BASIC FORMAL ONTOLOGY TUTORIAL

INSTRUCTOR

John Beverley, PhD

Co-Director, *National Center for Ontological Research*
Assistant Professor, *University at Buffalo*
Affiliate Faculty, *Institute of Artificial Intelligence and Data Science*

Outline

- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem

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- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem

It Bears Repeating...

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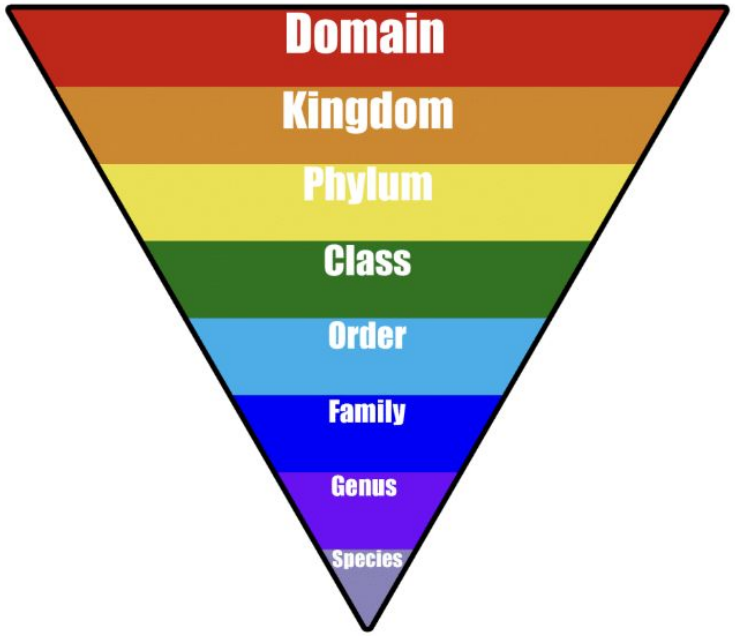
- You should seriously ask yourself, what distinguishes ontology engineering from:

Taxonomies



Science of Ontology Engineering

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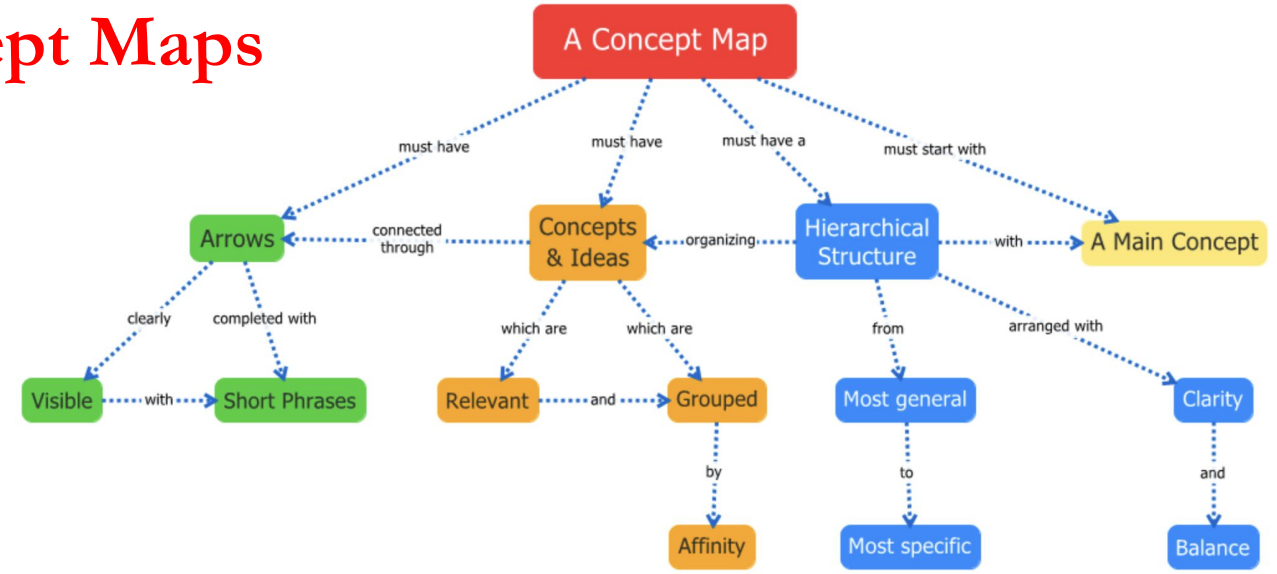
Concept Maps



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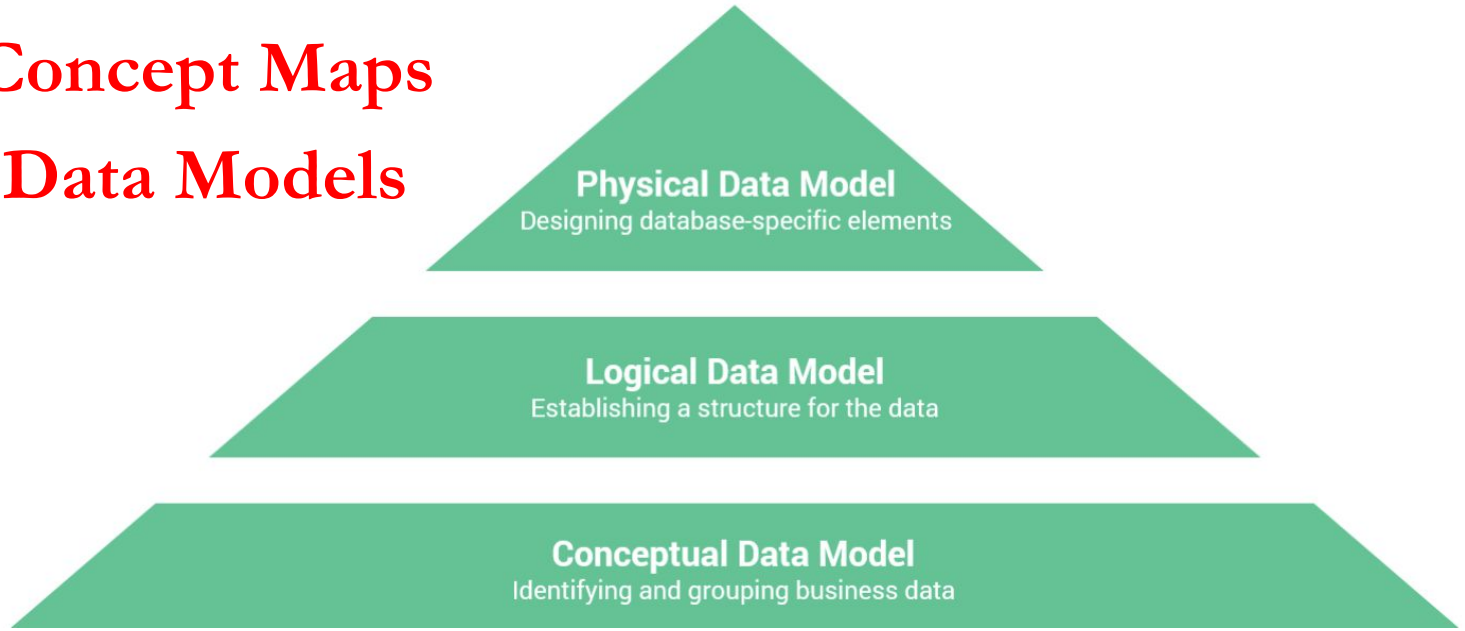

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Pop Quiz

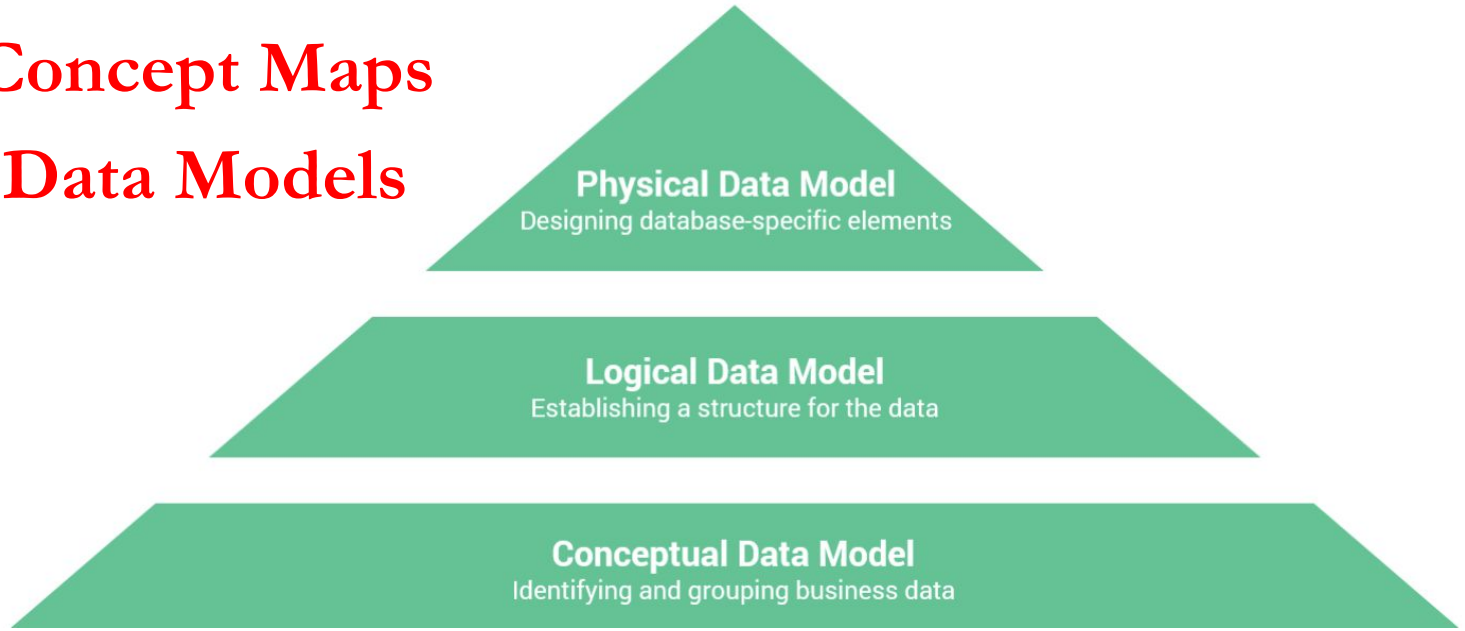
- You should seriously ask yourself, what distinguishes ontology engineering from:

Taxonomies

Concept Maps

Data Models

What distinguishes ontology engineering from data model development?



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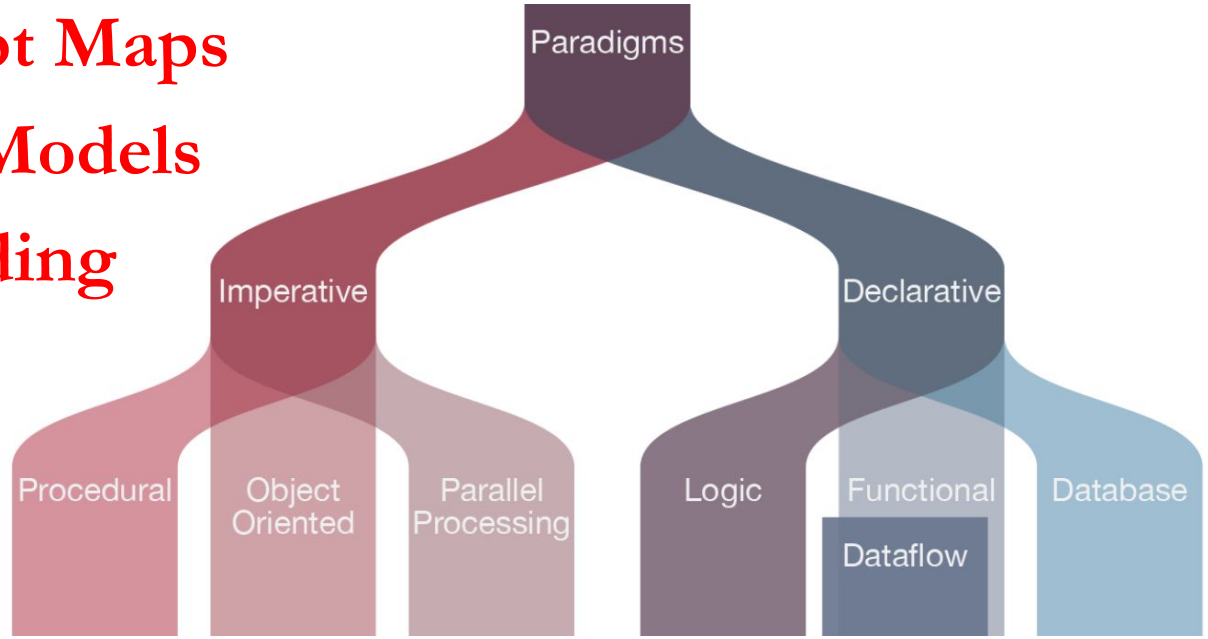
Data Models

Coding



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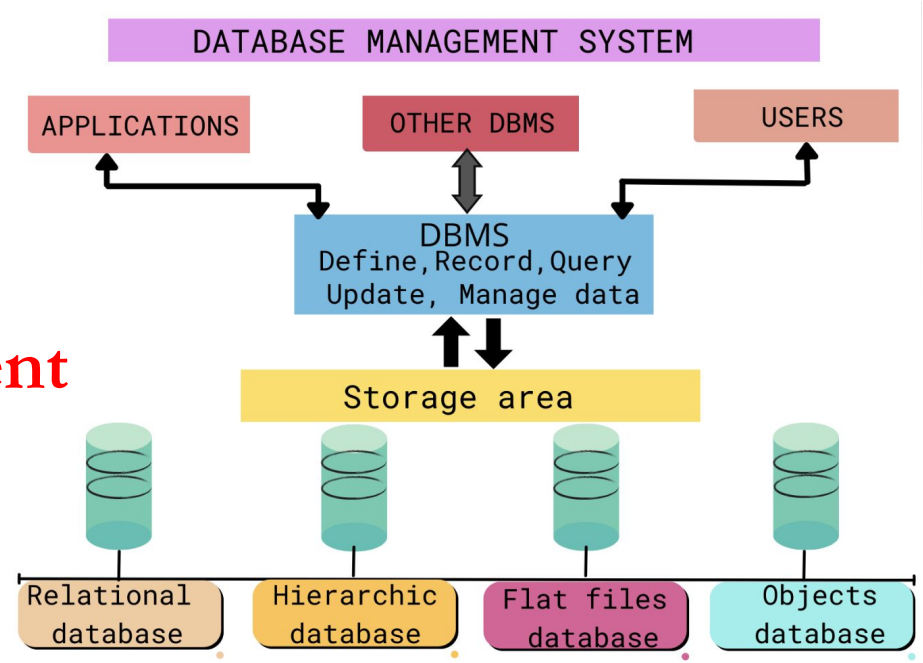
Database Management



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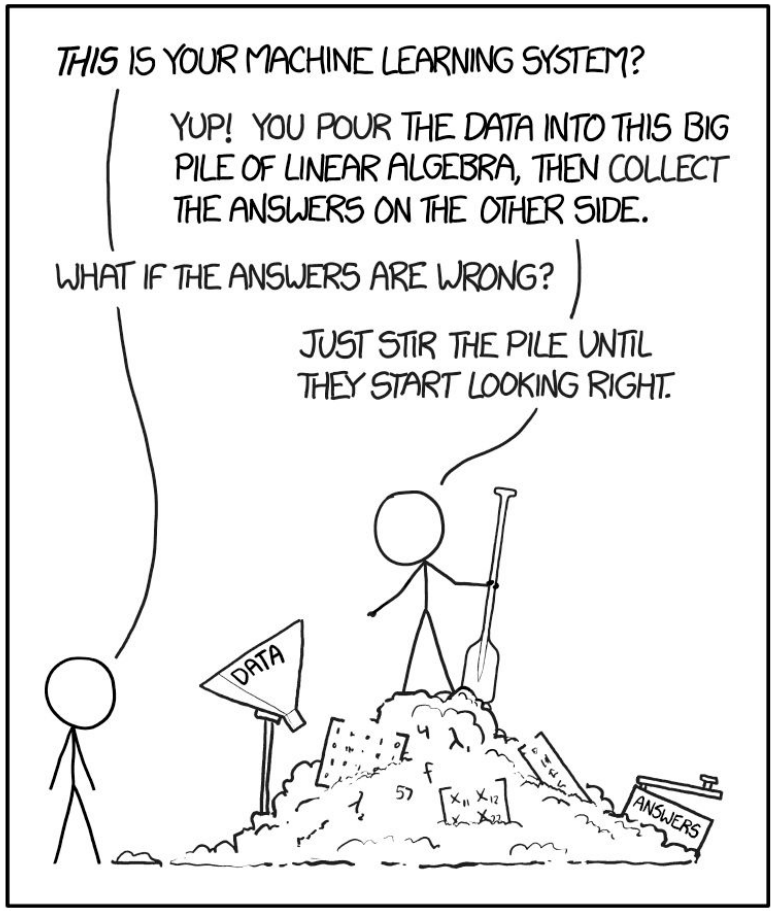
Machine Learning



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The development, curation, and management of application agnostic ontologies designed to make explicit the implicit semantics underwriting representations of data

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The development, curation, and management of application agnostic ontologies designed to make explicit the implicit semantics underwriting representations of data

I spoke of this philosophical topic yesterday

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I shall speak of this engineering topic today

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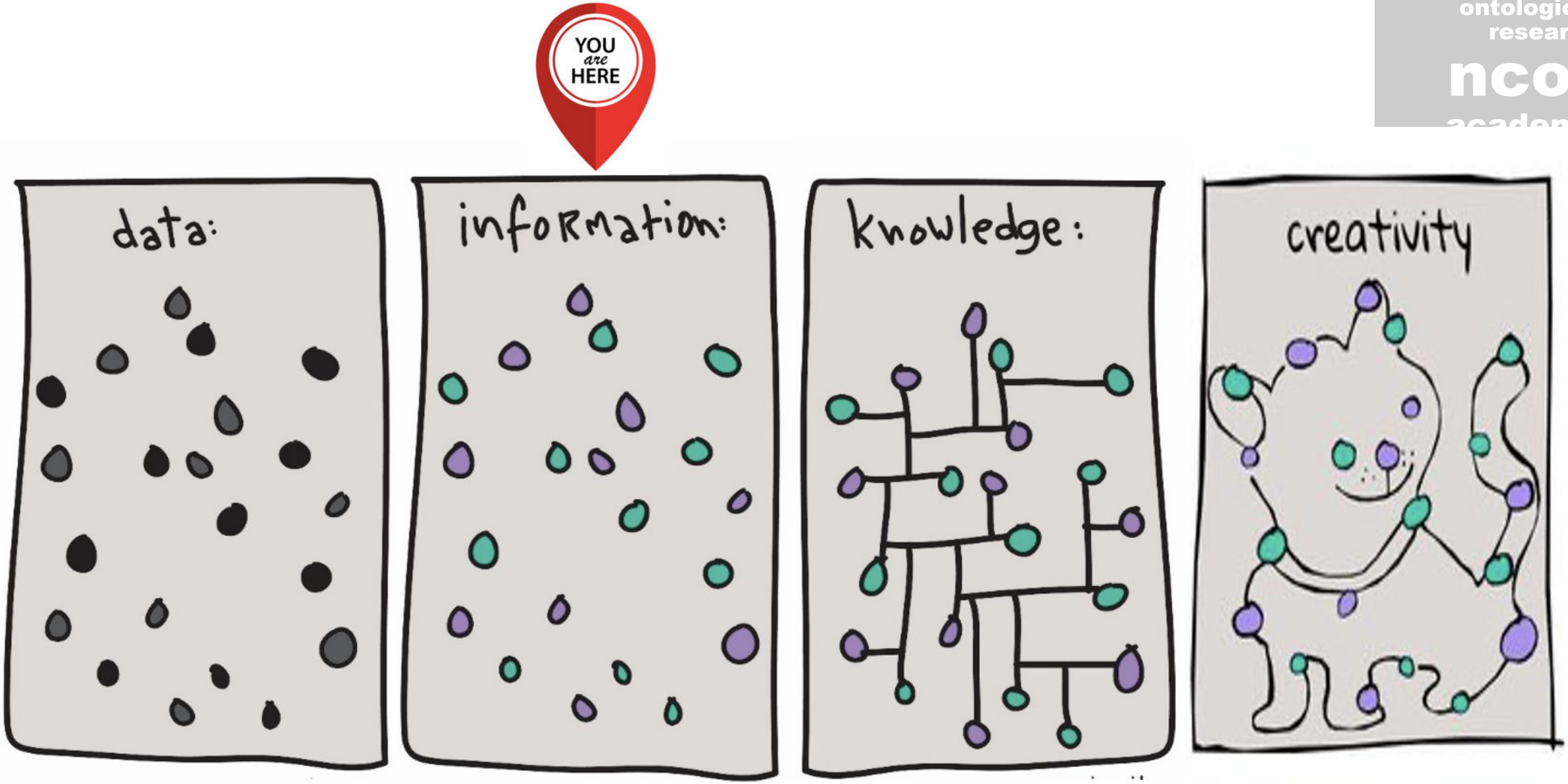

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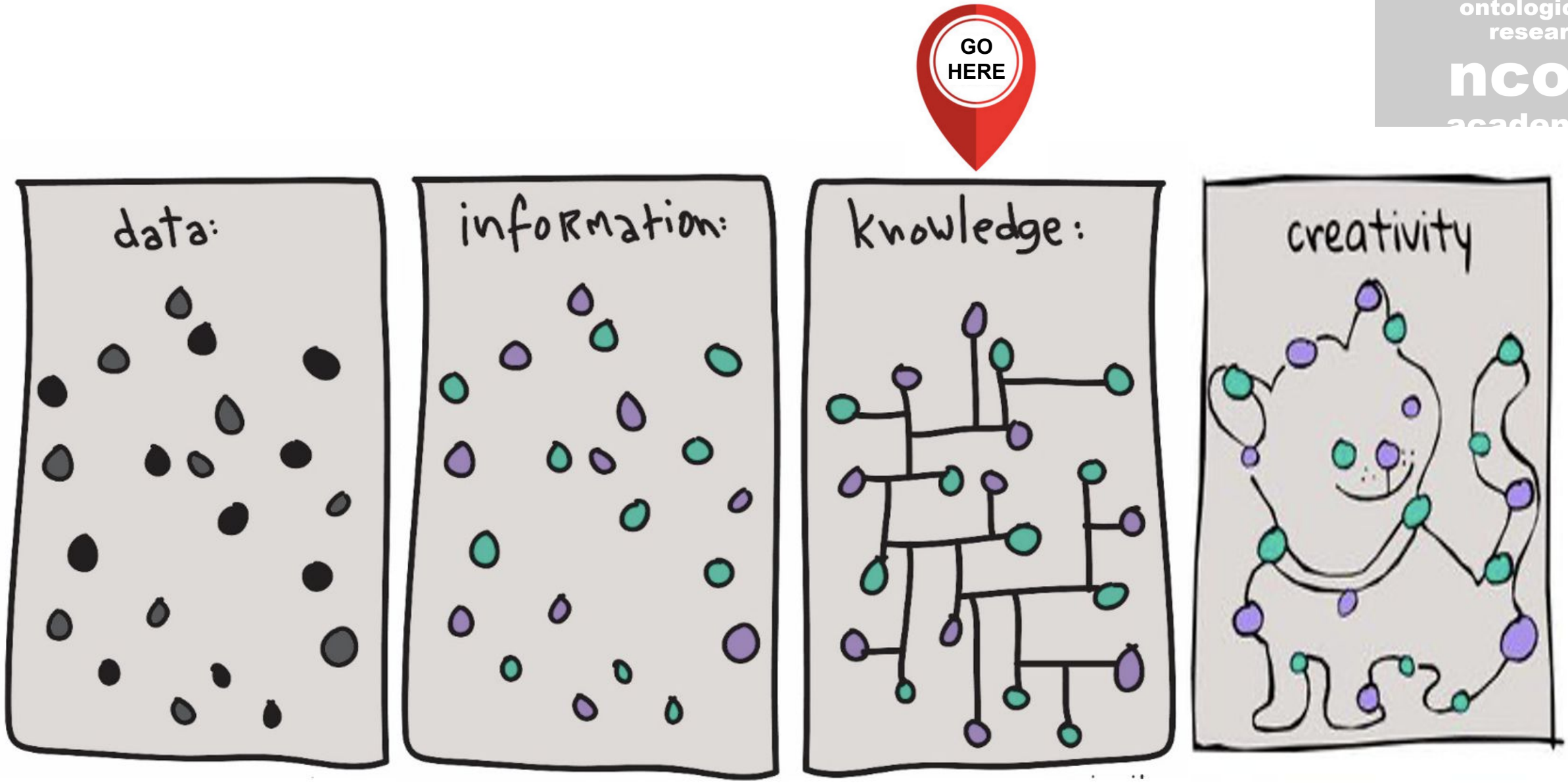

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Information Silos

An *information silo* is an information repository, e.g. management system, database, the content of which cannot be integrated with that of other information repositories using standard computing strategies

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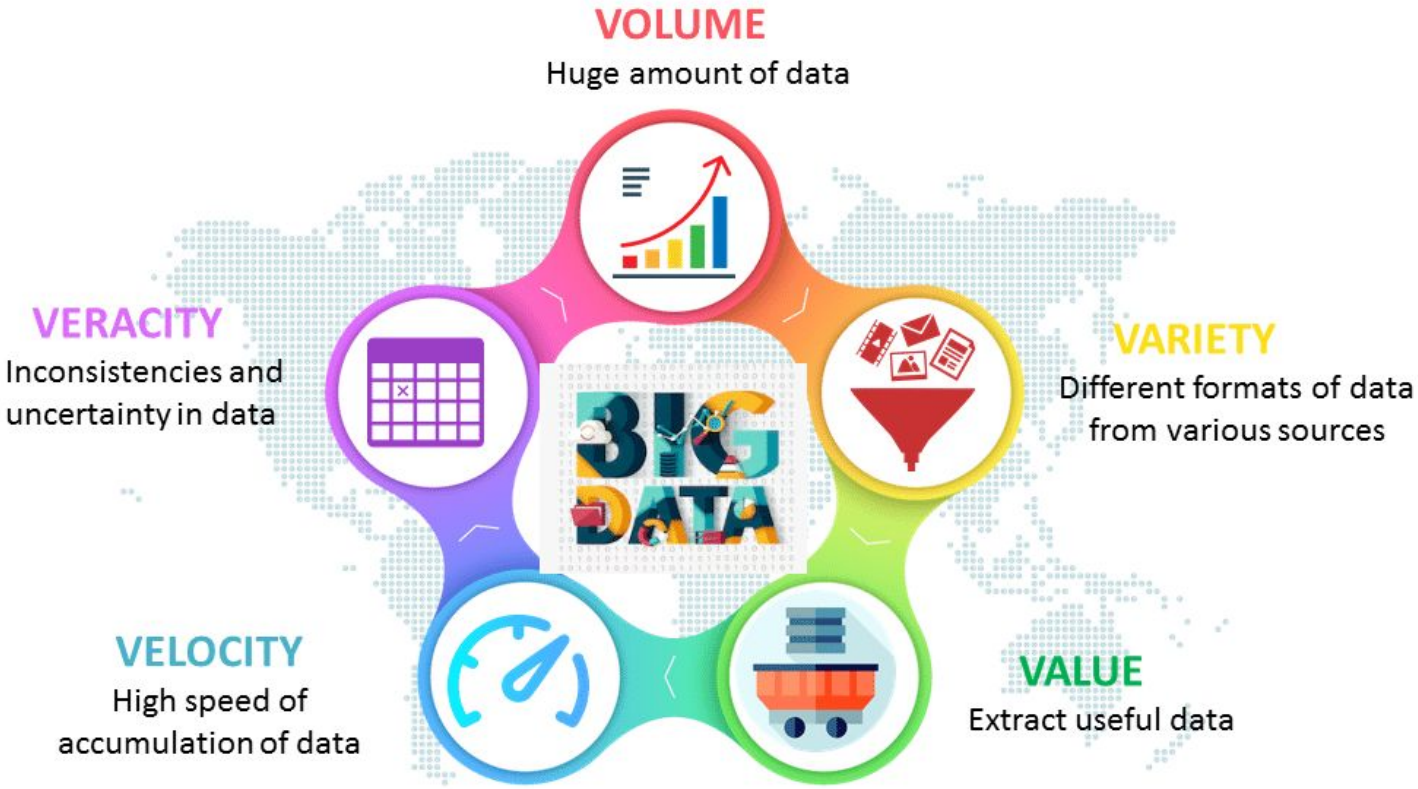
SILOS ARE EXPENSIVE

Cost of Silos

A 2020 report by NIST estimated the lack of interoperability across industrial datasets costs companies between **21-43 billion**

McKinsey estimates mid-size companies spend **20-50 million** annually due to silos



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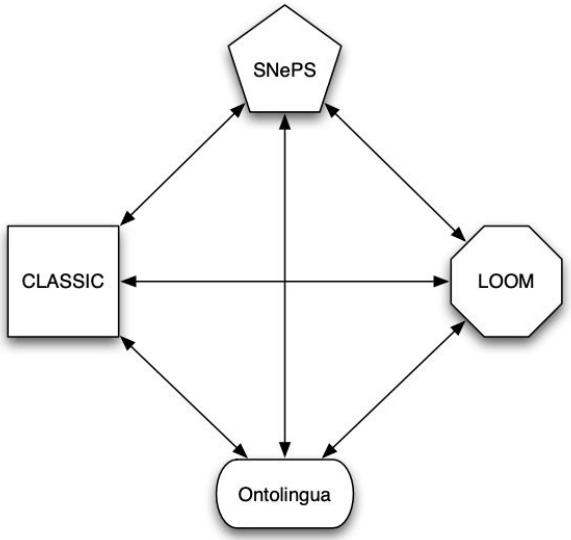
SILOS ARE NOT NEW

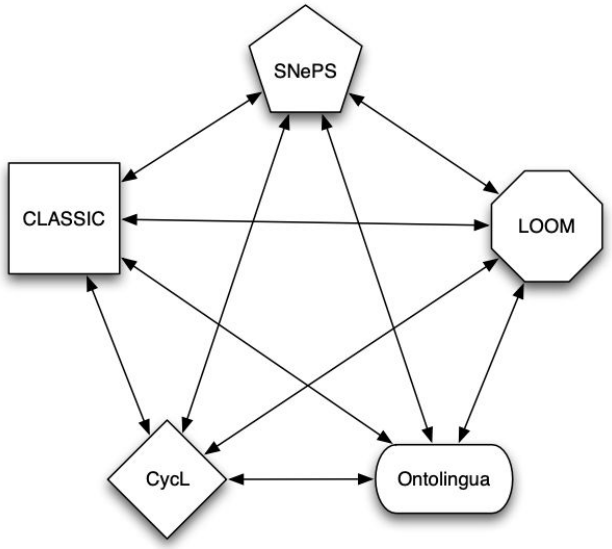
N-Squared Problem

- During the early days of the web, datasets were coded in **distinct syntax** without an eye towards interoperability with other datasets

- Connecting disparate datasets requires two-way mappings:
  - 2 datasets – 2 mappings
  - 3 datasets – 6 mappings
  - 4 datasets – 12 mappings

    ....

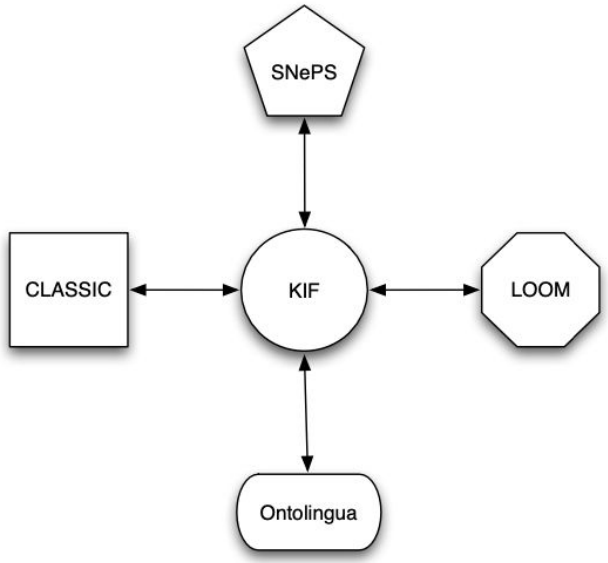


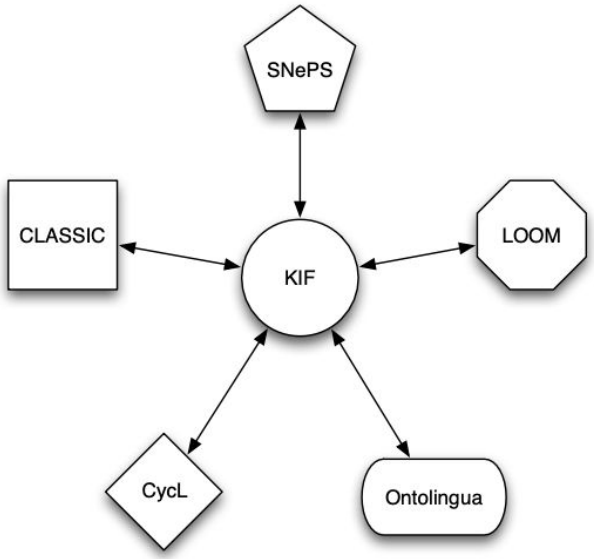


Semantic Web

- The advent of the "Semantic Web" ushered in a series of strategies for **promoting interoperability**, partly aimed at addressing this problem

- The **Resource Description Framework** was leveraged as a way to mitigate the n-squared problem, by creating hubs of interoperability





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STRATEGIES FOR ADDRESSING SILOS ARE NOT NEW

Promise of Ontology Engineering

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- Ontologies are formally well-defined machine-interpretable controlled vocabularies designed to represent entities and logical relationships among them

- Ontologies make **explicit** the **implicit** meanings buried in datasets, by using basic principles of formal logic

- Ontologies provide a **semantic layer** to connect information silos

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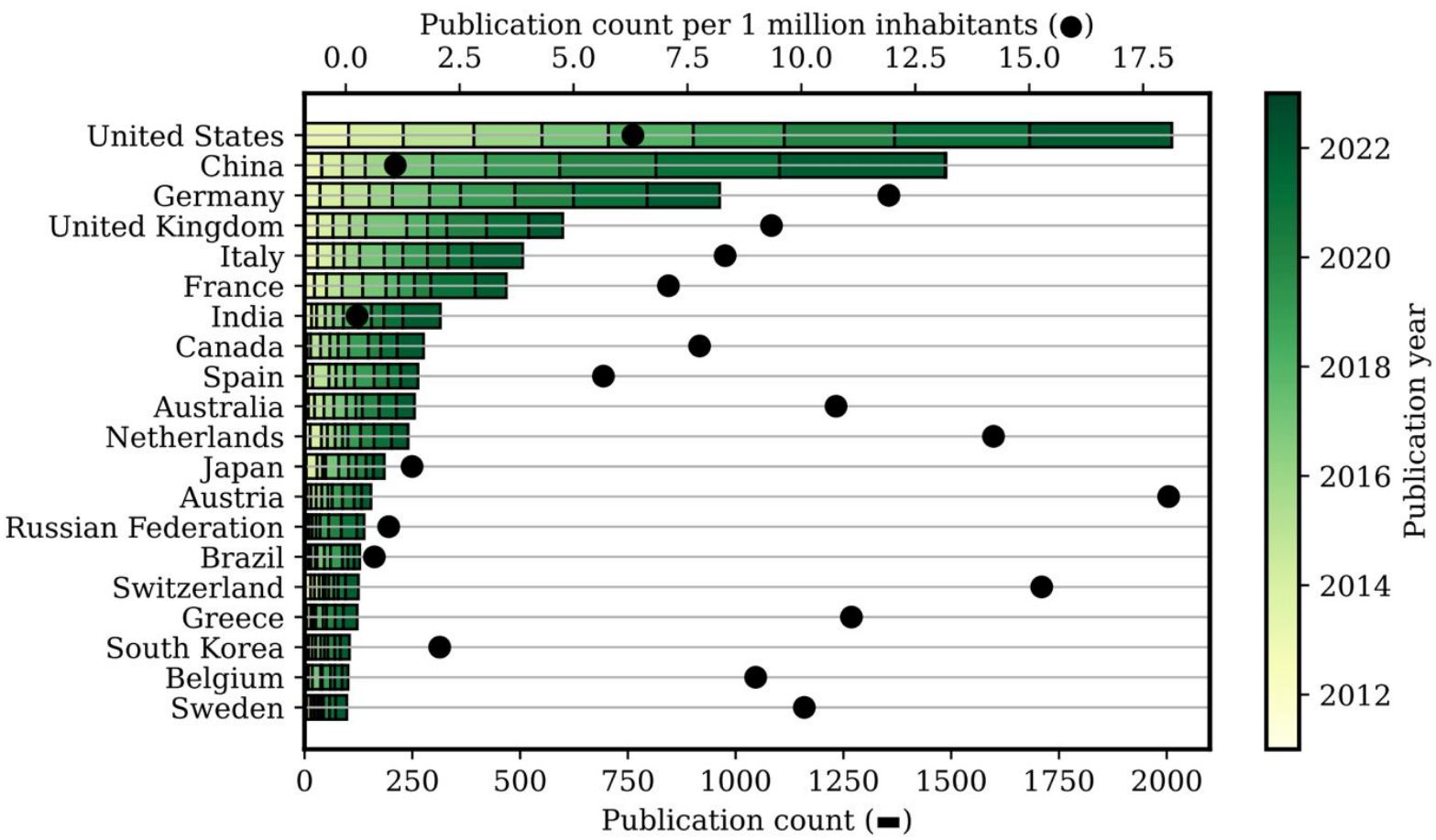
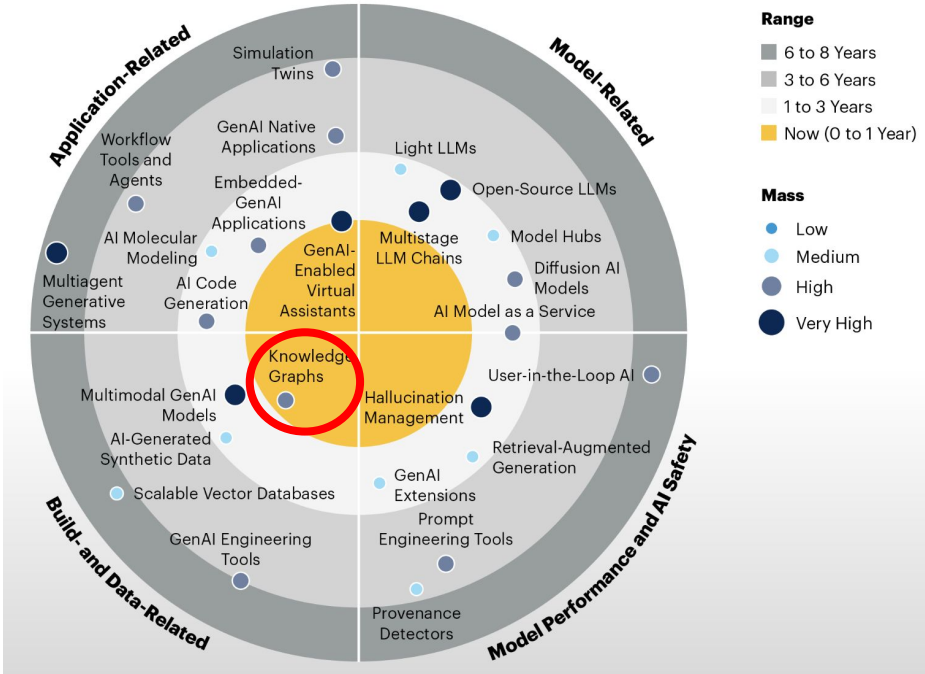
AS THE WORLD NOW SEEMS TO BE LEARNING

Building the Prototype Open Knowledge Network (Proto-OKN)

National Science Foundation



Chief Data Officers (CDOs) across DHS offices and Components play a critical role in supporting the overall technical infrastructure for AI systems, which relies on high-quality, well-structured data, for reliable and efficient performance. CDOs drive data management across the Department, focusing on model training, data ontology, and privacy as the Department develops AI algorithms. CDOs also ensure precision and responsiveness in outputs, thus enhancing the overall effectiveness of AI applications.



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HISTORY DOES NOT REPEAT BUT IT OFTEN RHYMES

How to Build a Knowledge Graph from Scratch Even If You're Not a Full-Blown Developer

Wolfgang Hoeck, Founder, Live Data Concepts

May 26, 2021 · 10 mins read

Building a knowledge graph sounds tricky enough – but doing so from scratch without any source code sounds like a mission impossible. That's exactly what I did even though I am not a full-blown developer and don't write code as my job on a daily basis, which means that you can do it too.

just another information silo

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Knowledge Representation is Easy!

