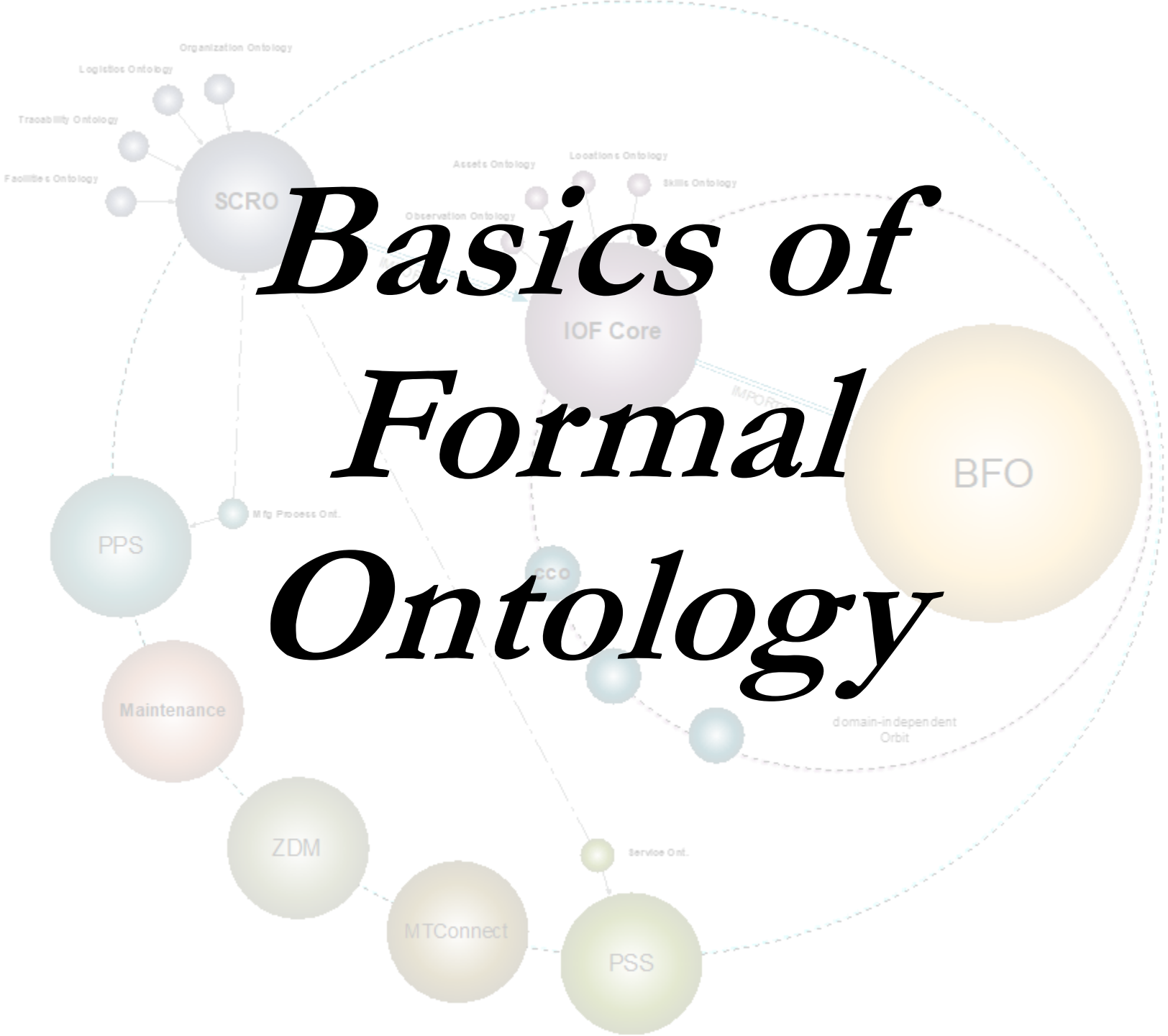


Basics of Formal Ontology

INSTRUCTOR

John Beverley, PhD

Co-Director, *National Center for Ontological Research*
Assistant Professor, *University at Buffalo*
Associate Director, *Institute of AI and Data Science*
CEO, *Acacia Knowledge Systems Inc.*

	Tuesday 20 May: **UFO**	Wednesday 21 May: **DOLCE**	Thursday 22 May: **BFO**	Friday 23 May: **BORO**
8.45-9.00	Welcome!			
9.00 - 10.45	Introduction to UFO Arne Næss auditorium	Introduction to DOLCE Arne Næss auditorium	Introduction to BFO Arne Næss auditorium	Introduction to BORO Arne Næss auditorium
10.45 - 11.00	coffee break	coffee break	coffee break	coffee break
11.00 - 12.00	Introduction to UFO (cont.) Arne Næss auditorium	Introduction to DOLCE (cont.) Arne Næss auditorium	Introduction to BFO (cont.) Arne Næss auditorium	Introduction to BORO (cont.) Arne Næss auditorium
12.00 - 13.15	lunch break	lunch break	lunch break	lunch break
13.15 - 15.15	Hands-on session Seminarrom (tbc)	Hands-on session Seminarrom (tbc)	Hands-on session Seminarrom (tbc)	Hands-on session Seminarrom (tbc)
15.15 - 15.30	coffee break	coffee break	coffee break	coffee break
15.30 - 17.00	Solution discussion Arne Næss auditorium	Solution discussion Arne Næss auditorium	Solution discussion Arne Næss auditorium	Solution discussion Arne Næss auditorium
17-.00 - 18.00				
18.00 - 19.00	Social activity: Hike @ Vettakollen (18.30)	Social activity: Munch Museum		
19.00 - 20.00			Social dinner: MelaCafé (19.30)	
20.00 - 21.00				
22.00 - 23.00				

Outline

- **Module 1**: Motivation for Ontology Engineering
- **Module 2**: Motivation for Basic Formal Ontology
- **Module 3**: Theory of BFO
- **Module 4**: Building Ontologies with BFO
- **Module 5**: Exercises

Outline

- **Module 1**: Motivation for Ontology Engineering
- **Module 2**: Motivation for Basic Formal Ontology
- **Module 3**: Theory of BFO
- **Module 4**: Building Ontologies with BFO
- **Module 5**: Exercises

