U.S. ARMY COMBAT CAPABILITIES DEVELOPMENT COMMAND – ARMAMENTS CENTER

Exploration of Semantic Web Technologies as an Enabler of Model-based Systems Engineering (MBSE) and Digital Engineering (DE)

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BACKGROUND

- **Name:** Hyun June Ferrabolli
- **Title:** System Engineer
- **Education:** Stevens Institute of Technology
  - » M.Eng. in Systems Engineering (concentration in Decision making and Risk mitigation)
  - » B.Eng. Mechanical Engineering

- **I research and develop system engineering infrastructure for the System Engineering Directorate at the Combat Capabilities Development Center Armaments Center, Picatinny Arsenal, NJ.**

- **My current work has focused on exploring integration and interoperability frameworks that connect engineering workflows.**

WHAT ARE SEMANTIC WEB TECHNOLOGIES?

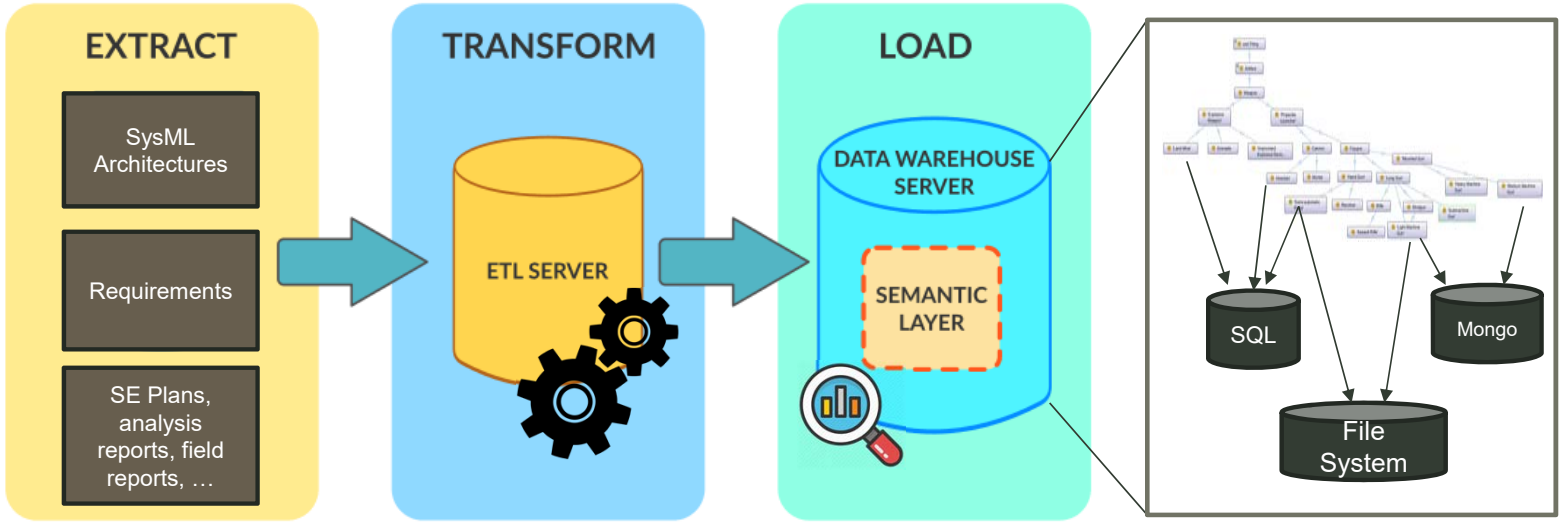
- **Semantic = machine readable** data and information
- **Web = interconnected** data and information

- Made up of **tools and standards**
  - Standards
    - RDF: Simple class hierarchies
    - OWL: RDF vocabulary for formal logic
    - SPARQL: Powerful language for querying RDF/OWL databases
    - Ontologies: formal naming and definition of the categories, properties and relations between the concepts
  - Tools
    - Ontology editors: Protégé, Composer
    - Knowledge repositories: Sesame (rdf4j, Oracle Semantic Database, Mulgara)
    - Application frameworks: Sesame, Jena