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- This myth exhibits a **grain of truth** and **distortion of fact**
- Constructing an ontology can be easy...just write some python to read a file and generate classes/relations from column headers
- Constructing an ontology **according to a standard** is more challenging
- But *that* is **how we avoid information silos**

Information Silos

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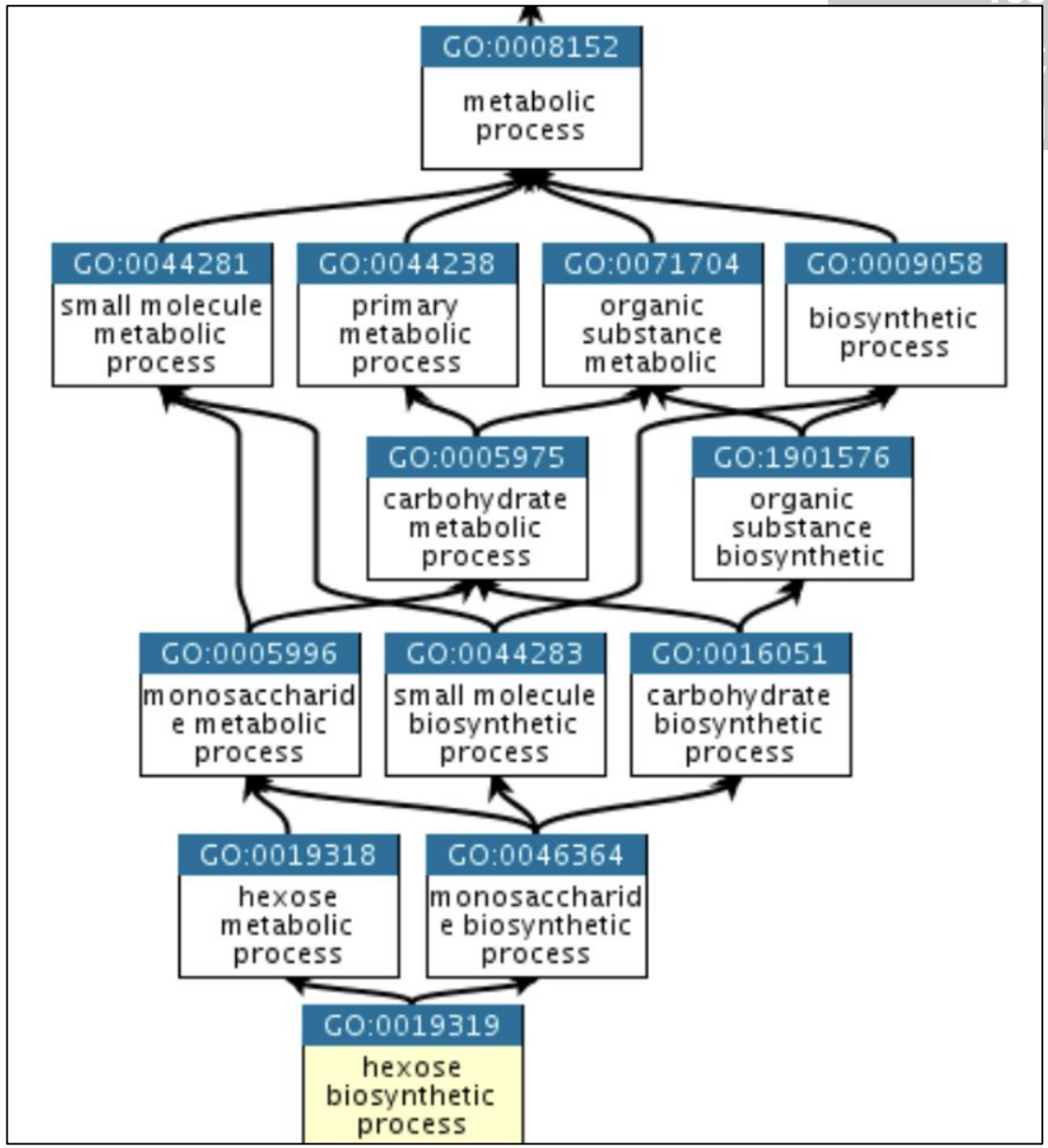
THIS HAS HAPPENED BEFORE

Gene Ontology - 1998

GENEONTOLOGY
Unifying Biology

The mission of the GO Consortium is to develop a comprehensive, **computational model of biological systems**, ranging from the molecular to the organism level, across the multiplicity of species in the tree of life.



Proliferation of Ontologies

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- When developed correctly, ontologies provide **common vocabularies** with **common semantics** across **multiple domains**

- The success of the Gene Ontology led to a proliferation of ontologies developed by subject-matter experts, computer scientists, and logicians

Proliferation of Ontologies

- When developed correctly, ontologies provide **common vocabularies** with **common semantics** across **multiple domains**

- The success of the Gene Ontology led to a proliferation of ontologies developed by subject-matter experts, computer scientists, and logicians

- Almost **none** of which were developed in coordination

- The result was **massive incompatibility** of terms and relations, confusion, in-fighting, name-calling, etc.

Information Silos

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THE SOLUTION BEFORE IS THE SAME SOLUTION NOW

Open Biological and Biomedical Ontologies

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- In 2005, a consortium of biologists decided to create standards for ontology development

- Such as requiring ontologies be open-source, have documentation, include definitions for vocabulary terms **and…**

- **Align to a top-level ontology…**

Overview
Open (principle 1)
Common Format (principle 2)
URI/Identifier Space (principle 3)
Versioning (principle 4)
Scope (principle 5)
Textual Definitions (principle 6)
Relations (principle 7)
Documentation (principle 8)
Documented Plurality of Users (principle 9)
Commitment To Collaboration (principle 10)
Locus of Authority (principle 11)
Naming Conventions (principle 12)
Notification of Changes (principle 13)
Maintenance (principle 16)
Responsiveness (principle 20)

Interoperability Guardrails

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- Shared governance provides **guardrails for promoting alignment between ontologies representing nearby and overlapping domains**

- By following the recipe, progress towards interoperability is ensured upfront, since elements inherited from the hub ontologies **overlap semantically**

- By **not** following such a strategy you get...**information silos**...

Information Silos

An *information silo* is an information repository, e.g. management system, database, the content of which cannot be integrated with that of other information repositories using standard computing strategies

IF WE ALLOW THE CREATION OF ONTOLOGIES WITHOUT SHARED SEMANTICS, WE UNDERMINE THE GOALS OF SEMANTIC INTEROPERABILITY

A Suggestion...

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- There is a **lot of good work** being done in this community

- I **worry** there is something analogous to the proliferation of ontologies that emerged from the successes of the Gene Ontology

Indeed, a Request

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- There is a **lot of good work** being done in this community
- I **worry** there is something analogous to the proliferation of ontologies that emerged from the successes of the Gene Ontology
- I would like to **request we work towards the creation of an ontology Foundry centered around your efforts** with shared governance principles, a common open-source repository or organization, etc.

Outline

- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem

Methodological Convictions

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REALISM

BFO is designed to represent the world, which includes within its scope concepts about the world

HUB & SPOKE

BFO is a hub from which spoke ontologies extend

Methodological Convictions

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REALISM

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HUB & SPOKE

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Conceptualism

- "An ontology is a specification of a conceptualization" –*Gruber, 1992*
- Interpreted as claiming that ontologies represent **concepts**
- "Taking a more pragmatic view, one can say that ontology is a tool and product of engineering and thereby defined by its use." –*Gruber, 2009*
- Interpreted as claiming ontologies represent **what they need to represent**

Realism

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- Ontologies are a specification of **the world**
- To put my own spin on this, ontologies are specifications of the **fundamental logic of the world**
- As I understand, this characterization encompasses conceptualism
- Rather than argue *a priori* over which is preferable, let us test

Pop Quiz

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- Provide a single definition based on **your own knowledge** for the each of the following terms

Building

Ocean

Alcohol

Realism

- Ontologies are a specification of **the world**

If we attempt to go from the words we use to the world, it is unlikely that we will end up in the same place

If we attempt to go from the world to the words we use, it is more likely we will remain coordinated

Methodological Convictions

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REALISM

BFO is designed to represent the world, rather than simply concepts about the world

HUB & SPOKE

BFO is a hub from which spoke ontologies extend

python™ *Analogy*

- BFO is analogous to the **Python programming language**; extensions of BFO are analogous to **Python libraries**

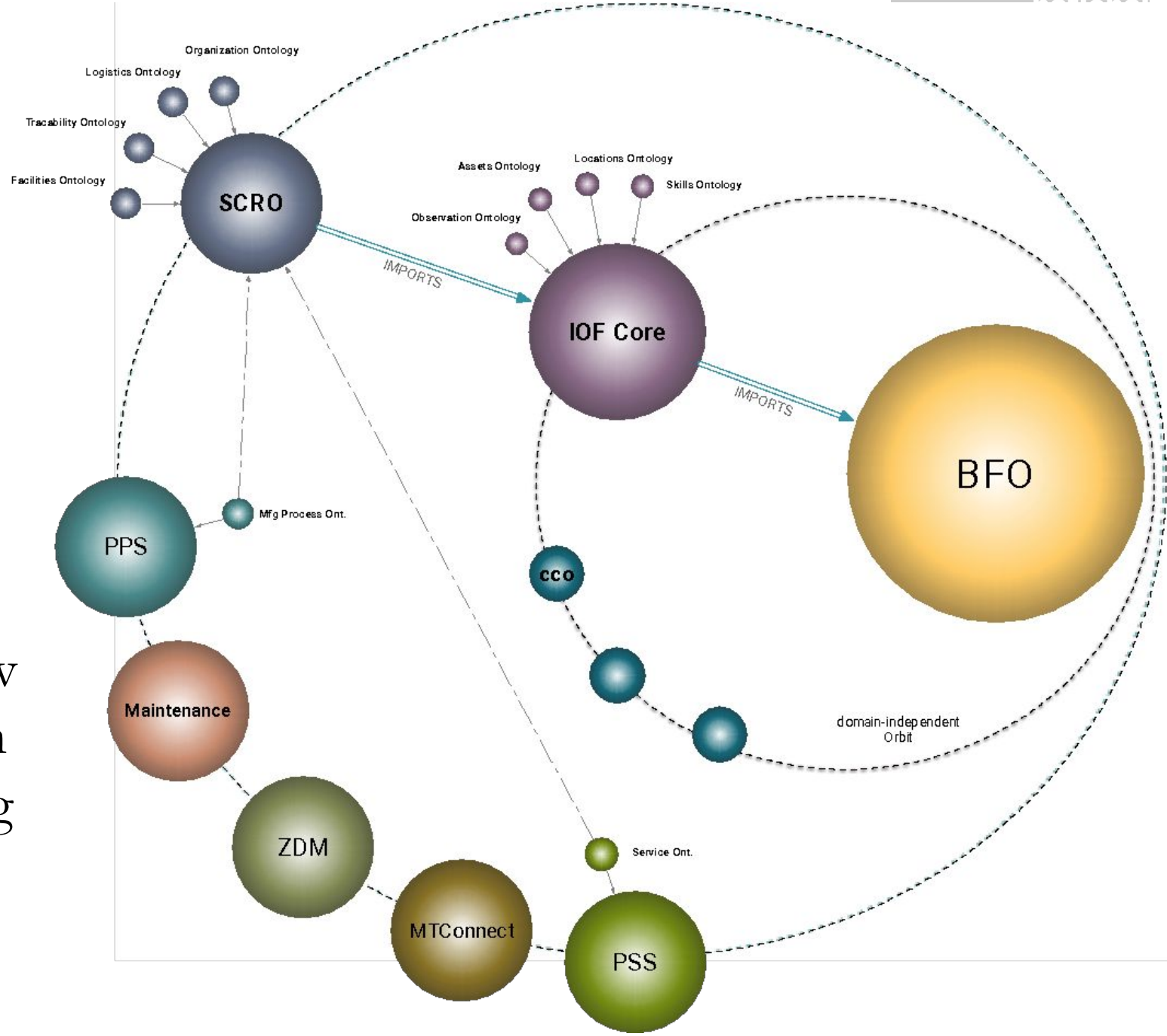
- You **could** create code that allows you to interact with, say, dataframes or you could **instead** start with Python and import a library like Pandas

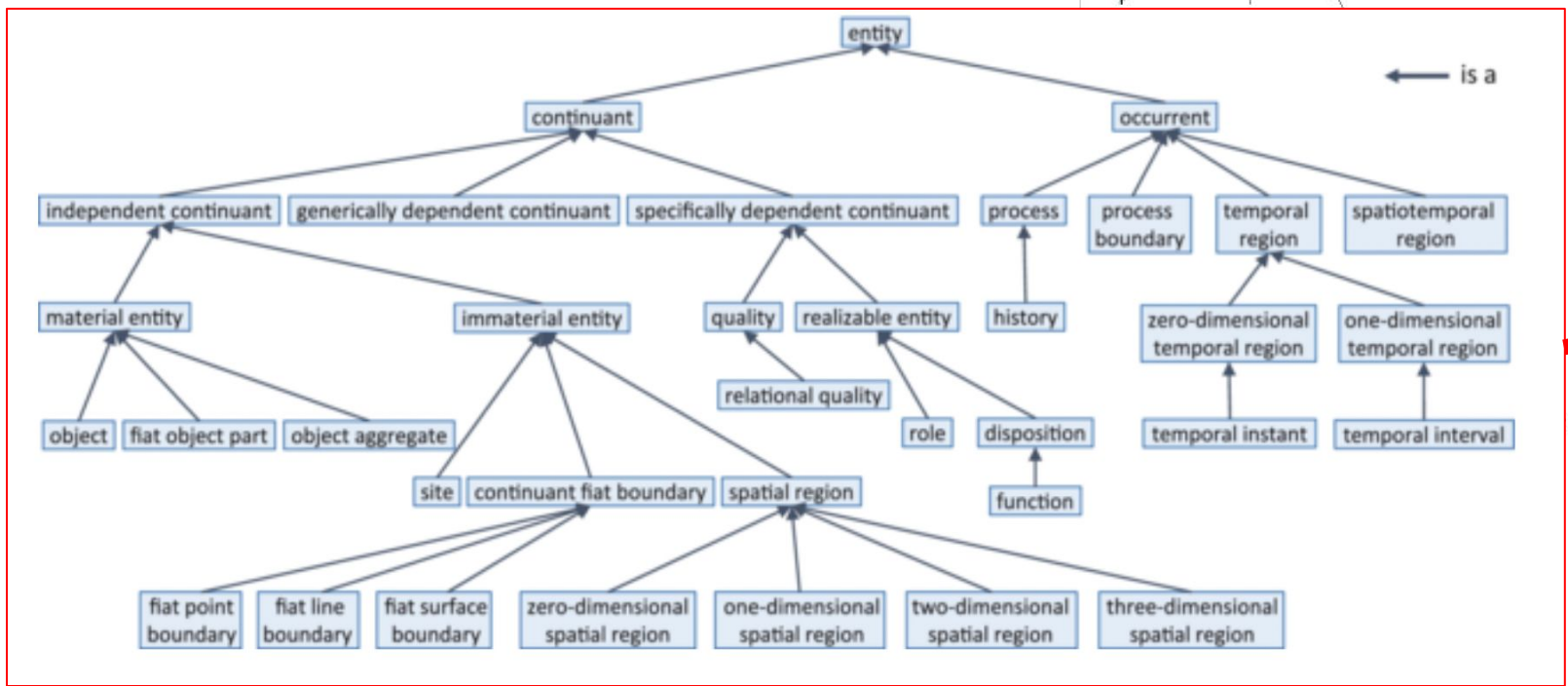
- You **could** create ontology elements that allow you to model artifacts and processes or you **could** instead start with BFO and import an extension

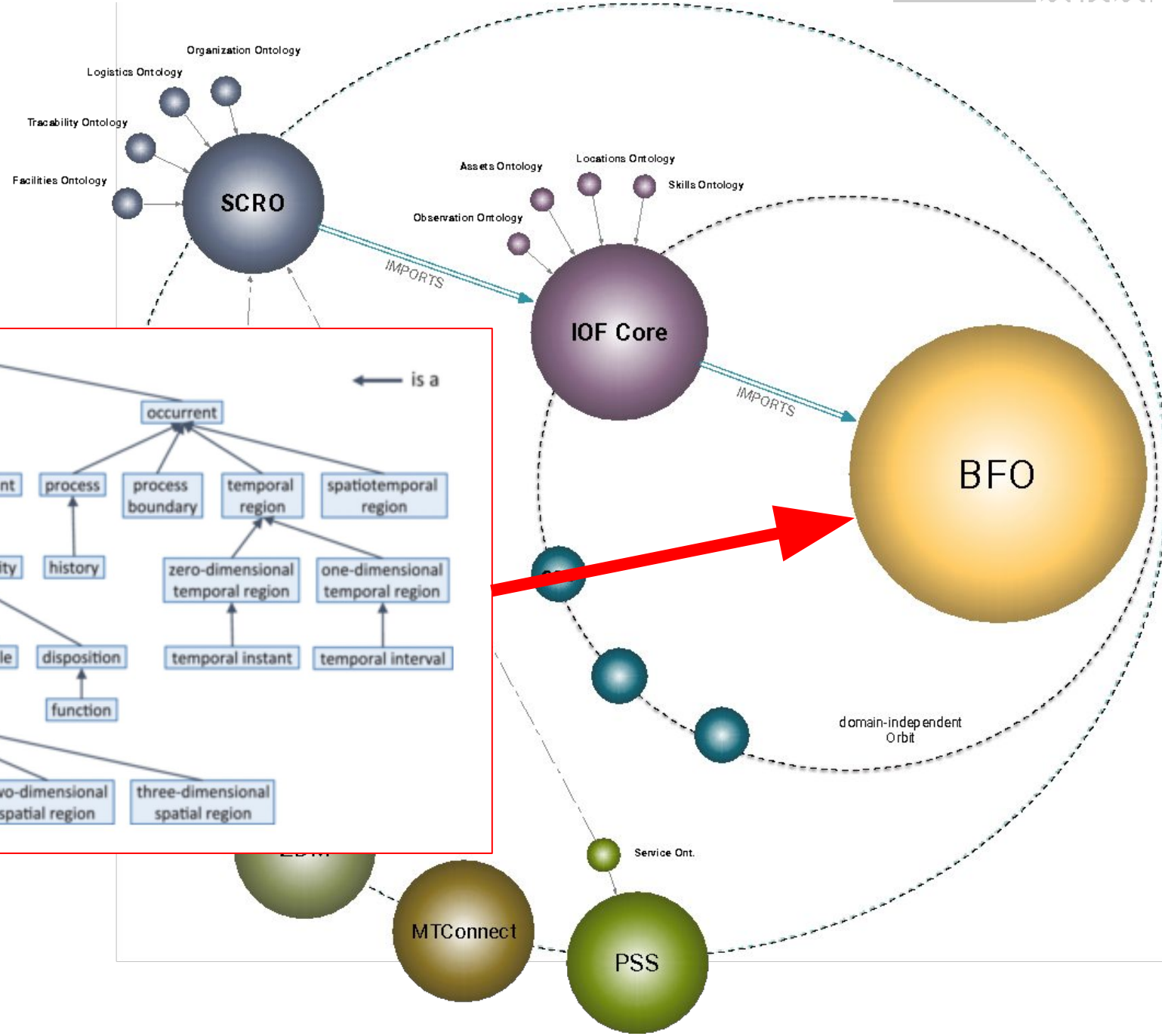
Hub & Spoke

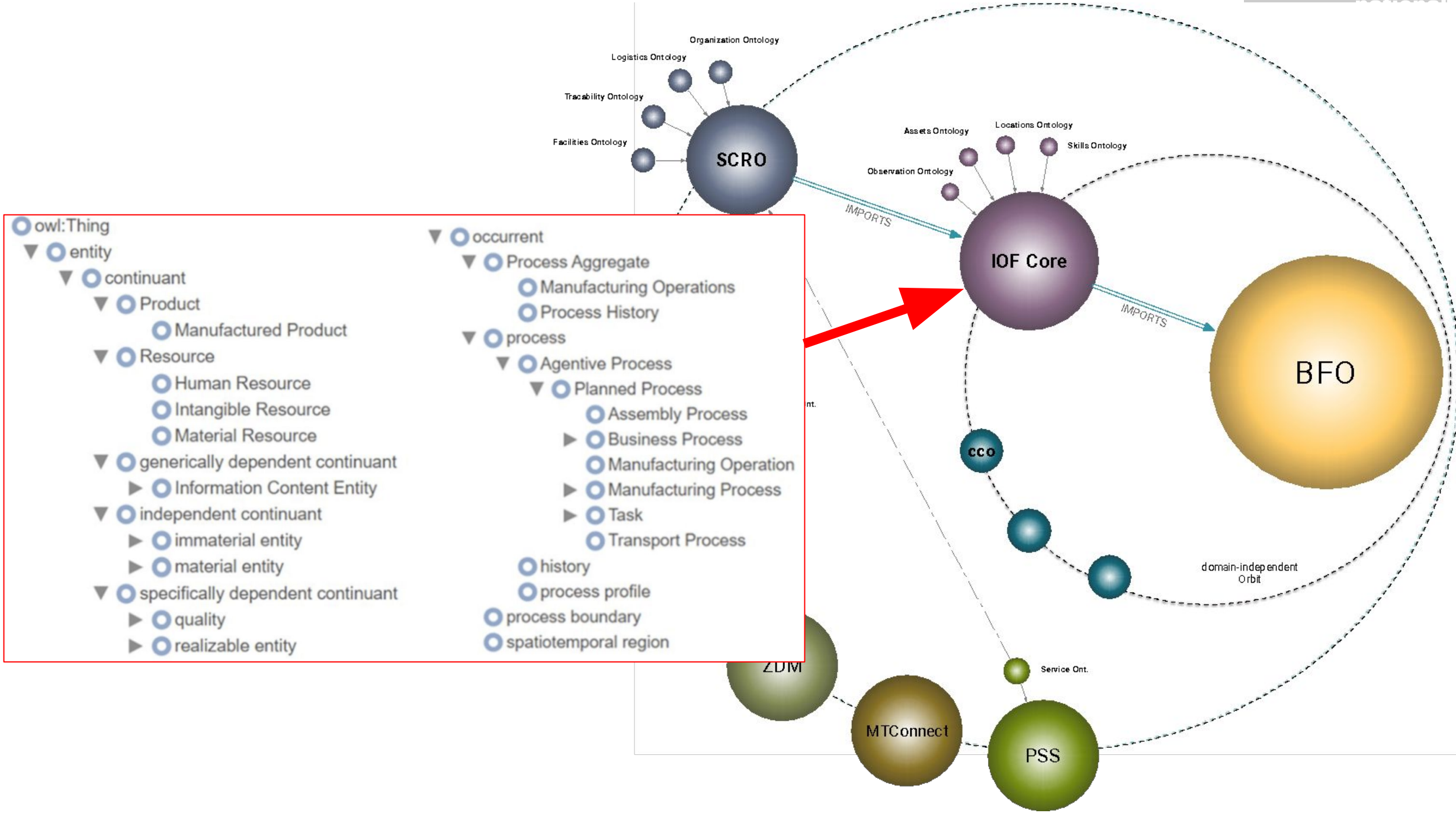
Ontologies extending from BFO are modules in a larger hub & spoke structure

Ontologies are extended by **downward population**, new classes have parent classes in a hierarchy ultimately leading to a BFO class




entity
is a
continuant
occurrent
independent continuant
generically dependent continuant
specifically dependent continuant
process
process boundary
temporal region
spatiotemporal region
material entity
immaterial entity
quality
realizable entity
history
zero-dimensional temporal region
one-dimensional temporal region
relational quality
object
fiat object part
object aggregate
role
disposition
temporal instant
temporal interval
site
continuant fiat boundary
spatial region
function
fiat point boundary
fiat line boundary
fiat surface boundary
zero-dimensional spatial region
one-dimensional spatial region
two-dimensional spatial region
three-dimensional spatial region


Organization Ontology
Logistics Ontology
Tracability Ontology
Facilities Ontology
SCRO
IMPORTS
Assets Ontology
Locations Ontology
Skills Ontology
Observation Ontology
IOF Core
IMPORTS
BFO
domain-independent
Orbit
Service Ont.
MTConnect
PSS


owl:Thing
entity
continuant
Product
Manufactured Product
Resource
Human Resource
Intangible Resource
Material Resource
generically dependent continuant
Information Content Entity
independent continuant
immaterial entity
material entity
specifically dependent continuant
quality
realizable entity
occurrent
Process Aggregate
Manufacturing Operations
Process History
process
Agentive Process
Planned Process
Assembly Process
Business Process
Manufacturing Operation
Manufacturing Process
Task
Transport Process
history
process profile
process boundary
spatiotemporal region
Organization Ontology
Logistics Ontology
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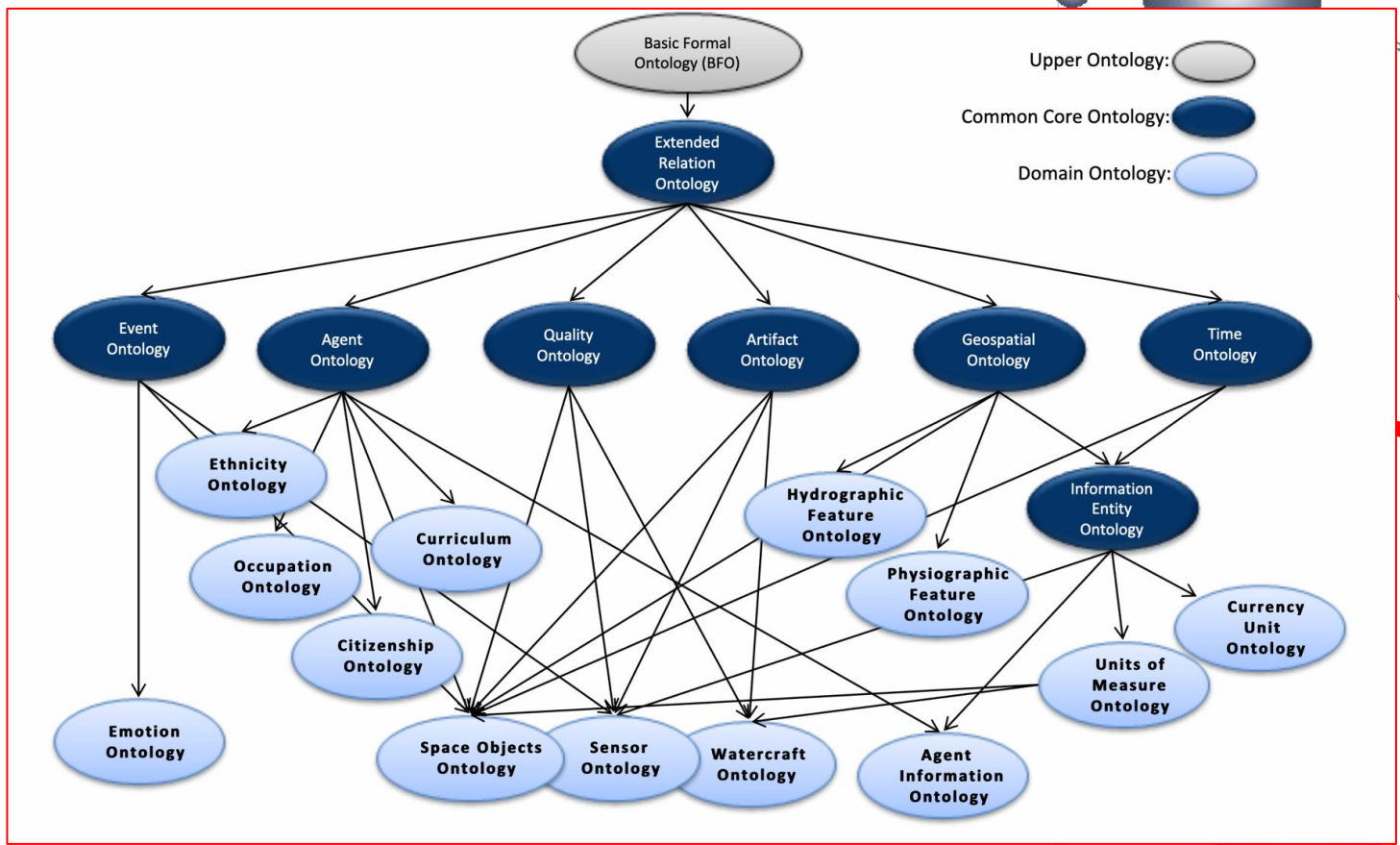
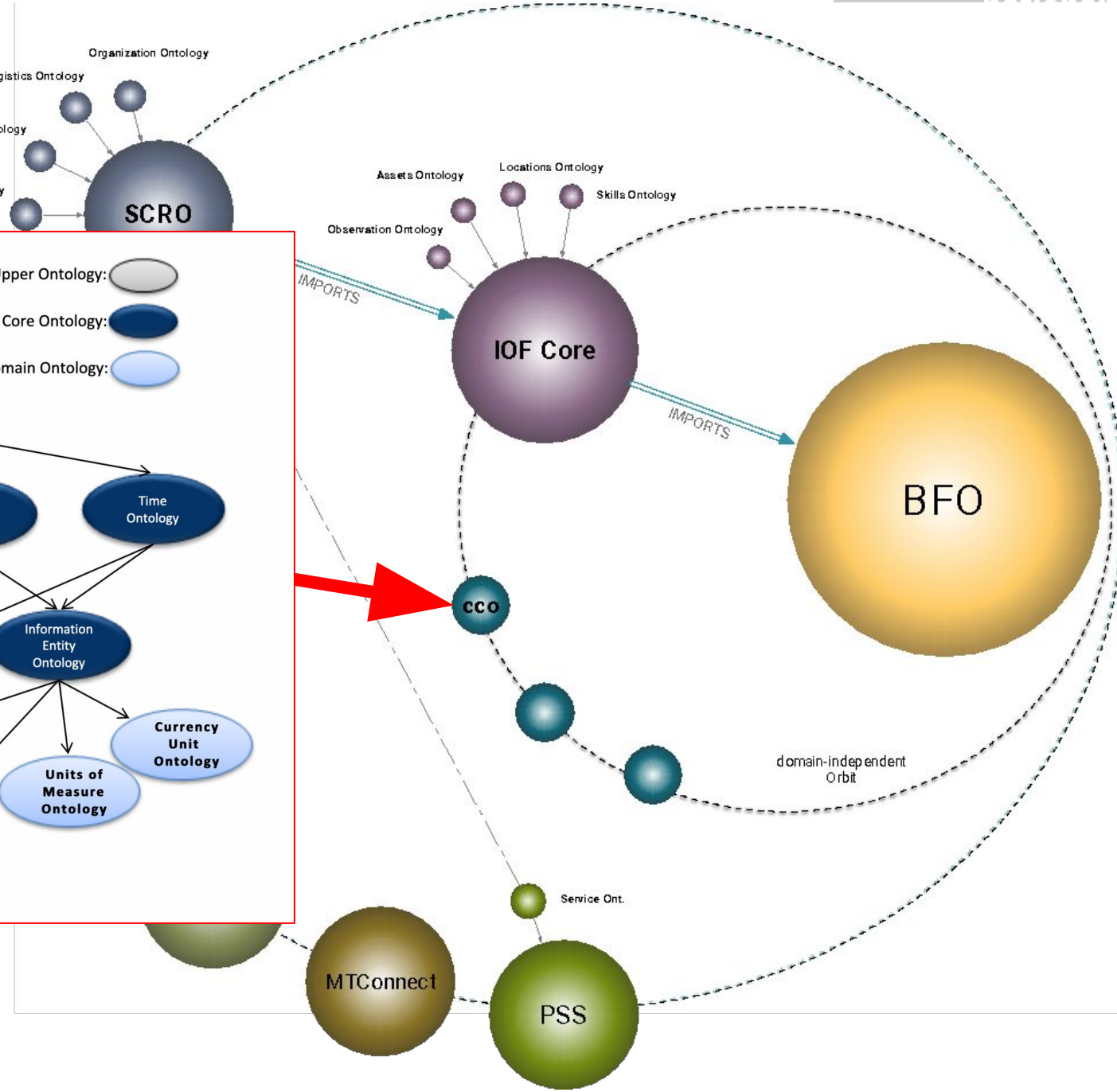

Basic Formal Ontology (BFO)
Upper Ontology:
Common Core Ontology:
Domain Ontology:
Extended Relation Ontology
Event Ontology
Agent Ontology
Quality Ontology
Artifact Ontology
Geospatial Ontology
Time Ontology
Ethnicity Ontology
Occupation Ontology
Curriculum Ontology
Citizenship Ontology
Hydrographic Feature Ontology
Physiographic Feature Ontology
Information Entity Ontology
Currency Unit Ontology
Units of Measure Ontology
Emotion Ontology
Space Objects Ontology
Sensor Ontology
Watercraft Ontology
Agent Information Ontology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- Ontology Engineering
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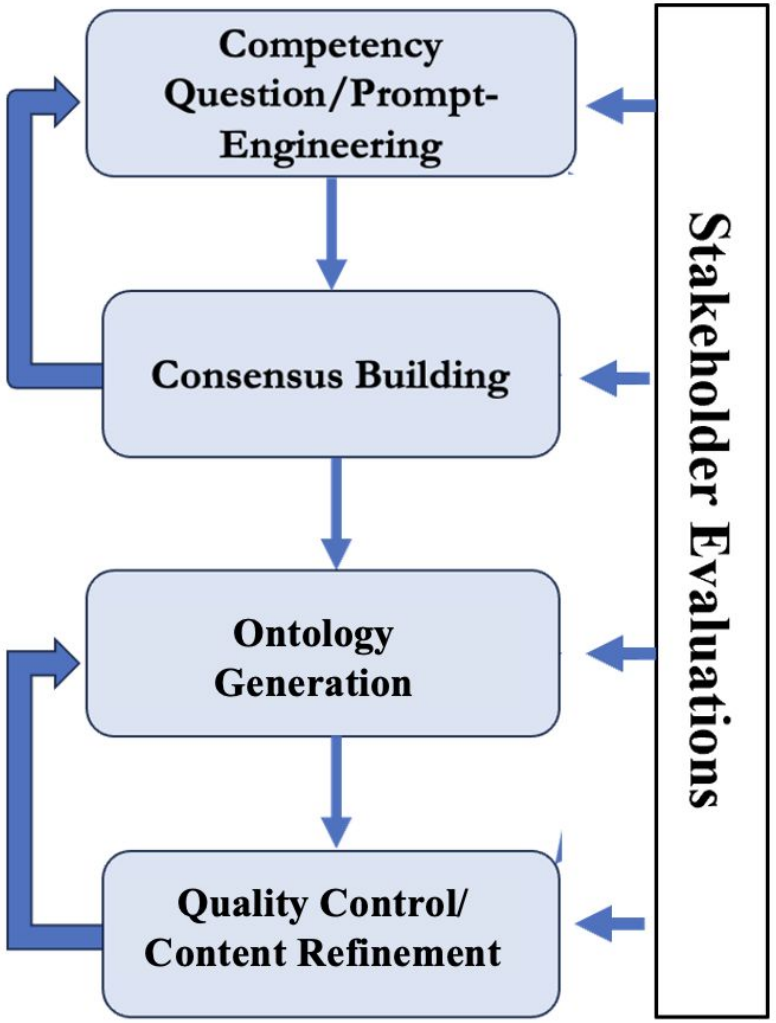
  - Application
  - Workflow
  - Collaboration
  - R&D
  - Education

Competency Question

- Ontologists rely on domain experts when modeling, using **competency questions**
- Competency questions allow us to check our understanding of stakeholder requirements...
- And when written in SPARQL or SHACL can automate validation of such requirements



Consensus-Building

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- Competency questions are **used to guide ontology development** and **generate automated checks** to ensure answers are sufficient

- They also provide **documentation** so users can easily grasp the scope of your ontology, which promotes **reuse**

1. *What articles found statistically significant relationships between loneliness and interiority in older adults?*
2. *What are the top 5 institutions associated with solitude research?*
3. *What are the primary results of refereed gerotranscendence articles published by non-experts between 2015 and 2023?*

Consensus-Building

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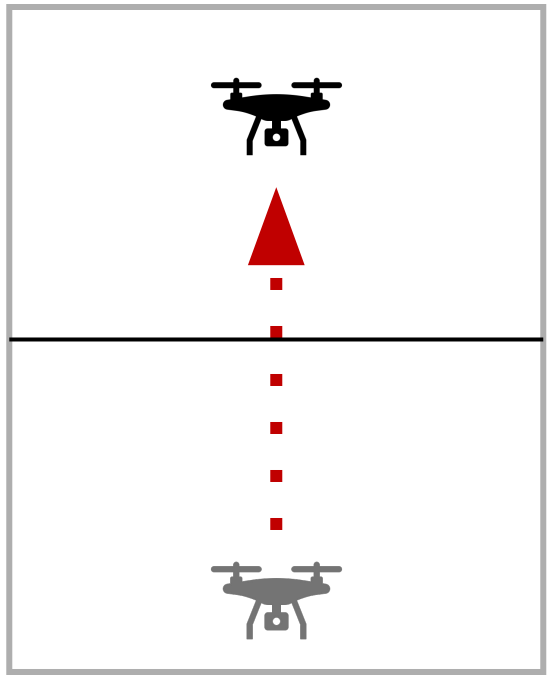
- Consensus-building exercises are where ontologists and domain experts work towards an agreed understanding of ontology terms, definitions, etc.

- Importantly, whatever agreement is reached is **meant to be added to the ontology**; domain experts can **continue speaking as they need**

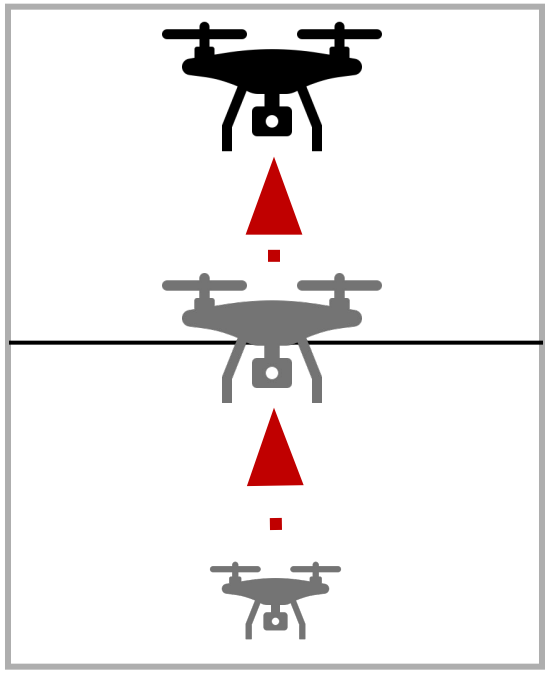
3.1.2 Consensus-Building Exercises

We understand ontology development as requiring **consensus-building** among stakeholders[70] and our team has an established record of reaching such consensus, e.g. coordinating coronavirus terms across distinct ontology communities and subject-matter experts.[50] Accordingly, **we will hold regular meetings for consensus-building exercises, aimed at generating agreement over the appropriateness of ontology terms, definitions, appropriateness, relationships to nearby terms, etc.** For example, if 80% or more stakeholders agree on the relevance/definition/etc. of a term, then the term exhibits *strong* agreement. If a term exhibits 50% agreement or less, then it exhibits *weak* agreement. Terms in between exhibit *moderate* agreement. Meetings will begin by reminding participants of items on which we strongly agree. Items for which there is weak agreement will then be discussed. At the halfway mark of the meeting, attention will turn to the list of moderate items. After each meeting, stakeholders will be given a 3-point Likert Scale vote reflecting levels of agreement for each term discussed in the meeting. If a term exhibits *strong* agreement over three consecutive votes, then it will be included into the ontology or final CQ list and not be voted on again unless a strong case is made for doing so. Importantly, our goal is not that all stakeholders must agree on all CQs and key content, but that we reach some agreement as to what CQs and key content to include, how it is defined, labeled, and related to other content.