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

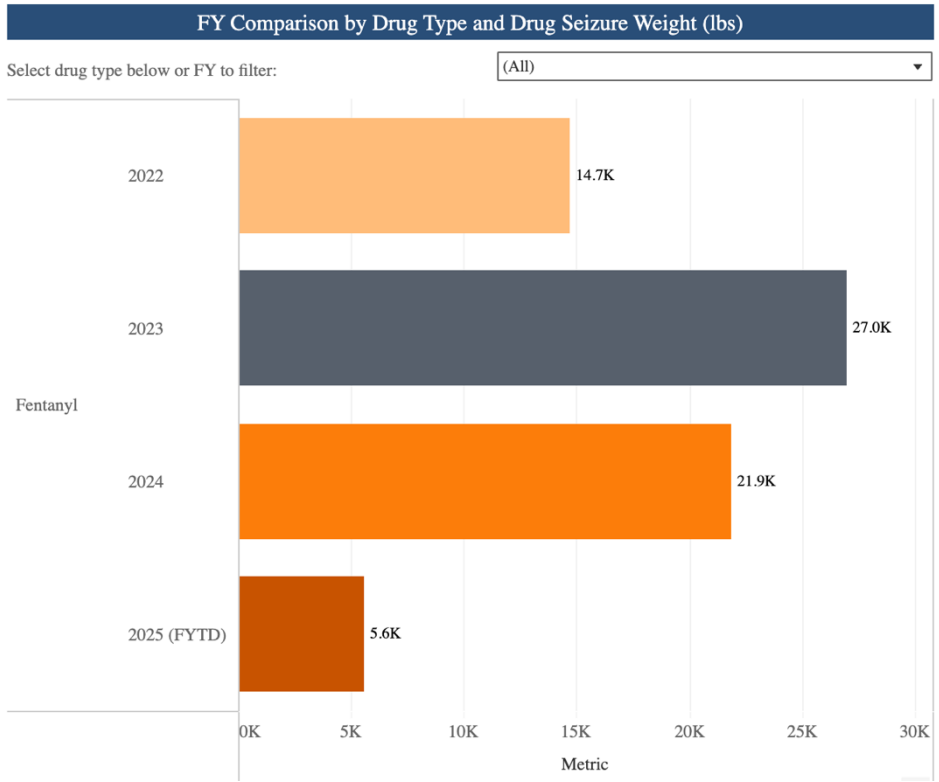
Information Silos

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

SILOS ARE DANGEROUS

Smuggling Narcotics

- Accurate and efficient fentanyl tracking across US borders is undermined by **high volume** of siloed data



Information Silos

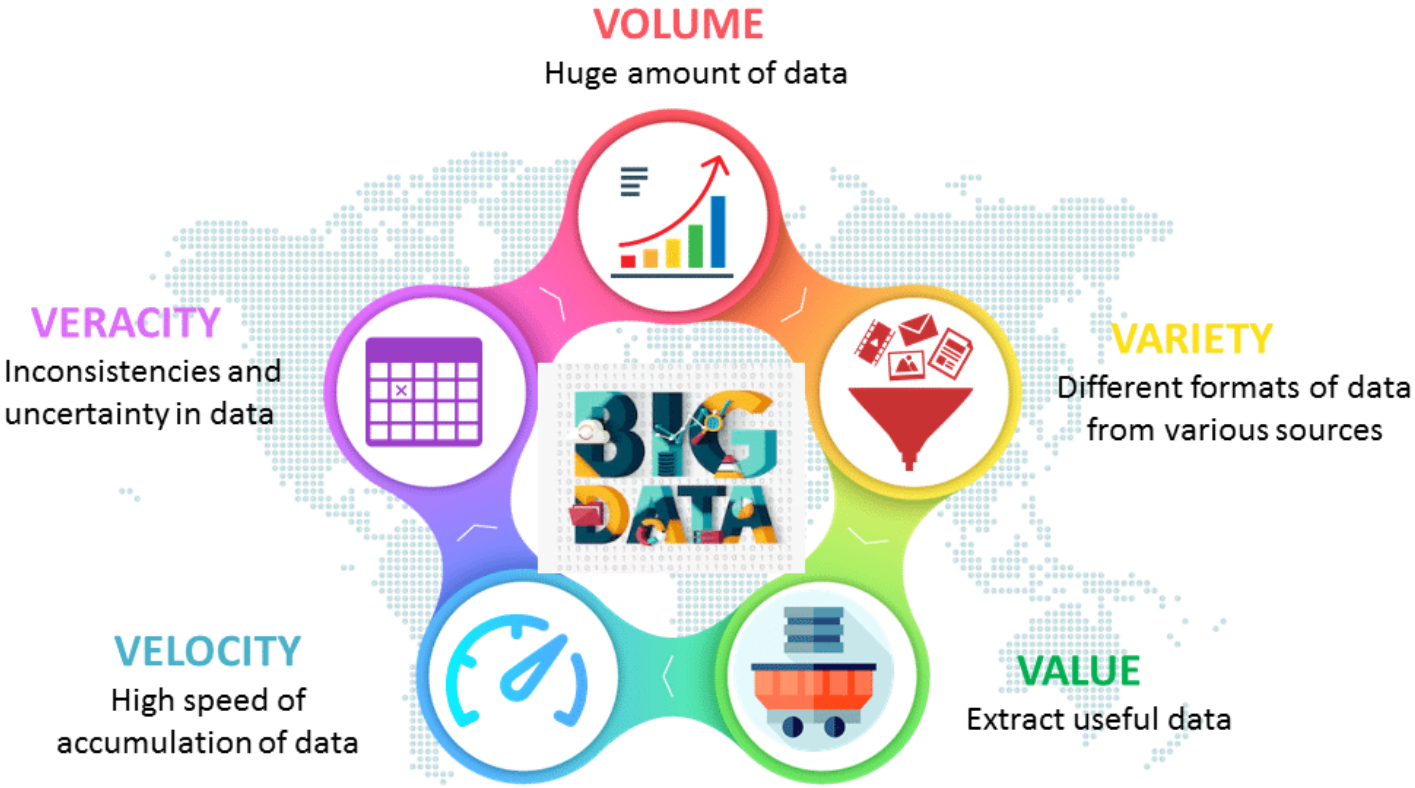
An *information silo* is an information repository, e.g. management system, database, the content of which cannot be integrated with that of other information repositories using standard computing strategies

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



Autos & Transportation

Wiring fixed for first A380 only -Airbus

By **Reuters**

August 9, 2007 5:10 PM EDT · Updated 18 years ago

HAMBURG, Germany, Jan 26 (Reuters) - Airbus on Friday toned down expectations of an immediate solution to all the technical glitches which delayed its A380 superjumbo project, saying wiring problems had been solved for the first aircraft only. A German news report last week said that Airbus had solved the wiring installation problems, which delayed A380 deliveries by an average two years and drove the planemaker into the red.

Engineers found last year that wiring designed in Hamburg could not be fitted into A380s on the assembly line in Toulouse. Experts blamed Airbus's failure to introduce sophisticated 3D design tools in Hamburg at the same time as Toulouse.

Airbus expects to start building a common design platform in the summer between its main French and German plants. It will be fully operational from the production of the 26th plane onwards.

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

SILOS ARE EVERYWHERE

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

HOW DO WE ADDRESS THEM?