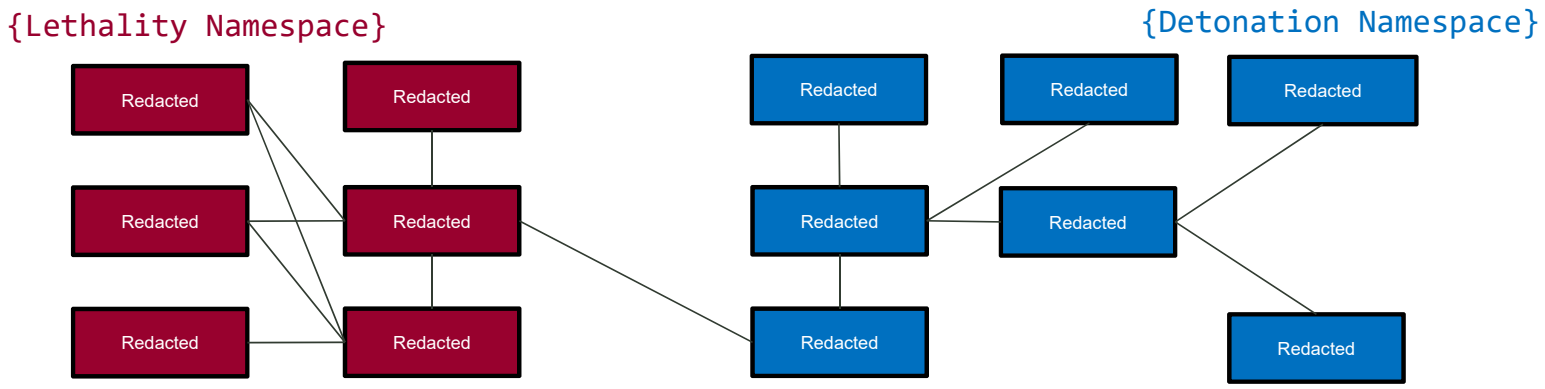
- Enables **building relationships between data from various sources in various formats**, allowing for domain knowledge capture, standardization, and reuse

- Technology provides a common framework that **allows data to be shared and reused** across application, enterprise, and community boundaries.

EXTRACT TRANSFORM LOAD (ETL)

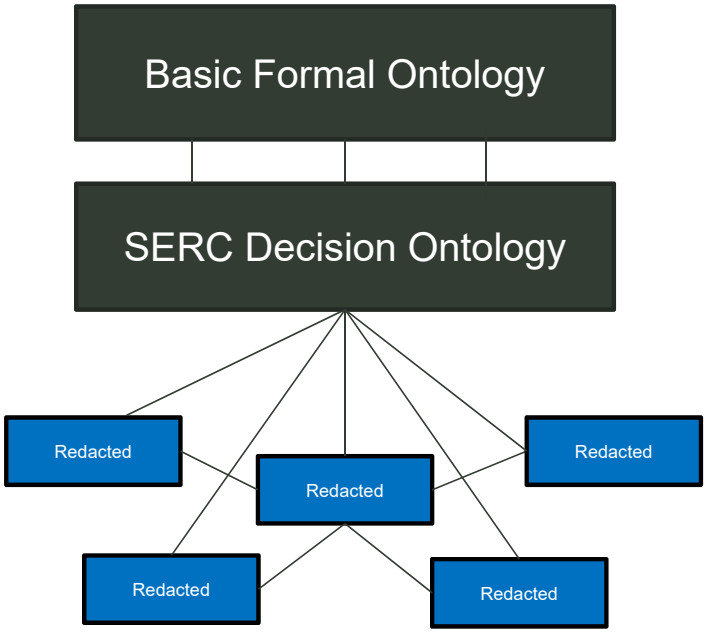


PHASE 1 RECAP



- **Focused on workflows using projectile data and lethality model**
- **Created ontologies from these two areas and linked them together**
- **Demonstrated use of SWT tools and standards in practice across these two domains**