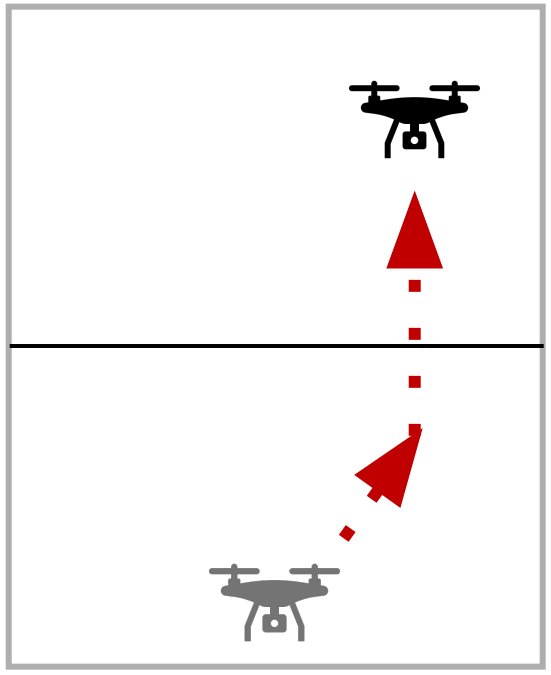
Competency Question



Flat, Linear Path



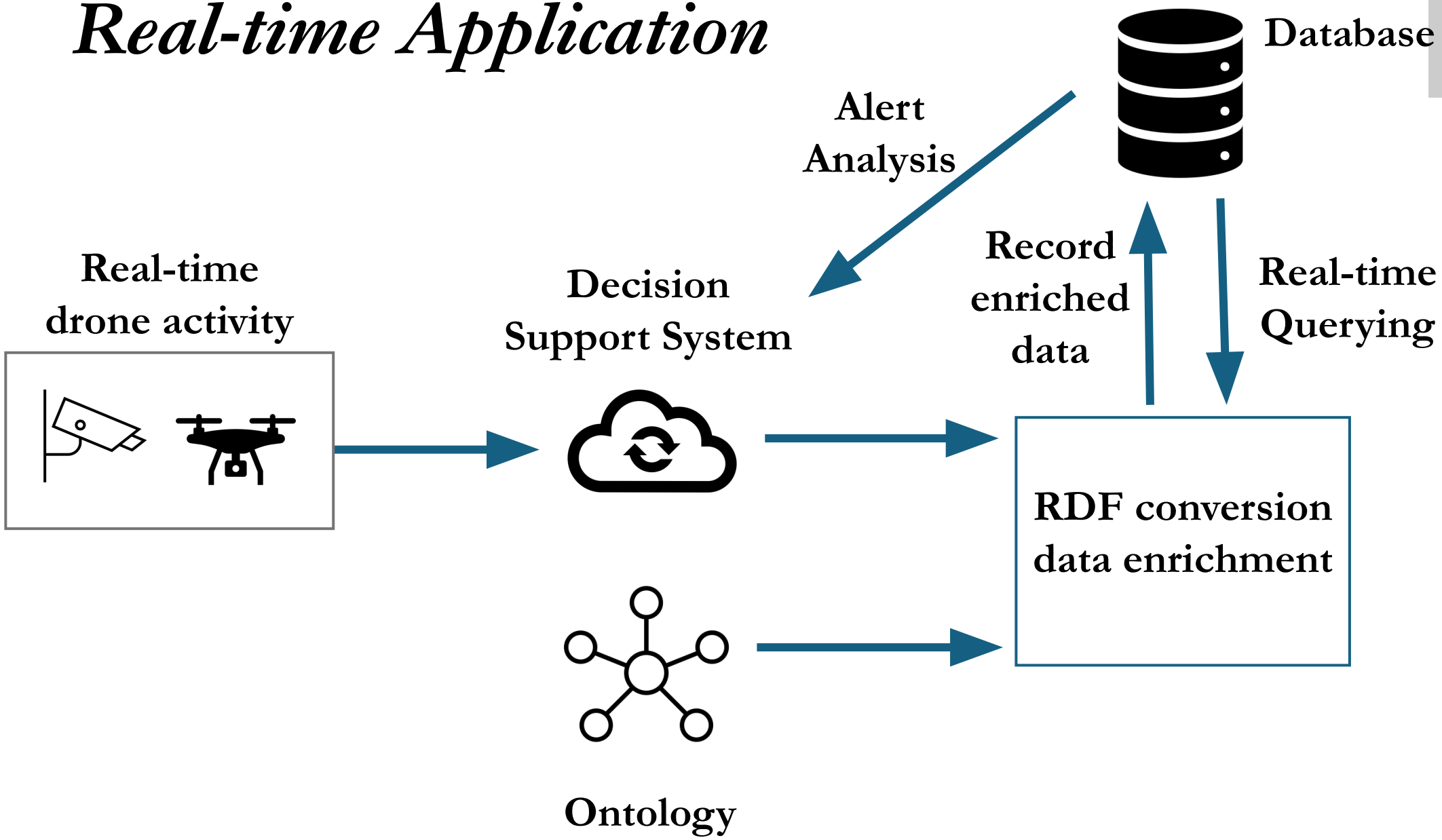
Climbing Linear Path



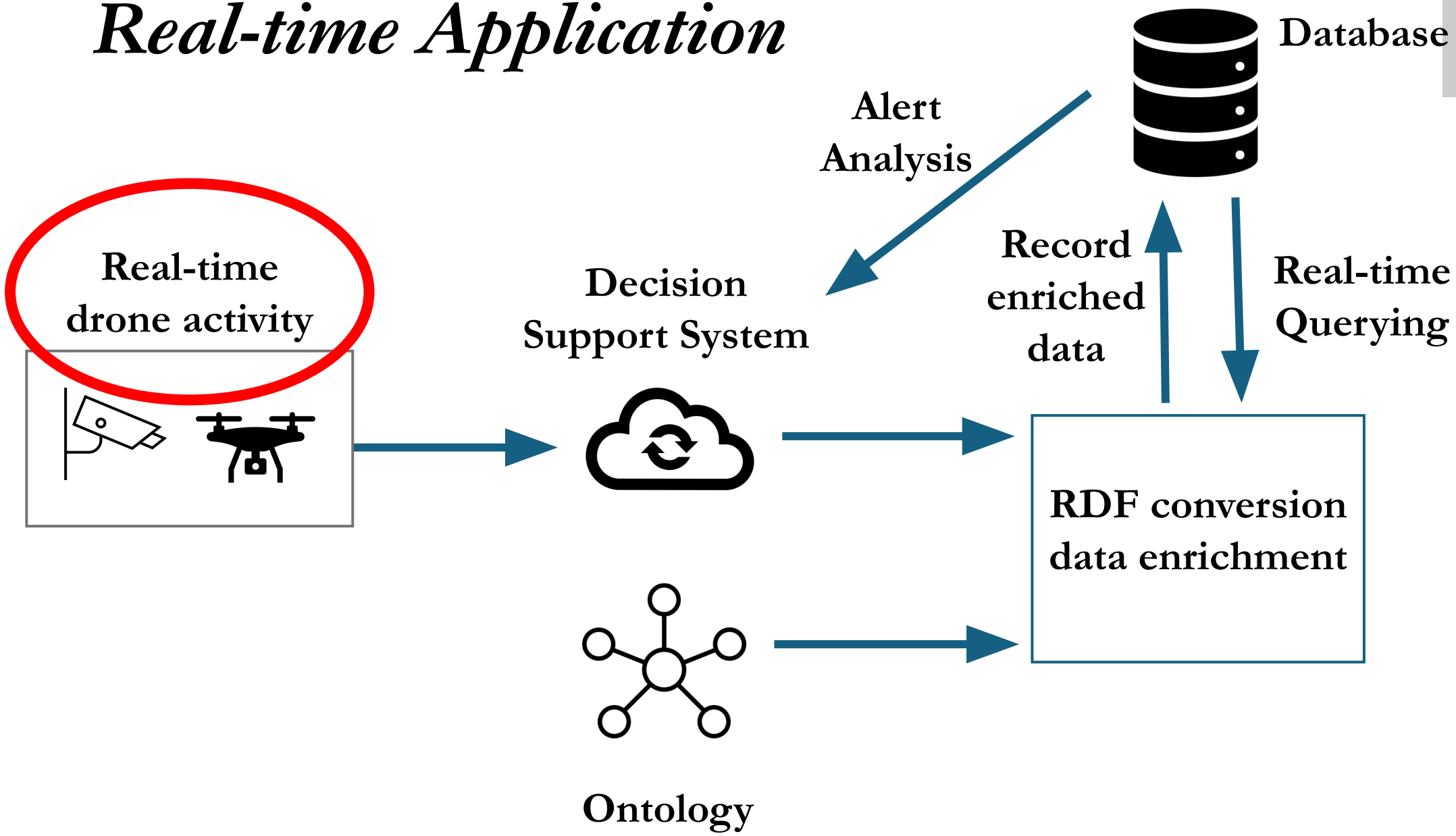
Flat Non-Linear Path

Has a drone cross the US-MZ border?

Real-time Application



Real-time Application



Sensor Data

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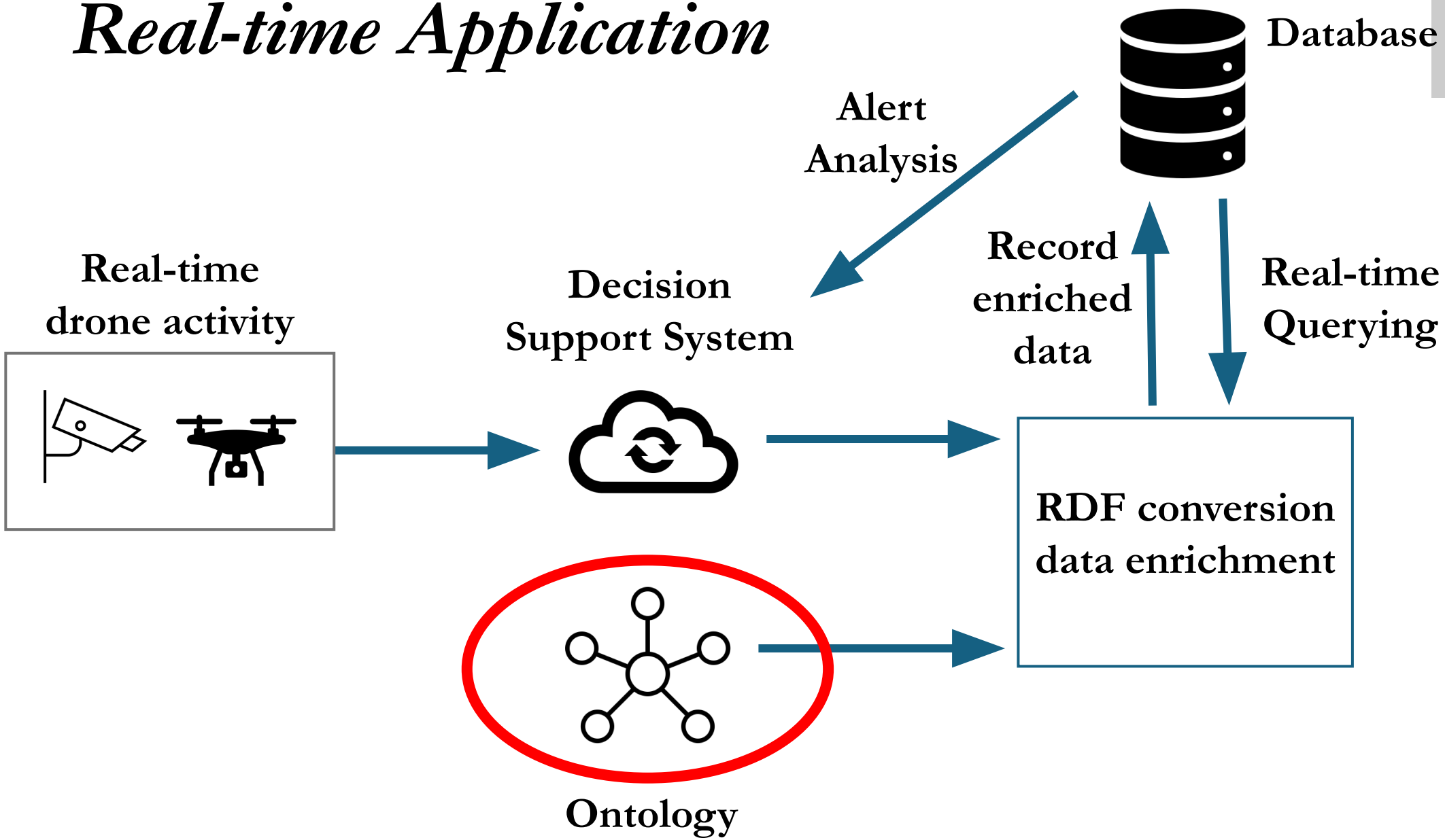
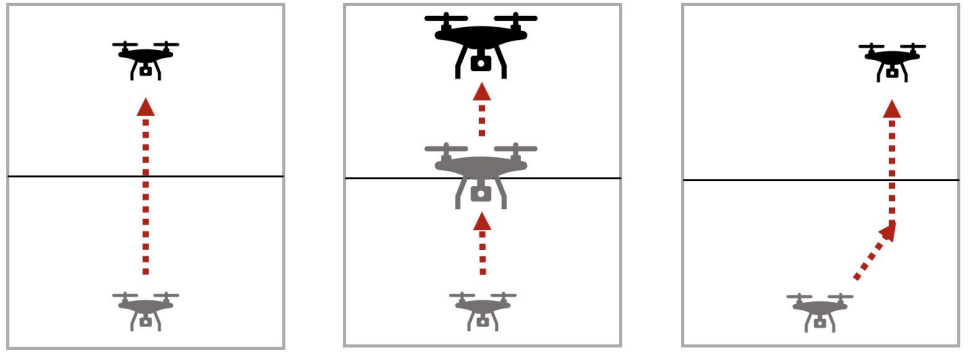
- Sample sensor data tracking an object at the AZ-MX border, formatted in XML:

```
<?xml version='1.0' encoding='UTF-8' standalone='yes'?>
<event version='2.0' uid='ANDROID-R52M909NL2E'  type='a-f-G-U-C'
   time='2021-04-14T23:41:59.244Z'  start='2021-04-14T23:41:59.244Z'
   stale='2021-04-14T23:43:14.244Z'  how='m-g'>
<point  lat='31.395719' lon='-110.923161'  hae='1357.091409609813' ce='3.2'/>
<detail><takv os='29' version='4.2.1.12 (1c3920a8).1616092734-CIV'
              device='SAMSUNG SM-T888' platform='ATAK-CIV'/>
          <contact endpoint='192.168.0.87:4242:tcp' callsign='WT14'/>
          <uid Droid='WT14'/>
          <precisionlocation altsrc='GPS' geopointsrc='GPS'/>
          <status battery='100'/>
          <track course='33.08718206324072' speed='5.0'/></detail></event>
```

Real-time Application



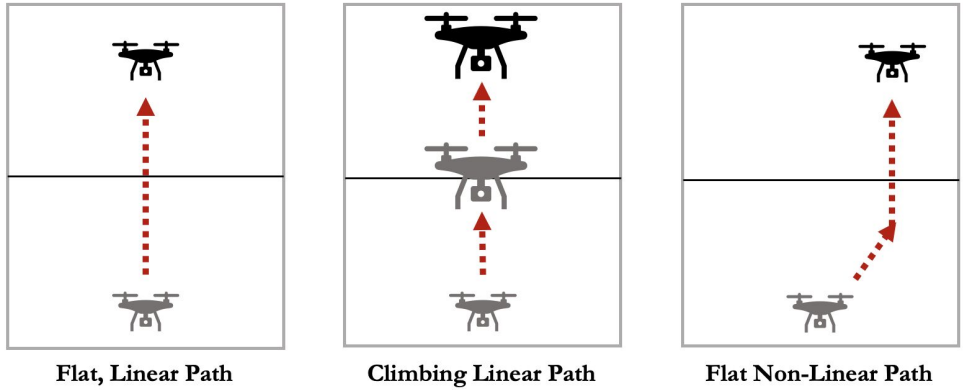
Ontology Design



Addressing the competency question requires ontologically representing sensor data relevant to the question

Has a drone cross the US-MZ border?

Pop Quiz



Addressing the competency question requires ontologically representing sensor data relevant to the question

Has a drone cross the US-MZ border?

What entities must be described in order to answer this question?

Ontology Design

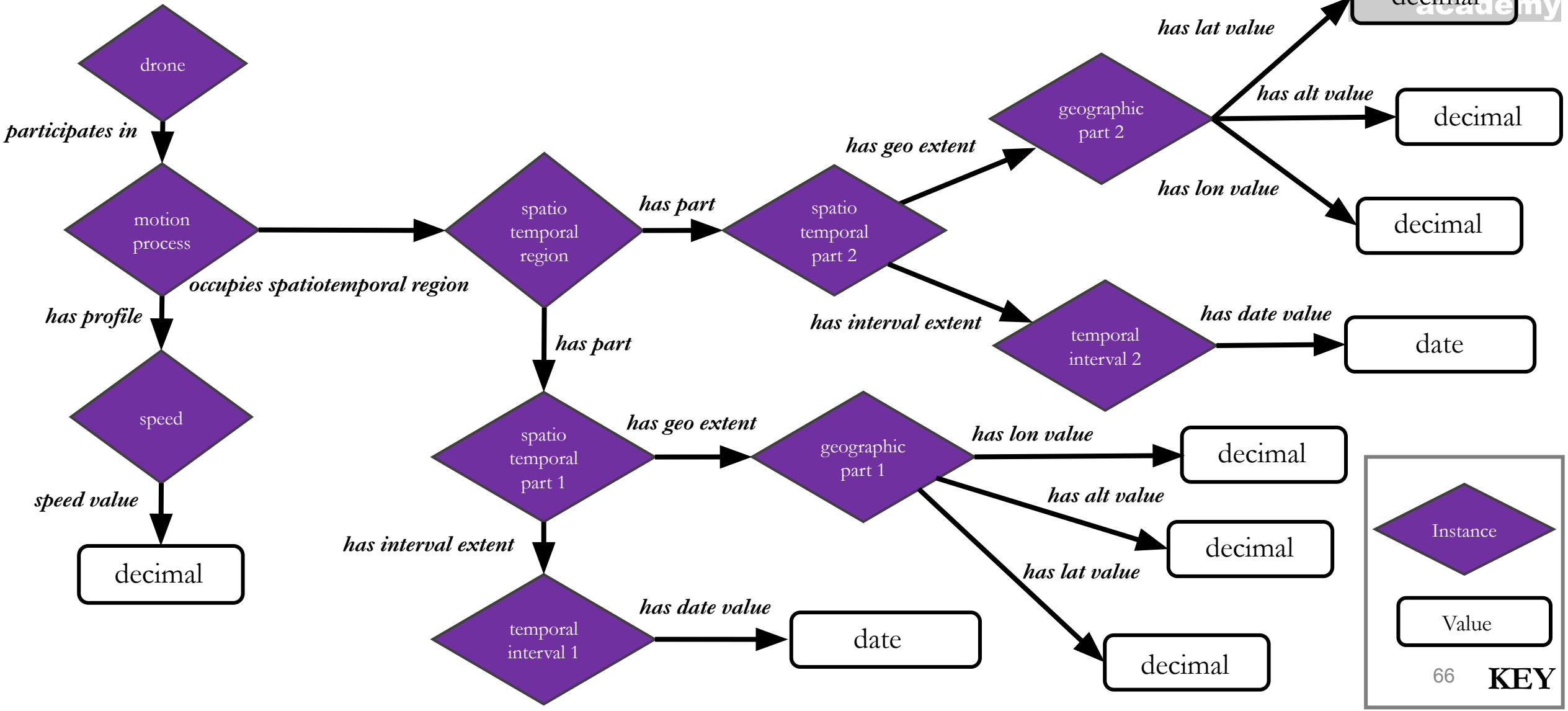
- Addressing the competency question requires ontologically representing sensor data relevant to the question

- For our example, we will need representations of:

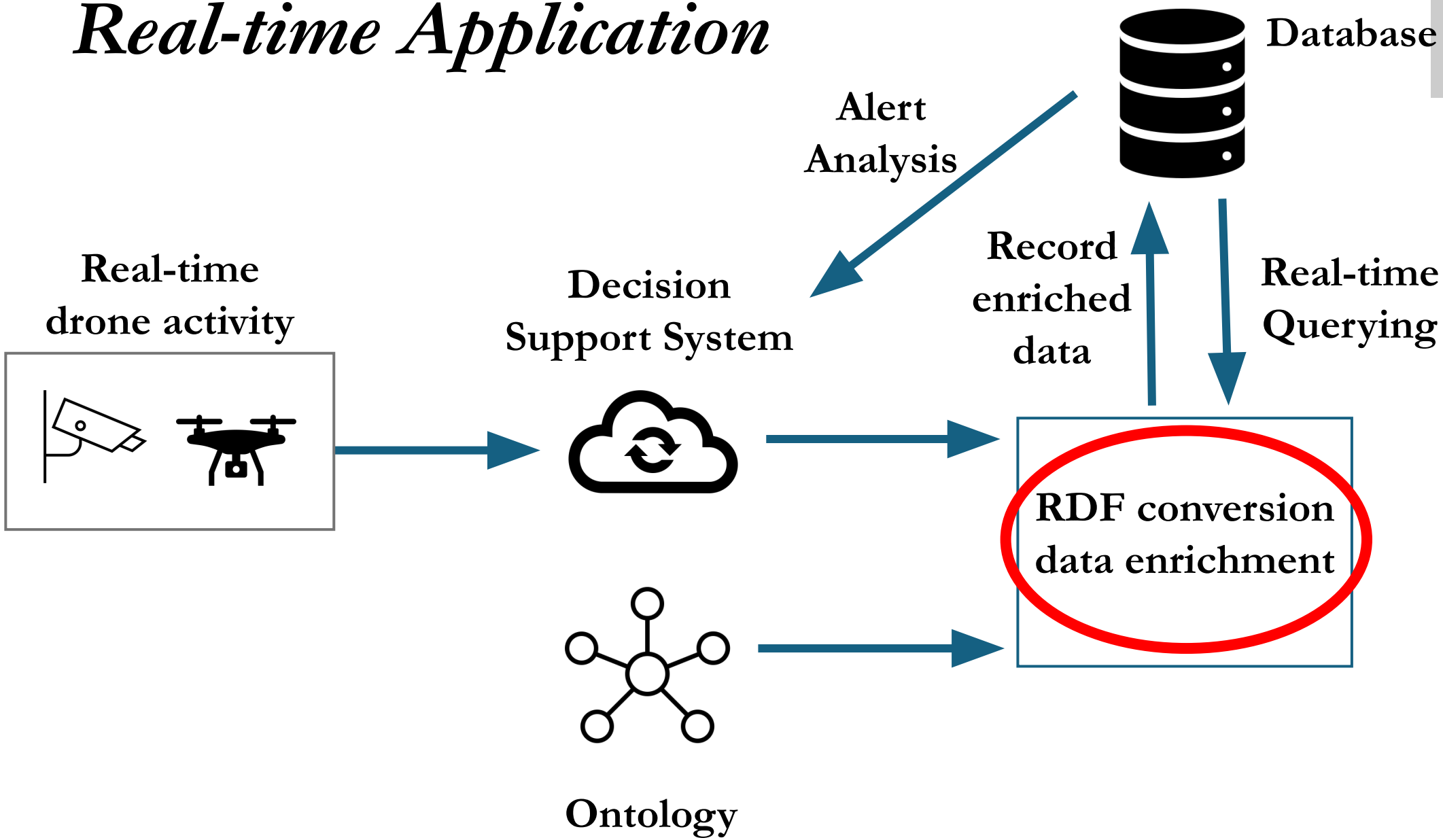
border/boundary	latitude
geographic region	altitude
drone	longitude
speed	time

*Classes not diagramed due to space constraints

Representing Drone Motion



Real-time Application



RDFLib Conversion Script

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- Sensor data can be converted to RDF to automatically update ontologies

```
<?xml version='1.0' encoding='UTF-8' standalone='yes'?>
<event version='2.0' uid='ANDROID-R52M909NL2E' type='a-f-G-U-C'
  time='2021-04-14T23:41:59.244Z' start='2021-04-14T23:41:59.244Z'
  stale='2021-04-14T23:43:14.244Z' how='m-g'>
<point lat='31.395719' lon='-110.923161' hae='1357.091409609813' ce='3.2'/>
<detail><takv os='29' version='4.2.1.12 (1c3920a8).1616092734-CIV'
          device='SAMSUNG SM-T888' platform='ATAK-CIV'/>
        <contact endpoint='192.168.0.87:4242:tcp' callsign='WT14'/>
        <uid Droid='WT14'/>
        <precisionlocation altsrc='GPS' geopointsrc='GPS'/>
        <status battery='100'/>
        <track course='33.08718206324072' speed='5.0'/></detail></event>
```

```
<NamedIndividual rdf:about="http://example.com/DEMO_0001421">
    <rdf:type rdf:resource="https://example.com/DEMO/GeographicRegion"/>
    <cco:has_latitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">110.123</cco:has_latitude_value>
    <cco:has_longitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">38.9</cco:has_longitude_value>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">geographic_point_1</rdfs:label>
</NamedIndividual>

<NamedIndividual rdf:about="http://example.com/DEMO_0001422">
    <rdf:type rdf:resource="https://example.com/DEMO/GeographicRegion"/>
    <cco:has_latitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">113.88</cco:has_latitude_value>
    <cco:has_longitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">38.7</cco:has_longitude_value>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">geographic_point_2</rdfs:label>
</NamedIndividual>

<NamedIndividual rdf:about="http://example.com/DEMO_0001423">
    <rdf:type rdf:resource="http://purl.obolibrary.org/obo/BFO_0000015"/>
    <ns1:DEMO_0001430 rdf:resource="http://example.com/DEMO_0001429"/>
    <ns1:DEMO_0001435 rdf:resource="http://example.com/DEMO_0001436"/>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">motion_process</rdfs:label>
</NamedIndividual>

<NamedIndividual rdf:about="http://example.com/DEMO_0001425">
    <rdf:type rdf:resource="http://purl.obolibrary.org/obo/BFO_0000008"/>
    <cco:interval_is_before rdf:resource="http://example.com/DEMO_0001426"/>
    <cco:has_datetime_value rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2022-10-26T21:32:52</cco:has_datetime_value>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">temporal_interval_1</rdfs:label>
</NamedIndividual>
```

sensor data input **rdflib script** **rdf output**

```
import csv
from rdflib import Graph, URIRef, Literal, Namespace, RDF, RDFS, OWL, XSD
import urllib.parse
from csv import DictReader
import uuid
import hashlib
import pandas as pd
```

Prior to ingest, the xml sensor data can be converted to a csv format using any of many publicly available xml to csv conversion tools

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Classes, instances, and relations from existing ontologies, such as BFO, have IRIs that can be reused during ontology development. The creation of new terms, however, requires creating new unique IRIs for each. For example, a new drone identified by a sensor will be represented by a new unique IRI, a new flight path of a drone will be represented with a new unique IRI, etc.

```
#loop through instances to create unique IRIs for every instance in the csv file
if __name__ == "__main__":
    for i in resource_index:
        seed = "index-" + str(i)
        m = hashlib.md5()
        m.update(seed.encode('utf-8'))
        guid = uuid.UUID(m.hexdigest(), version=5)
        iri_list.append('https://example.com/' + str(guid))
```

Unique IRIs can be automatically generated to align with desired format requirements, e.g. prepended by "https://example.com/"

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```
90  for row in df:
91      row = dict(row)
92
93      resource_iri = URIRef(row['IRI'])
94      uid = Literal((row['uid']))
95      latitude_value = Literal(row['lat'], datatype=XSD.decimal)
96      longitude_value = Literal(row['lon'], datatype=XSD.decimal)
97      altitude_value = Literal(row['hae'], datatype=XSD.decimal)
98      start_time = Literal(row['start'])
99      end_time = Literal(row['stale'])
```

Variables corresponding to the sensor data xml tags can be defined

And given numerical types such as decimal or date time

```
<?xml version='1.0' encoding='UTF-8' standalone='yes'?>
<event version='2.0' uid='ANDROID-R52M90...2E' type='a-f-G-U-C'
  time='2021-04-14T23:41:...244Z' start='2021-04-14T23:41:59.244Z'
  stale='2021-04-14T23:43:...244Z' how='m-g'>
<point lat='31.395719' lon='-110.923161' hae='1357.091409609813' ce='3.2'/>
<detail><takv os='29' version='4.2.1.12 (1c3920a8).1616092734-CIV'
          device='SAMSUNG SM-T888' platform='ATAK-CIV'/>
        <contact endpoint='192.168.0.87:4242:tcp' callsign='WT14'/>
        <uid Droid='WT14'/>
        <precisionlocation altsrc='GPS' geopointsrc='GPS'/>
        <status battery='100'/>
        <track course='33.08718206324072' speed='5.0'/></detail></event>
```

```
g.add((resource_iri, URIRef('http://example.com/DEMO_0001416'), uid))
g.add((resource_iri, RDF.type, OWL.NamedIndividual))
g.add((resource_iri, RDF.type, DEMO.Aircraft))
g.add((resource_iri, BFO['participates in'], motion_process_iri))
```

The RDF conversion script reads column headers from the csv file to populate ontology types

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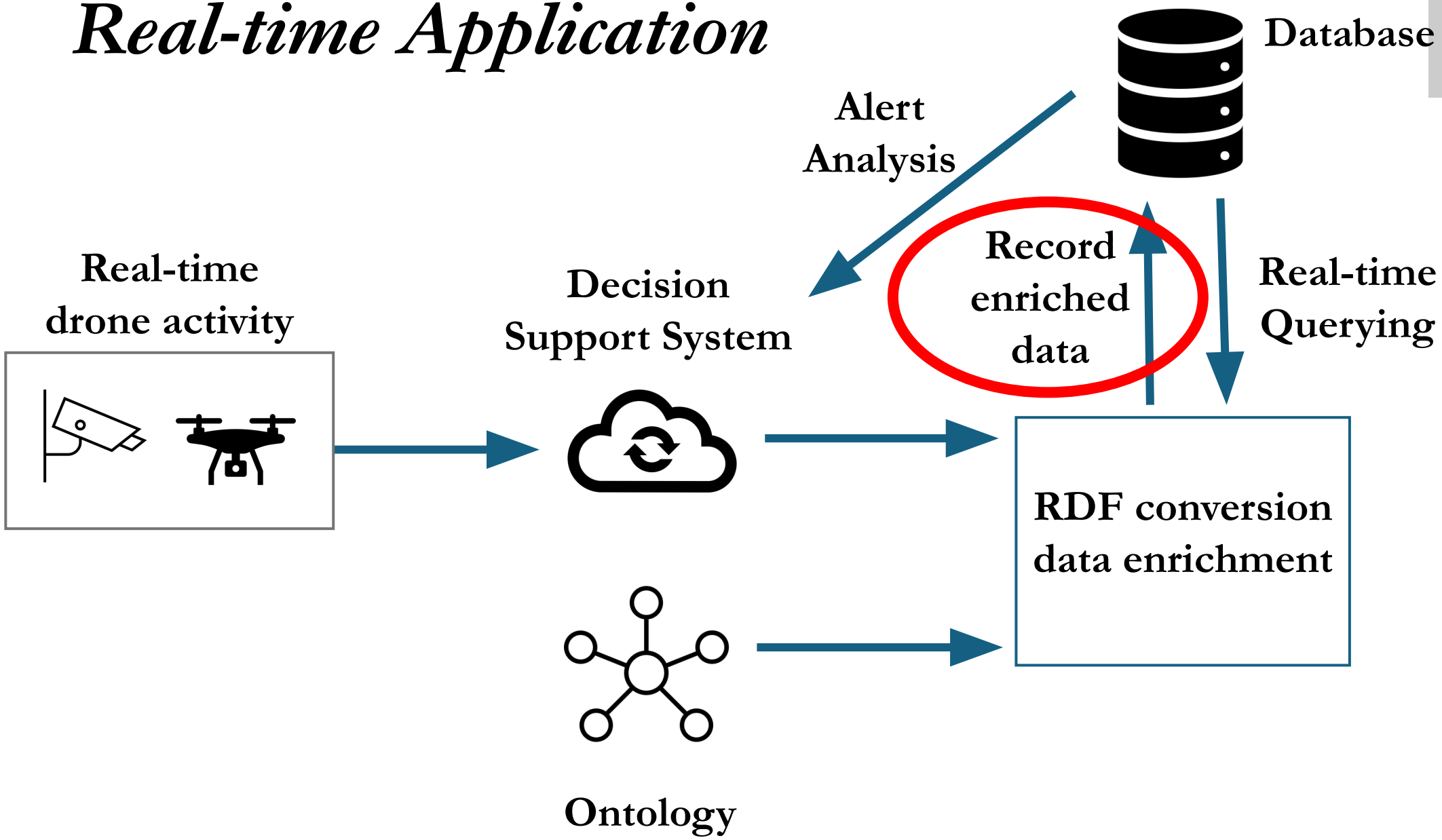
Functions from rdflib are then used to add the automatically generated IRIs to an ontology file, ensuring the IRIs bear relationships reflected in our diagrams.

```
g.add((motion_process_iri, RDF.type, OWL.NamedIndividual))
g.add((motion_process_iri, RDF.type, BFO['process']))
g.add((motion_process_iri, BFO['occupies spatiotemporal region'], spatiotemporal_region_iri))
g.add((motion_process_iri, BFO['has profile'], speed_iri))
```

```
g.add((geo_region_iri, RDF.type, OWL.NamedIndividual))
g.add((geo_region_iri, RDF.type, DEMO.GeographicRegion))
g.add((geo_region_iri, DEMO['has_latitude_value'], latitude_value))
g.add((geo_region_iri, DEMO['has_longitude_value'], longitude_value))
g.add((geo_region_iri, DEMO['has_altitude_value'], altitude_value))
```

For example, an instance of Geographic Region will have latitude, longitude, and altitude values

Real-time Application



The conversion script outputs valid RDF, and has enriched the sensor data with ontological relationships relevant to addressing the competency question.

The RDF conversion script output can be viewed in standard ontology editors, such as Protégé.

```
<NamedIndividual rdf:about="http://example.com/DEMO_0001421">
    <rdf:type rdf:resource="https://example.com/DEMO/GeographicRegion"/>
    <cco:has_latitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">110.123</cco:has_latitude_value>
    <cco:has_longitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">38.9</cco:has_longitude_value>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">geographic_point_1</rdfs:label>
</NamedIndividual>

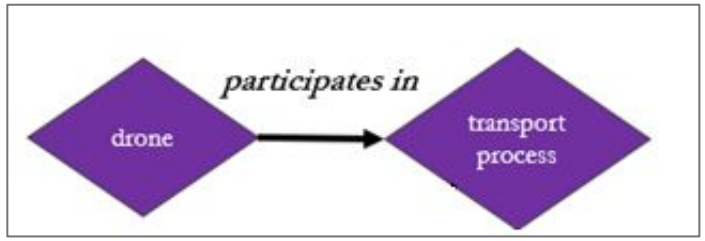
<NamedIndividual rdf:about="http://example.com/DEMO_0001422">
    <rdf:type rdf:resource="https://example.com/DEMO/GeographicRegion"/>
    <cco:has_latitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">113.88</cco:has_latitude_value>
    <cco:has_longitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">38.7</cco:has_longitude_value>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">geographic_point_2</rdfs:label>
</NamedIndividual>

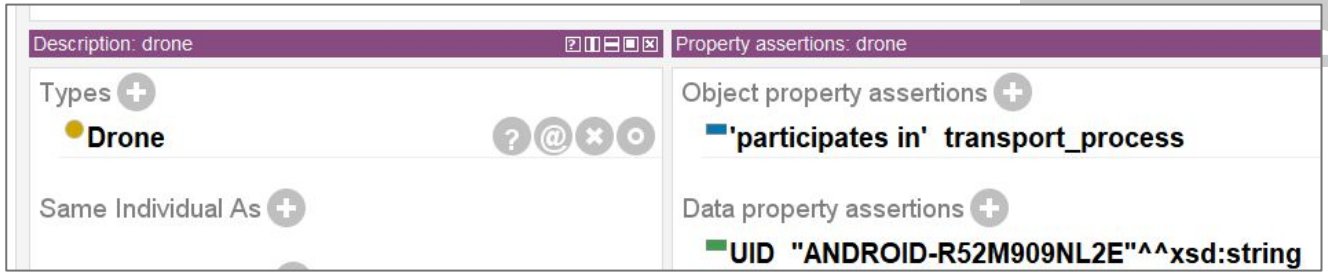
<NamedIndividual rdf:about="http://example.com/DEMO_0001423">
    <rdf:type rdf:resource="http://purl.obolibrary.org/obo/BFO_0000015"/>
    <ns1:DEMO_0001430 rdf:resource="http://example.com/DEMO_0001429"/>
    <ns1:DEMO_0001435 rdf:resource="http://example.com/DEMO_0001436"/>
    <oboInOwl:term_editor rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs:label xml:lang="en">motion_process</rdfs:label>
</NamedIndividual>

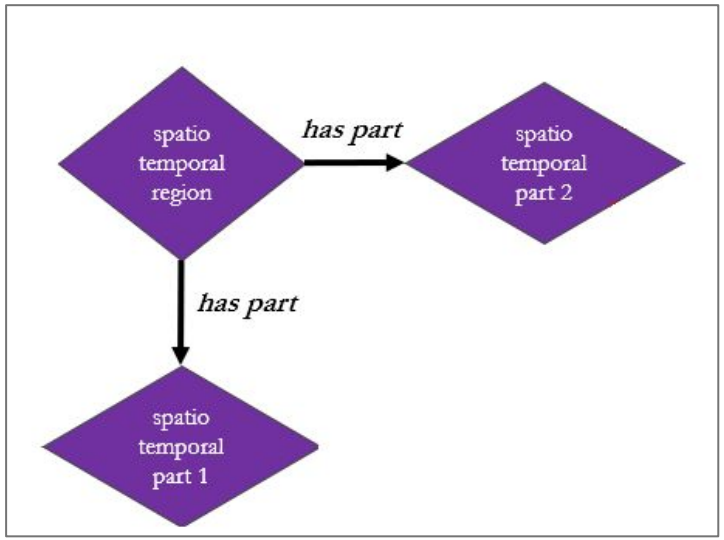
<NamedIndividual rdf:about="http://example.com/DEMO_0001425">
    <rdf:type rdf:resource="http://purl.obolibrary.org/obo/BFO_0000008"/>
    <cco:i erval_is_b fore rdf:resource="http://example.com/DEMO_0001426"/>
    <cco:h _datetime_ lue rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2022-10-26T21:32:52</cco:has_datetime_value>
    <oboIn l:term_ed r rdf:datatype="http://www.w3.org/2001/XMLSchema#string">John Beverley</oboInOwl:term_editor>
    <rdfs: bel xml:la ="en">temporal_interval_1</rdfs:label>
 amedInd idual>
```

subject predicate object

Protégé allows visual verification that our conversion process aligns with our diagrammed ontology representations

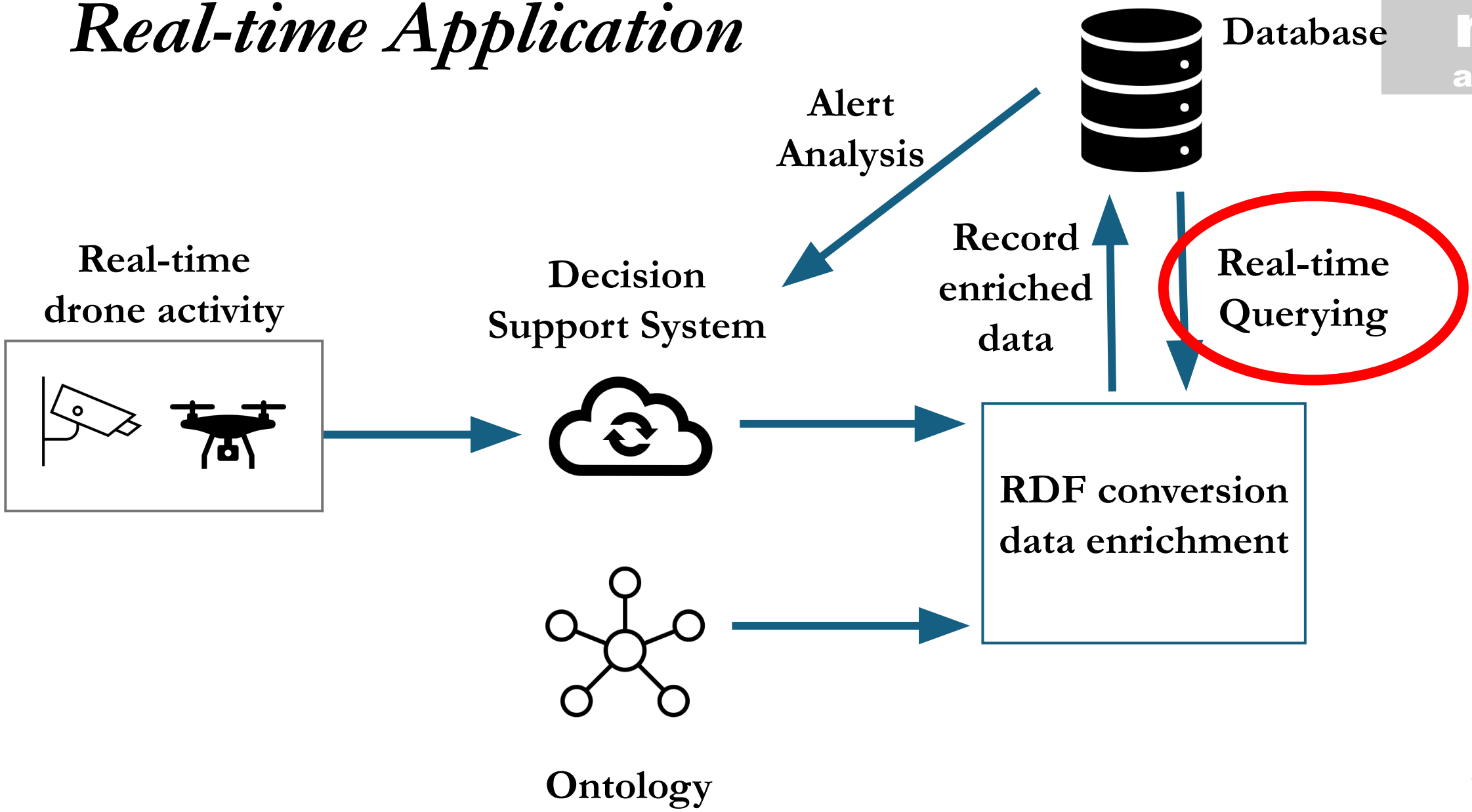






Protégé also facilitates the use of automated reasoners which can be used to uncover implicit relationships or infer unexpected consequences from the ontological relationships.

Real-time Application



SPARQL

- Protégé also provides an environment to query the ontology for information, for example, by using SPARQL queries

- SPARQL is a query language used to extract information from data stored as RDF, the results of which can be used to further enrich data

- Once an RDF database is updated with sensor data concerning a drone at distinct geographical locations at distinct times, SPARQL can be used to check the competency question:

Has a drone crossed a US-MX border?

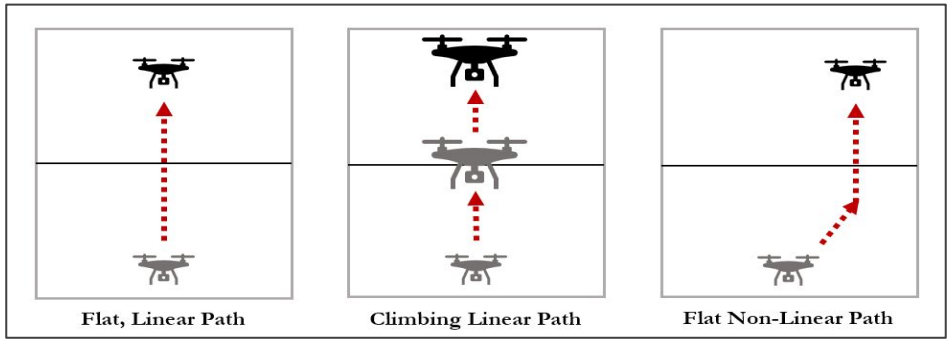
```
SELECT ?lat1 ?lon1 ?alt1 ?lat2 ?lon2 ?alt2 ?time1 ?time2
WHERE {
   ?drone rdf:type ex:DEMO_0001440 ;
          bfo:RO_0000056 ?motion_process .
   ?motion_process bfo:BFO_0000130 ?spt .
   ?spt bfo:BFO_0000051 ?spt1 ;
        bfo:BFO_0000051?spt2 .
   ?spt1 ex:DEMO_0001438 ?geo1 ;
         ex:DEMO_0001439 ?interval1 .
   ?spt2 ex: DEMO_0001438? geo2 ;
         ex:DEMO_0001439 ?interval2 .
   ?geo1 ex:has_lon_value ?lon1 ;
         ex:has_lat_value ?lat1 ;
         ex:has_ alt_value ?alt1 .
   ?interval1 ex:date_value ?time1 .
   ?geo1 ex:has_lon_value ?lon2 ;
         ex:has_lat_value ?lat2 ;
         ex:has_ alt_value ?alt2 .
   ?interval2 ex:date_value ?time2 .
```

Once updated with sensor data in valid RDF, this query will return information like the following:

time1	2021-04-14T23:41:59.244Z
time2	2021-04-14T23:43:59.244Z
lat1	31.395719
lon2	-110.923161
alt1	1357.0914096
lat2	31.178655
lon2	-110.923172
alt2	1357.0914096

```
FILTER(trck_fnct:contains_geometry(AZ_border_side, ?lat1, ?lon1, ?alt1)=true &&
       trck_fnct:contains_geometry(MX_border_side, ?lat2, ?lon2, ?alt2)=true &&
       intv_fnct:connected_interval(?lat1, ?lon1, ?alt1, ?interval1, ?lat2, ?lon2, ?alt2, interval2)=true )}
```

```
SELECT ?lat1 ?lon1 ?alt1 ?lat2 ?lon2 ?alt2 ?time1 ?time2
WHERE {
   ?drone rdf:type ex:DEMO_0001440 ;
          bfo:RO_0000056 ?motion_process .
   ?motion_process bfo:BFO_0000130 ?spt .
   ?spt bfo:BFO_0000051 ?spt1 ;
        bfo:BFO_0000051?spt2 .
   ?spt1 ex:DEMO_0001438 ?geo1 ;
         ex:DEMO_0001439 ?interval1 .
   ?spt2 ex: DEMO_0001438? geo2 ;
         ex:DEMO_0001439 ?interval2 .
   ?geo1 ex:has_lon_value ?lon1 ;
         ex:has_lat_value ?lat1 ;
         ex:has_ alt_value ?alt1 .
   ?interval1 ex:date_value ?time1 .
   ?geo1 ex:has_lon_value ?lon2 ;
         ex:has_lat_value ?lat2 ;
         ex:has_ alt_value ?alt2 .
   ?interval2 ex:date_value ?time2 .
```



If a drone crosses the AZ-MX border, an ontology updated with this information can be queried to confirm this fact.

Moreover, differences in altitude, latitude, and longitude can be queried to track flight paths.