Interoperability Strategies

- For the sake of argument, let us call "interoperability strategies" those strategies that mitigate or eliminate information silos

- Interoperability strategies may be divided along at least three axes

Machine-Machine
Human-Human
Human-Machine

Machine-Machine Interoperability

- Involves addressing the more familiar information silos

- Associated interoperability strategies often emphasize common metadata standards, business logic, APIs, etc.

Any two heterogeneous information systems share some underlying formal structure

Human-Human Interoperability

- Involves addressing what we might call social silos, which undermine consistent communication among agents

- Human-Human Interoperability strategies often emphasize consensus-building exercises, dictionaries, evaluation of natural language, etc.

Any two speakers of a given natural language share some underlying formal structure

FOR HUMANS

acceptability — The joint operation plan review criterion for assessing whether the contemplated course of action is proportional, worth the cost, consistent with the law of war; and is militarily and politically supportable. See also **adequacy; feasibility.** (JP 5-0)

access — In counterintelligence and intelligence use, a. a way or means of approach to identify a target; or b. exploitable proximity to or ability to approach an individual, facility, or information that enables target to carry out the intended mission. (JP 2-01.2)

access to classified information — The ability and opportunity to obtain knowledge of classified information by persons with the proper security clearance and a need to know of specified classified information. (JP 2-01)

accompanying supplies — Unit supplies that deploy with forces. (JP 4-01.5)

accountability — The obligation imposed by law or lawful order or regulation on an officer or other person for keeping accurate record of property, documents, or funds. (JP 1)

acoustic intelligence — Intelligence derived from the collection and processing of acoustic phenomena. Also called **ACINT.** (JP 2-0)

DOD Dictionary of Military and Associated Terms

Human-Machine Interoperability

- Involves encoding human-human interoperable solutions in a machine-readable manner

- Associated interoperability strategies often emphasize data schemas, ontologies, knowledge graphs, etc.

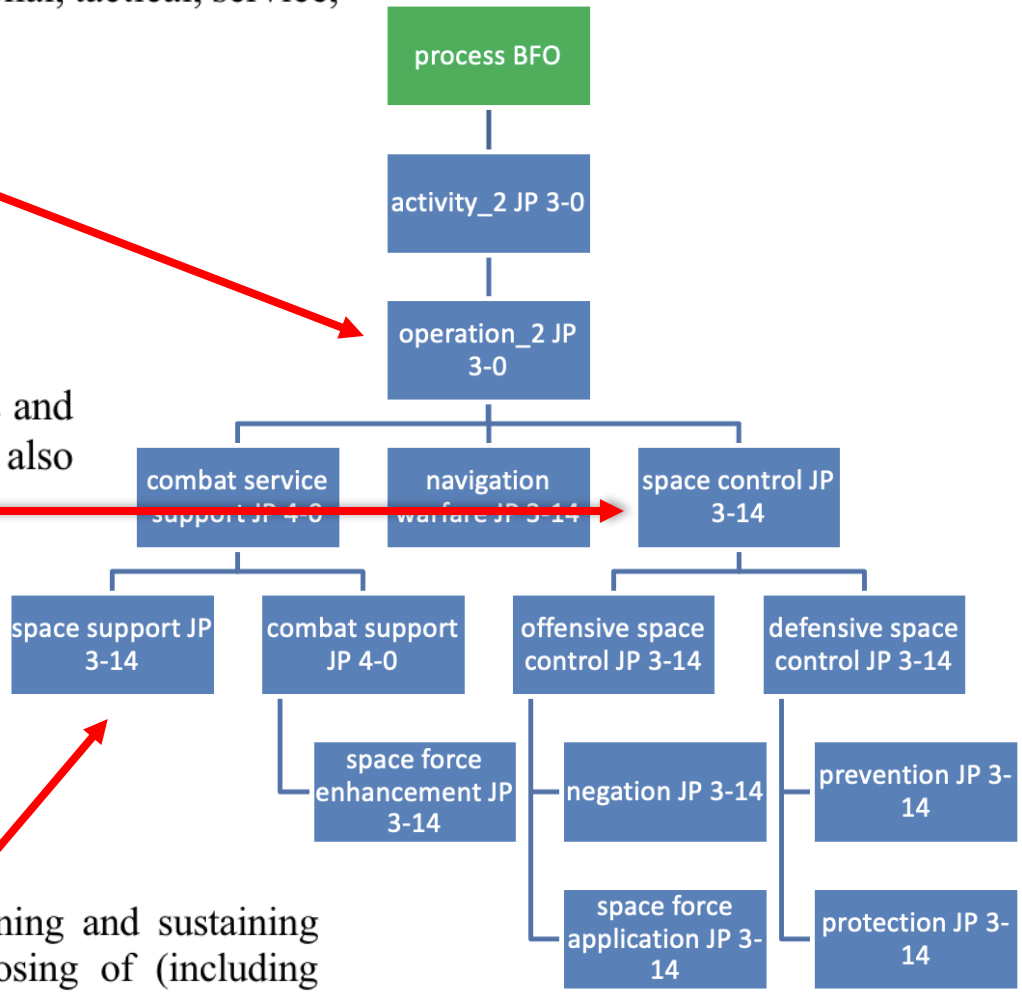
We encode our shared formal structures into machine-readable languages

FOR MACHINES

operation — 1. A sequence of tactical actions with a common purpose or unifying theme. (JP 1) 2. A military action or the carrying out of a strategic, operational, tactical, service, training, or administrative military mission. (JP 3-0).

space control — Operations to ensure freedom of action in space for the United States and its allies and, when directed, deny an adversary freedom of action in space. See also **combat service support; combat support; negation; space systems.** (JP 3-14)

space support — Launching and deploying space vehicles, maintaining and sustaining spacecraft on-orbit, rendezvous and proximity operations, disposing of (including deorbiting and recovering) space capabilities, and reconstitution of space forces, if required. See also **combat service support.** (JP 3-14)



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

INTEROPERABILITY STRATEGIES ARE NOT NEW

Promise of Ontology Engineering

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

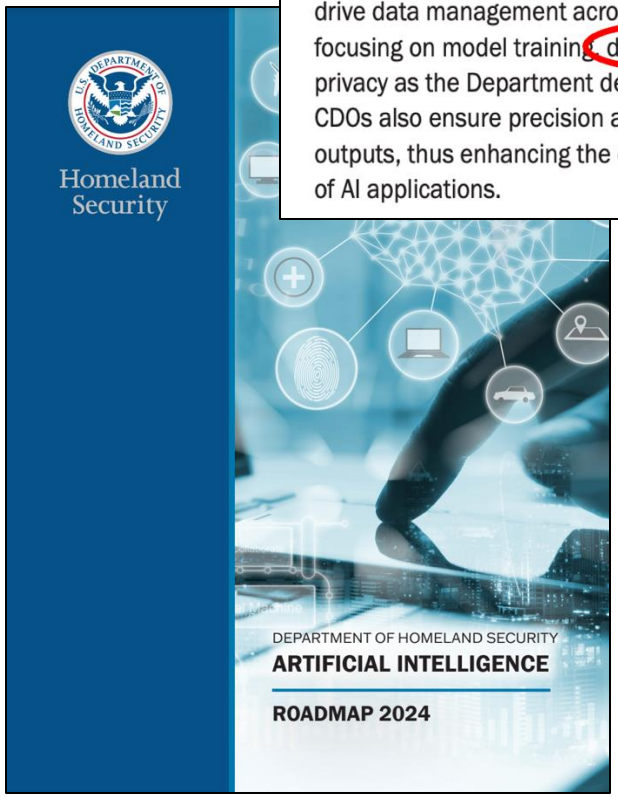
- Ontologies make **explicit** the **implicit** meanings buried in datasets, by using basic principles of formal logic

