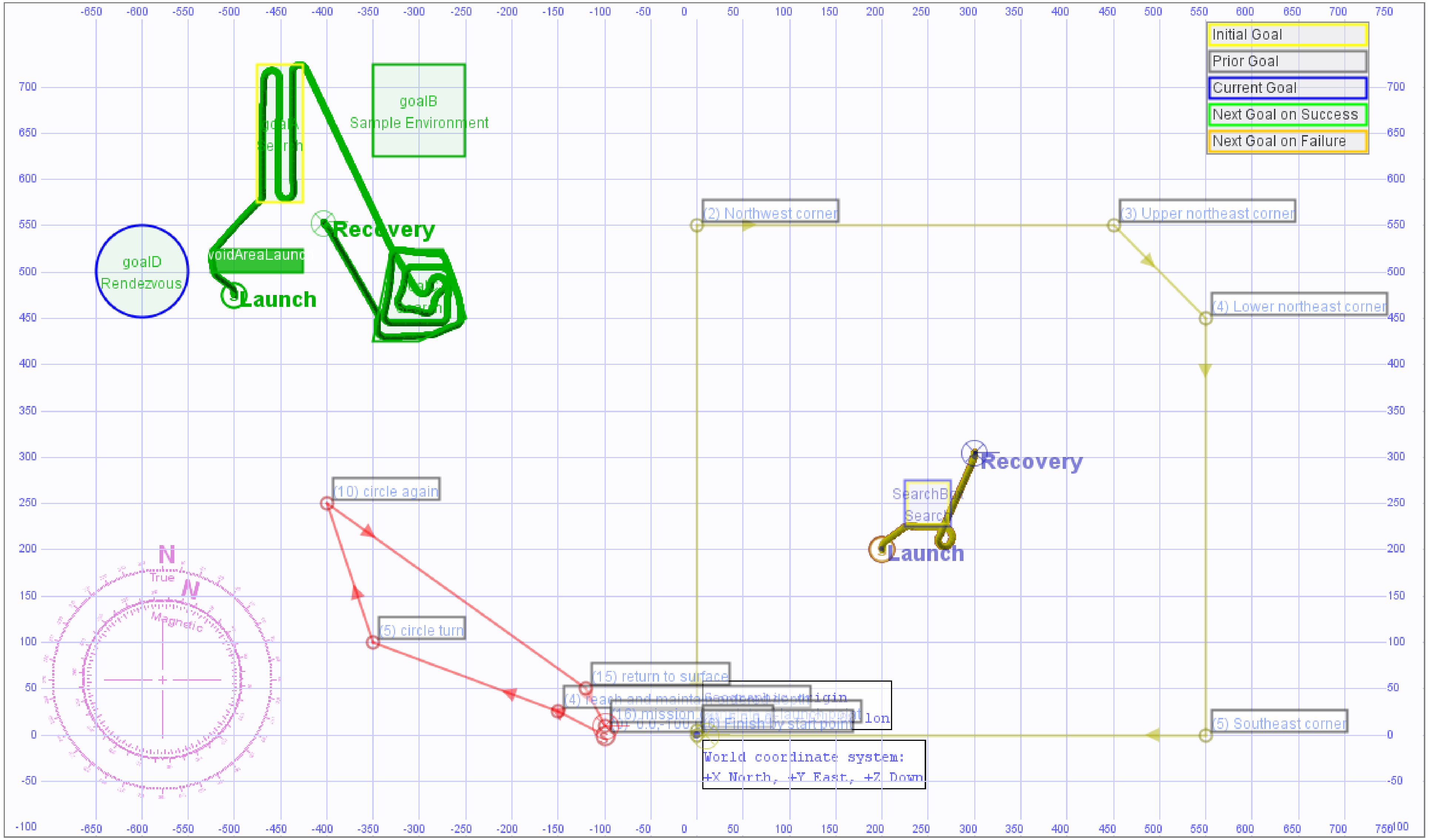
Mission	InitialGoal	isPartOfPhase	goalDescription
:SailorOverboard	:Goal1	"Launch"	"Deploy, Launch: Sailor Overboard Immediate Action"

Example simulation using AUV Workbench

UPDATE IN PROGRESS



4 earlier example missions, UUV and USV



Not suitable for brute-force numerical computation

- AI algorithms for Machine Learning (ML) and Data Mining are often based on statistically training against large datasets to find patterns for filters.
    - For example, **convolutional neural networks**, **genetic algorithms**, **reinforcement learning**, etc.
- Often requires identifying right/wrong matches within large search spaces.
- Such predictive analytics are useful for classification models using detailed and noisy sensor data. Given the central importance of IFFNU and some conditional communications to ethical control, ML filters can be helpful if carefully applied.
- Nevertheless such approaches are not appropriate for carefully following Rules of Engagement (ROEs), Laws of Armed Conflict (LOAC) or other ethical prerequisites, especially when human expertise and judgement is essential for robot teams.
- (Similarly, massive computation or Quantum Computing approaches might be useful in some problems, but are not of practical use for Ethical Control mission orders given by human commanders judiciously guiding remote mobile robots)

Naval history has long shown that sound human judgement is crucial for assessing best strategies and courses of action in ill-structured contexts. Semantic Web approaches are preferable and actionable for Ethical Control.