```
FILTER(trck_fnct:contains_geometry(AZ_border_side, ?lat1, ?lon1, ?alt1)=true &&
       trck_fnct:contains_geometry(MX_border_side, ?lat2, ?lon2, ?alt2)=true &&
       intv_fnct:connected_interval(?lat1, ?lon1, ?alt1, ?interval1, ?lat2, ?lon2, ?alt2, interval2)=true )}
```

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Outline

- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem
  - Application
  - Workflow
  - Collaboration
  - R&D
  - Education

The Common Core Ontologies (CCO)

What is CCO?

The Common Core Ontologies (CCO) is a widely-used suite of eleven ontologies that consist of logically well-defined generic terms and relations among them reflecting entities across all domains of interest.

These eleven ontologies constitute a mid-level ontology that extends from the Basic Formal Ontology (BFO), an ISO-standard top-level ontology. Whereas BFO represents only the most generic entities and relations, CCO contains classes that users will find common across data sets in many domains. Such classes include, for example, person, facility, date, employment, nickname, and measurement.

Both BFO and CCO have been directed for use as "baseline standards" for formal ontology development across the United States Department of Defense and Intelligence Community.

CCO is currently being evaluated as a mid-level ontology standard by the IEEE Standards Association under PAR3195.1.

CCO itself is not intended to grow indefinitely by including content that is proper to particular domains. Users are encouraged to create their own domain extensions with content particular to those domains and publish these ontologies for re-use by others.

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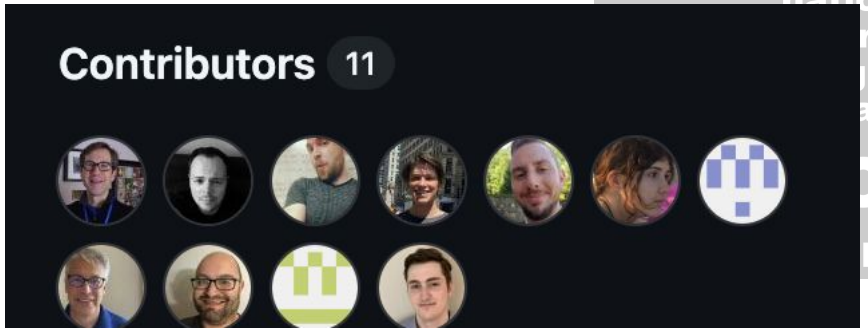
https://github.com/CommonCoreOntology/CommonCoreOntologies

The Common Core Ontologies

- **Geospatial Ontology** - An ontology whosse scope is the representation of sites, spatial regions, and other entities, especially those that are located near the surface of Earth, as well as the relations that hold between them.
- **Information Entity Ontology** - An ontology whose scope is the representation of generic types of information as well as the relationships between information and other entities.
- **Event Ontology** - An ontology whose scope is the representation of processual entities, especially those performed by agents, that occur within multiple domains.
- **Time Ontology** - An ontology whose scope is the representation of temporal regions and the relations that hold between them.
- **Agent Ontology** - An ontology whose scope is the representation of represent agents, especially persons and organizations, and their roles.
- **Quality Ontology** - An ontology whose scope is the representation of a range of attributes of entities especially qualities, realizable entities, and process profiles.
- **Units of Measure Ontology** - An ontology whose scope is the representation of standard measurement units that are used when measuring various attributes of entities.
- **Currency Unit Ontology** - An ontology whose scope is the representation of currencies that are issued and used by countries.
- **Facility Ontology** - An ontology whose scope is the representation of buildings and campuses that are designed to serve some specific purpose, and which are common to multiple domains.
- **Artifact Ontology** - An ontology whose scope is the representation of artifacts that are common to multiple domains along with their models, specifications, and functions.
- **Extended Relation Ontology** - An ontology whose scope is the representation of the relations that hold between entities at the level of the mid-level Common Core Ontologies.



https://github.com/CommonCoreOntology/CommonCoreOntologies

The Common Core Ontologies

- **Geospatial Ontology** - An ontology whosse scope is the representation of sites, spatial regions, and other entities, especially those that are located near the surface of Earth, as well as the relations that hold between them.
- **Information Entity Ontology** - An ontology whose scope is the representation of generic types of information as well as the relationships between information and other entities.
- **Event Ontology** - An ontology whose scope is the representation of processual en performed by agents, that occur within multiple domains.
- **Time Ontology** - An ontology whose scope is the representation of temporal regio hold between them.
- **Agent Ontology** - An ontology whose scope is the representation of represent age organizations, and their roles.
- **Quality Ontology** - An ontology whose scope is the representation of a range of at especially qualities, realizable entities, and process profiles.
- **Units of Measure Ontology** - An ontology whose scope is the representation of st that are used when measuring various attributes of entities.
- **Currency Unit Ontology** - An ontology whose scope is the representation of curre used by countries.
- **Facility Ontology** - An ontology whose scope is the representation of buildings an designed to serve some specific purpose, and which are common to multiple doma
- **Artifact Ontology** - An ontology whose scope is the representation of artifacts tha domains along with their models, specifications, and functions.
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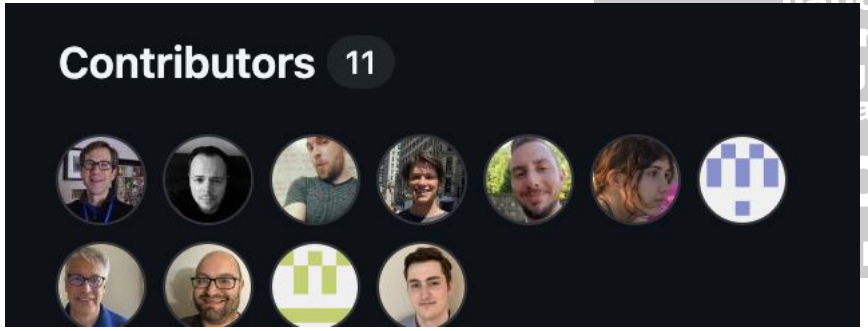

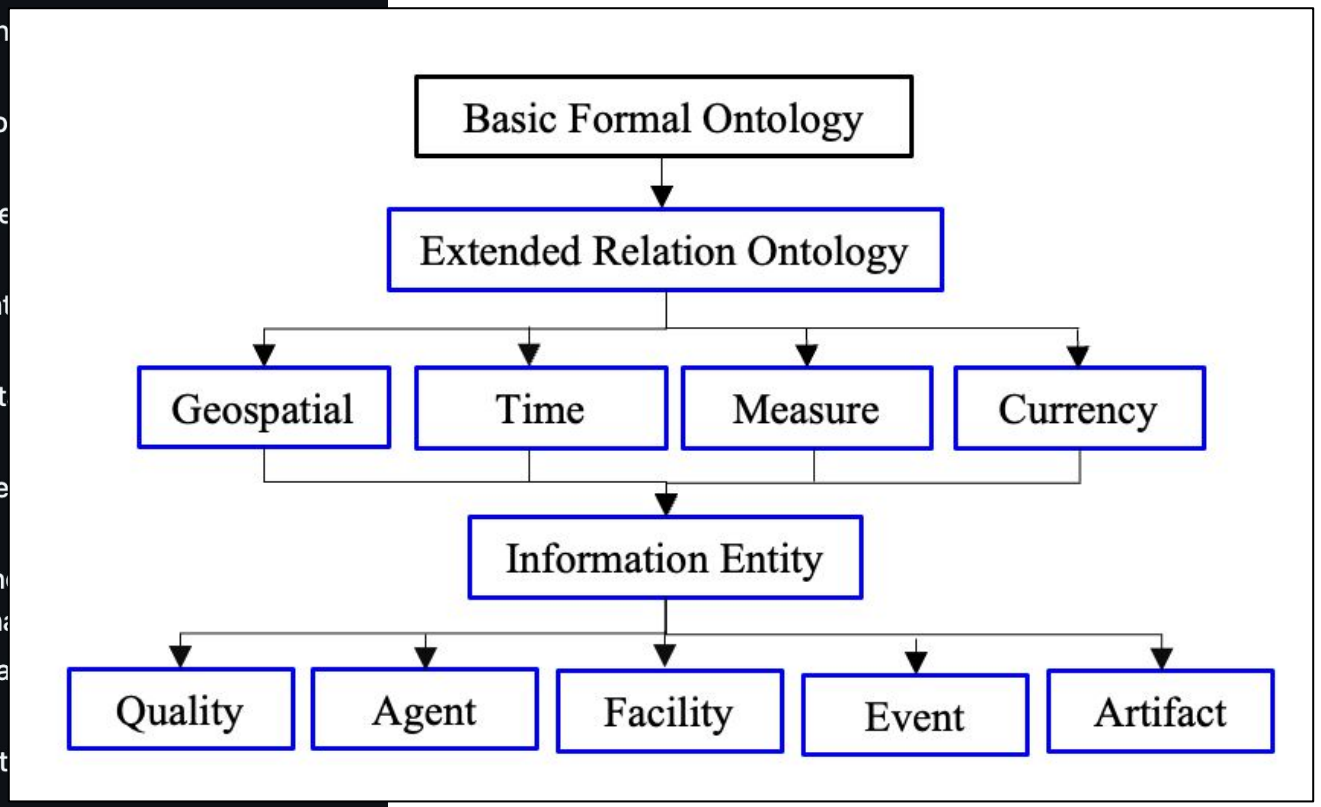

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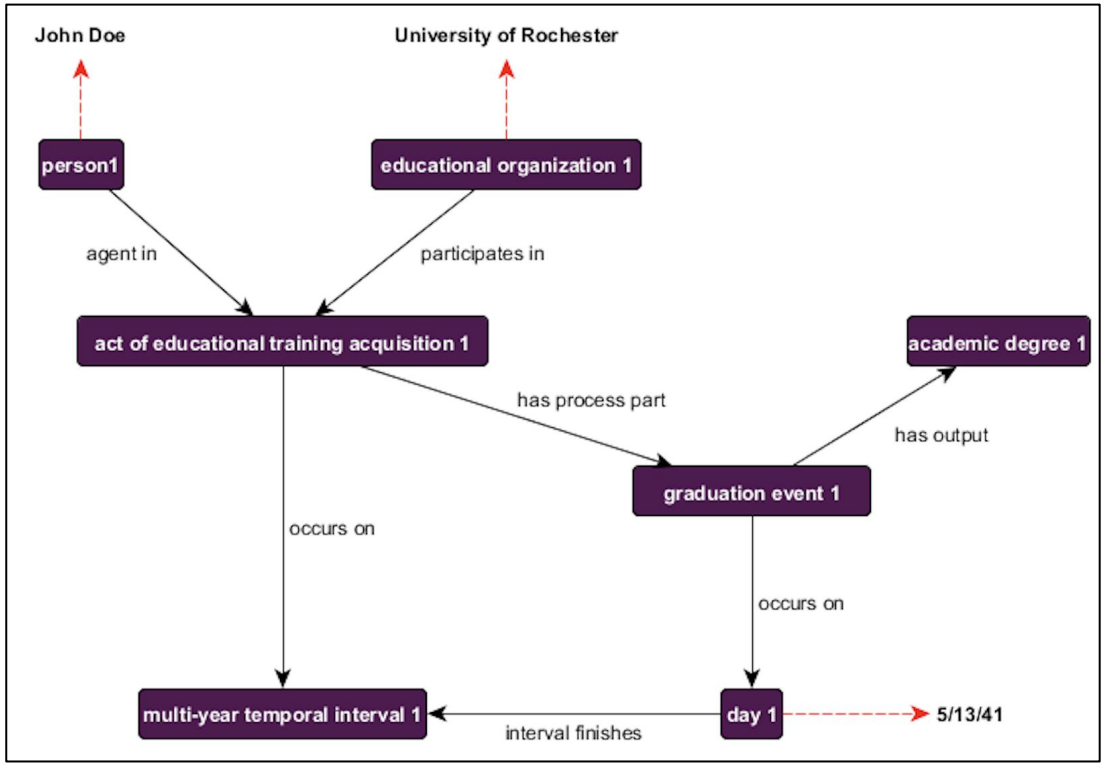

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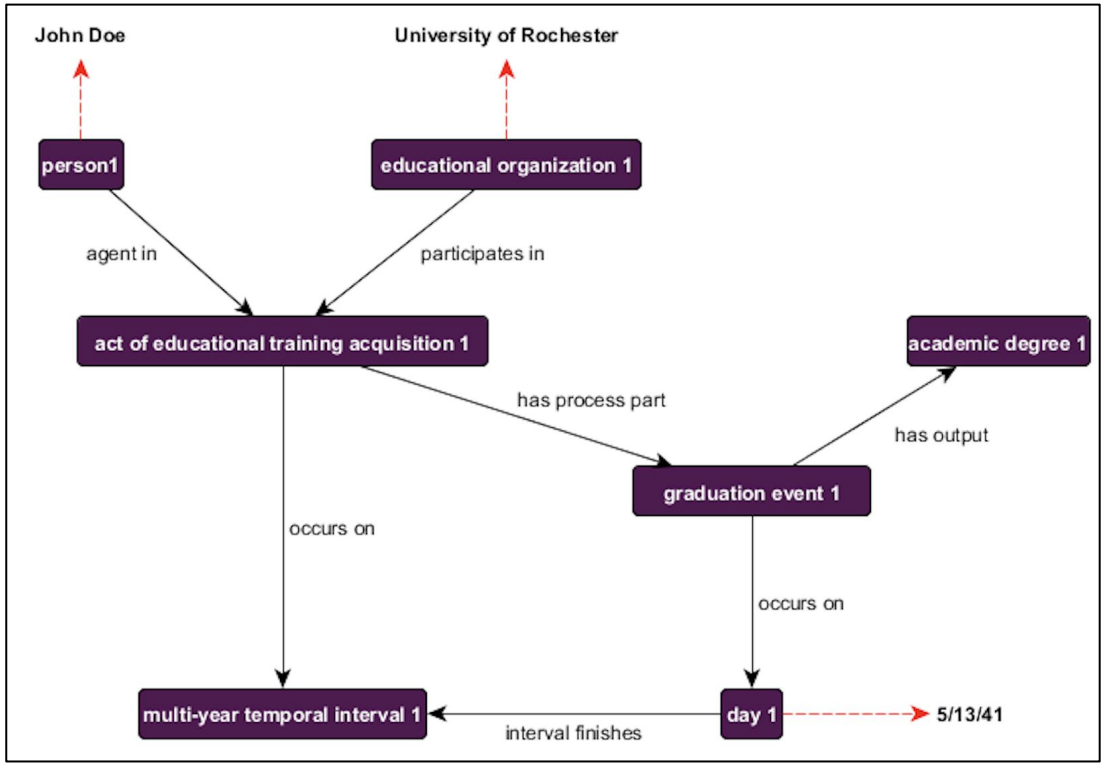
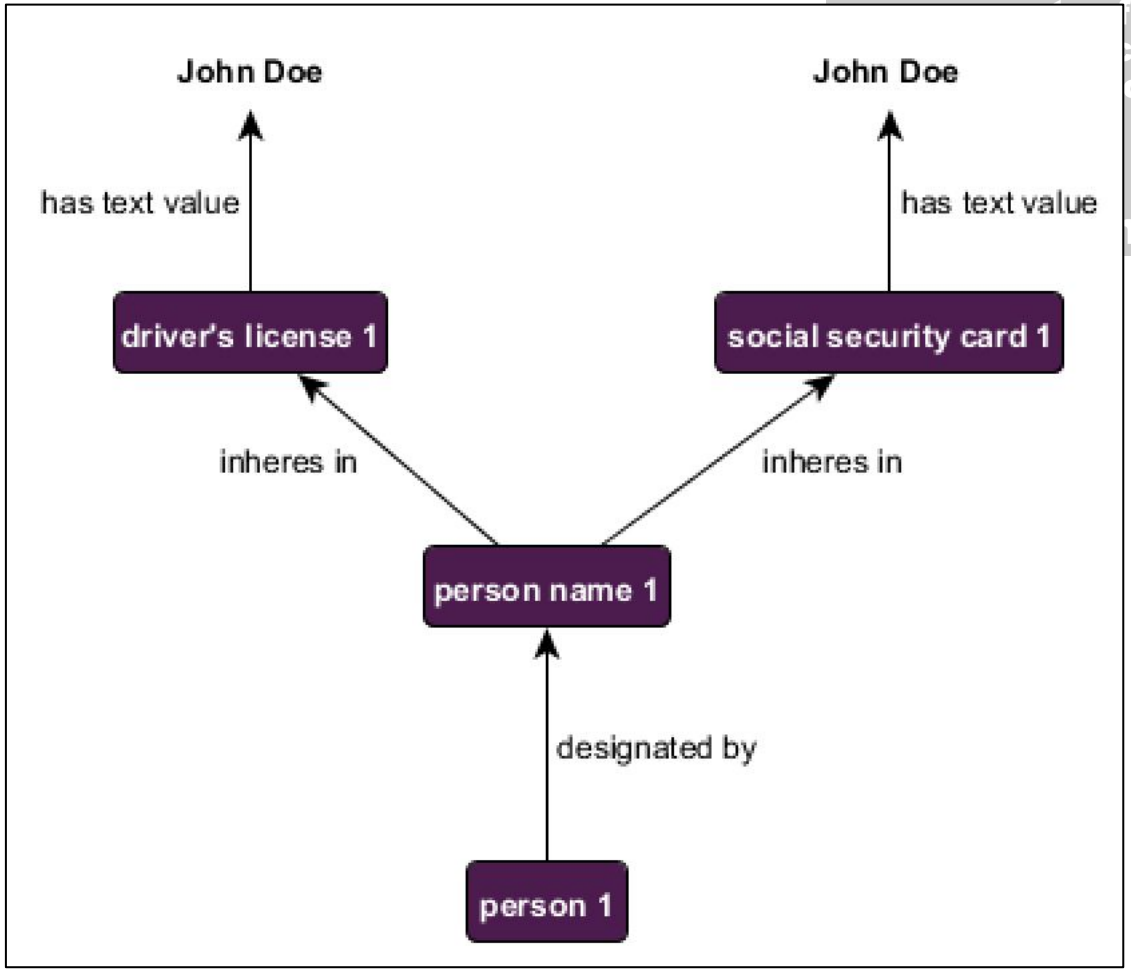
High-level design pattern representing a graduation and the acquisition of an academic degree

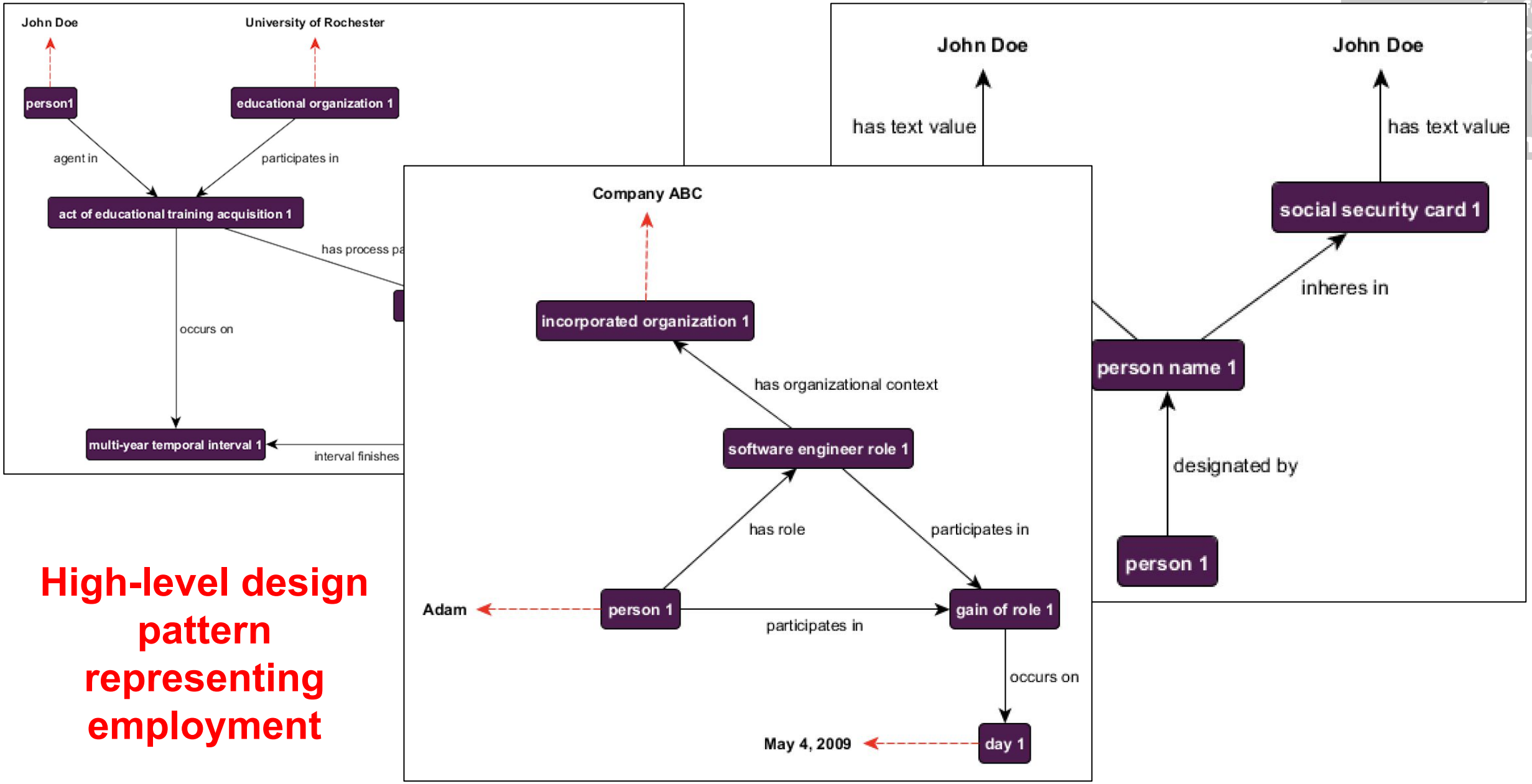
https://github.com/CommonCoreOntology/CommonCoreOntologies





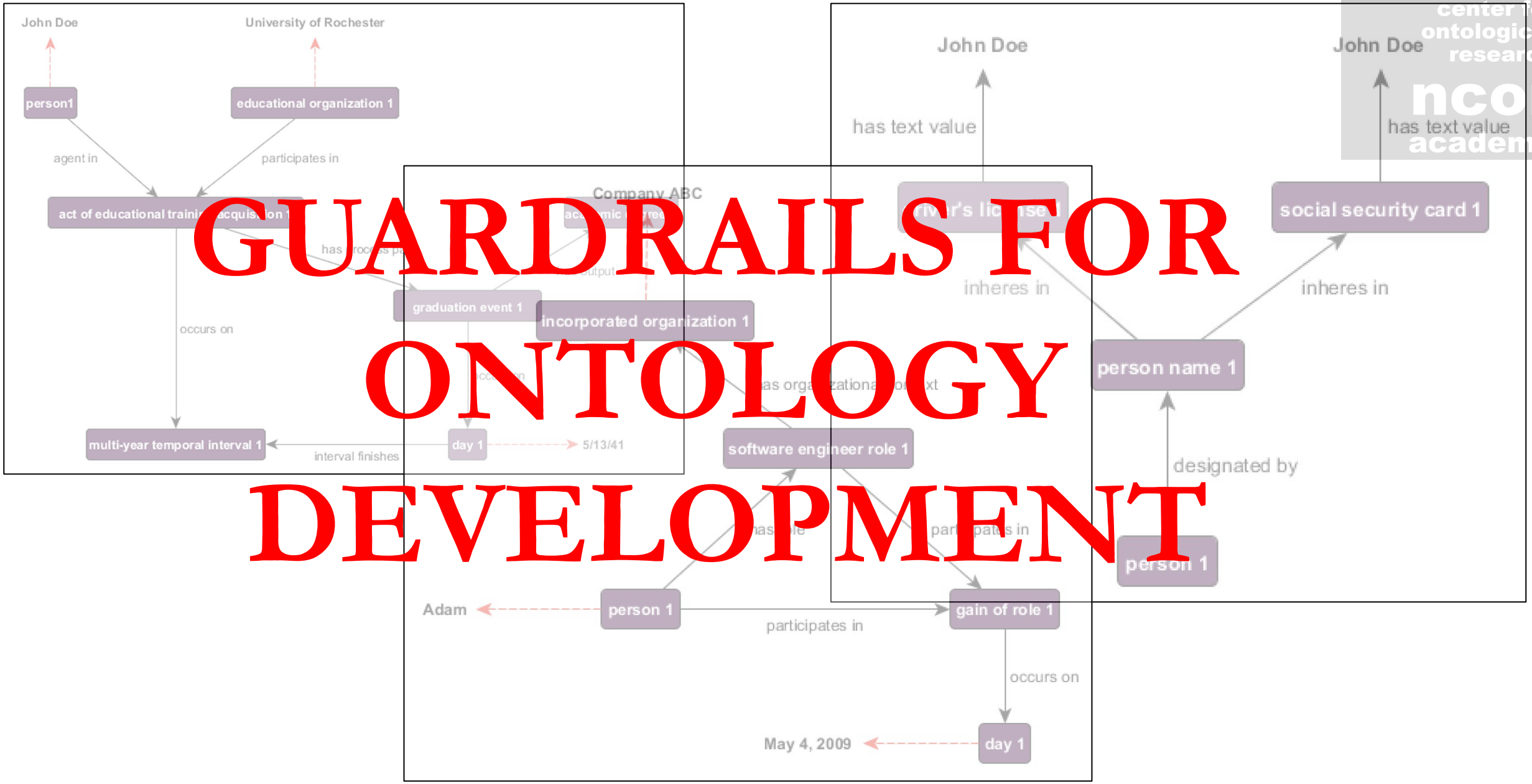
High-level design pattern representing credentials

https://github.com/CommonCoreOntology/CommonCoreOntologies



High-level design pattern representing employment

https://github.com/CommonCoreOntology/CommonCoreOntologies



GUARDRAILS FOR ONTOLOGY DEVELOPMENT

https://github.com/CommonCoreOntology/CommonCoreOntologies

CommonCoreOntologies

Public

Edit Pins | Unwatch 39

develop | 19 Branches | 11 Tags | Go to file t | Add file | Code

neilotte Merge pull request #473 from gregfowlerphd/463-acts-of-expressi... 8ba59d5 · 5 days ago 383 Commits

.github	Merge pull request #469 from CommonCoreOntology/spa...	last week
documentation	Re-adding the v1.3 CCO docs	3 weeks ago
src	Merge pull request #473 from gregfowlerphd/463-acts-of...	5 days ago
.gitignore	Update .gitignore	last week
LICENSE	Update LICENSE	2 months ago
Makefile	so close to a build	last month
README.md	Update README.md	last month
robots.txt	repo updates	last month

CommonCoreOntologies

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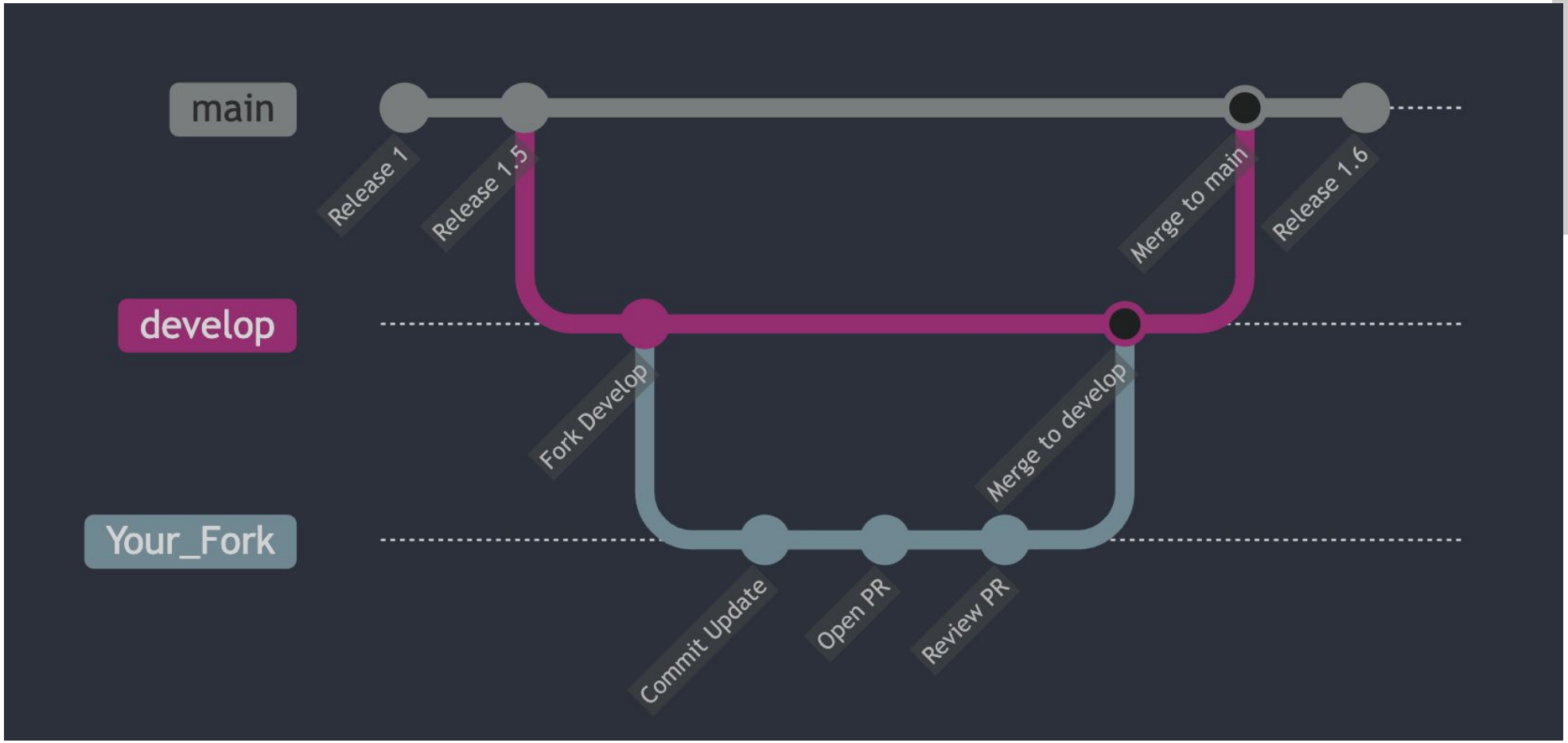

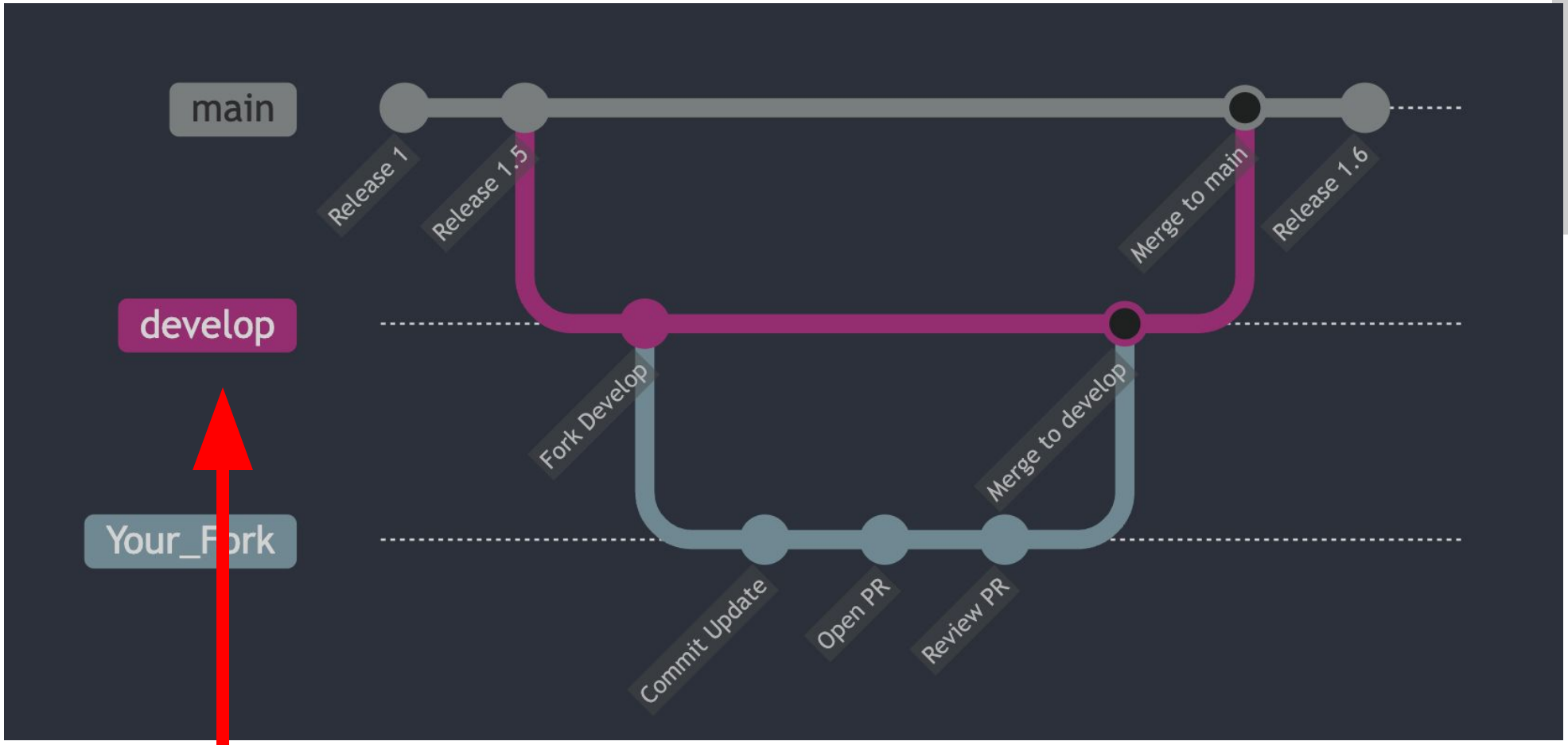

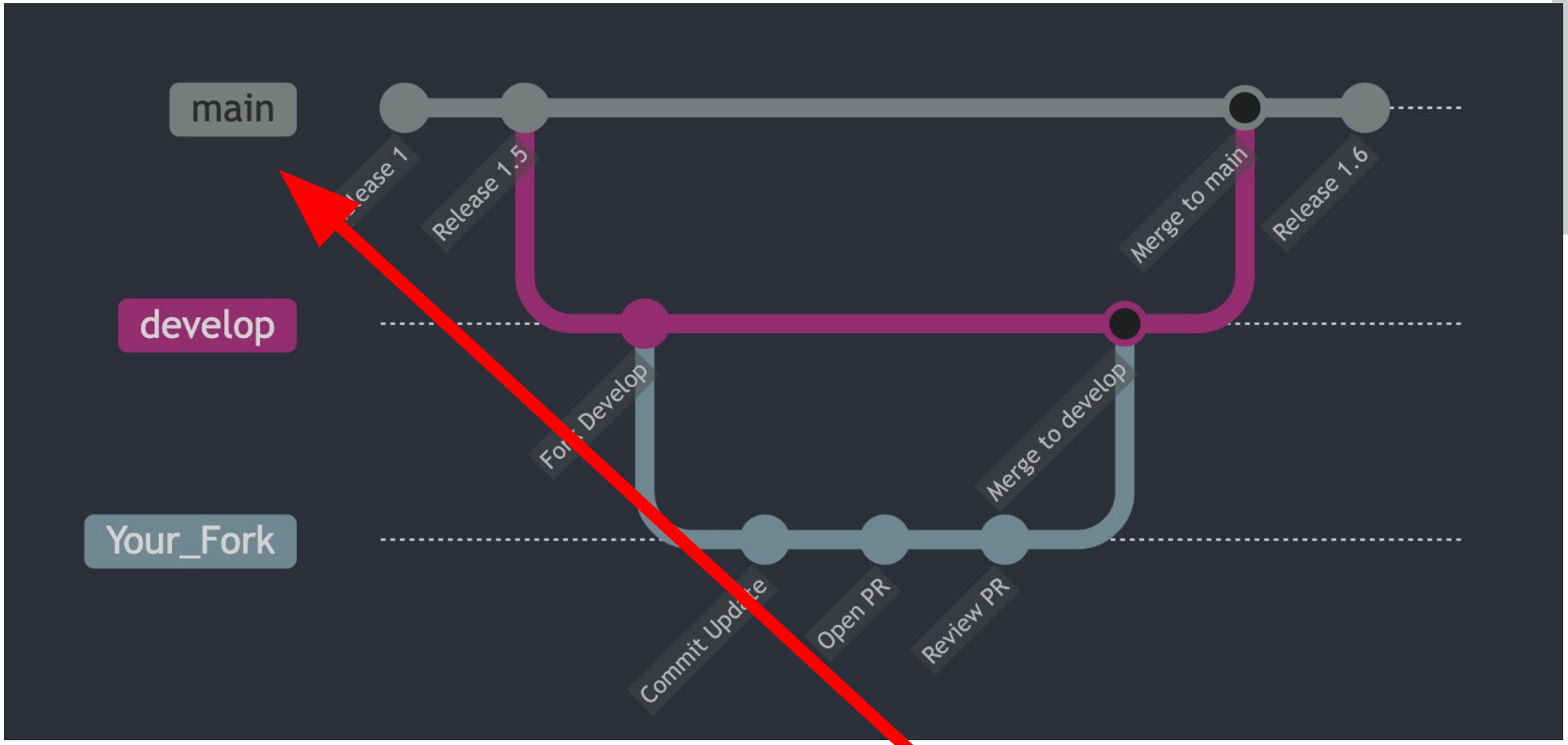

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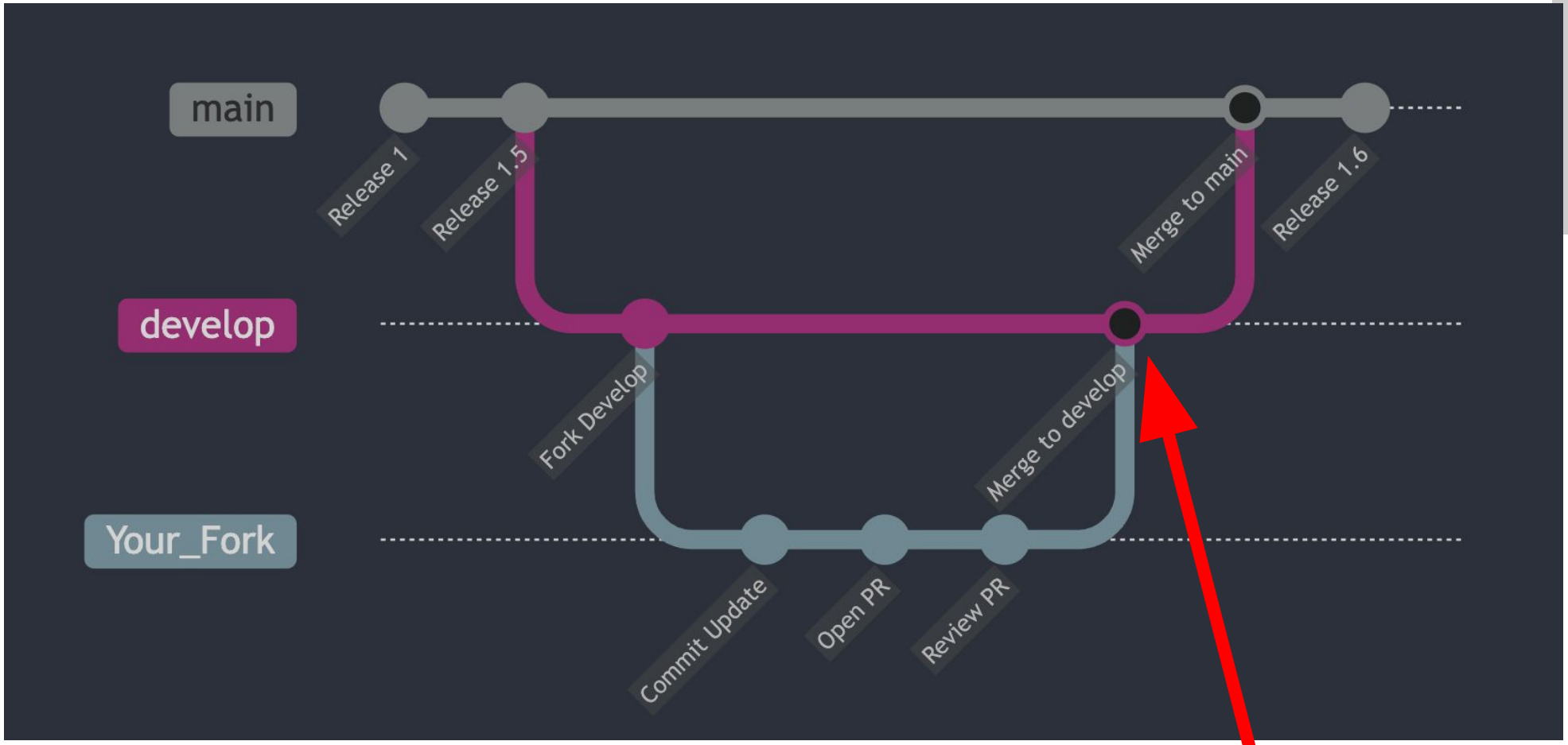
CommonCoreOntologies Public

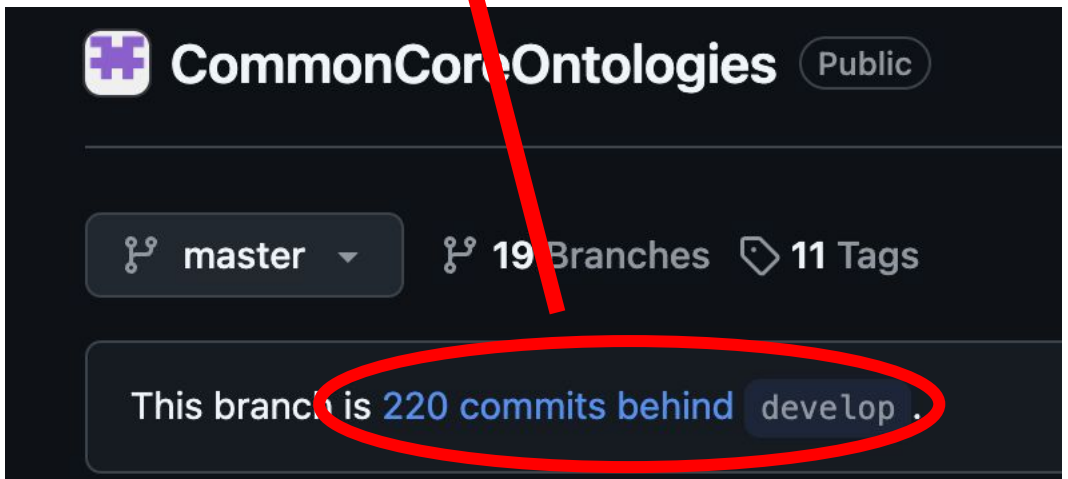
develop 19 Branches 11 Tags

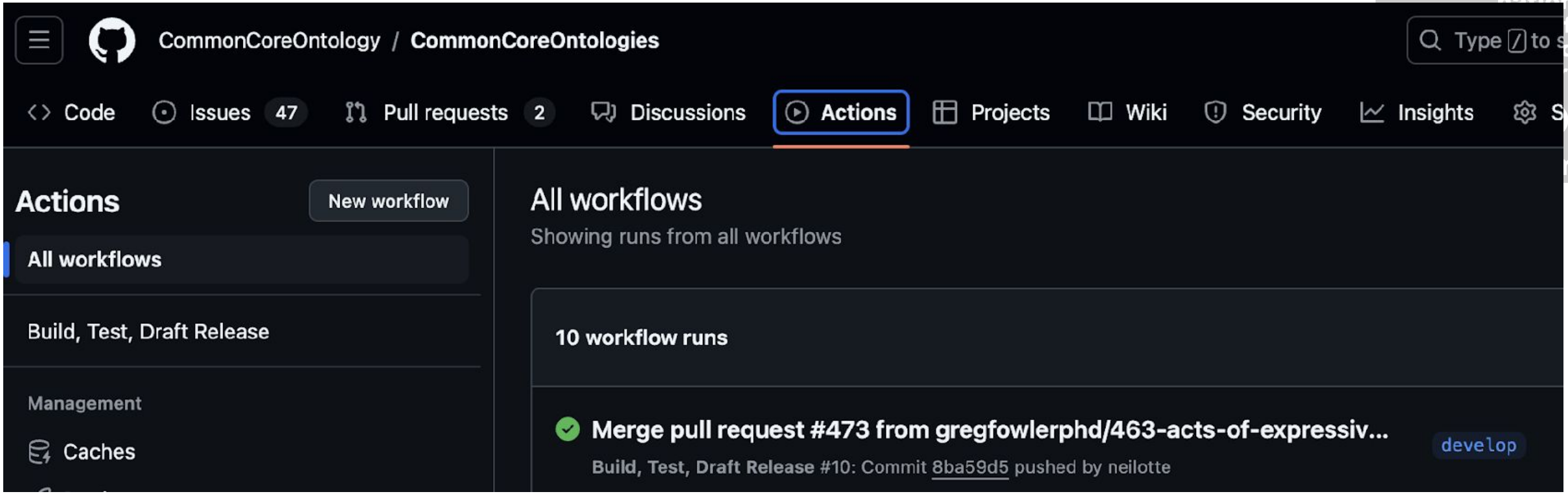
CommonCoreOntologies Public

master 19 Branches 11 Tags

This branch is 220 commits behind develop .



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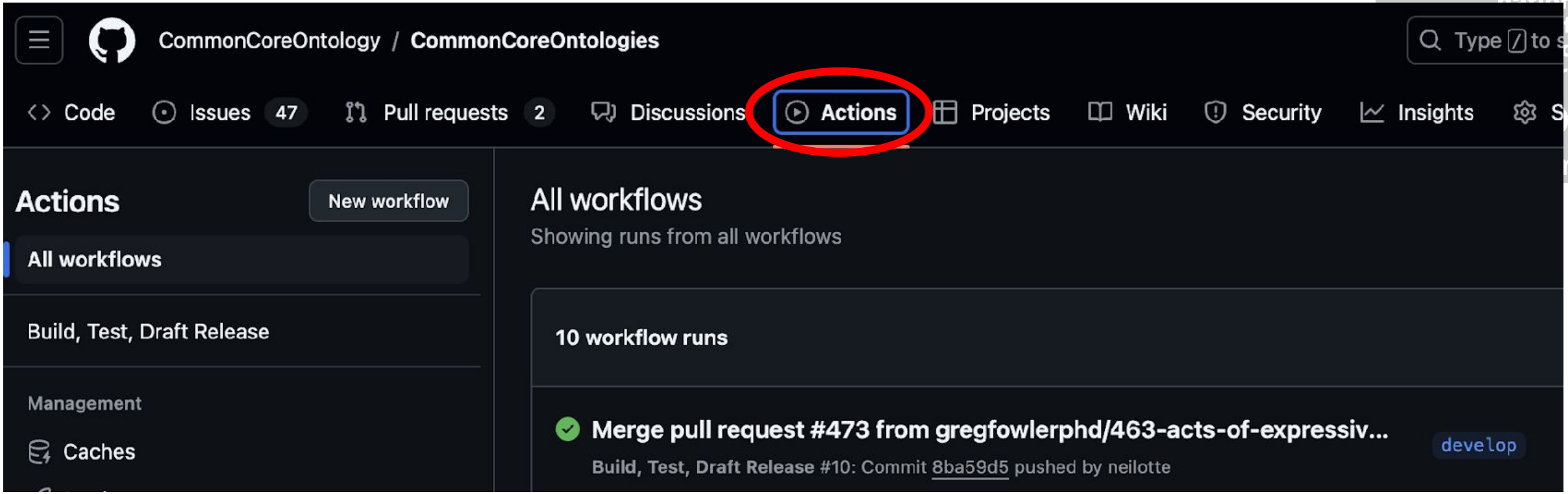
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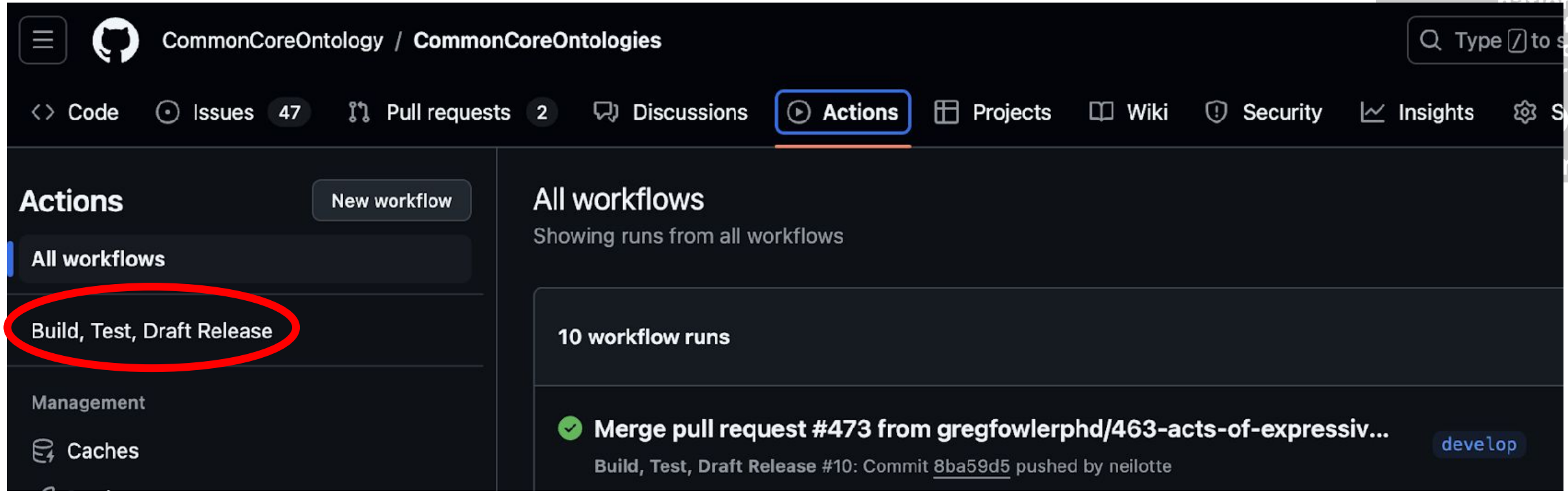
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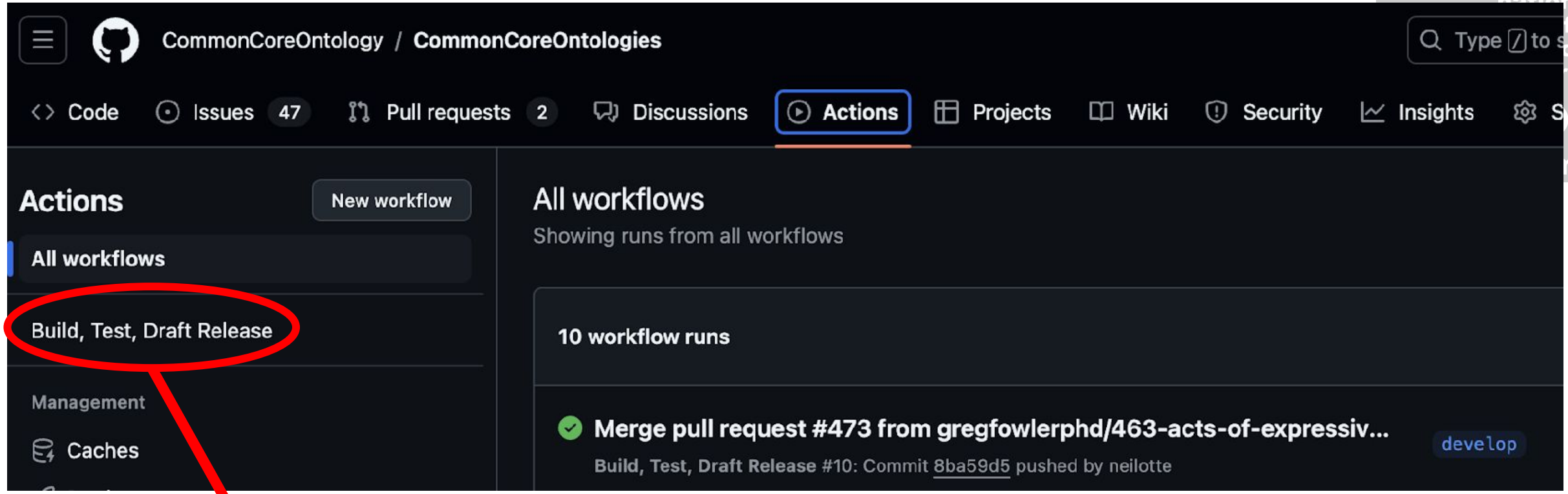
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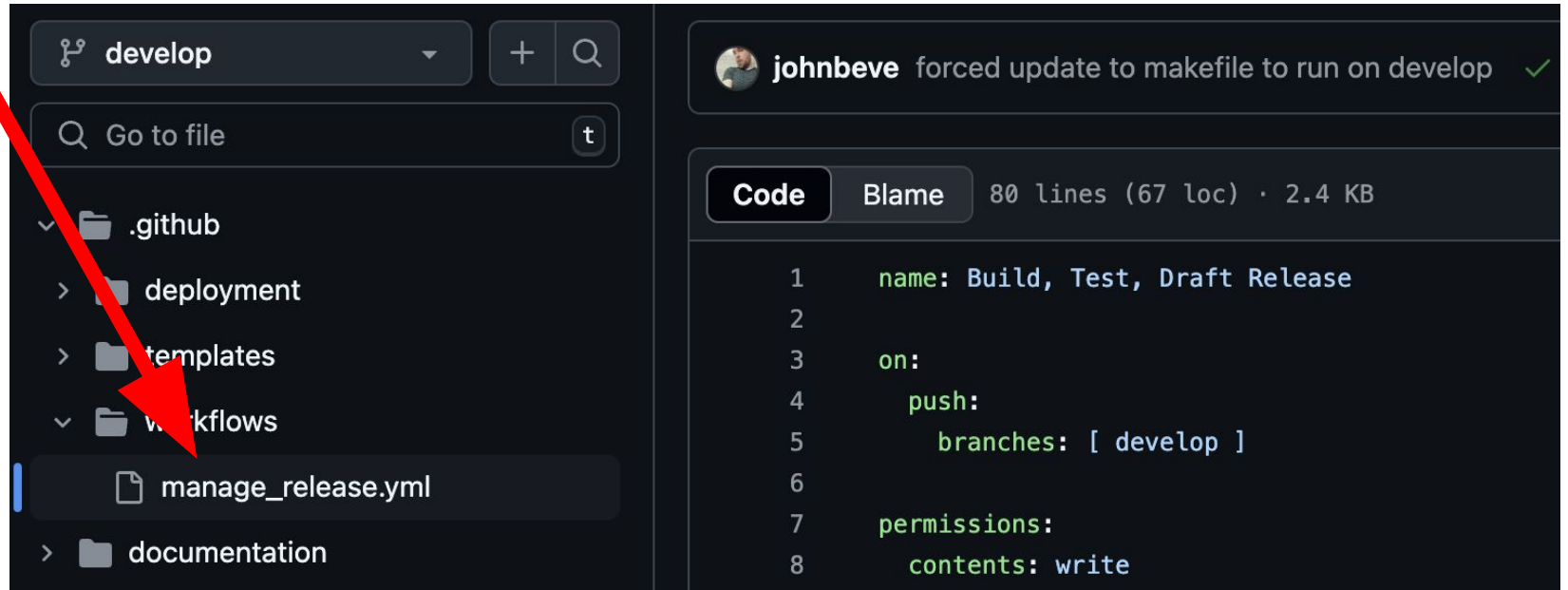
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documentation
johnbeve forced update to makefile to run on develop
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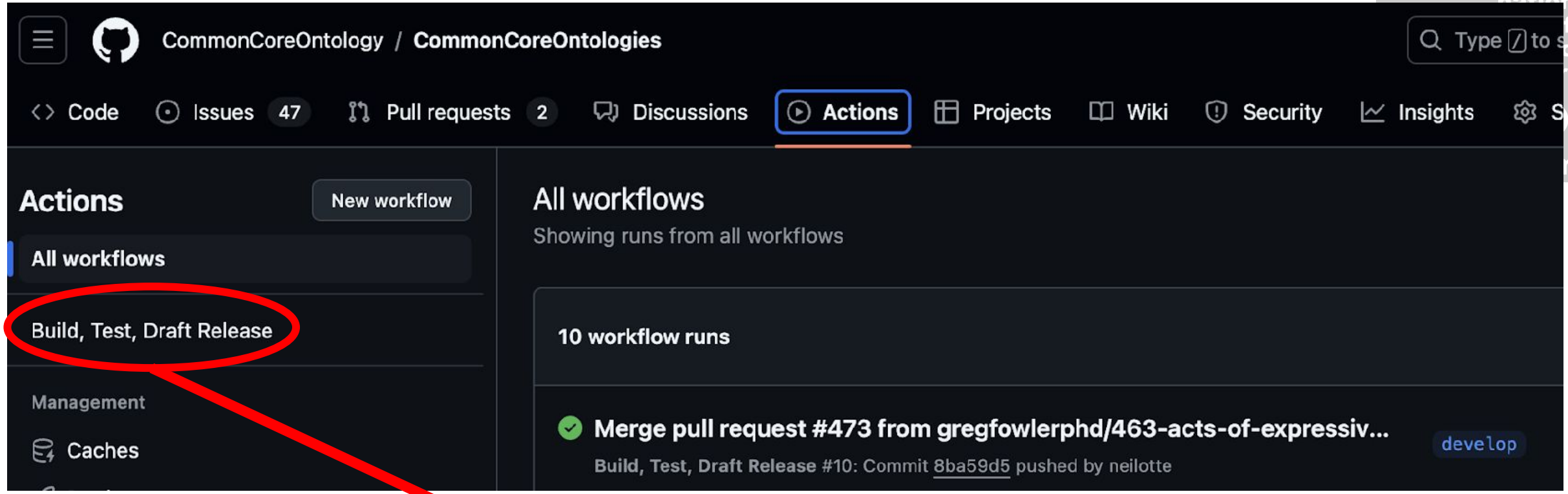
4 push:
5 branches: [develop]
6
7 permissions:
8 contents: write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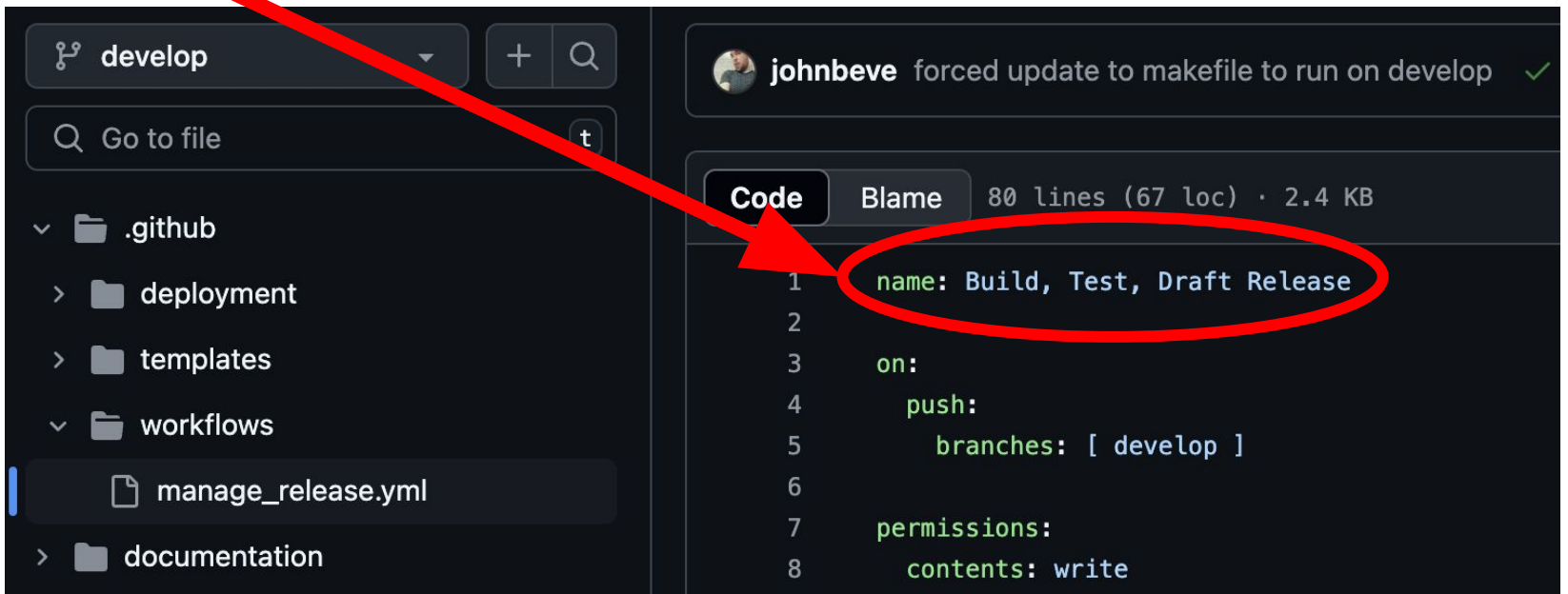
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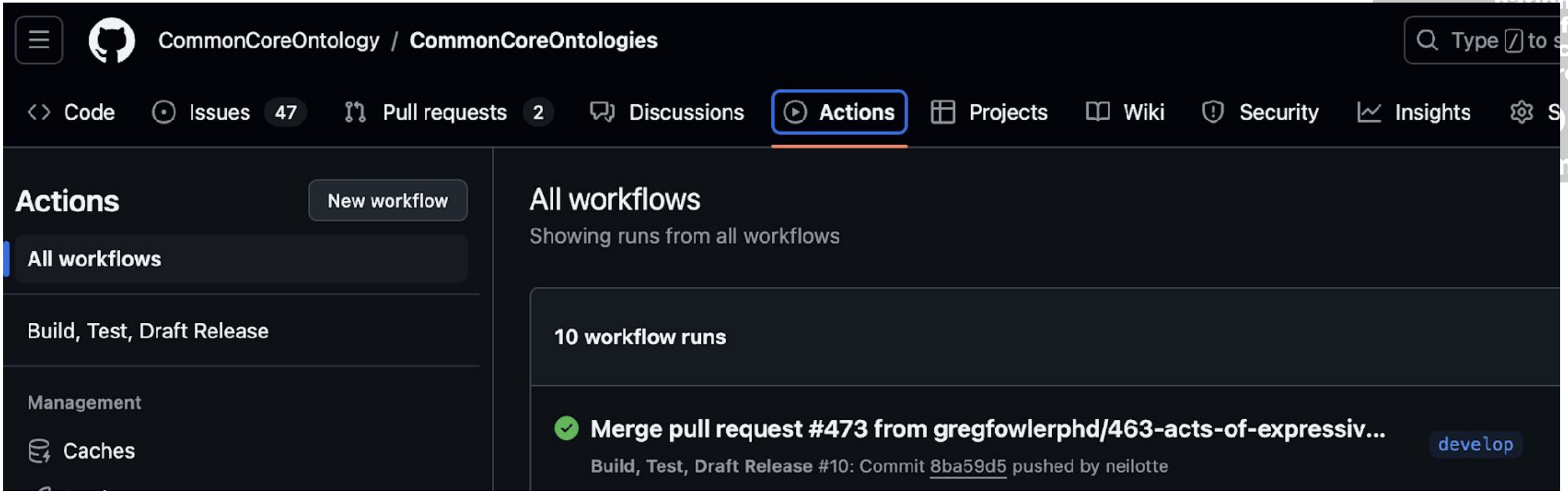
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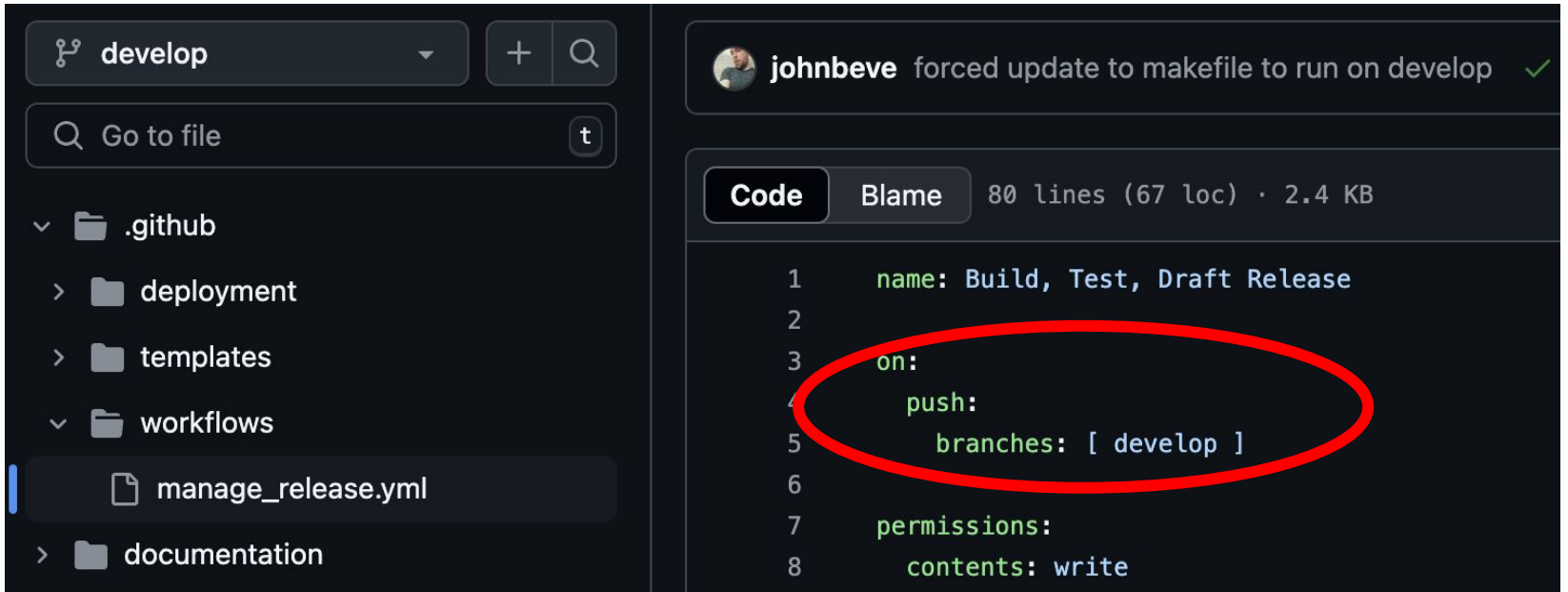
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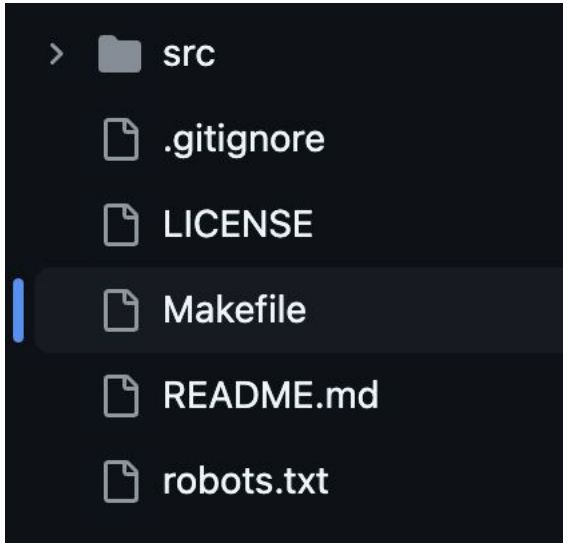
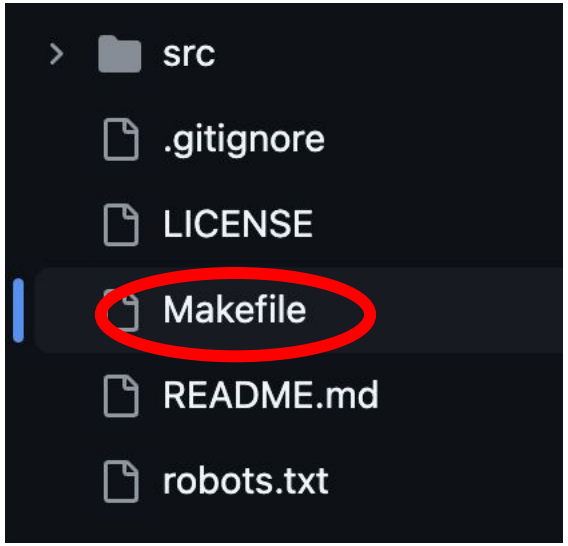
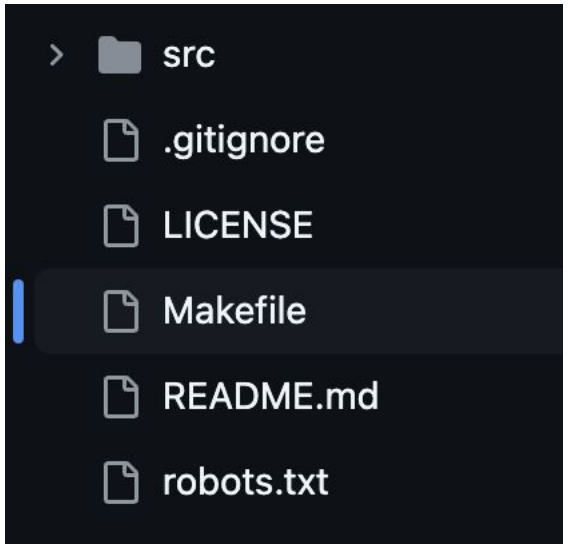