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

Department of Homeland Security Core Ontology for Maritime Domain Awareness Fact Sheet

The objective of the Department of Homeland Security (DHS) Core Ontology for Maritime Domain Awareness effort is to provide DHS with the base of a semantic framework, in the form of a DHS Core Ontology, a Maritime Domain Awareness Ontology, and a Computational Analytic Ontology. The semantic framework will be an evolving part of the DHS data architecture enabling the functionality to create data that is integrated, familiar and trusted. The base framework will enable evolution by having a core ontology of DHS terms which are then reused to create interoperable ontologies covering the numerous and diverse domains of interest to DHS.

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.



NGA Seeks an AI Data Steward for Ontology

Original Job Opening Posted on USAJobs.gov: https://www.usajobs.gov/job/812538000

The DOD's National Geospatial-Intelligence Agency (NGA) is searching for an **AI Data Steward for Ontology**, according to a job posting on USAJobs.gov.

CAPITAL ONE

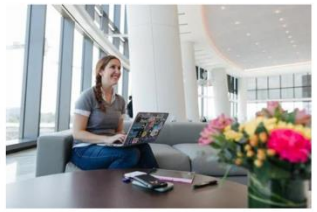
Manager, Ontology and Data Modeling

3 days ago • Boston, MA (+2 more)

Viewed on February 25, 2025

ABOUT US

Capital One is a nationally recognized and high-tech business banking company, offering better customized consumer and commercial lending and deposit financial services.



Size: 10,000+ employees

Industry: Consumer Goods & Services, Financial Services, Technology

VIEW COMPANY PROFILE >

KGA

KNOWLEDGE GRAPH ALLIANCE

Data to Wisdom:
KGA is pioneering the future of Knowledge-Driven Innovation

Worth the Hype: Palantir's Ontology, Switching Costs Warrant Quadrupling of Our Fair Value Estimate

Mark Giarelli
Jan 30, 2025

Share

Onto-IKEA: A Knowledge Retrieval Framework based on IKEA Ontology

Alexandros Vassiliades[1,2], Nikos Zarkadas[1], Nick Bassiliades[1] and Theodore

WebMD

Ontology Engineer

Newark, NJ · Reposted 2 weeks ago · 34 people clicked apply

✓ Hybrid ✓ Full-time

Apply Save

Amazon

Ontologist, Amazon

Seattle, WA · Reposted 2 weeks ago · Over 100 people clicked apply

$74.4K/yr - $166.5K/yr ✓ Full-time

Apply Save

CUBRC

Ontologist
Buffalo, NY

Apply

Description

The CUBRC, Inc. Buffalo NY office has an immediate need for an Ontologist to work on state-of-the-art research and development projects. The successful candidate will join an established team of ontologists and software engineers in creating and maintaining ontologies and knowledge graphs that deliver data analysis capabilities to our customers. As a member of the team, the successful candidate will perform requirements collections, domain analysis, ontology development, testing, and data alignment under the direction of a Principal or Senior Ontologist. Additional responsibilities will include documentation, customer education, and training.

Bloomberg

Senior Ontologist - Data Management Lab

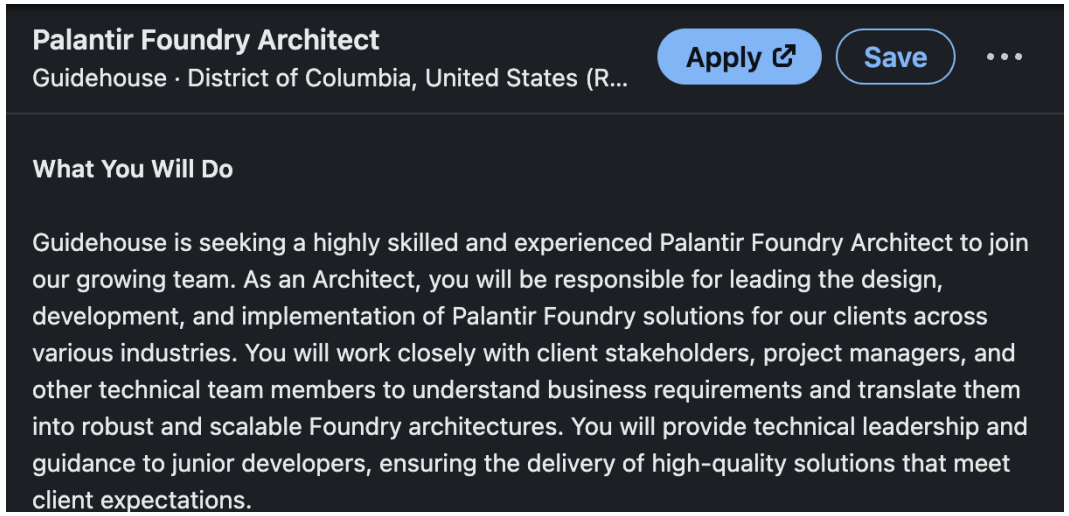
New York, NY · 1 week ago · **13 people clicked apply**

$110K/yr - $170K/yr ✓ On-site ✓ Full-time

Nike

Manager, Taxonomy & Ontology

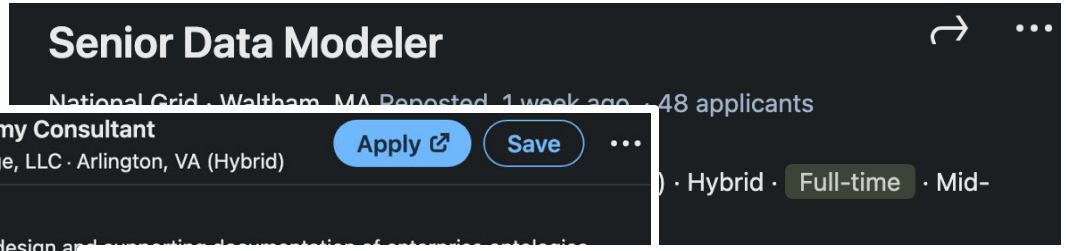
Beaverton, OR · Reposted 1 week ago · Over 100 people clicked apply