PHASE 2 OVERVIEW

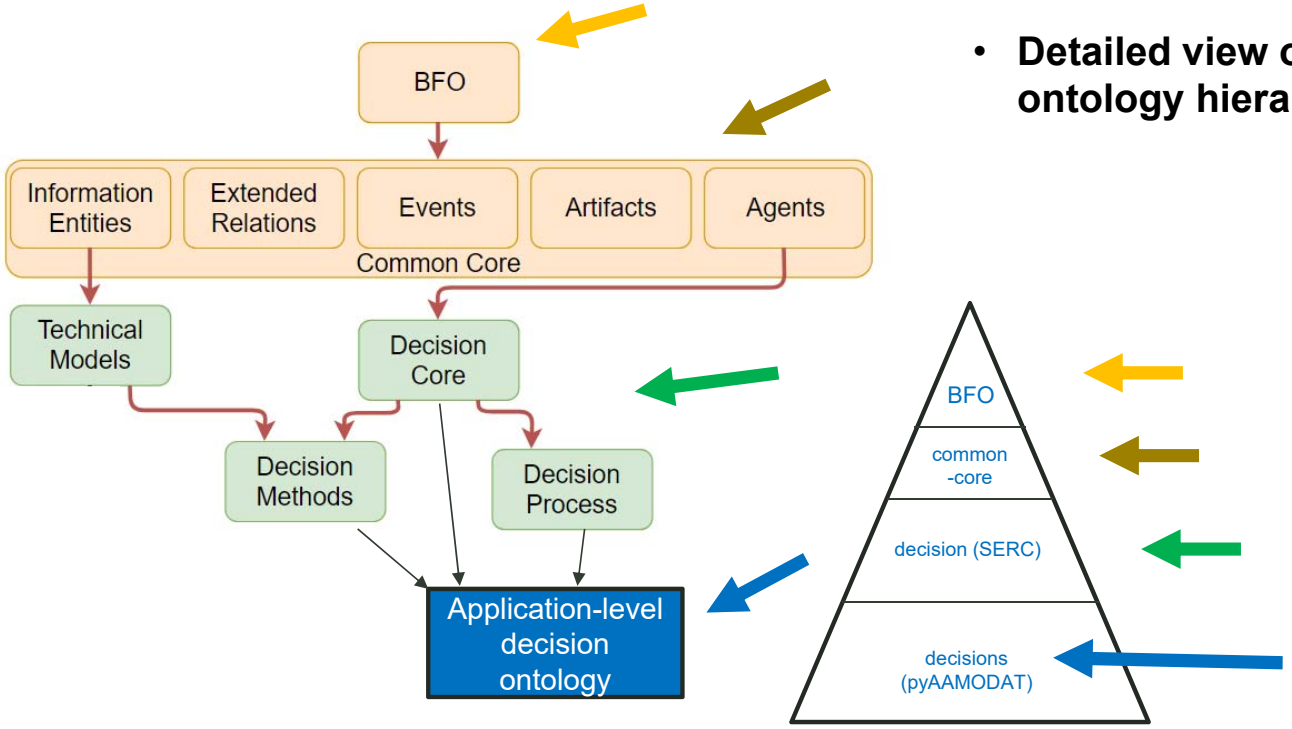


{Python Decision Tool}

- **Focused on decision analysis resolution (DAR) workflow**
- **More proper development of ontology (inheritance from upper level ontologies)**
- **Close collaboration with academic partners (Systems Engineering Research Center)**