```
# Common Core Ontology Pipeline
# Adapted from previous works; see header comments for full attribution.
# Contact - John Beverley <johnbeve@buffalo.edu>

### Explanation ###
# The workflow involves two major steps: first, individual ontology files are checked and tested.
# After passing, they are merged into a single file, which is then checked and tested again.

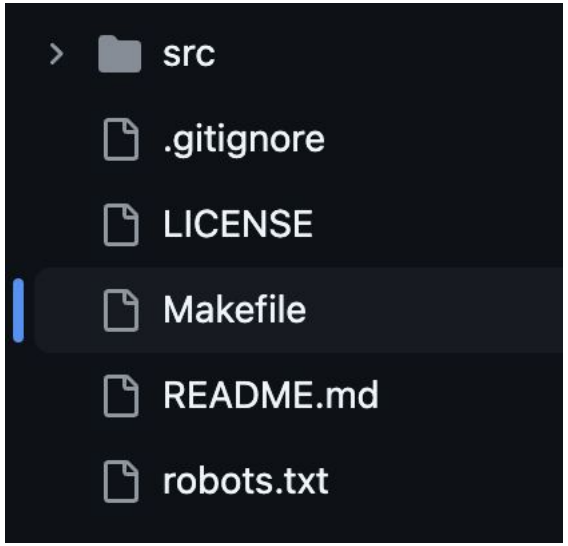
# ----------------------------------------
# Project essentials
config.ONTOLOGY_PREFIX := CCO
config.BASE_IRI := http://www.ontologyrepository.com/CommonCoreOntologies/Mid/
config.DEV_IRI := $(config.BASE_IRI)/dev
config.MODULES_IRI := $(config.DEV_IRI)/modules

# Local project directories
config.SOURCE_DIR := src/
config.TEMP_DIR := build/artifacts
config.RELEASE_DIR := /
config.REPORTS_DIR := $(config.TEMP_DIR)
config.QUERIES_DIR := .github/deployment/sparql
config.LIBRARY_DIR := build/lib

# Settings
config.FAIL_ON_TEST_FAILURES := false
config.REPORT_FAIL_ON := none

# Branch-specific configurations
BRANCH := $(shell git rev-parse --abbrev-ref HEAD)

# File names for dev branch
DEV_FILES = \
    src/cco-modules/AgentOntology.ttl \
    src/cco-modules/ArtifactOntology.ttl \
    src/cco-modules/CurrencyUnitOntology.ttl \
    src/cco-modules/EventOntology.ttl \
    src/cco-modules/ExtendedRelationOntology.ttl \
    src/cco-modules/FacilityOntology.ttl \
    src/cco-modules/GeospatialOntology.ttl \
    src/cco-modules/QualityOntology.ttl \
    src/cco-modules/UnitsOfMeasureOntology.ttl \
    src/cco-modules/TimeOntology.ttl \
    src/cco-modules/InformationEntityOntology.ttl
```

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config.LIBRARY_DIR := build/lib

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config.REPORT_FAIL_ON := none

# Branch-specific configurations
BRANCH := $(shell git rev-parse --abbrev-ref HEAD)

# File name[illegible] for dev branch
DEV_[illegible]ILES = \
    src/cco-modules/AgentOntology.ttl \
    src/cco-modules/ArtifactOntology.ttl \
    src/cco-modules/CurrencyUnitOntology.ttl \
    src/cco-modules/EventOntology.ttl \
    src/cco-modules/ExtendedRelationOntology.ttl \
    src/cco-modules/FacilityOntology.ttl \
    src/cco-modules/GeospatialOntology.ttl \
    src/cco-modules/QualityOntology.ttl \
    src/cco-modules/UnitsOfMeasureOntology.ttl \
    [illegible]/cco-modules/TimeOntology.ttl \
    src/cc[illegible]odules/InformationEntityOnt[illegible]ogy.ttl
```

```
# Download ROBOT JAR
ROBOT_FILE := $(config.LIBRARY_DIR)/robot.jar
$(ROBOT_FILE): setup
	curl -L -o $@ https://github.com/ontodev/robot/releases/download/v1.8.4/robot.jar
	chmod +x $@
```

```
# Download ROBOT JAR
ROBOT_FILE := $(config.LIBRARY_DIR)/robot.jar
$(ROBOT_FILE): setup
	curl -L -o $@ https://github.com/ontodev/robot/releases/download/v1.8.4/robot.jar
	chmod +x $@
```

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ROBOT

- - - - - - - - - -

view on github
getting started
common errors
chaining commands
global options
makefile
plugins

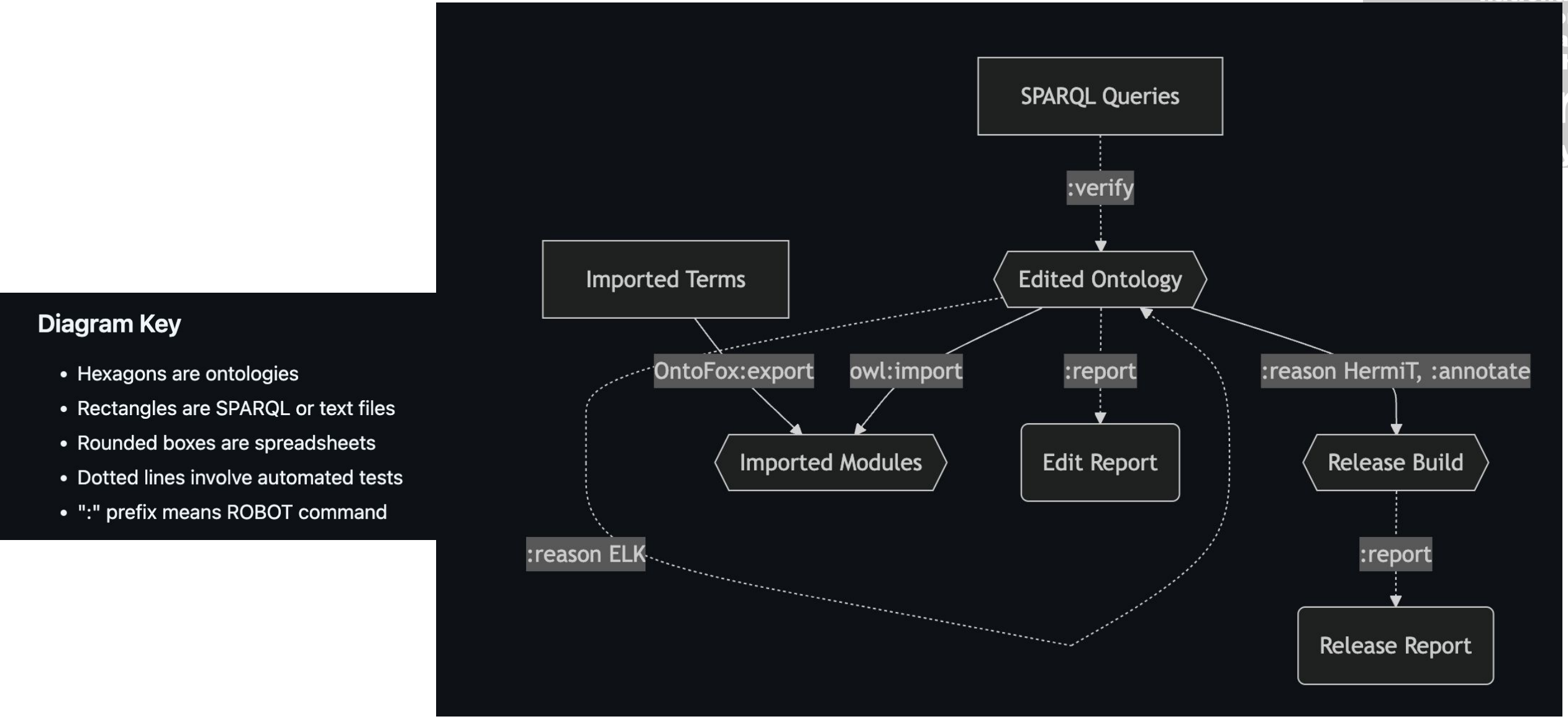
ROBOT is an OBO Tool

ROBOT is a tool for working with Open Biomedical Ontologies. It can be used as a command-line tool or as a library for any language on the Java Virtual Machine.

Click on the command names in the sidebar for documentation and examples, and visit our JavaDocs for `robot-core` and `robot-command` for technical details.