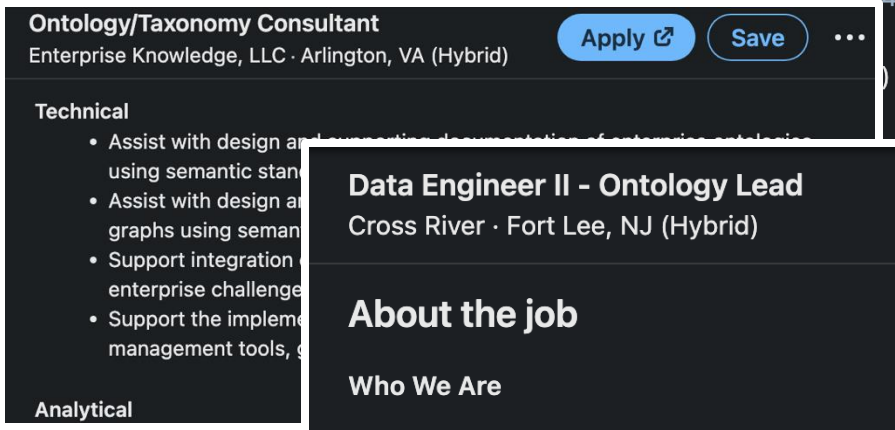
Palantir Foundry Architect
Guidehouse · District of Columbia, United States (R...
Apply Save

What You Will Do

Guidehouse is seeking a highly skilled and experienced Palantir Foundry Architect to join our growing team. As an Architect, you will be responsible for leading the design, development, and implementation of Palantir Foundry solutions for our clients across various industries. You will work closely with client stakeholders, project managers, and other technical team members to understand business requirements and translate them into robust and scalable Foundry architectures. You will provide technical leadership and guidance to junior developers, ensuring the delivery of high-quality solutions that meet client expectations.



Senior Data Modeler
National Grid · Waltham, MA Reposted 1 week ago · 48 applicants
· Hybrid · Full-time · Mid-

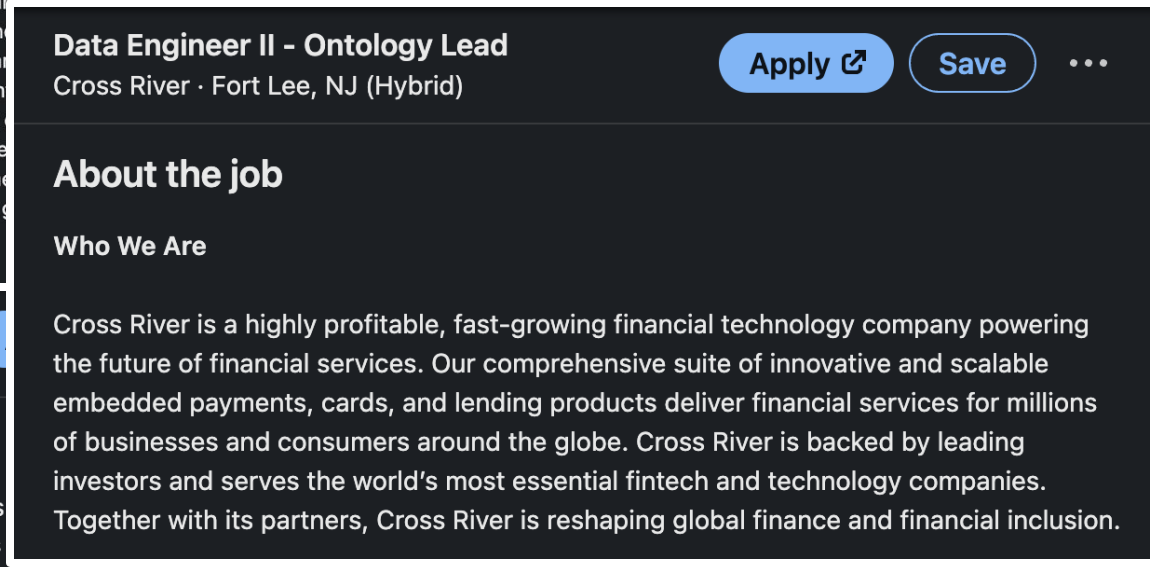


Ontology/Taxonomy Consultant
Enterprise Knowledge, LLC · Arlington, VA (Hybrid)
Apply Save

Technical

- Assist with design a
  using semantic stan
- Assist with design a
  graphs using seman
- Support integration
  enterprise challenge
- Support the impleme
  management tools,

Analytical



Data Engineer II - Ontology Lead
Cross River · Fort Lee, NJ (Hybrid)
Apply Save

About the job

Who We Are

Cross River is a highly profitable, fast-growing financial technology company powering the future of financial services. Our comprehensive suite of innovative and scalable embedded payments, cards, and lending products deliver financial services for millions of businesses and consumers around the globe. Cross River is backed by leading investors and serves the world's most essential fintech and technology companies. Together with its partners, Cross River is reshaping global finance and financial inclusion.

Ontology/Taxonomy Consultant

Motion Recruitment · Clarendon, VA 2 weeks ago · 7 ap

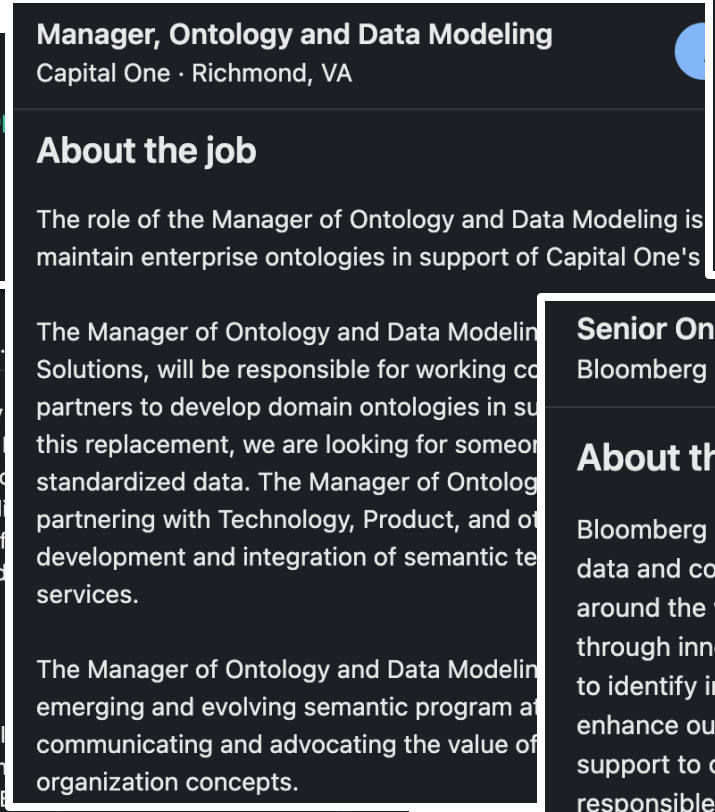
Hybrid · Full-time · Mid-Senior level

501-1,000 employees · Staffing and Recruiting

S

S

V



Manager, Ontology and Data Modeling
Capital One · Richmond, VA

About the job

The role of the Manager of Ontology and Data Modeling is
maintain enterprise ontologies in support of Capital One's

The Manager of Ontology and Data Modelin
Solutions, will be responsible for working co
partners to develop domain ontologies in su
this replacement, we are looking for someor
standardized data. The Manager of Ontolog
partnering with Technology, Product, and ot
development and integration of semantic te
services.