OODA Significance for Ethical Control

Classical robotic Sense-Decide-Act cycle for closed-loop control is insufficient for proper delegation of lethal (or lifesaving) force to unmanned systems.

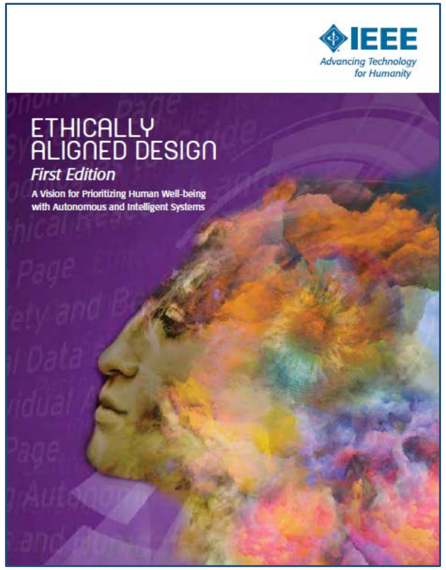
Observe-Orient-Decide-Act (OODA) Loop is essential for coherent operations.

- *Observe* includes direct sensing and communication inputs.
- *Orientation* includes thorough Rules of Engagement (ROE) constraints and identification friend/foe/neutral/unknown (IFFNU) of all relevant contacts.
- *Decision* logic of unmanned system tactics, techniques, procedures (TTP) includes authorization and confirmation by human supervisors, either in real-time or in advance, for critical steps leading to lethal force.
- *Actions* in tandem with direct or intermittent human supervisory command enables effective Ethical Control of remote systems.

Feedback loops are essential, generally leading to… *more effective operations.*

IEEE P7000-series Standards Projects

https://ethicsinaction.ieee.org

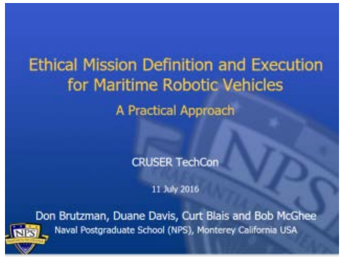


- P7000 Model Process for Addressing Ethical Concerns during System Design
- P7001 Transparency of Autonomous Systems
- P7002 Data Privacy Process
- P7003 Algorithmic Bias Considerations
- P7004 Standard on Child and Student Data Governance
- P7005 Standard on Employee Data Governance
- P7006 Standard 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

- 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.

Key Insights regarding Human Ethical Control



1. **Humans in military units are able to deal with moral challenges without ethical quandaries,**
   - **by using formally qualified experience, and by following mission orders that comply with Rules of Engagement (ROE) and Laws of Armed Conflict (LOAC)**.

2. Ethical behaviors don't define the mission plan. Instead, **ethical constraints inform the mission plan**.

3. **Naval forces can only command mission orders that are**
   - **Understandable by (legally culpable) humans, then**
   - **Reliably and safely executed by robots**.

Reference: CRUSER TechCon Overview 2016
https://gitlab.nps.edu/Savage/EthicalControl/tree/master/documents/presentations

Conclusions

- Human supervision is required for any unmanned systems holding potential for lethal force.
  - Cannot push “big red shiny AI button” and hope for best – immoral, unlawful.
  - Similar imperatives exist for supervising systems holding life-saving potential.
- Human control of unmanned systems is possible at long ranges of time-duration and distance through well-defined mission orders.
  - Readable and sharable by both humans and unmanned systems.
  - Validatable syntax and semantics through logical constraints.
  - Testable and confirmable using simulation and visualization.
- Coherent human-system team approach is feasible and repeatable.
  - Semantic Web confirmation can ensure orders are comprehensive, consistent.
  - Human role remains essential for life-saving and potentially lethal scenarios.

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Consortium for Robotics and Unmanned Systems Education and Research

NPS PRAESTANTIA PER SCIENTIAM

ETHICAL MISSION DEFINITION AND EXECUTION FOR MARITIME ROBOTS UNDER HUMAN SUPERVISION

- Lethality requires ethical and legal basis, supervised by military teams.
- Executable robot tasking can resemble tactical tasking of humans afloat.
- Careful application of goal constraints makes ethical control feasible.
- Robot missions then complement and extend naval operation orders.
- Semantic Web logic can confirm ethical correctness and completeness.
- Next steps: continue 2 decades of work with realistic scenario testing.

> “Ethical constraints on robot mission execution are possible today. There is no need to wait for future developments in Artificial Intelligence (AI). It is a moral imperative that ethical constraints in some form be introduced immediately into the software of all robots that are capable of inflicting unintended or deliberate harm to humans or property.” Robert McGhee, April 2016

- IEEE Journal of Oceanic Engineering (JOE) paper along with online references.
- Authors Don Brutzman, Curtis Blais, Duane Davis and Robert McGhee, NPS.
- Feedback and recommendations always welcome. Contact: brutzman@nps.edu