For a "how-to" covering the major commands and features of ROBOT, visit our tutorial located here.

https://robot.obolibrary.org/



https://github.com/tmprd/ontology-pipeline/blob/master/docs/Architecture.md

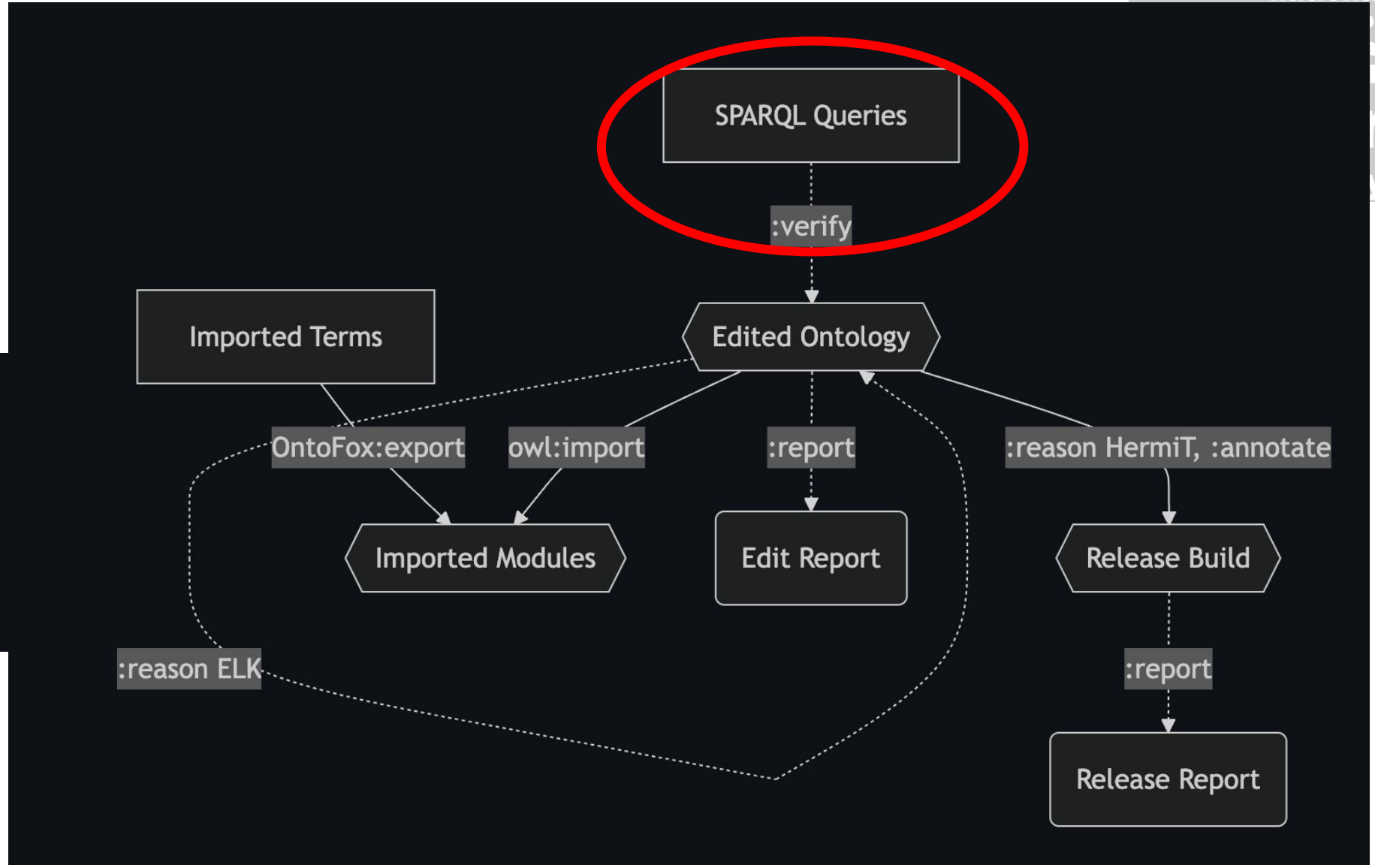
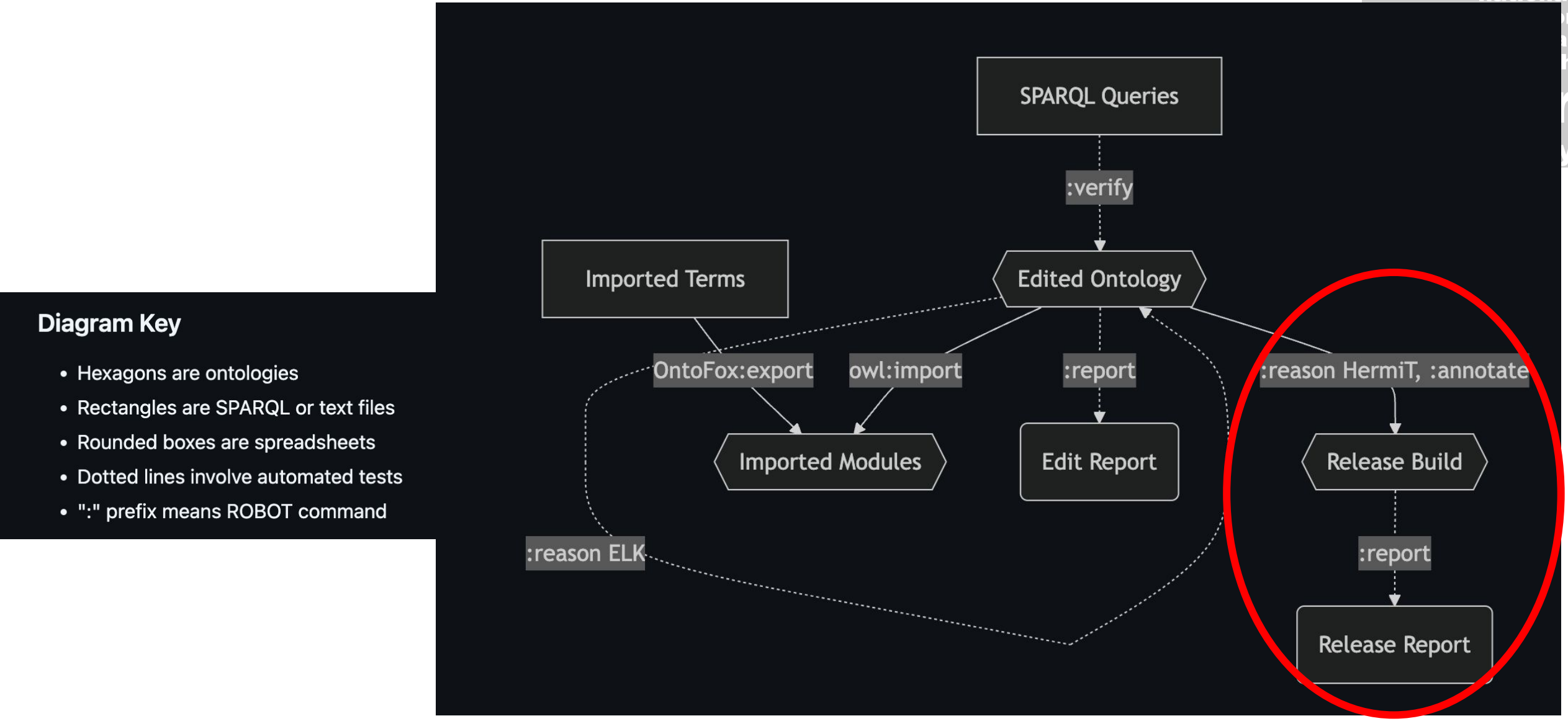


Diagram Key

- Hexagons are ontologies
- Rectangles are SPARQL or text files
- Rounded boxes are spreadsheets
- Dotted lines involve automated tests
- ":" prefix means ROBOT command

https://github.com/tmprd/ontology-pipeline/blob/master/docs/Architecture.md



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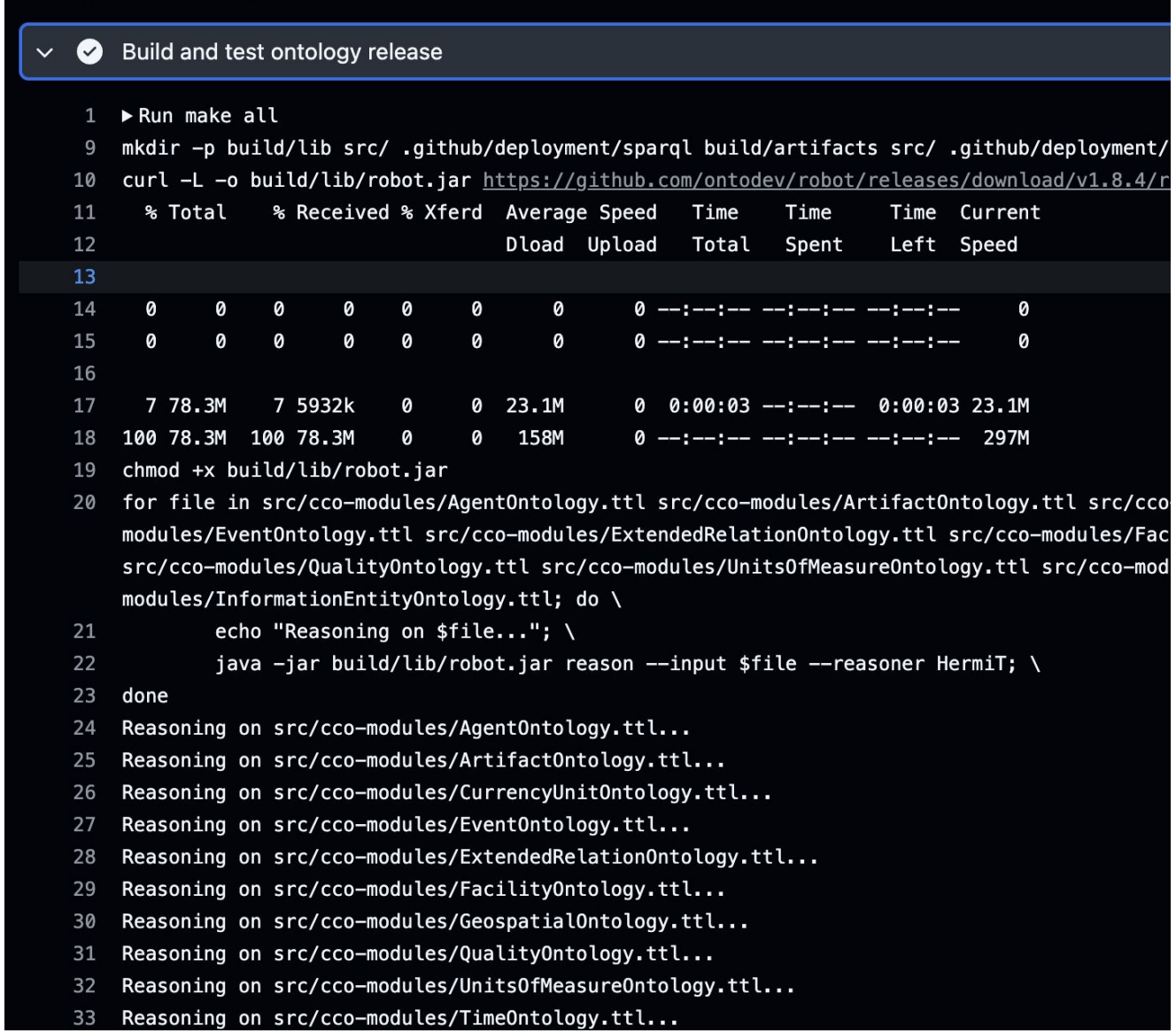

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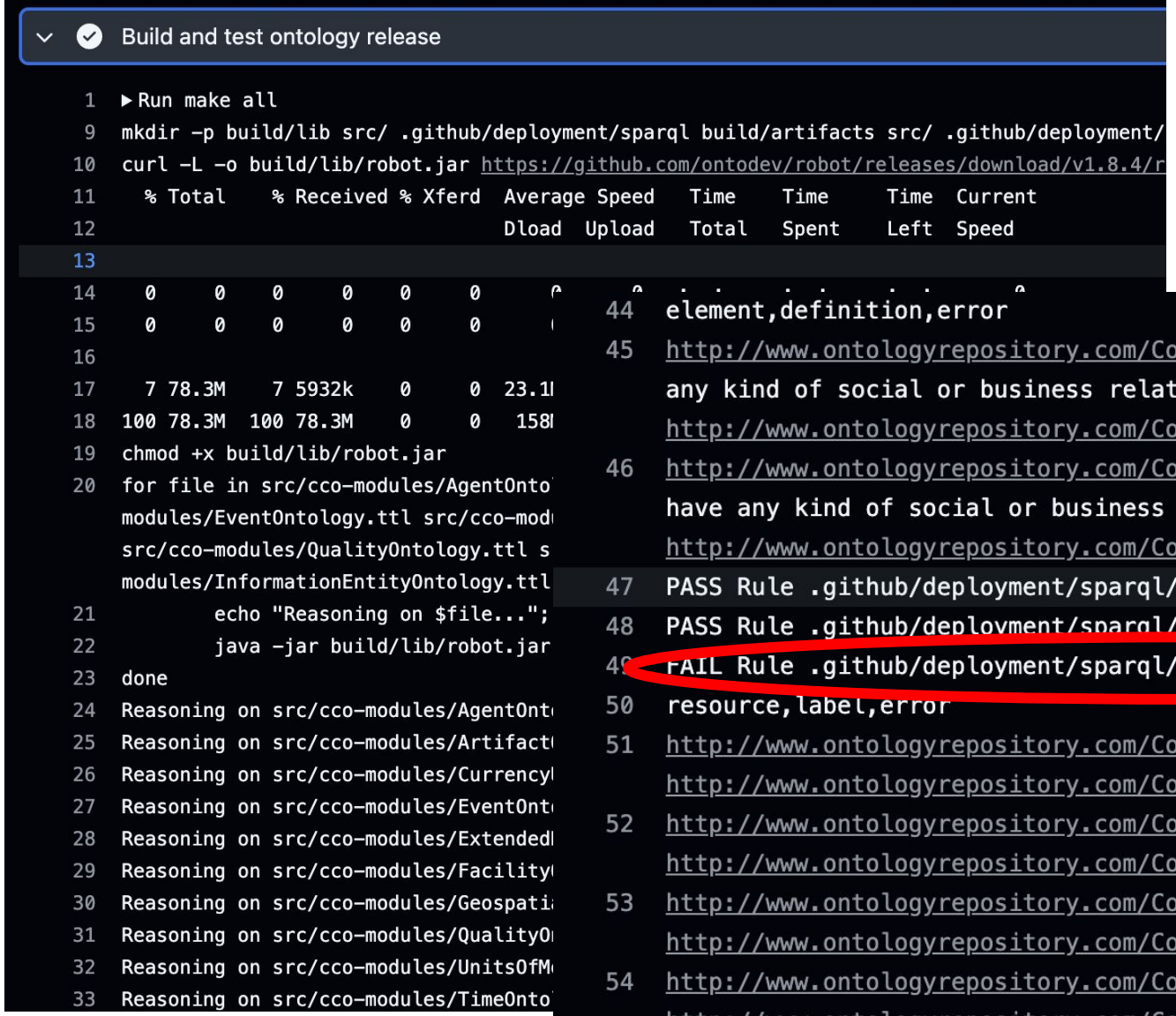

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```
element,definition,error
http://www.ontologyrepository.com/CommonCoreOntologies/has_affiliate,"x is_affiliated_with y iff x and y are
any kind of social or business relationship.",WARNING: The following ontology elements have the same cco:defi
http://www.ontologyrepository.com/CommonCoreOntologies/has_affiliate and http://www.ontologyrepository.com/Co
http://www.ontologyrepository.com/CommonCoreOntologies/is_affiliated_with,"x is_affiliated_with y iff x and y
have any kind of social or business relationship.",WARNING: The following ontology elements have the same cco
http://www.ontologyrepository.com/CommonCoreOntologies/is_affiliated_with and http://www.ontologyrepository.c
PASS Rule .github/deployment/sparql/duplicate_label.sparql: 0 violation(s)
PASS Rule .github/deployment/sparql/exactly_1_prefLabel_per_lang.sparql: 0 violation(s)
FAIL Rule .github/deployment/sparql/min_1_eng_def.sparql: 86 violation(s)
resource,label,error
http://www.ontologyrepository.com/CommonCoreOntologies/has_aunt,,WARNING: Missing definition for
http://www.ontologyrepository.com/CommonCoreOntologies/has_aunt
http://www.ontologyrepository.com/CommonCoreOntologies/has_brother,,WARNING: Missing definition for
http://www.ontologyrepository.com/CommonCoreOntologies/has_brother
http://www.ontologyrepository.com/CommonCoreOntologies/has_brother_in_law,,WARNING: Missing definition for
http://www.ontologyrepository.com/CommonCoreOntologies/has_brother_in_law
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http://www.ontologyrepository.com/CommonCoreOntologies/has_daughter
http://www.ontologyrepository.com/CommonCoreOntologies/has_daughter_in_law,,WARNING: Missing definition for
http://www.ontologyrepository.com/CommonCoreOntologies/has_daughter_in_law
http://www.ontologyrepository.com/CommonCoreOntologies/has_father,,WARNING: Missing definition for
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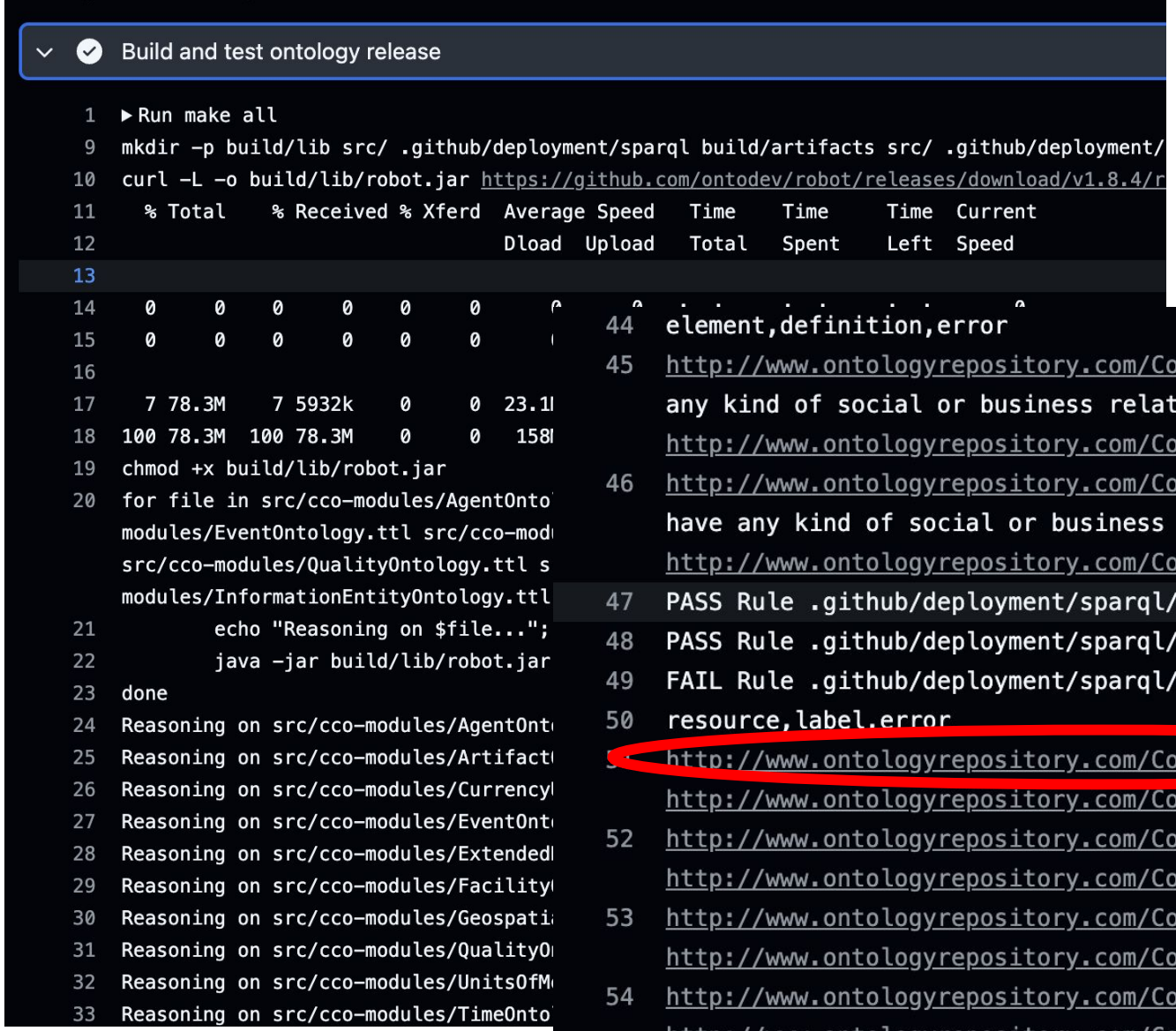
http://www.ontologyrepository.com/CommonCoreOntologies/has_father_in_law,,WARNING: Missing definition for
```



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```
44 element,definition,error
45 http://www.ontologyrepository.com/CommonCoreOntologies/has_affiliate,"x is_affiliated_with y iff x and y are
   any kind of social or business relationship.",WARNING: The following ontology elements have the same cco:defi
   http://www.ontologyrepository.com/CommonCoreOntologies/has_affiliate and http://www.ontologyrepository.com/Co
46 http://www.ontologyrepository.com/CommonCoreOntologies/is_affiliated_with,"x is_affiliated_with y iff x and y
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47 PASS Rule .github/deployment/sparql/duplicate_label.sparql: 0 violation(s)
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49 FAIL Rule .github/deployment/sparql/min_1_eng_def.sparql: 86 violation(s)
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52 http://www.ontologyrepository.com/CommonCoreOntologies/has_brother,,WARNING: Missing definition for
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53 http://www.ontologyrepository.com/CommonCoreOntologies/has_brother_in_law,,WARNING: Missing definition for
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54 http://www.ontologyrepository.com/CommonCoreOntologies/has_daughter,,WARNING: Missing definition for
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56 http://www.ontologyrepository.com/CommonCoreOntologies/has_father,,WARNING: Missing definition for
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57 http://www.ontologyrepository.com/CommonCoreOntologies/has_father_in_law,,WARNING: Missing definition for
```

https://www.ontologyrepository.com/CommonCoreOntologies/has_aunt

This XML file does not appear to have any style information associated with it. The document tree is shown below.

```
▼<rdf:RDF xmlns="http://www.w3.org/2002/07/owl#" xmlns:owl="http://www.w3.org/2002/07/owl#" xmlns:rdf="http://www.w3.or
 xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#" xmlns:CommonCoreOntologies="http://www.ontologyrepository.com/Commo
   <Ontology/>
   <!--
       ///////////////////////////////////////////////////////////////////////////////////////
       //
       // Annotation properties
       //
       ///////////////////////////////////////////////////////////////////////////////////////
         -->
   <!--  http://www.ontologyrepository.com/CommonCoreOntologies/is_curated_in_ontology  -->
   <AnnotationProperty rdf:about="http://www.ontologyrepository.com/CommonCoreOntologies/is_curated_in_ontology"/>
   <!--
       ///////////////////////////////////////////////////////////////////////////////////////
       //
       // Object Properties
       //
       ///////////////////////////////////////////////////////////////////////////////////////
         -->
   <!--  http://www.ontologyrepository.com/CommonCoreOntologies/has_aunt  -->
  ▼<ObjectProperty rdf:about="http://www.ontologyrepository.com/CommonCoreOntologies/has_aunt">
     <rdfs:subPropertyOf rdf:resource="http://www.ontologyrepository.com/CommonCoreOntologies/has_familial_relationship_
     <inverseOf rdf:resource="http://www.ontologyrepository.com/CommonCoreOntologies/is_aunt_of"/>
     <CommonCoreOntologies:is_curated_in_ontology
     rdf:datatype="http://www.w3.org/2001/XMLSchema#anyURI">http://www.ontologyrepository.com/CommonCoreOntologies/Mid/A
     <rdfs:label xml:lang="en">has aunt</rdfs:label>
   </ObjectProperty>
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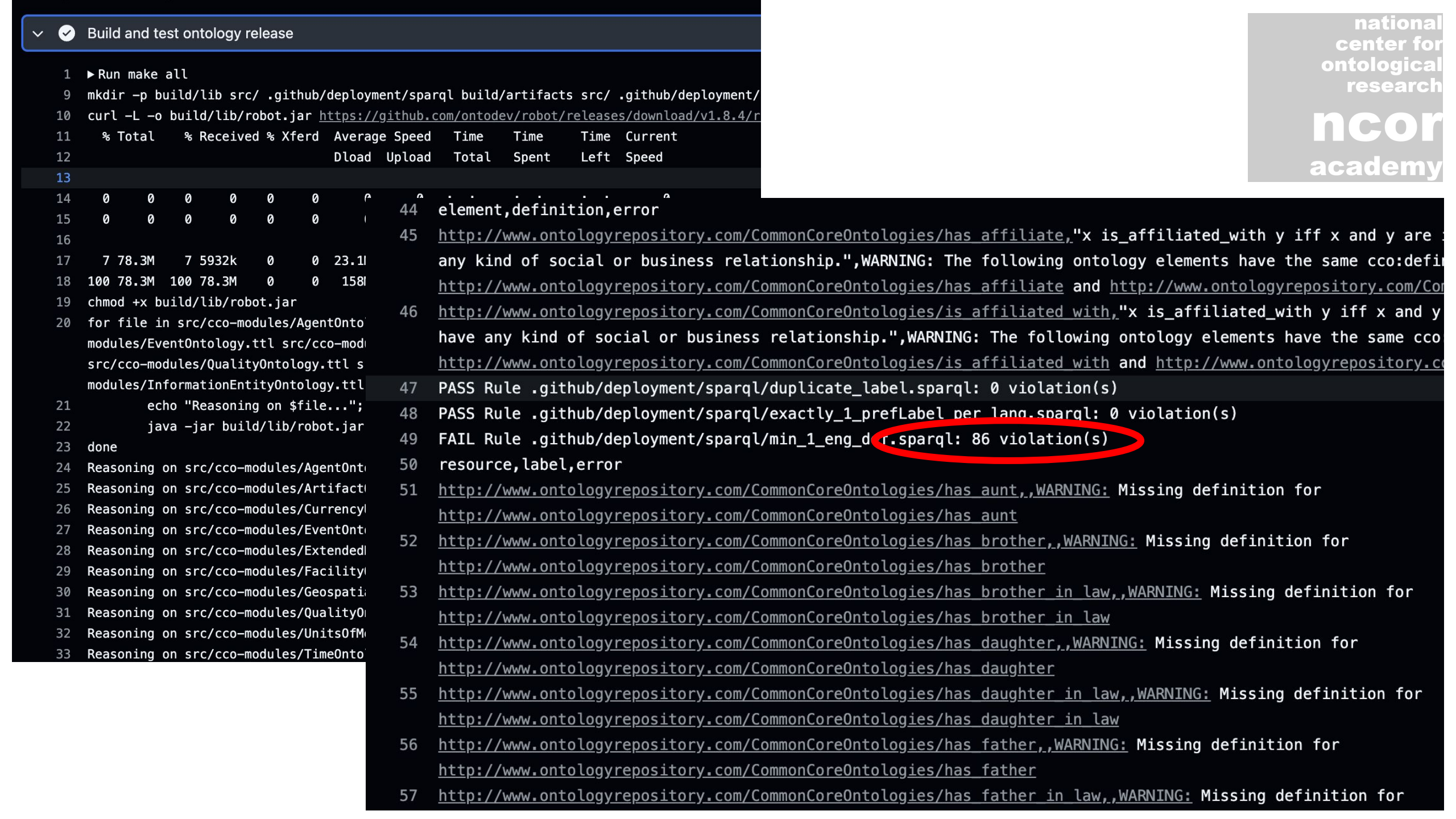
   <ObjectProperty rdf:about="http://www.ontologyrepository.com/CommonCoreOntologies/has_familial_relationship_to"/>
   <!--  http://www.ontologyrepository.com/CommonCoreOntologies/is_aunt_of  -->
   <ObjectProperty rdf:about="http://www.ontologyrepository.com/CommonCoreOntologies/is_aunt_of"/>
 </rdf:RDF>
 <!--  Generated by the OWL API (version 4.5.6) https://github.com/owlcs/owlapi  -->
```



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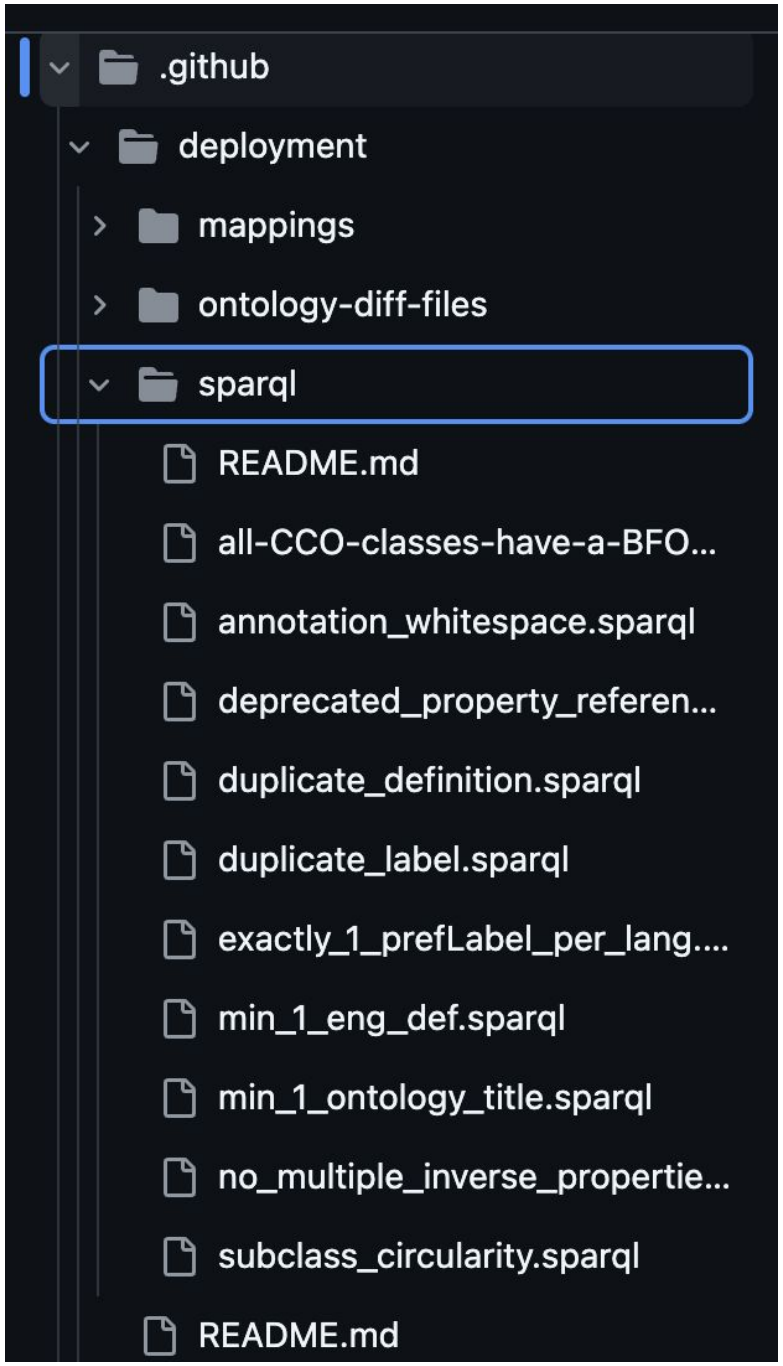

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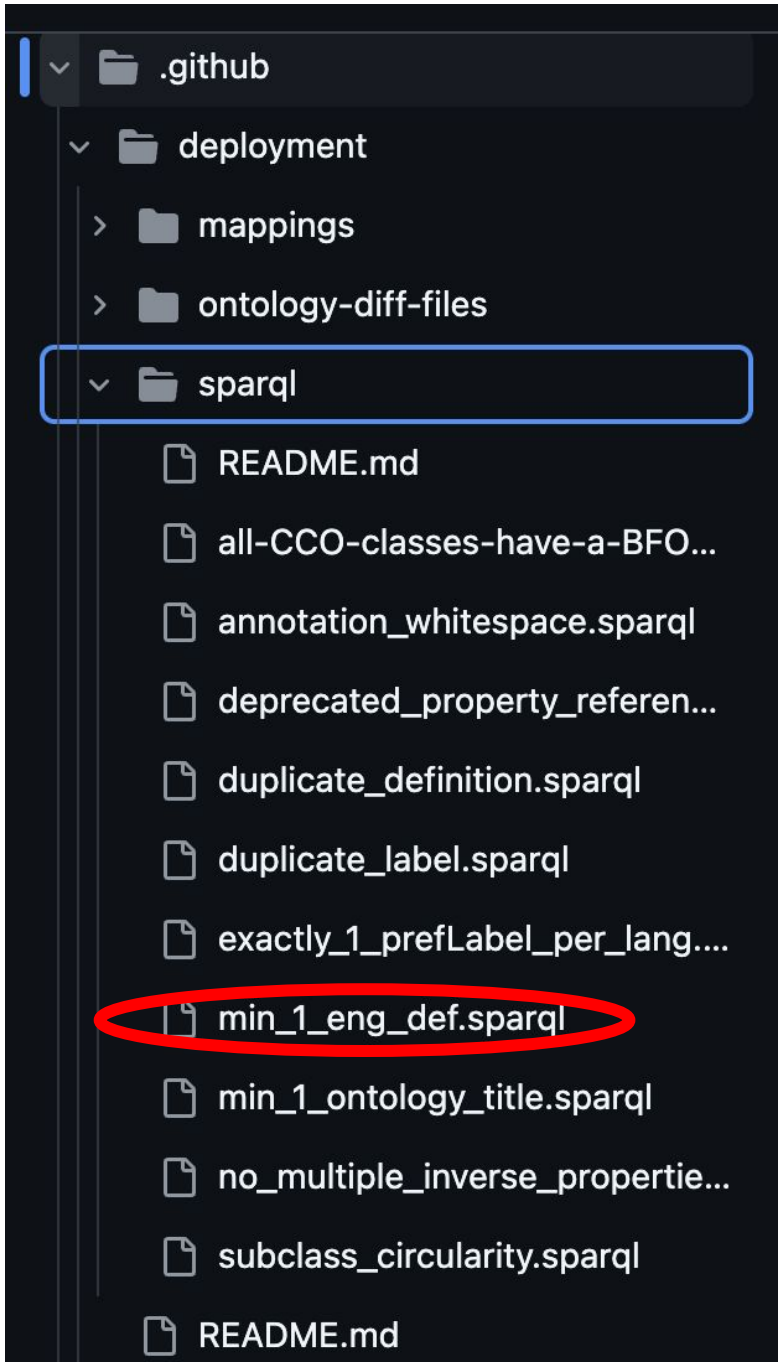

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```
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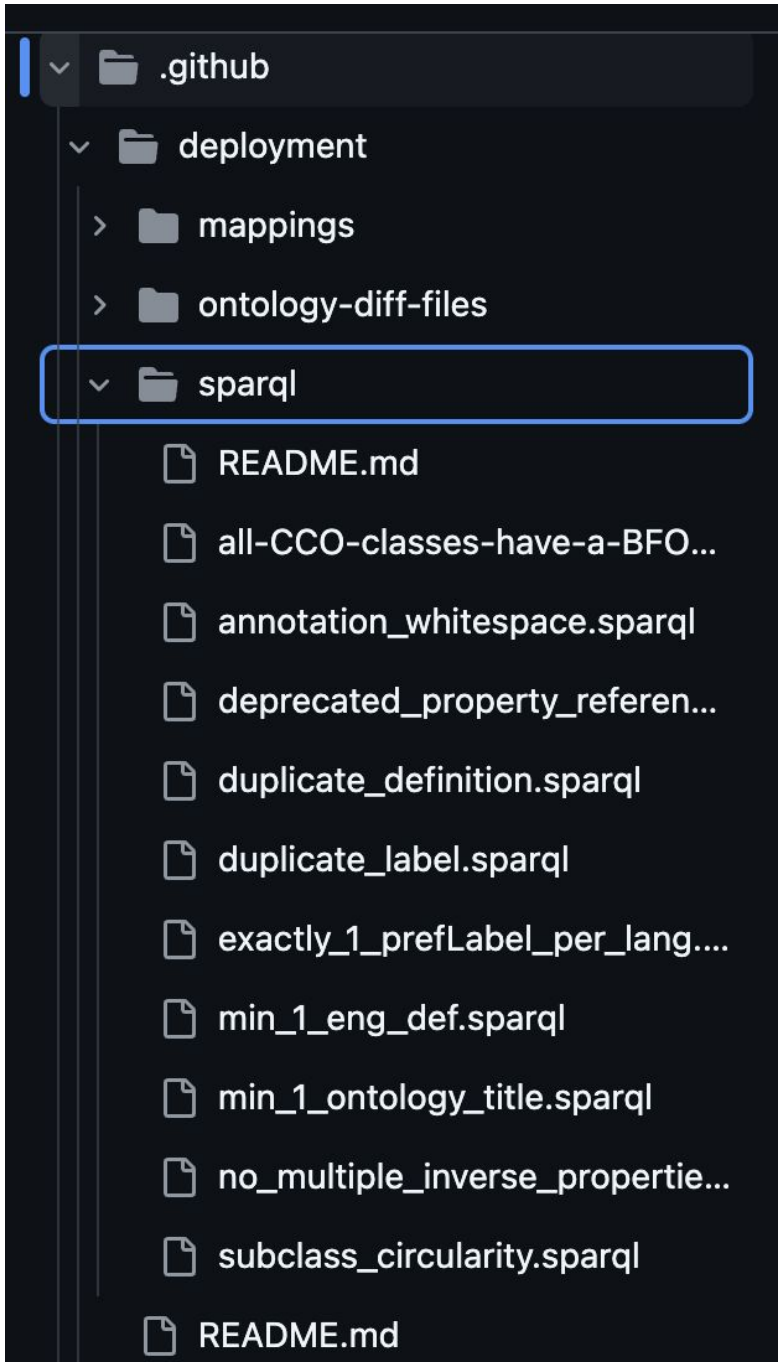
#    Definition Required
# Constraint Description:
#    Any class or object property must have a non-empty definition with an English language tag.
# Severity:
#     Warning

PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX cco: <http://www.ontologyrepository.com/CommonCoreOntologies/>