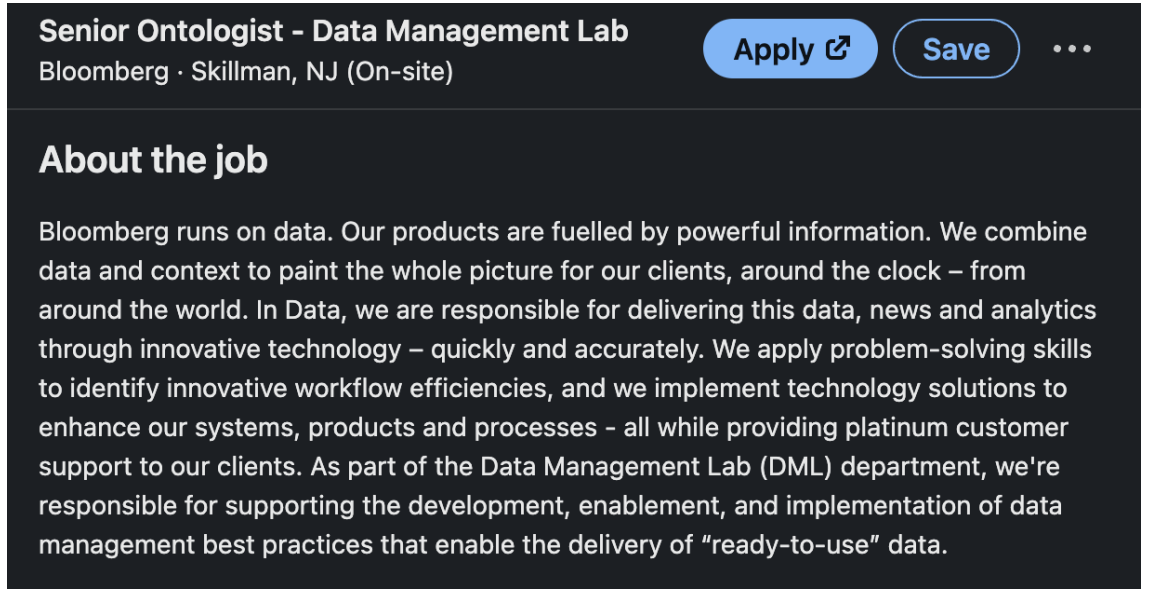
The Manager of Ontology and Data Modelin
emerging and evolving semantic program at
communicating and advocating the value of
organization concepts.

Application Developer / Ontologist
University of Pennsylvania · Philadelphia, PA (On-si.

The Perelman School of Medicine at the University
of the finest medical schools in the United States.
and at the same time consistently at the forefront
in medical education and research. Since its found
strong presence in the community and prides itself
tomorrow in patient care, biomedical research, and
http://www.med.upenn.edu/

Job Description

The successful candidate will use biomedical ontol
Penn Health System resources to integrate data an
patient cohorts. This activity will draw upon Open
(obofoundry.org). Ontologies and graph databases are part of an exciting new
movement in information technology that elevates data to the level of knowledge. The



Senior Ontologist - Data Management Lab
Bloomberg · Skillman, NJ (On-site)
Apply Save