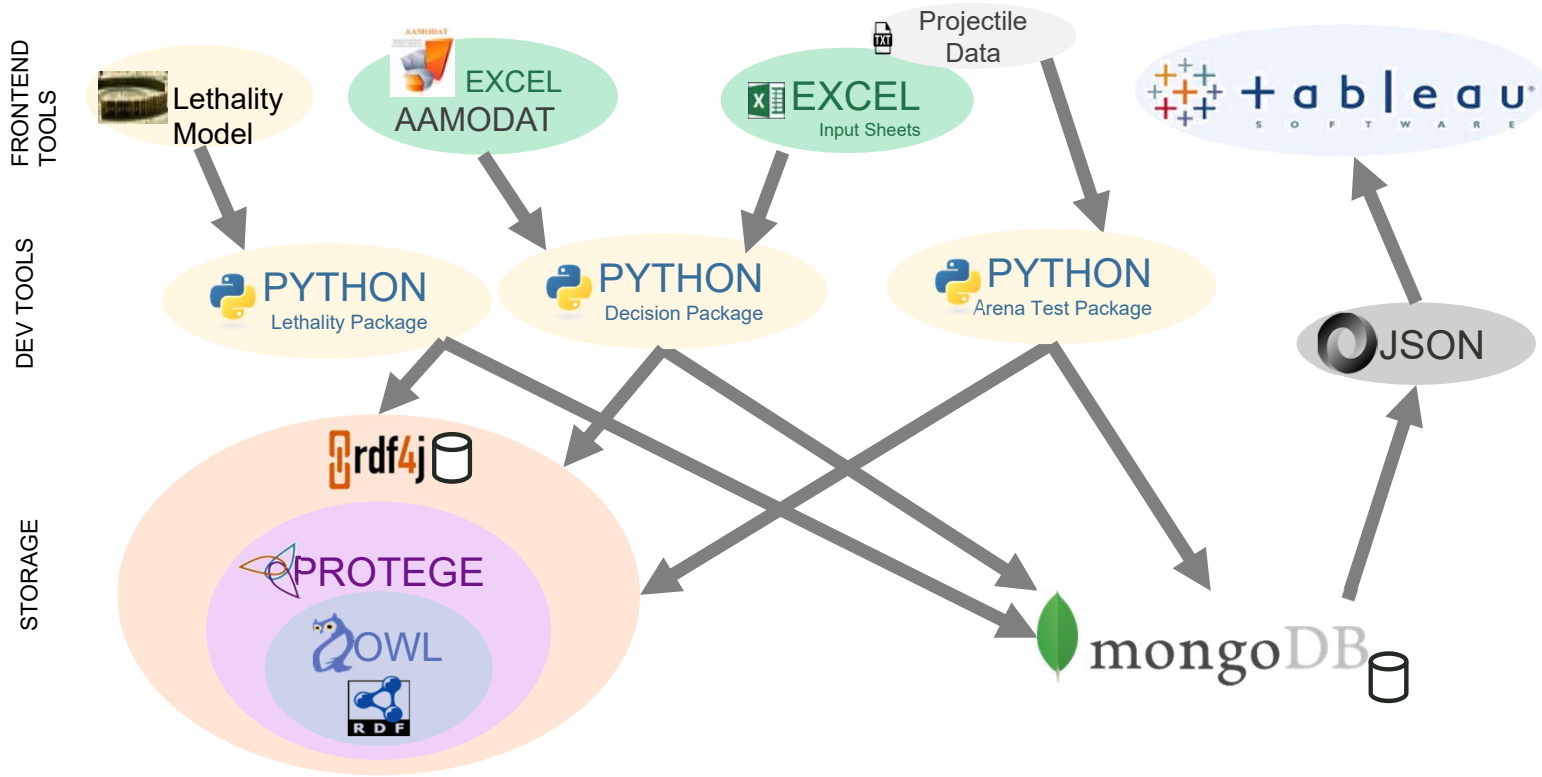
- **Byproduct: Python toolkit for decision analysis (AAMODAT) equipped with embedded mongoDB utility**