SELECT DISTINCT ?resource ?label ?error
WHERE {
VALUES ?type {owl:Class owl:ObjectProperty}
    ?resource a ?type .
    OPTIONAL {
        ?resource cco:definition ?englishDefinition .
        FILTER (langMatches(lang(?englishDefinition), "en"))
        }
    FILTER(!bound(?englishDefinition))
    FILTER(!isBlank(?resource))
    BIND (concat("WARNING: Missing definition for ", str(?resource)) AS ?error)
}
ORDER BY ?resource
```

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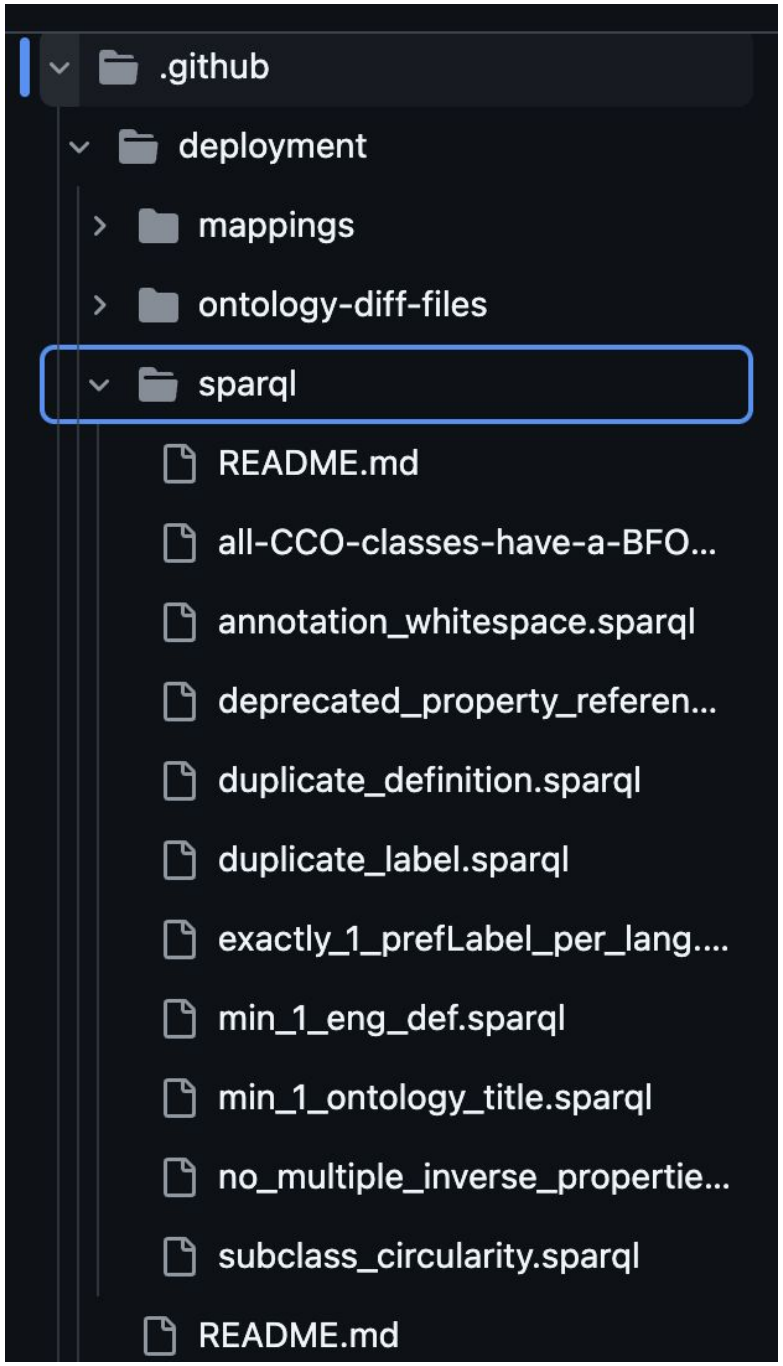


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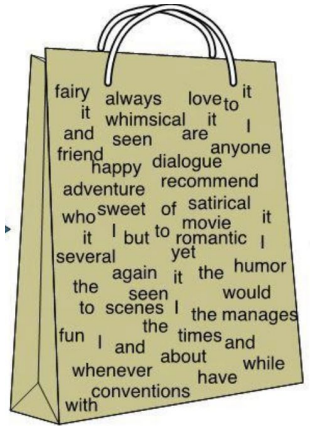
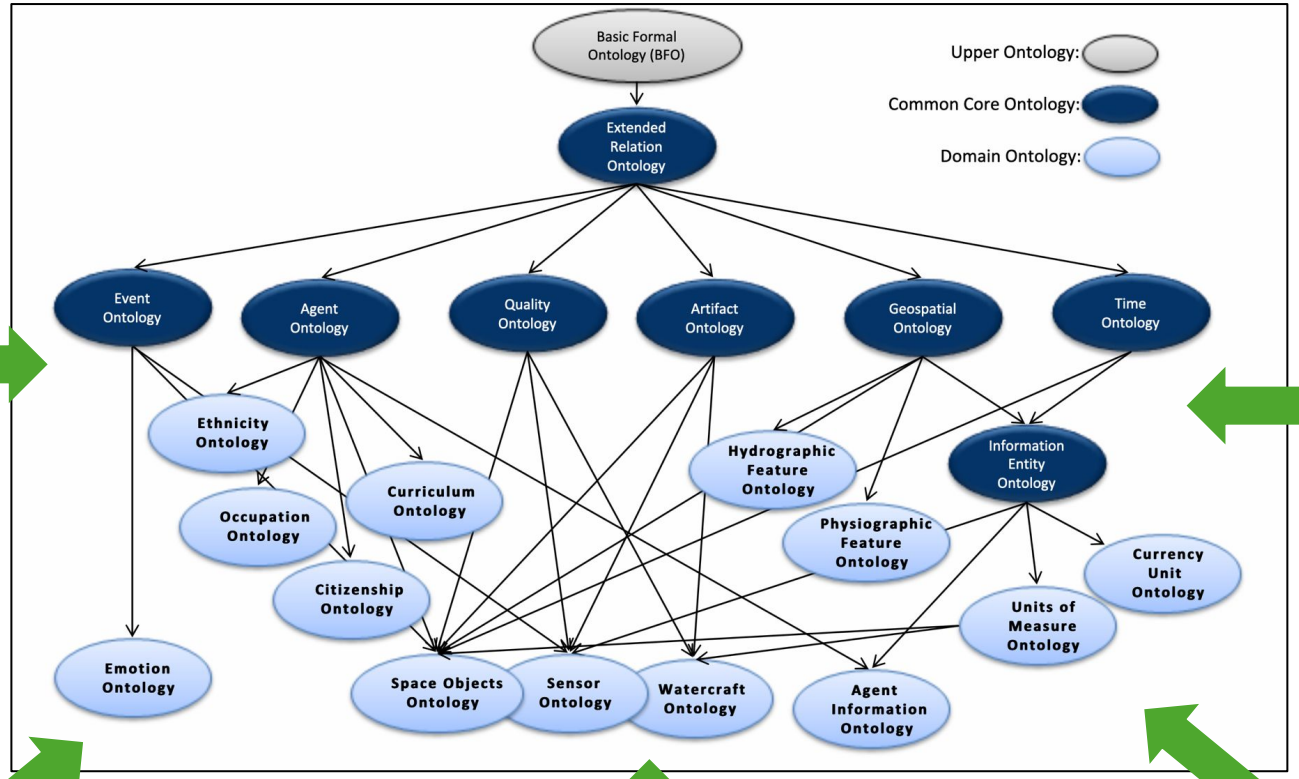
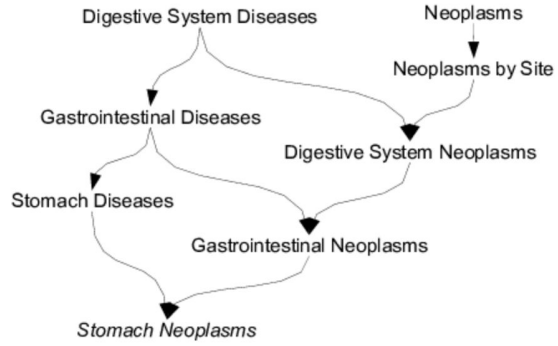
Outline

- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem
  - Application
  - Workflow
  - Collaboration
  - R&D
  - Education

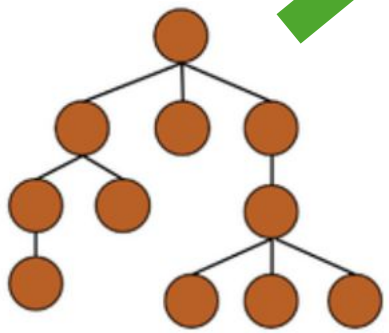


Bag of Words

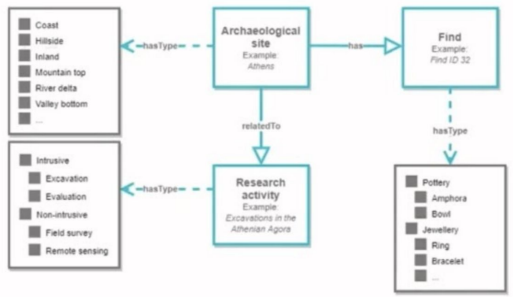




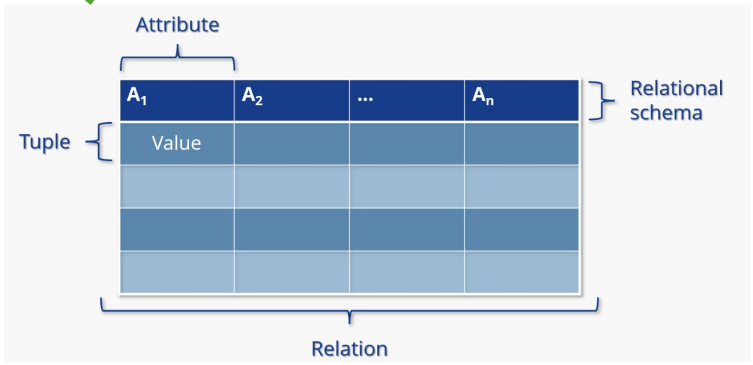
Thesaurus



Ontology



Controlled Vocabulary

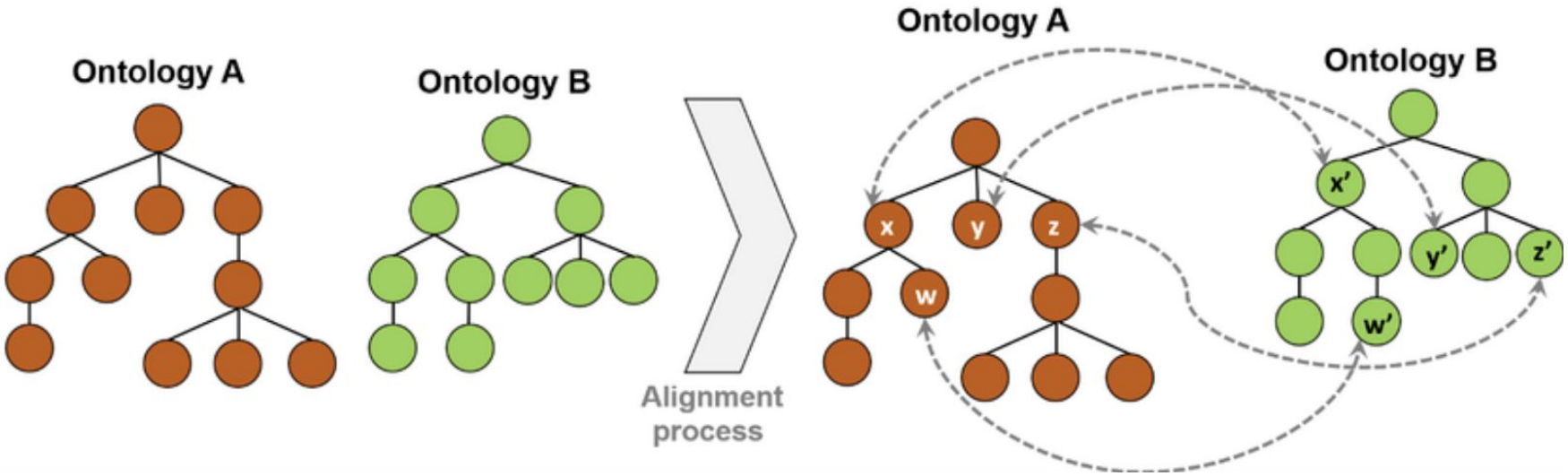


Relational Database

Caveat: Mono-Ontology Myth

- Insisting on a single ontology standard used by everyone **is unwise**

- The point is, rather, that progress towards interoperability can be made by leveraging suites of ontologies with common semantics which adopt wise design principles of the sort exhibited in the BFO community



Pop Quiz

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- For so long there have been disputes in our community over, say, which top-level ontology to use

Suppose you are tasked with combining two top-level ontologies

Pop Quiz

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- For so long there have been disputes in our community over, say, which top-level ontology to use

Suppose you are tasked with combining two top-level ontologies

Pick your favorites

Outline how you would proceed

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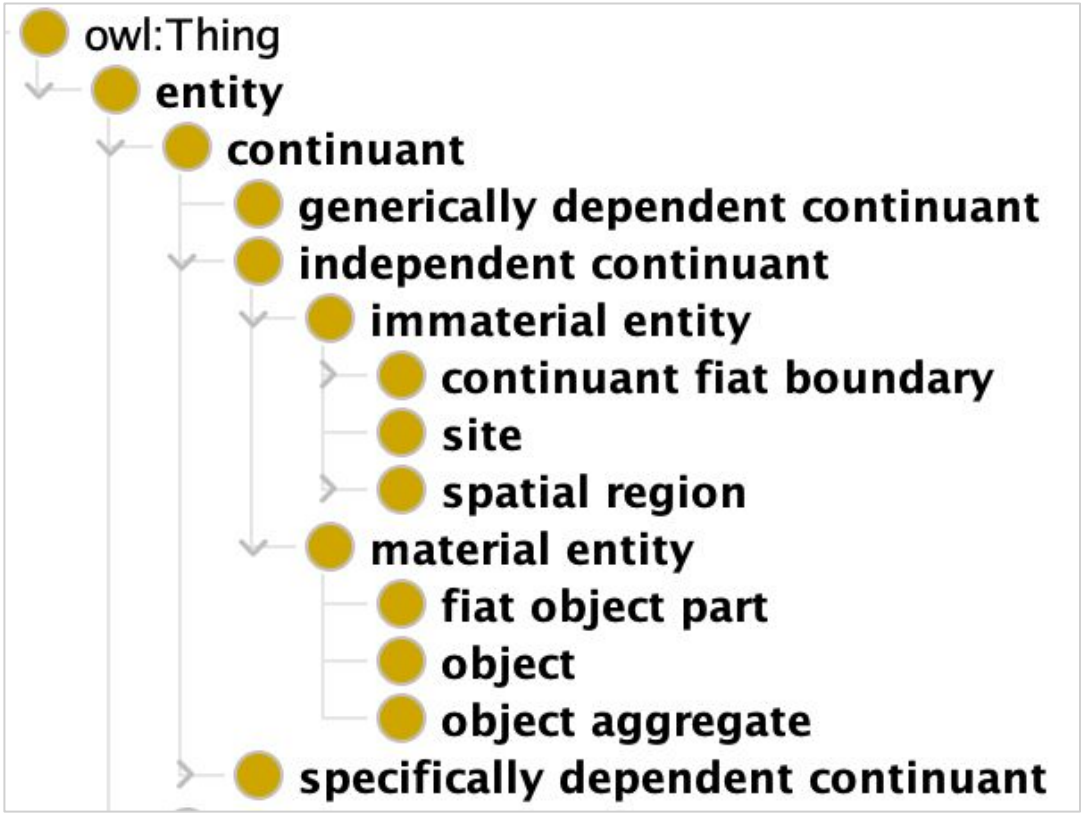
The choice of top-level does not matter as much as you might think

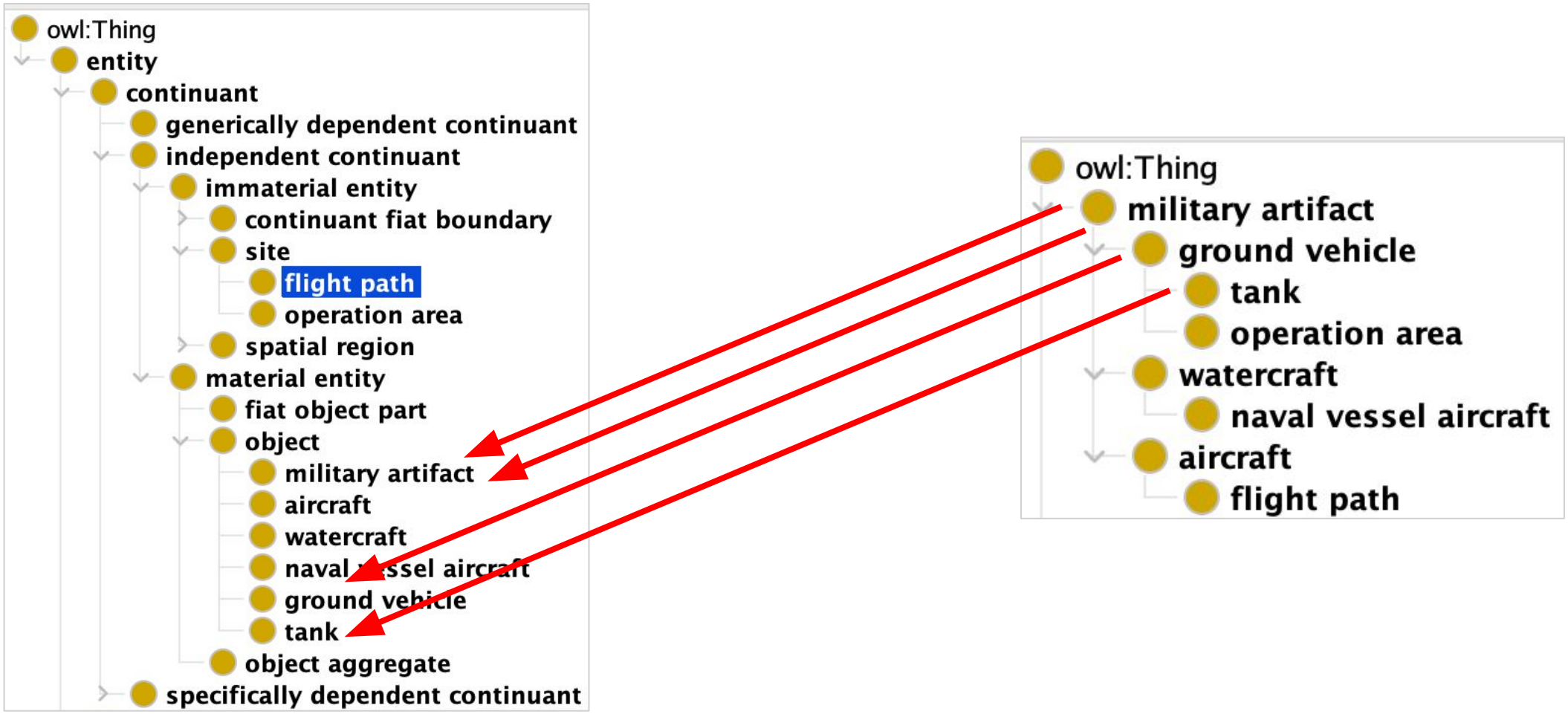
Generating Implicit Hierarchy



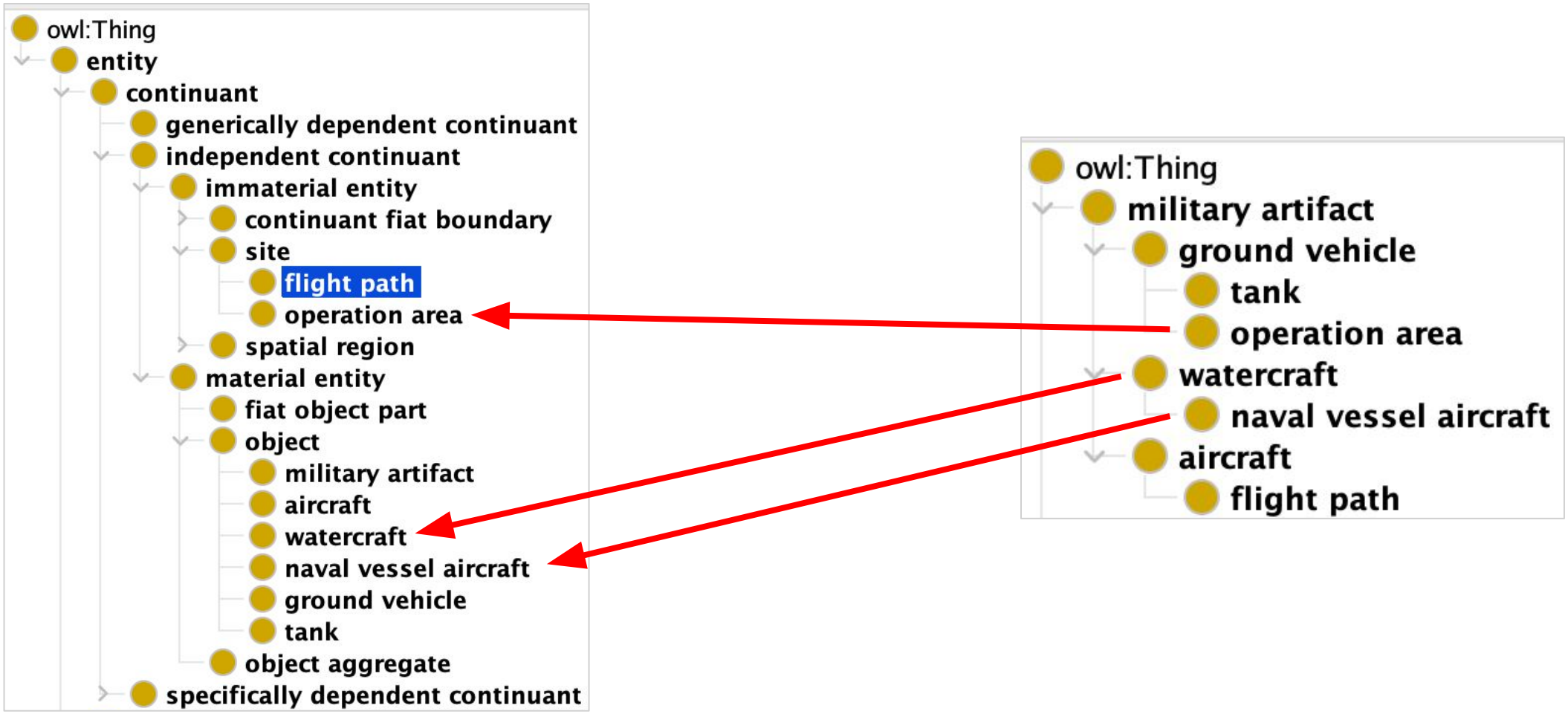
≠

Suppose there is a need to maintain an application ontology that is not aligned to BFO

Generating Implicit Hierarchy



Generating Implicit Hierarchy



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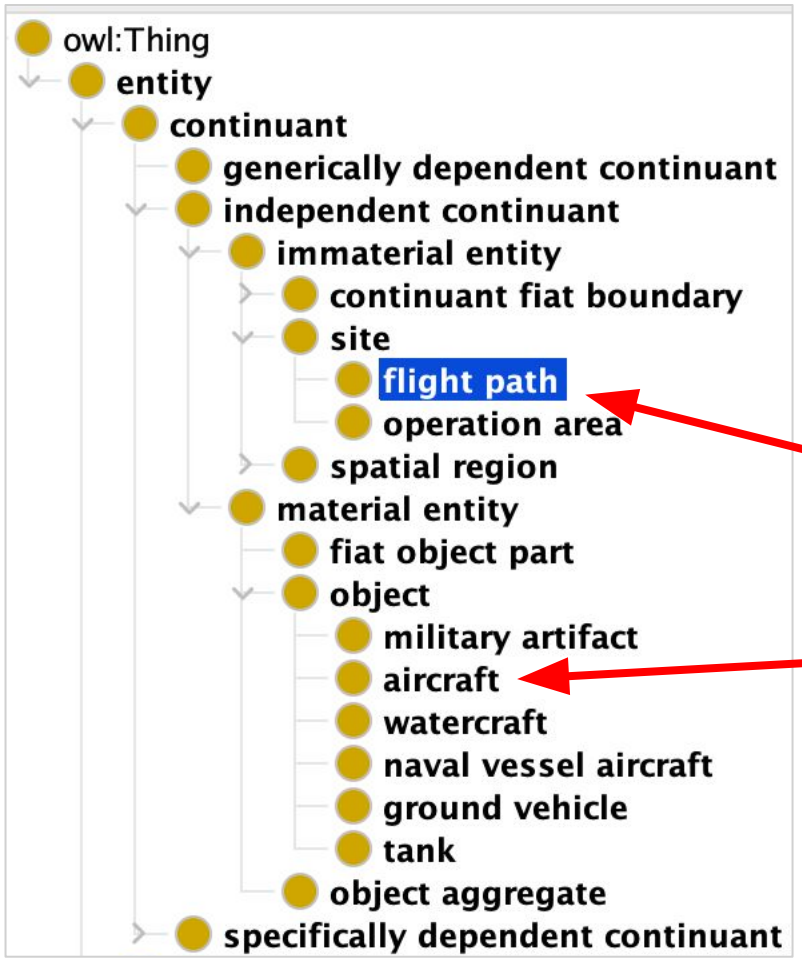

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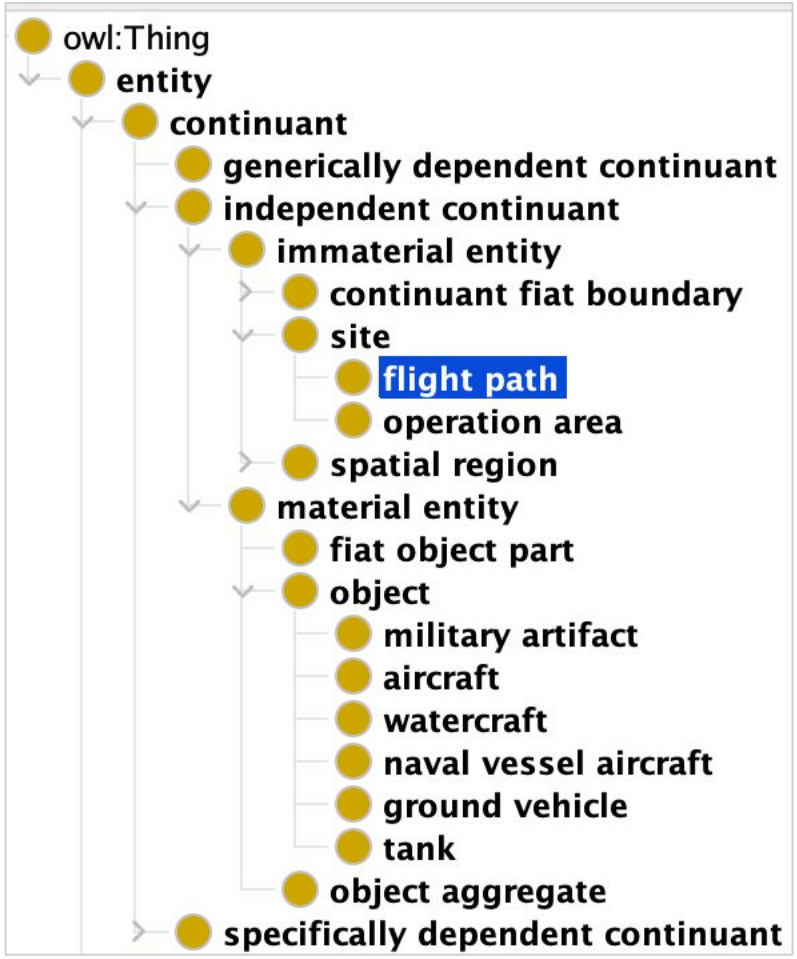


≠

military taxonomy relation

- One way forward is to introduce an object property – call it **military taxonomy** – that connects instances of the reference ontology to those of the military artifact class

- To simulate the **subclass of** relation, we assert that **military taxonomy** is **reflexive** and **transitive**

- And is such that any entity in the domain can be related **only** to instances under military artifact

Reflexivity

- For all x, x is related to x

THING

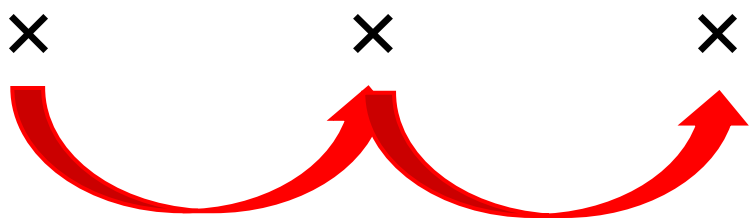
$$\{(x,x) \mid x \in \text{Domain}\} \subseteq R^I$$

Transitivity

- If x related to y and y related to z, then x related to z

THING

$$\mathbf{Trans(R) = R^I \circ R^I \subseteq R^I}$$



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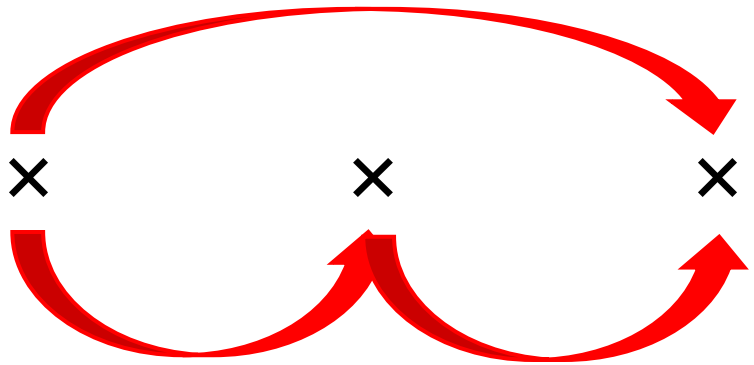
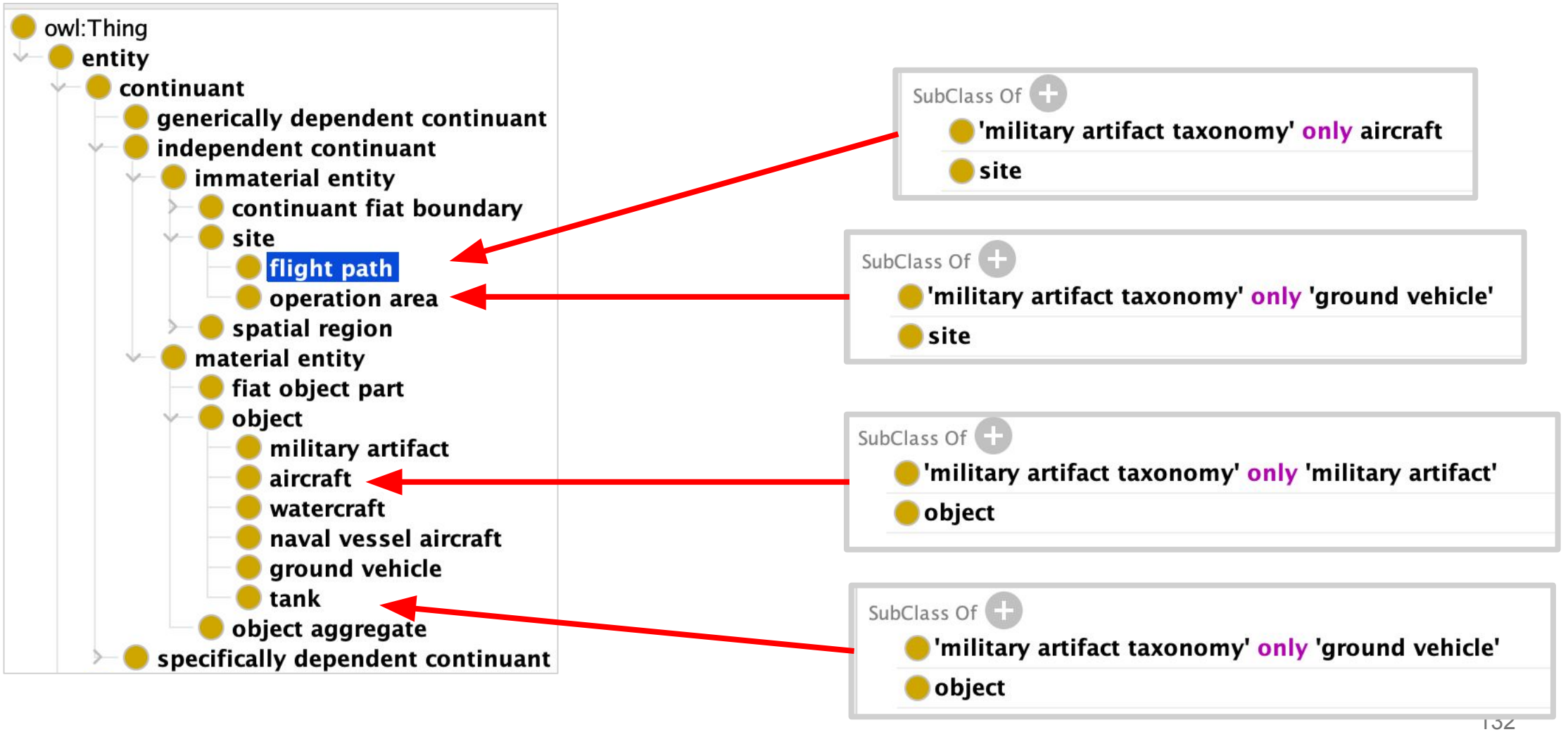


Generating Implicit Hierarchy



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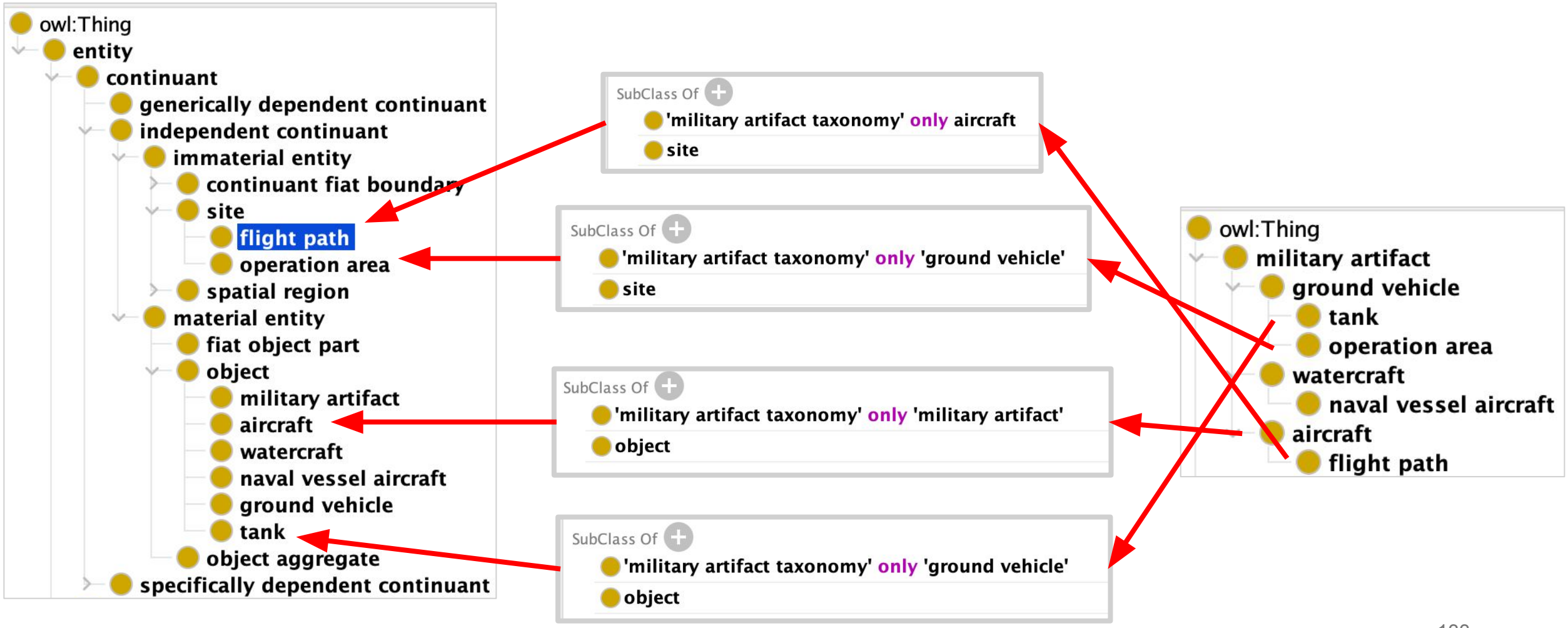

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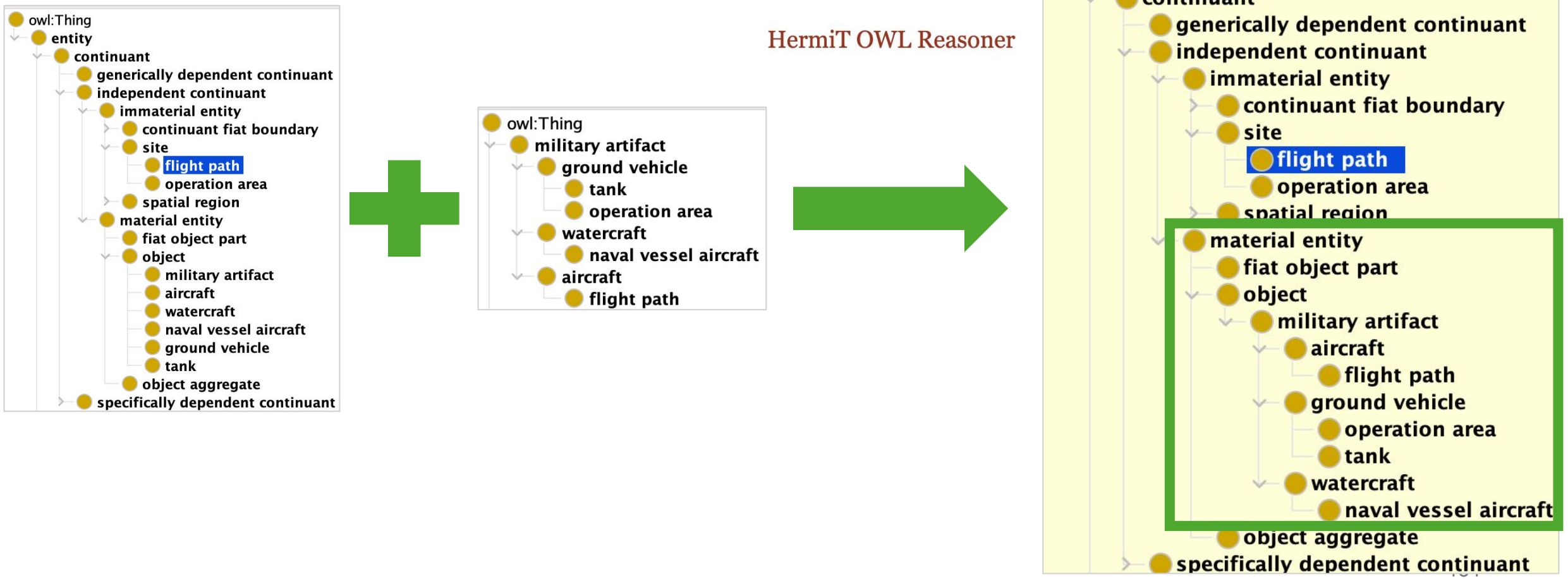
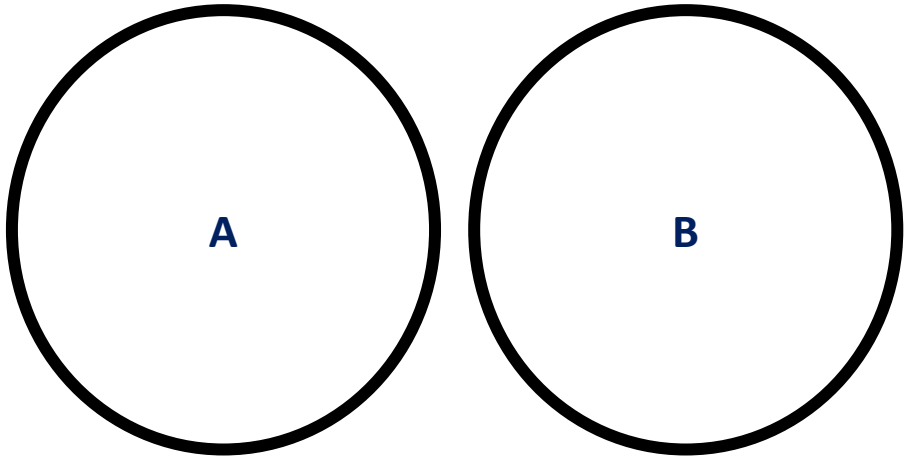


Caveat: Disjointness

- Disjointness – A and B are disjoint just in case they share no individuals

THING

$$\mathbf{DisjointWith(A, B) = A^I \cap B^I = \varnothing}$$



Caveat: Disjointness Must be Dropped

- In BFO, the class **site** and the class **object** are **disjoint**, which means they may share no instances in common

- Consequently, **operation area** cannot – strictly speaking – be an asserted subclass of **object** and inferred subclass of **site**

- Importantly, such constraints should be understood as applying at the level of reference ontologies, **not necessarily** application ontologies

Real-World Ontology Engineering

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- Converting across top-level perspectives using reasoning requires deviating slightly from semantic commitments

- But **most implementations** of ontologies **do not even leverage** the full – albeit limited – semantics of OWL

- Those rare cases where the full semantics are needed can be handled on a case by case basis

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CONFIGURATION MANAGEMENT

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Outline

- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem
  - Application
  - Workflow
  - Collaboration
  - R&D
  - Education

Semantic Web Vulnerabilities

- I have been exploring the space of vulnerabilities stemming from:
  - **SPARQL Injections patterned on SQL Injections**
  - **Semantic Web DevOps vulnerabilities**
  - **Logic-Based Exploits**
- There is **very little** literature on semantic web vulnerabilities

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SQL Injection

- 'Injecting' SQL into a database via input fields from the client-side

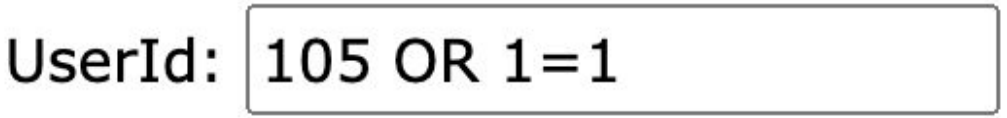
- Suppose you navigate to a website and input a user ID to a field to return a username; this might generate a SQL query like:

```
SELECT *
FROM Users
WHERE UserId = '" + txtUserId + "'
```

- For a given row in the database, if "row = `txtUserId`" is true, then the username is returned

SQL Injection

- If users are allowed to enter whatever input they like in the field, one might enter, say, user ID "105" alongside:



- Generating the SQL query:

```
SELECT *
FROM Users
WHERE UserId = 105 OR 1=1;
```

- Which would return *all* rows since "105 OR 1=1" is trivially true

SPARQL Injection

- 'Injecting' SPARQL into a database via input fields from the client-side

- Suppose you navigate to a website and input a user ID to a field to return a credit card number; this might generate a SPARQL query like:

```
SELECT *
WHERE {?uri ex:UserId = 'txtUserId' ;
            ex:credit_card_number ?cc . }
```

- Which returns any triples matching `txtUserId` with a credit card number

SPARQL Injection

- Suppose instead of `txtUserId` a user writes `‘“ . }#’` resulting in the following SPARQL query in the backend:

```
SELECT *
WHERE {?uri ex:UserId = ‘“ . }#’ .
            ex:credit_card_number ?cc . }
```

- Where # comments out the rest of the query, which may result in unexpected behavior, such as all credit cards numbers being returned

Semantic Web Vulnerabilities

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Pop Quiz

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Consider for a moment how you typically work with and work on ontologies as an ontology engineer

Pop Quiz

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Consider for a moment how you typically work with and work on ontologies as an ontology engineer

- Some guidance:
  - What ontologies do you use?
  - Where do you store your created ontologies?
  - What tools do you use to interface with them?

RDF Vulnerability Scenarios

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- **Scenario A**
  - A malicious actor opens a pull request on GitHub that includes annotation properties with malicious code.
  - Using standard techniques for hiding the malicious code from the diff, the pull request is eventually merged.

- **Scenario B**
  - An individual uses Protege to open an ontology by a URL.
  - The user does not realize that an obsoleted class has an annotation property whose content is malicious code.

Semantic Web Vulnerabilities

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Case Study: Air Traffic Ontology

- *"An Ontology for Decision-Making Support in Air Traffic Management"*

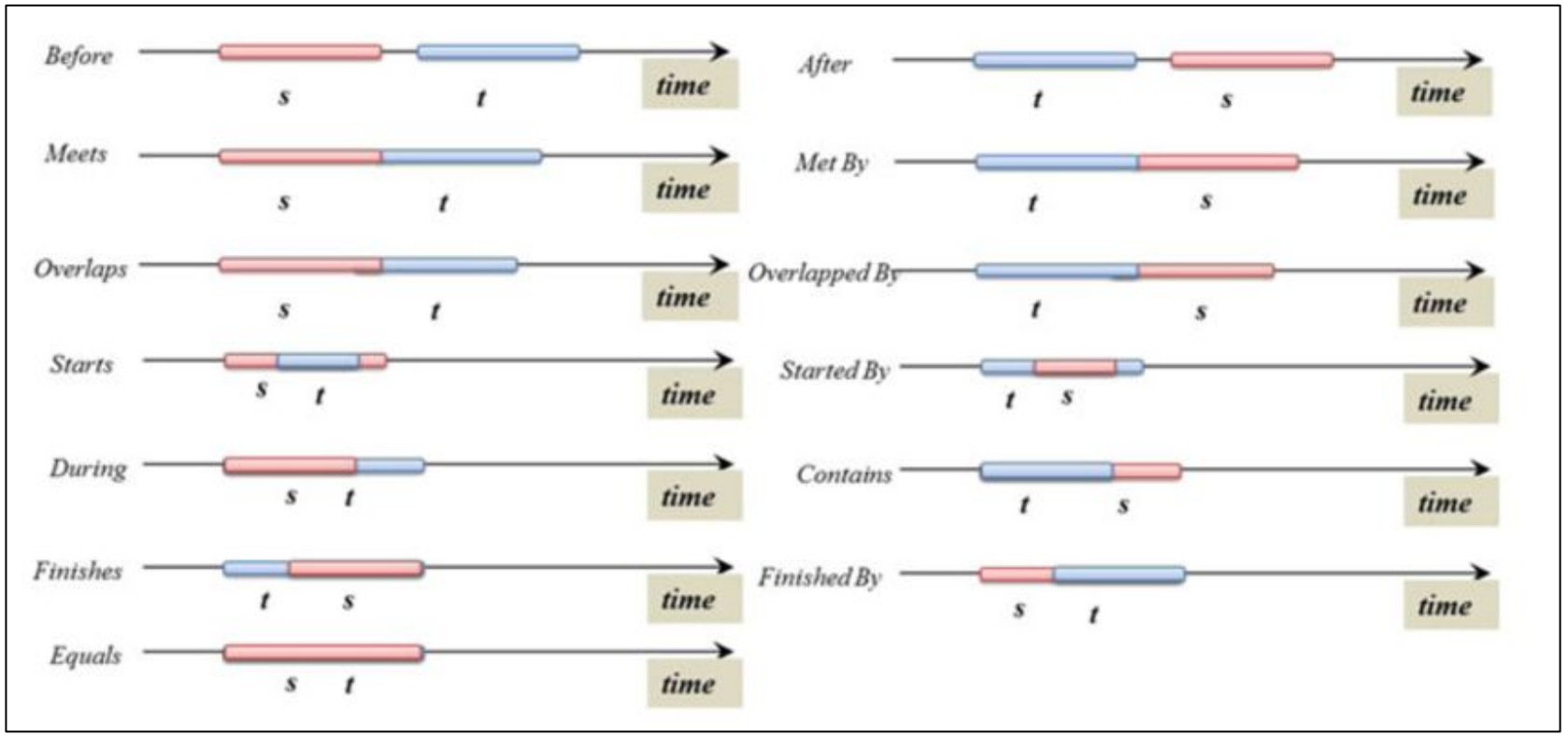
- Authors touted SWRL rule as a test of the accuracy of the ATM ontology

$$FourDTrajectory(?tr1) \wedge hasFlightRouteElement(?tr1, ?re1) \wedge$$
$$hasTrajectoryPoint(?re1, ?pd1) \wedge hasTime(?pd1, ?t1) \wedge hasRoutePoint(?pd1, ?r)$$
$$\wedge ThunderStorm(?th2) \wedge hasForcast(?th2, ?fc2) \wedge hasTime(?th2, ?t2)$$
$$\wedge hasAffectedArea(?th2, ?aa) \wedge TemporalConflict(?t1, ?t2)$$
$$\wedge SpatialConflict(?aa, ?r) \rightarrow conflictWith(?tr1, ?th2).$$

- If a given trajectory intersects in space and time with the trajectory of a thunderstorm, then that conflict is recorded in the ontology

Allen Interval Relations

- The authors claim the SWRL rule is based on the Allen Interval Relations, **but these relations can't be formally expressed in OWL**



Allen Interval Relations

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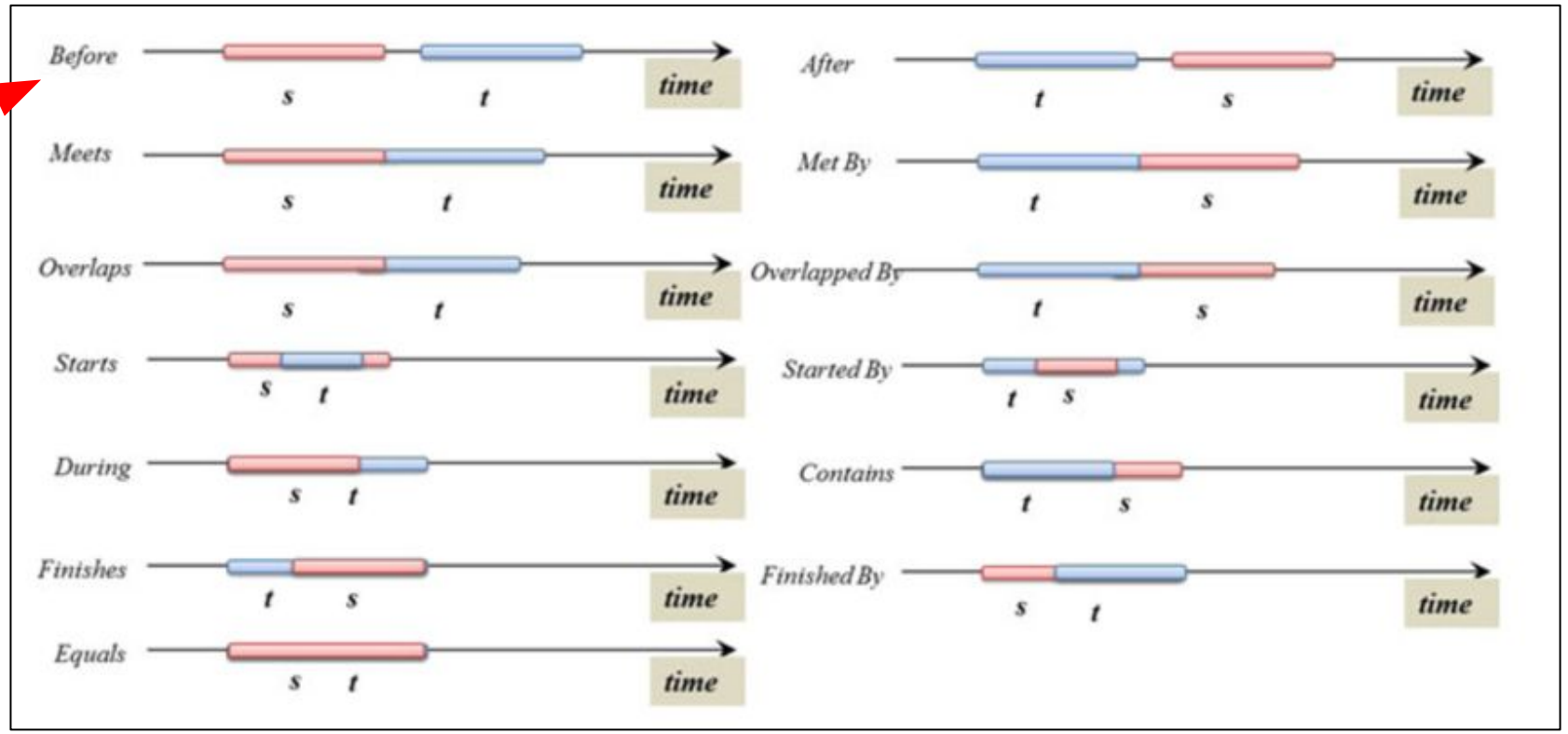
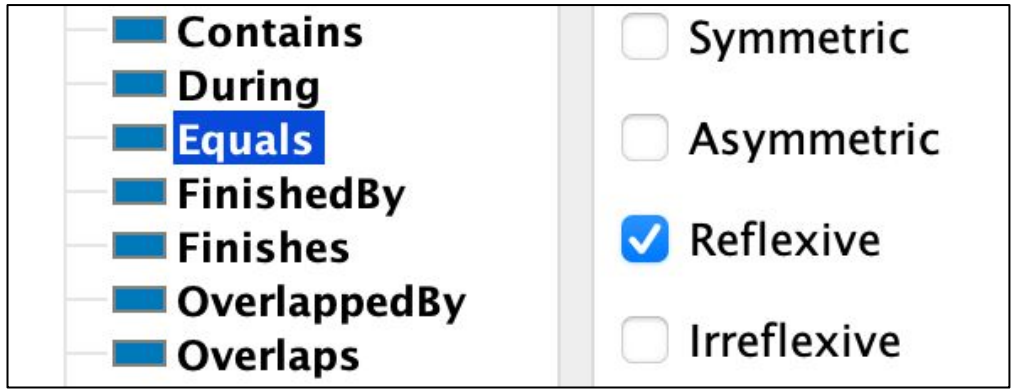
E.g. irreflexive & transitive, but asserting so would result in a non-simple role chain



Interval Equals

- Observe that *equals* – one of Allen's relations – is plausibly **reflexive**

- In OWL2, asserting reflexivity of an object property applies **globally**



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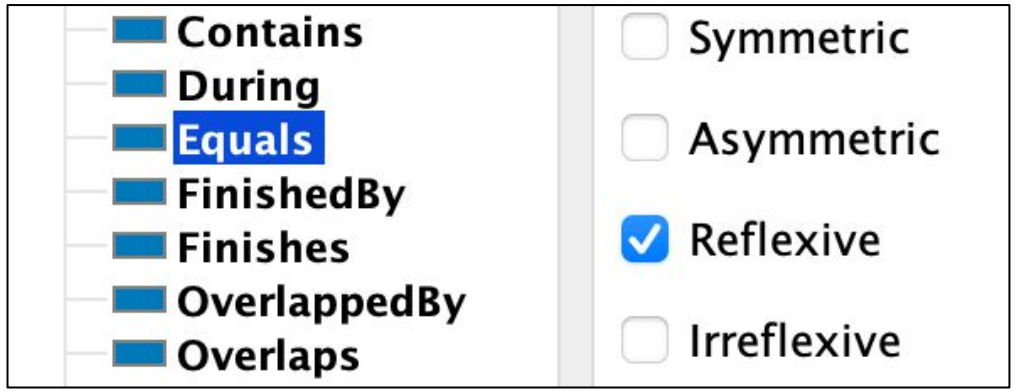
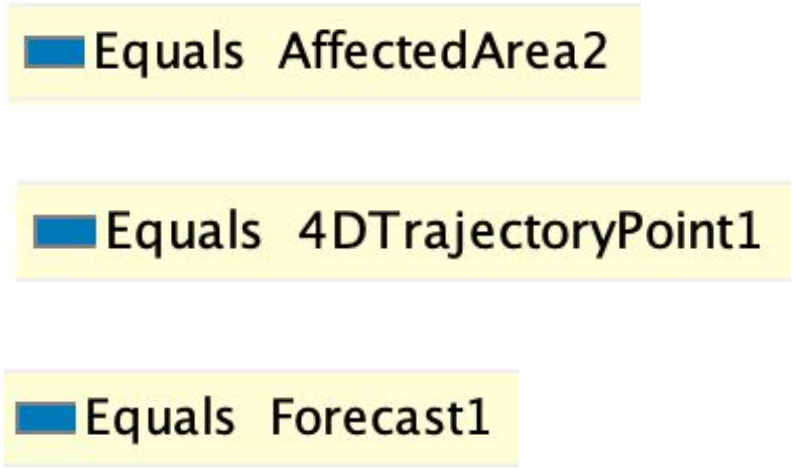
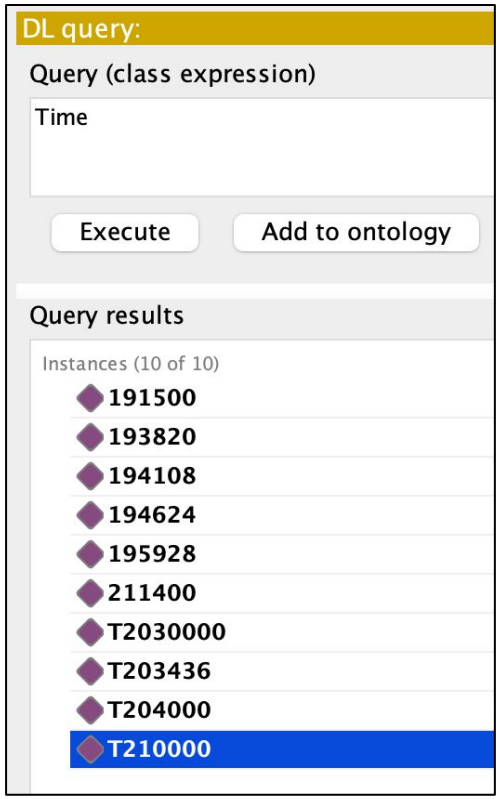




Interval Equals

- Restricting the domain and range of interval *equals* does not help, e.g. if restricted to Time, then every instance falls under Time

equals *is not reflexive* but has domain/range Time



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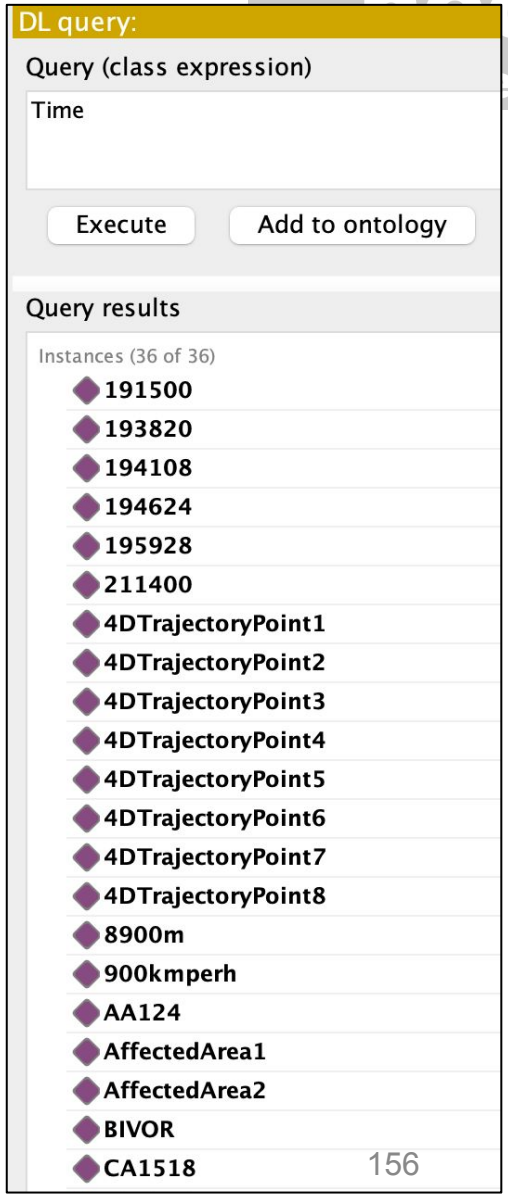

Red Team Attack

- By using SPARQL to inject reflexivity on *equals*, it will follow that...

- For every instance x in the ontology, there are triples

  x *TemporalConflict* x
  x *SpatialConflict* x

- Resulting in the SWRL antecedent satisfied

$$FourDTrajectory(?tr1) \wedge hasFlightRouteElement(?tr1, ?re1) \wedge$$
$$hasTrajectoryPoint(?re1, ?pd1) \wedge hasTime(?pd1, ?t1) \wedge hasRoutePoint(?pd1, ?r)$$
$$\wedge ThunderStorm(?th2) \wedge hasF\ldots ast(?th2, ?f\ldots 2) \wedge hasTime(?th2, ?t2)$$
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Outline

- Ontology Engineering
- BFO Methodological Convictions
- Fitting into the BFO Ecosystem
  - Application
  - Workflow
  - Collaboration
  - R&D
  - Education

Rhetorical Query

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Where can you find support to learn SQL?

Rhetorical Query

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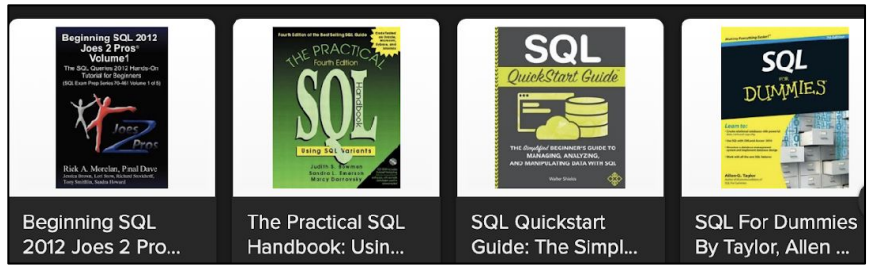
Where can you find support to learn SQL?

Everywhere



Rhetorical Query

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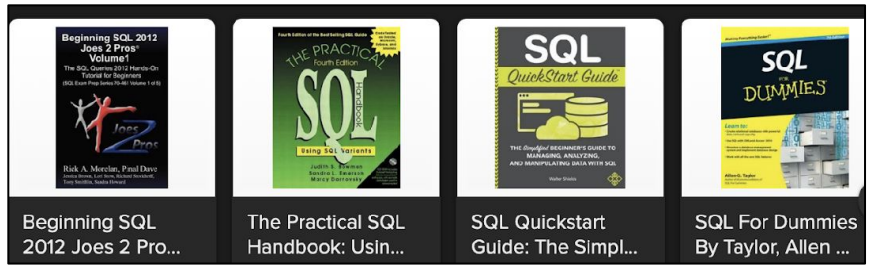

Where can you find support to learn SPARQL?

Rhetorical Query

Where can you find support to learn SQL?

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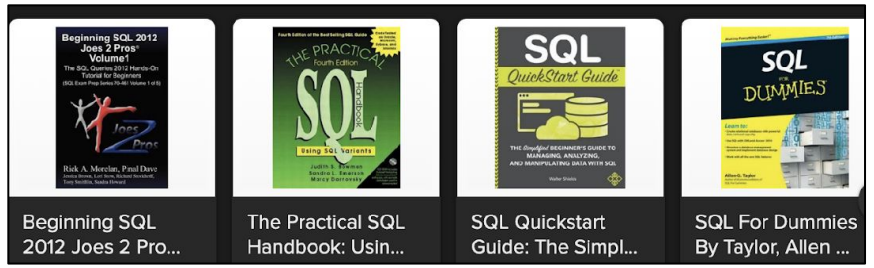

Where can you find support to learn SPARQL?

Good Luck

SPARQL Education

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- Competency with SPARQL is *crucial* for using ontologies and knowledge graphs in many real-world applications

- Comprehending SPARQL can be challenging; developing competency with SPARQL requires dedicated study

- Which can be eased through **gamification** of the sort exhibited on programming training sites such as Codewars

https://www.codewars.com

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WELL I HOPE YOU LIKE GOOD NEWS

The Project #4

The SPARQL Library of Buffalo

Codewars is a website designed to facilitate algorithmic training for various programming languages. Users supply problem statements and others provide coding solutions to those problems. For example, you might find a problem for Python such as:

```
Define a function that returns the length of a given string.
```

With a solution like:

```
def length_of_string(s):
        return len(s)
```

Codewars is not limited to traditional programming languages like Python, but also facilitates training for languages like SQL. As you have learned, SQL and SPARQL are both query languages, but what might surprise you is that there is currently no option for training SPARQL in Codewars. This project will go some way to remedy that.

For this project, you will be tasked with constructing SPARQL problems for the codewars site.

The Project #4

Spring 2023
Logic for Ontologists
Seminar

national center for ontological research
ncor academy

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All that was needed, was **the problem sets**, or 'kata'

Being an uncle of someone depends on certain parent-child relationships, and not the other way around. This is a useful relationship to derive instead of adding as a separate fact (or "materialized inference") in a database, which would need to be kept consistent with the parent-child relationships.

Given a set of pairs of individuals who are related by the "parent of" relationship, find all pairs of individuals who are related by the "uncle of" relationship.

RDF Data:

```
@prefix : <http://example.com/family-tree#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .

:parentOf rdf:type owl:ObjectProperty .

:Grandpa_Ted  rdf:type owl:NamedIndividual ;
              :parentOf :Jim ,
                        :Bob .

:Jim  rdf:type owl:NamedIndividual ;
      :parentOf :Jimmy .

:Bob  rdf:type owl:NamedIndividual ;
      :parentOf :Bobby .

:Bobby rdf:type owl:NamedIndividual .

:Jimmy rdf:type owl:NamedIndividual .
```

All that was needed, was **the problem sets**, or 'kata'

Accompanied by solutions and tests

Initial Solution:

```
PREFIX : <http://example.com/family-tree#>
SELECT ?uncle ?nephew
WHERE {
  ?grandpa :parentOf ?father .
  ?grandpa :parentOf ?uncle .
  ?father :parentOf ?nephew .
  # Missing condition here. We need to exclude the parents of each nephew.
}
```

Solution:

SPARQL Query:

```
PREFIX : <http://example.com/family-tree#>
SELECT ?uncle ?nephew
WHERE {
  ?grandpa :parentOf ?father .
  ?grandpa :parentOf ?uncle .
  ?father :parentOf ?nephew .
  FILTER(?father != ?uncle)
}
```

uncle	nephew
Bob	Jimmy
Jim	Bobby

Project #4 Results

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- Difficulty levels of problems range from 8 (easiest) to 1 (hardest)

- From one seminar, graduate students created:
  - 15 level 8 problems
  - 23 level 7 problems
  - 22 level 6 problems
  - 19 level 5 problems
  - 20 level 4 problems
  - 7 level 3 problems
  - 3 level 2 problems
  - 2 level 1 problems

111 high-quality SPARQL Problems and Solutions

Project #4 Results

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  - 20 level 4 problems
  - 7 level 3 problems
  - 3 level 2 problems
  - 2 level 1 problems

Most languages don't even have level 1 problems, as they're quite challenging to construct

I HOPE YOU ALSO LIKE LESS GOOD NEWS...

johnbeve commented on Jul 24, 2023

Please complete the following information about the language:

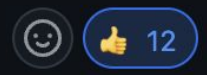
- Name: SPARQL
- Website: https://www.w3.org/TR/sparql11-query/
- Language Version: 1.1

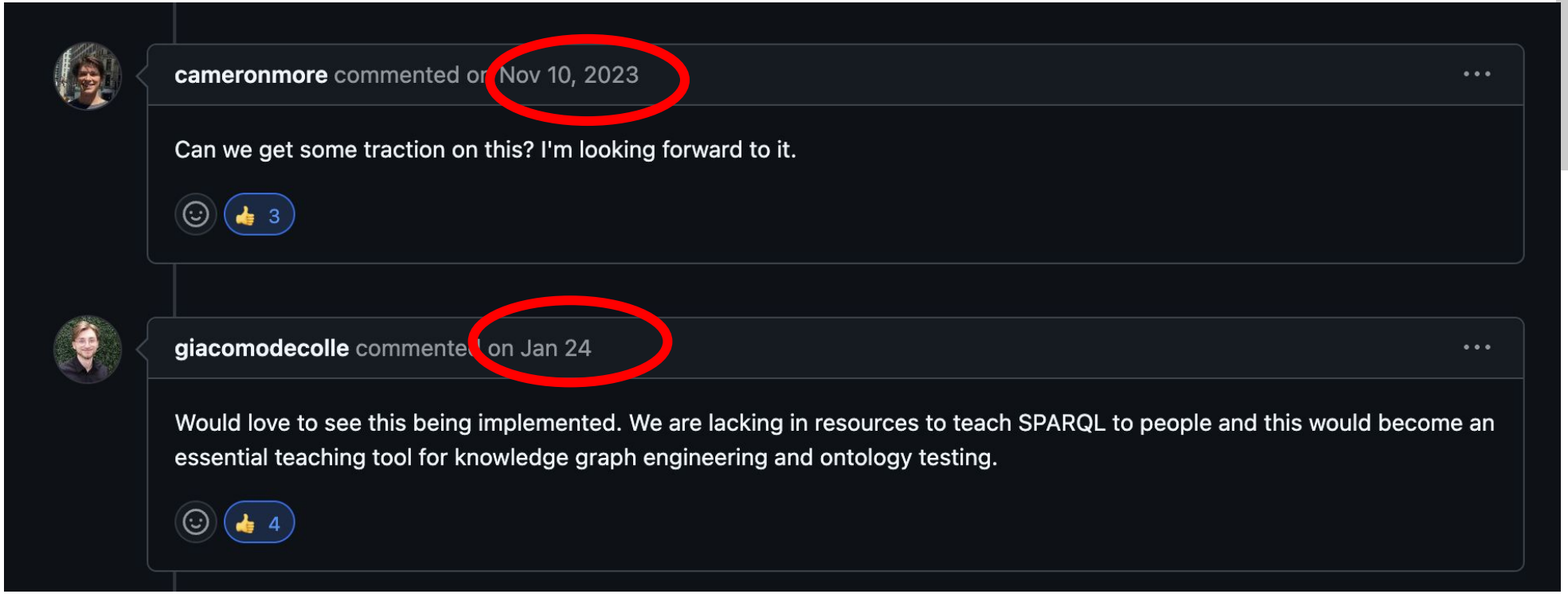
The following are optional, but will help us add the language:

- Test Frameworks:
- How to install:
- How to compile/run:
- Any comments:
  -- SPARQL is widely used among ontology and knowledge graph developers
  -- Taught a course where I required students create SPARQL problems, in the interest of adding to codewars, for example

---

👍 reaction *might* help to get this request prioritized.





cameronmore commented on Nov 10, 2023

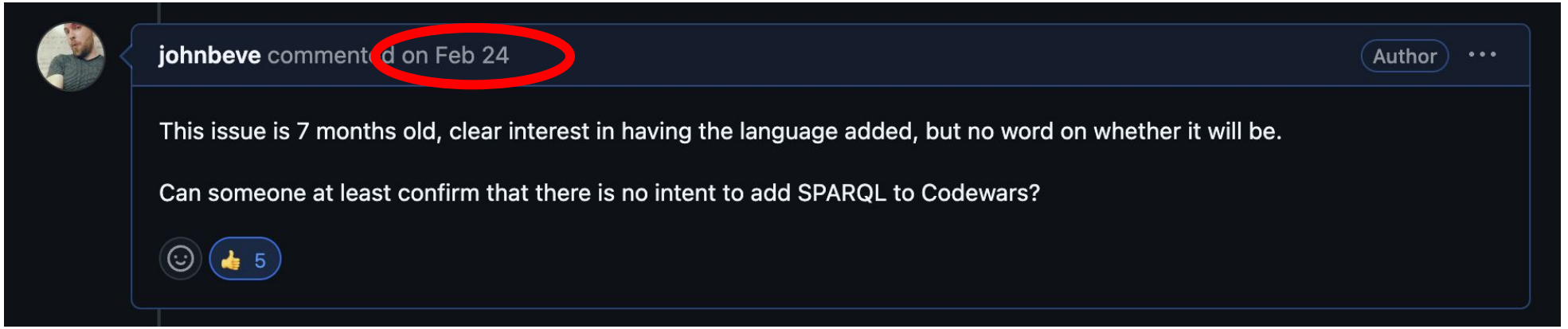
Can we get some traction on this? I'm looking forward to it.

3

giacomodecolle commented on Jan 24

Would love to see this being implemented. We are lacking in resources to teach SPARQL to people and this would become an essential teaching tool for knowledge graph engineering and ontology testing.

4

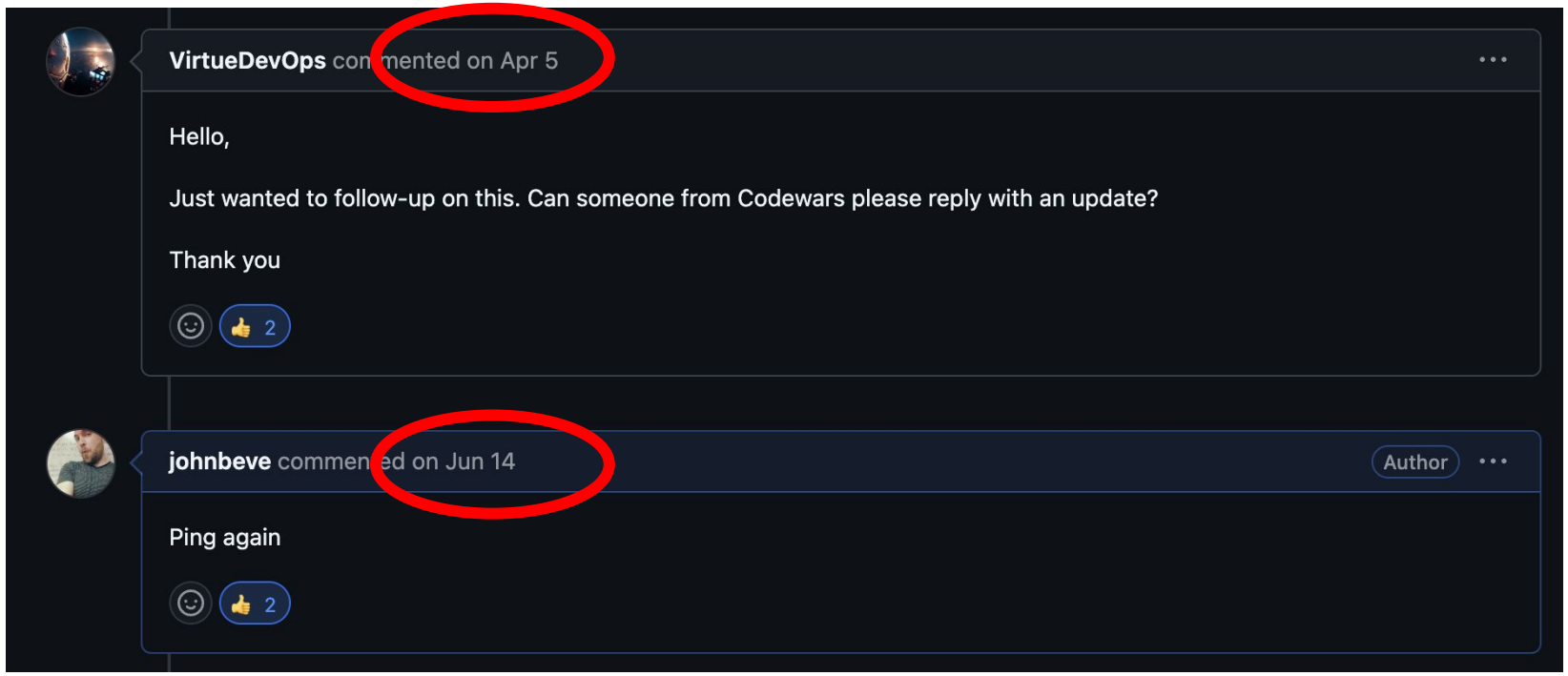


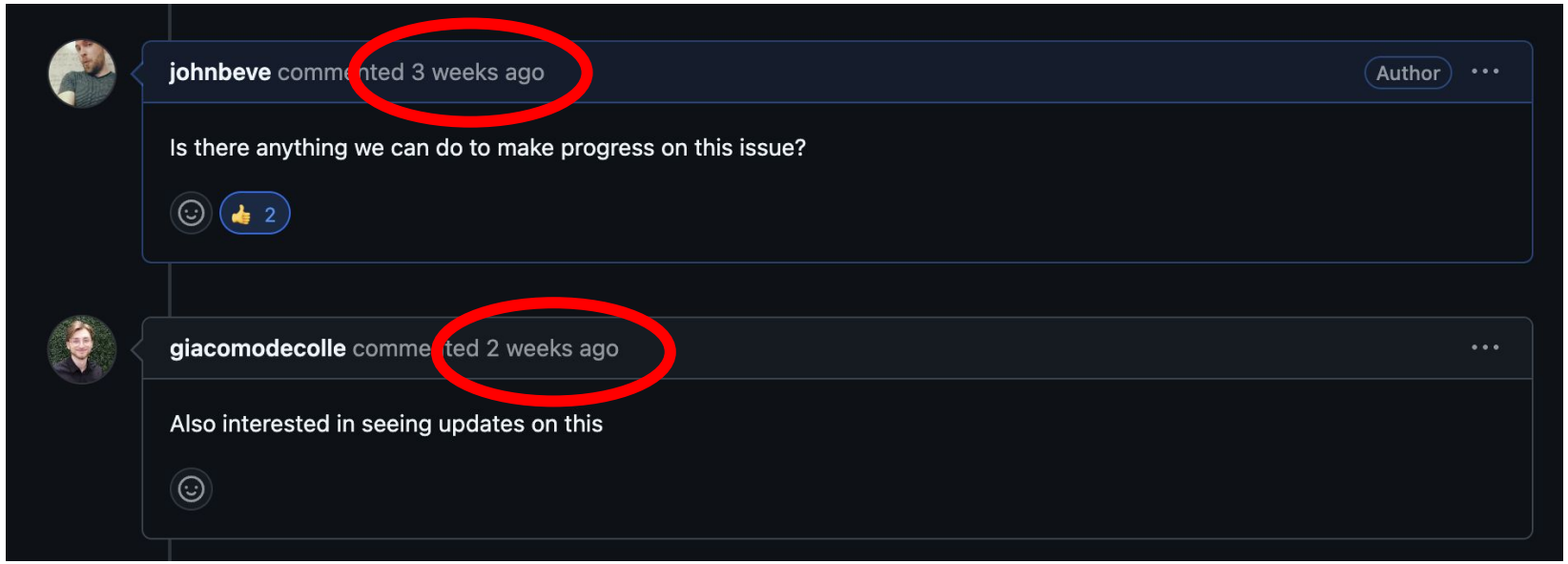
johnbeve commented on Feb 24 Author

This issue is 7 months old, clear interest in having the language added, but no word on whether it will be.

Can someone at least confirm that there is no intent to add SPARQL to Codewars?

5





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MORE GOOD NEWS!

hobovsky commented 2 weeks ago

I would be willing to try and create a setup which hopefully could be used to add SPARQL to Codewars. I cannot add the language myself, but maybe I would be able to create something what would make adding SPARQL to Codewars easy for admins. Problem is, I know nothing about SPARQL. I more or less know how Codewars runner works w.r.t. running tests, but I would need some support with SPARQL-specific things. If someone would be interested with sharing some knowledge, reach out to me on Codewars Discord, and maybe we can figure something out together.


johnbeve commented 2 weeks ago Author

@avsculley would you mind giving **@hobovsky** a hand?

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BUT THAT'S NOT ALL

Aligning Training Goals

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- Aim to *align training goals* relevant to ontology engineering across institutions

- To that end, I have given talks promoting alignment to:

George Mason University (C4I & Cyber)
Northwestern University (Philosophy)
University of Maryland (Physics)
UB Bioinformatics Department
Colgate University (Philosophy)
Ohio State University (Logic)

Fidelity (Knowledge Representation Group)
University of Michigan (Bioinformatics)
Florida State University (Information)
University of Virginia (Data Science)
Syracuse University (CSE)
KadSci

Training Consortium

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- To align training, aim to create *training consortium*

- Whose members may:
  - Enter articulation agreements
  - Supervise new ontologists
  - Host tutorials, bootcamps, certificates, full programs, etc.
  - Provide internships
  - Create and disseminate training material and documentation for existing and future ontology training

Institution	Point(s) of Contact
National Center for Ontological Research (NCOR) University at Buffalo, Department of Philosophy (UB)	*John Beverley* *Barry Smith*
George Mason University C4I and C5I Centers of Excellence	*Michael Hieb* *Sherry Crissman*
University of Virginia (UVA)	*Andreas Tolk*
National Intelligence University (NIU)	*Mayur Gossai*
KadSci	*Dan Maxwell*
CUBRC	*Mark Jensen* *Alex Cox*
University at Buffalo, Department of Biomedical Informatics, Division of Biomedical Ontology	*Peter Elkin* *Werner Ceusters*
Johns Hopkins University Applied Physics Laboratory (JHU/APL)	*Neil Otte*

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Ontology Weekly Trainings

- Ontology & Intelligence Analysis – T/R 11 – 12:30pm
- Logic for Ontologists – Thursdays 1 – 4pm

- Common Core Ontologies – Thursdays 2 – 3pm
- Ontology 101 – Wednesdays 11am – 12pm
- Semantic Mapping – Fridays 1 – 2pm

Open to the public
Remote, recorded, minutes online
https://johnbeve.github.io/NCOR-Test

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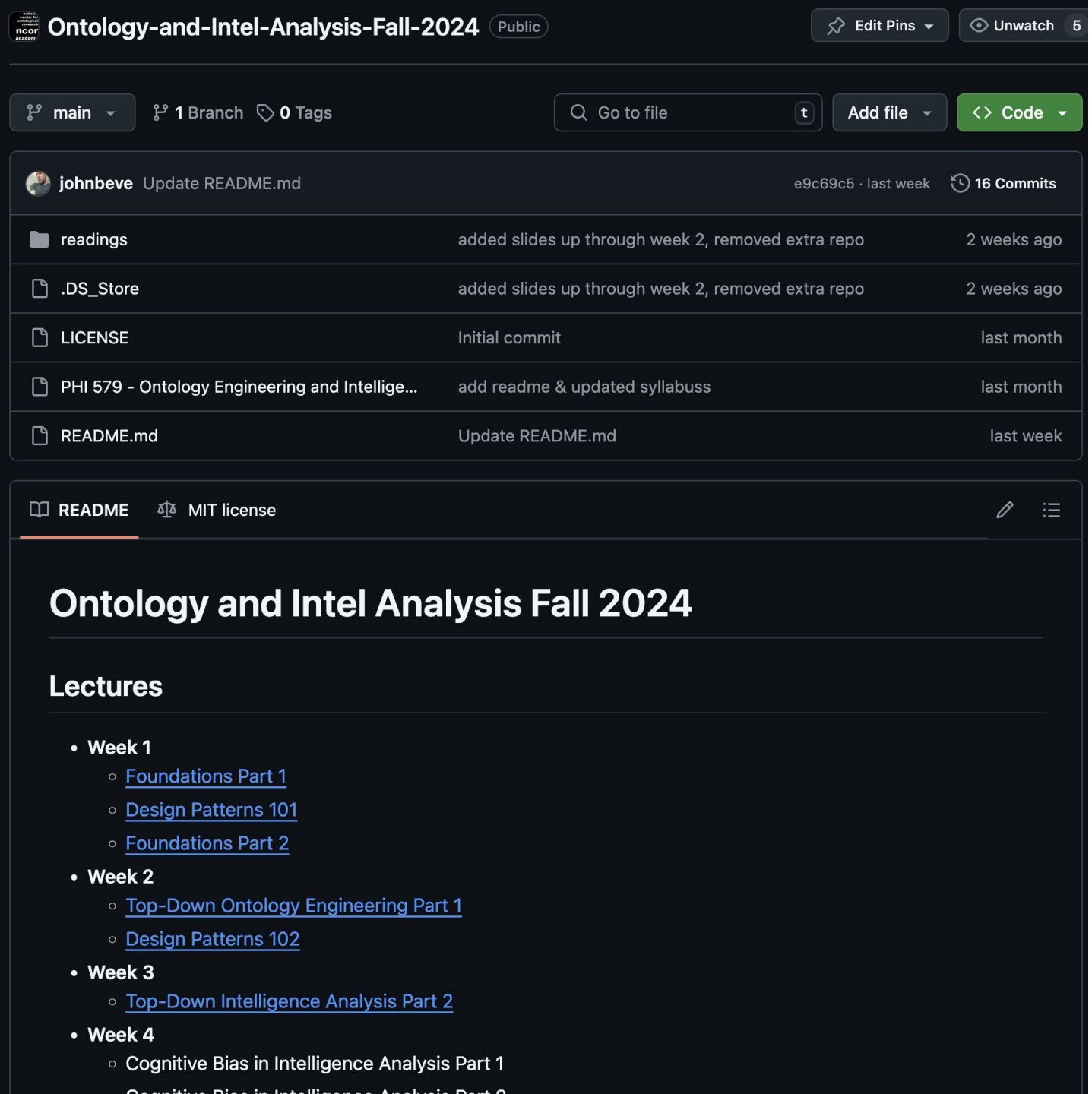

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https://github.com/Applied-Ontology-Education/Ontology-and-Intel-Analysis-Fall-2024

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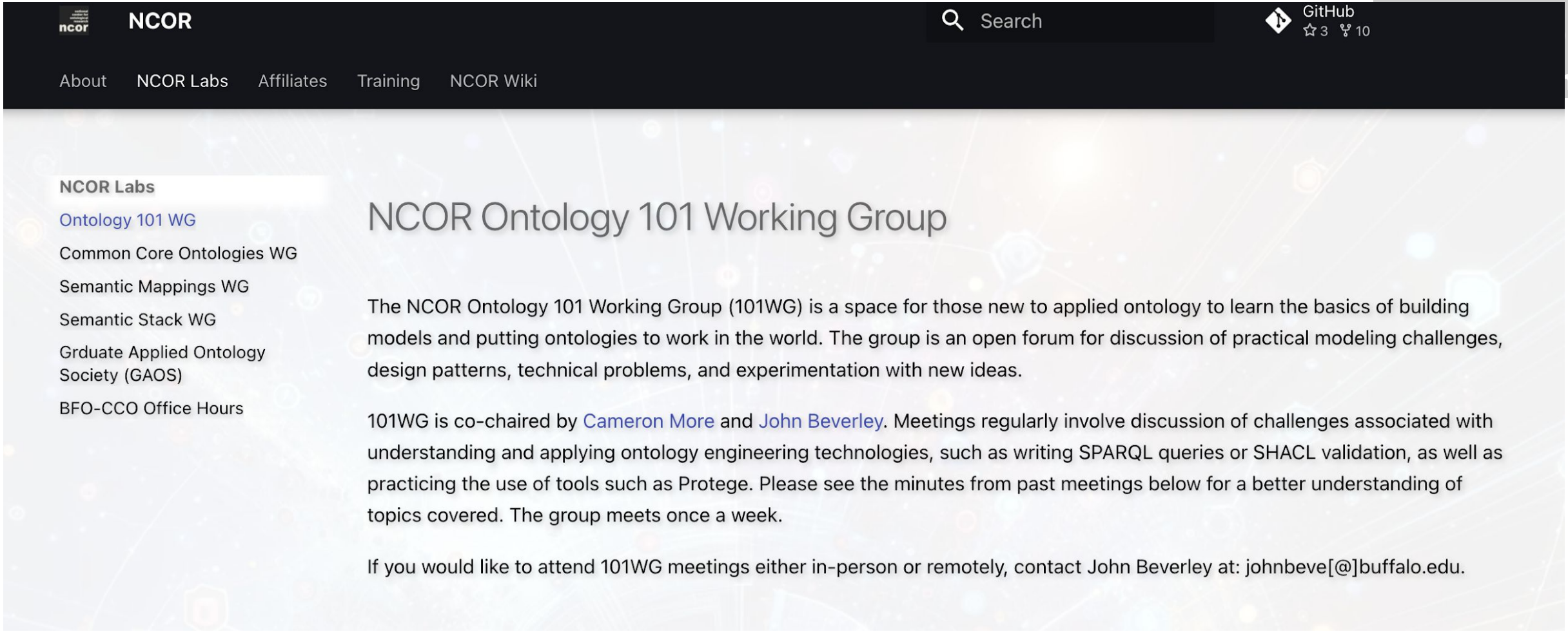

https://ncor-organization.github.io/NCOR-Test/ontology-101-wg/

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Summary

- Over the course of this tutorial, we have seen motivation for ontology engineering **as a science**
- We discussed **two major methodological convictions** of BFO before discussing aspects of the **BFO ecosystem**
- The point here being to highlight **applications**, development **workflows**, lowering barriers to **collaborating**, demonstrating hopefully **frightening R&D**, and free **educational resources**