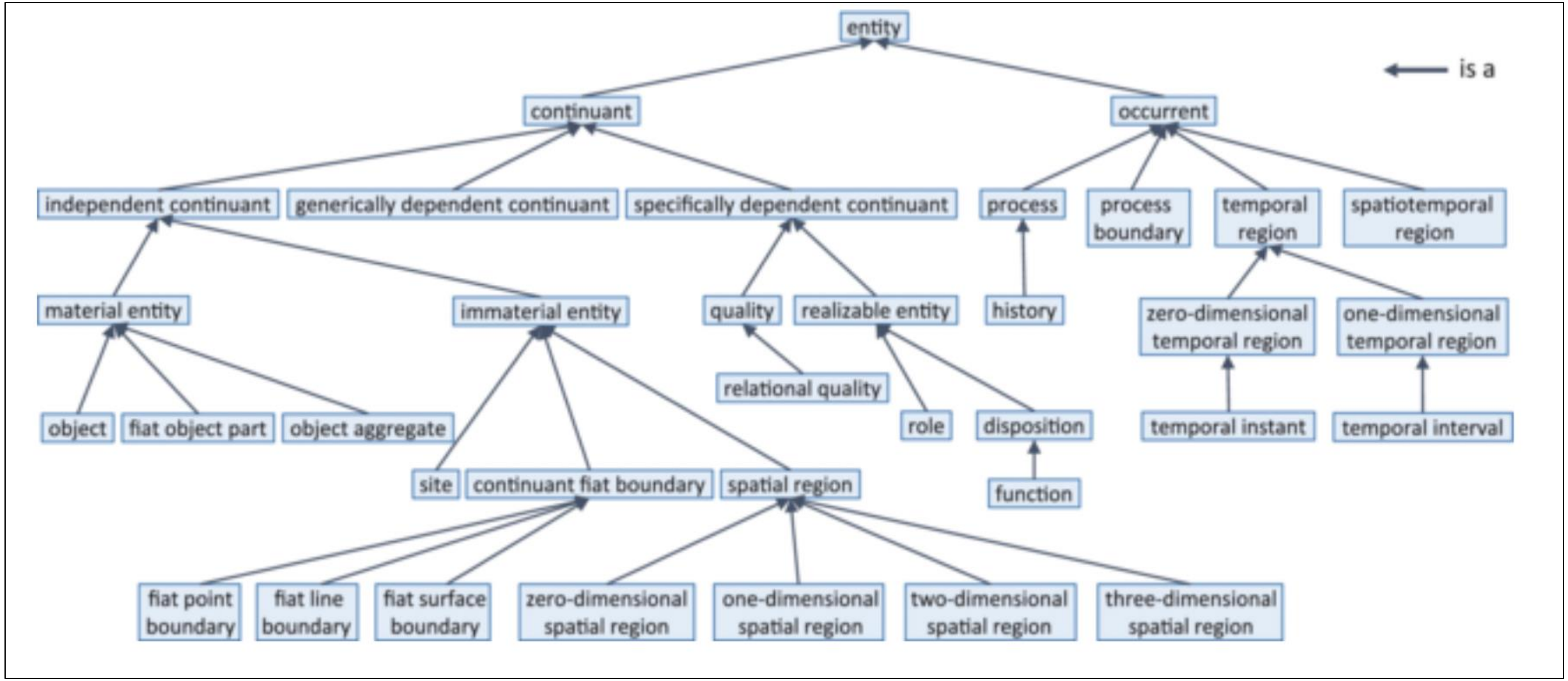
About the job

Bloomberg runs on data. Our products are fuelled by powerful information. We combine data and context to paint the whole picture for our clients, around the clock – from around the world. In Data, we are responsible for delivering this data, news and analytics through innovative technology – quickly and accurately. We apply problem-solving skills to identify innovative workflow efficiencies, and we implement technology solutions to enhance our systems, products and processes - all while providing platinum customer support to our clients. As part of the Data Management Lab (DML) department, we're responsible for supporting the development, enablement, and implementation of data management best practices that enable the delivery of "ready-to-use" data.

Outline

- **Module 1**: Motivation for Ontology Engineering
- **Module 2**: Motivation for Basic Formal Ontology
- **Module 3**: Theory of BFO
- **Module 4**: Building Ontologies with BFO
- **Module 5**: Three Use Cases

CERTAIN INTEROPERABILITY STRATEGIES SUPPORT IMPROVED DATA QUALITY BETTER THAN OTHERS


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

Standards About us News Taking part Store EN ≡ MENU

ICS › 35 › 35.060

ISO/IEC 21838-2

Information technology — Top-level ontologies (TLO) — Part 2: Basic Formal Ontology (BFO)

GENERAL INFORMATION

Status : Under development **Publication date :** 2020-03

Edition : 1

Technical Committee : ISO/IEC JTC 1/SC 32 Data management and interchange

ICS : 35.060 Languages used in information technology | 01.040.35 Information technology (Vocabularies)

MEMORANDUM FOR CHIEF DIGITAL AND ARTIFICIAL INTELLIGENCE OFFICER COUNCIL MEMBERS
INTELLIGENCE COMMUNITY CHIEF DATA OFFICER COUNCIL MEMBERS

SUBJECT: Baseline Standards for Formal Ontology within the Department of Defense and the Intelligence Community

In April 2023, the Chief Digital and Artificial Intelligence Officer Council and the Intelligence Community Chief Data Officer Council chartered the joint Department of Defense (DoD) and Intelligence Community (IC) Ontology Working Group (DIOWG). It was tasked with developing coordinated ontologies to set the agreed definitions and standard necessary to make data machine understandable. Based on the DIOWG's recommendations, both Councils direct the use of three baselines: Top-Level Ontology, Basic Formal Ontology, and Common Core Ontology. These will set the baseline standards for formal DoD and IC ontology.

By aligning the DoD and IC ontologies to a common set of top and mid-level standards, the combined enterprise will realize significant gains in data interoperability, federated search and discovery, decreased analytic timelines, and better cost efficiency. This common approach to data ontology is key to deriving value from shared data assets at speed and scale. The DIOWG has provided additional background information on these international ontological standards in Attachment A.

The nation's warfighters and intelligence professionals will need to have a decisional advantage in the immediate future and that can only be unlocked through the sharing of interoperable data. The next steps for the DIOWG are to codify recommended principles and governance processes to manage the DoD-IC Ontology Foundry. The DIOWG collaboration site can be accessed by visiting https://www.trmc.osd.mil/wiki/display/DIOWG/.

WADE LORI C VYTRP0 Digitally signed by WADE LORI C VYTRP0 Date: 2024.01.25 14:33:16 -05'00'

MARTELL.CRAIG.HARRY.1269768998 Digitally signed by MARTELL.CRAIG.HARRY.1269768998 Date: 2024.01.04 15:11:45 -08'00'

Lori Wade
Intelligence Community Chief Data Officer
Office of the Director of National Intelligence

Dr. Craig H. Martell
Chief Digital and Artificial Intelligence Officer
Department of Defense

DoD-IC Enterprise Standards Baseline

Standards Citations for ISO 21838: Parts 1 and 2

Joint Enterprise Standards Committee (JESC) Plenary was held 23 Oct 2024 . DoD IT Standards Registry (DISR) 24-2.0 (i.e., the DoD-IC joint enterprise standards baseline) was published 07 Nov 2024 . The baseline includes the two Change Requests (CRs) for TLO and BFO. Congratulations all and thank you!

DISR 24-2 Baseline (published on 7 Nov 2024) Includes Entries for ISO/IEC 21838 Parts 1 and 2. Their citations are below:		
Standard Reference Number	303330	303321
Standard Identifier	ISO/IEC 21838-1:2021	ISO/IEC 21838-2:2021
Standard Title	Information Technology – Top Level Ontologies (TLO) – Part 1: Requirements	Information Technology – Top Level Ontologies (TLO
Standard Class	Standard	Standard
DoD Status	Mandated	Mandated
DoD Sunset Date		
DoD Sunset Event		
Date Introduced to Registry	07-Nov-2024	07-Nov-2024
Date DoD Emerging		
Date DoD Mandated	07-Nov-2024	07-Nov-2024

Joint Enterprise Standards Committee (JESC) Applications Technical Working Group

About JESC

The JESC serves as the governance body for DoD information technology (IT) standards, and for Intelligence Community (IC) enterprise standards. These include data standards critical to the ADL Initiative's development of a Total Learning Architecture (TLA) for DoD education and training.

The JESC, which includes subordinate committees, working groups, and ad-hoc enterprise standards activities, recommends common enterprise standards, profiles, and specifications for DoD and IC information environments. Standards approved by this committee are mandated by DoD's Chief Information Officer for Department-wide use and acquisitions.