PHASE 2 OVERVIEW



- **Detailed view of ontology hierarchy**

RESEARCH EXAMPLE: TRADE STUDY



LOADING ONTOLOGIES

In [2]:
```
conn = rdf.Connection()

conn.repository = 'decisions'

leif_file = ['permanence/rdf4j/artifacts/leif.owl']

bfo_files = ['permanence/rdf4j/artifacts/ontologies/top/bfo.owl']

mid_files = ['permanence/rdf4j/artifacts/ontologies/mid/GeospatialOntology.owl',
             'permanence/rdf4j/artifacts/ontologies/mid/InformationEntityOntology.owl',
             'permanence/rdf4j/artifacts/ontologies/mid/model.owl',
             'permanence/rdf4j/artifacts/ontologies/mid/ExtendedRelationOntology.owl',
             'permanence/rdf4j/artifacts/ontologies/mid/UnitsOfMeasureOntology.owl',
             'permanence/rdf4j/artifacts/ontologies/mid/TimeOntology.owl',
             'permanence/rdf4j/artifacts/ontologies/mid/Math.owl',
            ]


decision_files = ['permanence/rdf4j/artifacts/decision_core.owl',
                  'permanence/rdf4j/artifacts/decision_method.owl',
                  'permanence/rdf4j/artifacts/decision_process.owl',
                  'permanence/rdf4j/artifacts/DecisionToolOntology.owl',
                 ]

all_files = bfo_files + mid_files + decision_files

conn.reset_repo('decisions', decision_files + leif_file)
```

In [3]:
```
t = rdf.Translator(conn)
```

LOADING AND SEARCHING THE TRADESTUDY RESULTS

In [7]:
```
t.to_rdf_entity(tradestudy)
```

Out [7]:
```
Entity(5d84f400cd04ed05e270b84a-Instance-TradeStudy,
```

In [8]:
```
t.commit()
```

In [24]:
```
# TradeStudy results (alternative information )

u_id = str(alt[0].id)

populate_sparql_prefix(conn)

query = """
        SELECT ?name ?cost ?rdtime ?valuation
        WHERE {{
            ?x rdf:type dec:Alternative .

            ?x rdfs:label ?name .
            ?x dec:hasCost ?cost .
            ?x dec:hasRDTime ?rdtime.
            ?x dec:hasValuation ?valuation
        }}""".format(u_id)

response = conn.query(query, debug=0)
response
```

Out [24]:
```
[{'cost': {'type': 'literal', 'value': '1.01'},
  'name': {'type': 'literal', 'value': 'A155614"NGFC'},
  'rdtime': {'type': 'literal', 'value': '1000000000.0'},
  'valuation': {'type': 'literal', 'value': '44.19511706921283'}},
 {'cost': {'type': 'literal', 'value': '1.66'},
  'name': {'type': 'literal', 'value': '1158_55626"BullpupNGFC'},
  'rdtime': {'type': 'literal', 'value': '1000000000.0'},
  'valuation': {'type': 'literal', 'value': '57.6675972993607'}},
 {'cost': {'type': 'literal', 'value': '2.16'},
  'name': {'type': 'literal', 'value': '1158_762CTA14"NGFC'},
  'rdtime': {'type': 'literal', 'value': '1000000000.0'},
  'valuation': {'type': 'literal', 'value': '65.02420891230992'}},
 {'cost': {'type': 'literal', 'value': '4.63'},
  'name': {'type': 'literal', 'value': 'AK762Tapered100ksiHighCharge20"GANFC'},
  'rdtime': {'type': 'literal', 'value': '0.0'},
  'valuation': {'type': 'literal', 'value': '70.02739887447437'}},
 {'cost': {'type': 'literal', 'value': '2.17'},
  'name': {'type': 'literal', 'value': '1158_762CTA26"BullpupNGFC'},
  'rdtime': {'type': 'literal', 'value': '1000000.0'},
  'valuation': {'type': 'literal', 'value': '64.51305766622613'}},
 {'cost': {'type': 'literal', 'value': '2.37'},
  'name': {'type': 'literal', 'value': 'AK762Cylinder100ksiLowCharge20"GANFC'},
  'rdtime': {'type': 'literal', 'value': '0.0'},
  'valuation': {'type': 'literal', 'value': '73.8190291578237'}},
```

TAKEAWAY

- **Semantic Web Technologies have a future in Systems Engineering tooling**
  - There is still a gap that needs to be traversed between academic research (i.e. the "art of the possible"), and polished, user friendly vendor tools.

- **Has a lot of potential for vendors to begin to include these technologies in their future versions of their tools**
  - Looking forward to using tools that are built with the mindset of being more accessible, and more integration focused

Questions, comments?

THE POWER OF INFERENCE AND REASONING

- **Formal and explicit definitions of a system's concepts enables inferencing and reasoning on those concepts—characteristics lacking in most current MBSE implementations.**
- **The user is able to impose axioms to construct a self-governing model.**

(I) The sum of two real numbers is a real number.

(II) α and β are real numbers.

(III) $\mu = \alpha+\beta$

(IV) [*Inferred*] μ is a real number.

(I) A system has a requirement "the system needs a bearing that withstands a static load of 50000 Mpa".

(II) A viable system alternative satisfies all requirements.

(III) Alternative ABC uses a bearing with a static load capacity of 41000 MPa.

(IV) [*Inferred*] Alternative ABC is not a viable system alternative.

ONTOLOGY & SEMANTIC WEB TECHNOLOGY

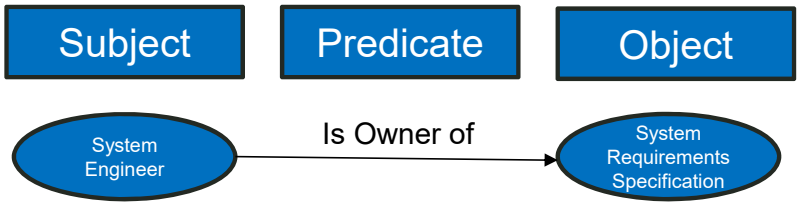
- **An ontology is a controlled vocabulary for representing the types of entities in a given domain(1). It describes entities/concepts and relationships between them in an object-oriented, machine-readable manner.**

- **formal:** machine-readable, utilize first-order logic (FOL).
- **explicit:** structural components are clearly defined
- **shared:** knowledge captured is consensual by group

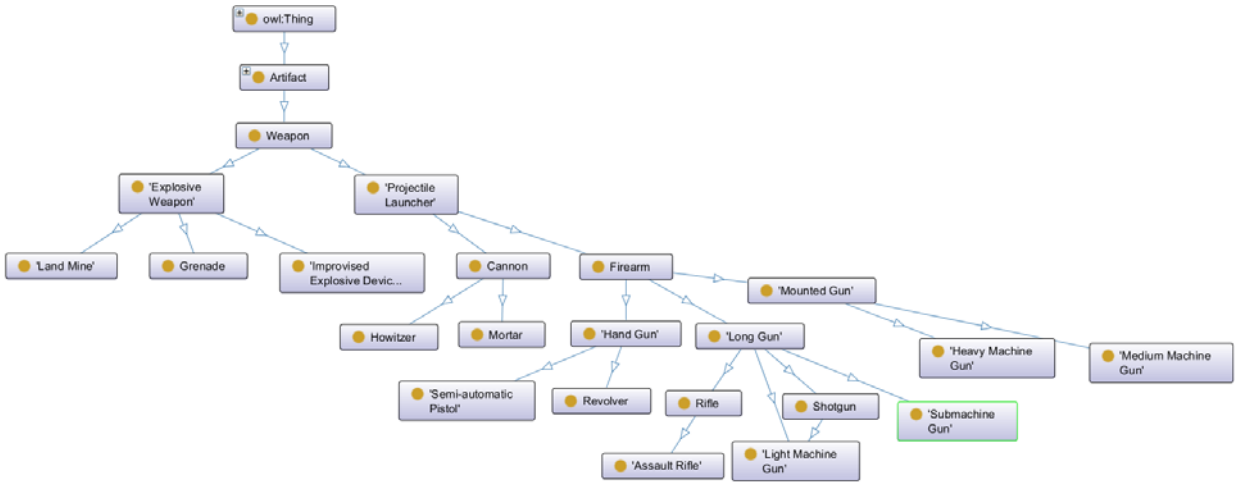
- **Semantic web technology (SWT) is a collection of tools and internet standards that help enable linked-data capabilities across the web. In conjunction with SWT, ontological models can be utilized to attain higher levels of integration.**

(1) Smith, Barry. Building Ontologies with Basic Formal Ontology

ONTOLOGY REVIEW



- **Ontologies are constructed of triple statement axioms.**



- **To the left is a view of an ontology from an ontology editing software named Protégé**
  - The nodes are subjects/objects
  - The edges are predicates