BFO Ecosystem

700+ Projects

BFO Basic Formal Ontology

Home GitHub Guidebook Publications FOL Users Tutorials

Users

Below you will find an alphabetical list of ontologies and institutions/groups usin

Ontologies

- ACGT Master Ontology (ACGT MO)
- Actionable Intelligence Retrieval System (AIRS)
- Addiction Ontology (Addict-O)
- Additive Manufacturing Ontology (AMO)
- Adolescent Depression Ontology (ADO)
- Adverse Event Reporting Ontology (AERO)
- AFO Foundational Ontology
- African Wildlife Ontology (AWO)
- Agronomic Linked Data (AgroLD)
- Agronomy Ontology (AGRO)
- Aircraft System Ontology
- Algorithm-Implementation-Execution Ontology Design Pattern
- Alzheimer Disease Ontology (ADO)
- Alzheimer's Disease Diagnosis Ontology (ADDO)
- Anatomy of the Insect Skeleto-Muscular system ontology (AISM)
- Animals in Context Ontology (ACO)
- Anthropological Notation Ontology (ANNO)
- Antimicrobial-Microorganism Ontology
- Apollo Structured Vocabulary (Apollo-SV)
- Argument Ontology (ARGO)
- ARIES (Arkansas Imaging Enterprise System) Knowledge Graph
- Asset Management Ontology (AMODO)
- Autism-DSM-ADI-R Ontology (ADAR)
- Bacterial Clinical Infectious Diseases Ontology (BCIDO)
- Baden Württemberg Materials Digital Domain Ontology (BWMD)
- Bank Ontology
- Battle Management Ontology (BMO)
- Behavior Change Intervention Ontology (BCIO)
- Behaviour Change Technique Ontology
- Behavior Perspective Model (BPM)
- Beta Cell Genomics Application Ontology (BCGO)
- Bio-Knowledge Network Ontology (BioKNO)
- BioAssay Ontology
- Bioinformatics Web Service Ontology (OBIWS)
- Biological Collections Ontology (BCO)
- Biomedical Ethics Ontology
- Biomedical Grid Terminology (BiomedGT, retired)
- Biomedical Study - Lifecycle Management (BMS-LM) core ontology
- Biomimetic Ontology
- BioTop: a biomedical top-domain ontology

- OntoAlign++: A Combined Strategy for Improving Ontologies Alignment
- OntoBuildableSpace Ontology
- OntoDM Core
- OntoForInfoScience
- Ontologies for Representing Surgical Procedure Models (OntoSPM)
- Ontologized Minimum Information About Biobank data Sharing (OMIAB
- Ontology Based Clinical Decision Support System for Geriatrics
- Ontology Based Decision Support System for Tuberculosis Manageme
- Ontology for Adverse Events (OAE)
- Ontology for Autism Spectrum Disorder
- Ontology for Biobanking (OBIB)
- Ontology for Biofilms (BIFO)
- Ontology for Biomedical Investigations (OBI)
- Ontology for Cancer research variables (OCRV)
- Ontology for Computable Eligibility Criteria - Hepatitis C Virus (OCEC-H
- Ontology for Dengue Fever (IDODEN)
- Ontology for Documentation of Variable/Data Source Selection (ODVD
- Ontology for Drug Discovery Investigations (DDI)
- Ontology for Energy Investigations (OEI)
- Ontology for Functionally Graded Materials (OFGM)
- Ontology for General Medical Science (OGMS)
- Ontology for Genes and Genomes - Mouse (OGG-MM)
- Ontology for Genetic Interval (OGI)
- Ontology for Guiding Appropriate Antibiotic Prescribing
- Ontology for Information Science (OntoforInforScience)
- Ontology for Laparoscopic Surgeries (LapOntoSPM)
- Ontology for MIcroRNA Target Prediction (OMIT) (here)
- Ontology for Newborn Screening and Translational Research (ONSTR
- Ontology for Next Generation Sequencing Experiments (NGS Ontology
- Ontology for Nutritional Epidemiology (ONE)
- Ontology for Nutritional Studies (ONS)
- Ontology for Pain and Related Disability, Mental Health and Quality of
- Ontology for Parasite LifeCycle (OPL)
- Ontology for Periodontitis (PERIO)
- Ontology for Petroleum Production
- Ontology for Prognostic Health Management (PHM) in Spacecraft Avio
- Ontology for Stem Cell Investigations (OSCI)
- Ontology for the Documentation of Variable Selection and Data source
- Ontology for Thoracentesis
- Ontology of Autonomous Driving Based on the SAE J3016 Standard
- Ontology of Arthropod Circulatory Systems (OArCS)
- Ontology of Biological and Clinical Statistics (OBCS)
- Ontology of Cancer Related Social-Ecological Variables (OCRSEV)
- Ontology of Card Sleights
- Ontology of Cardiovascular Drug Adverse Events (OCVDAE)
- Ontology of Chinese Medicine for Rheumatism (OCMR)
- Ontology of Clinical Research (OCRe)
- Ontology of Commercial Exchange (OCE)
- Ontology of Data Mining (OntoDM)

- Shop-Floor Digital Twin (DT) ontology
- Situated and Interactive Multimodal Conversations
- Situation Awareness Ontology (SAO)
- Sketch Map Ontology
- Skin Physiology Ontology (SPO)
- Sleep Domain Ontology (SDO)
- SMART Protocols: SeMAntic RepresenTation for Experimental Protocols
- Smart Ultrasound in Obstetrics and Gynecology (SUOG) Ontology
- SNOMED CT (SCT) Standard Ontology
- Social Determinants of Health Ontology (SDoHO)
- Social Psychology Ontology (SPO)
- Socialog Ontology for Social Simulation
- Software Ontology (SWO)
- Software, Disabilities and Competences Ontology (SODIC)
- Soil Food Web Ontology
- Space Domain Ontologies (SDO)
- Space Object Ontology (SOO)
- Spatial Graph Adapter (SGA) Ontology Design Pattern
- Spatial Relation Ontology
- Spatiotemporal Ontology for the Administrative Units of Switzerland (SONADUS
- Special Nuclear Materials Detection Ontology (SNM-DO)
- Statistics Ontology (STATO)
- STATO-LMM Linear Mixed Model Ontology
- Style of Delivery Ontology
- Subcellular Anatomy Ontology (SAO)
- Suggested Ontology for Pharmacogenomics (SO-Pharm)
- Supply Chain Traceability Ontology
- Surface Water Ontology (SWO)
- Survey Ontology
- Sustainable Development and Climate (SDC) Ontology
- Symptomatic Treatment of Multiple Sclerosis Ontology (STMSO)
- Taxonomy for Rehabilitation of Knee Conditions (TRAK)
- The Common Rule Ontology (CRO)
- The Trope Ontology
- Time Event Ontology (TEO)
- Toxic Process Ontology (TXPO)
- Trade-Space Analysis Tool for Constellations (TAT-C) ontology
- Traditional Chinese Drugs Ontology (TCDO)
- Translational Medicine Ontology (TMO)

Methodological Convictions

- **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

- **Fallibilism** – BFO is committed to tracking scientific research over time, which might change

- **Adequatism** – BFO is non-reductive, classes and relations motivated by research communities are not 'paraphrased away' for example

Methodological Convictions

- **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

- **Fallibilism** – BFO is committed to tracking scientific research over time, which might change

- **Adequatism** – BFO is non-reductive, classes and relations motivated by research communities are not 'paraphrased away' for example

Realism

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

- Which encompasses both **conceptualism** and **pragmatism**

- You will find realism underwriting not just ontologies but logical models, formal specifications, mathematics, etc.

Realism

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

- **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

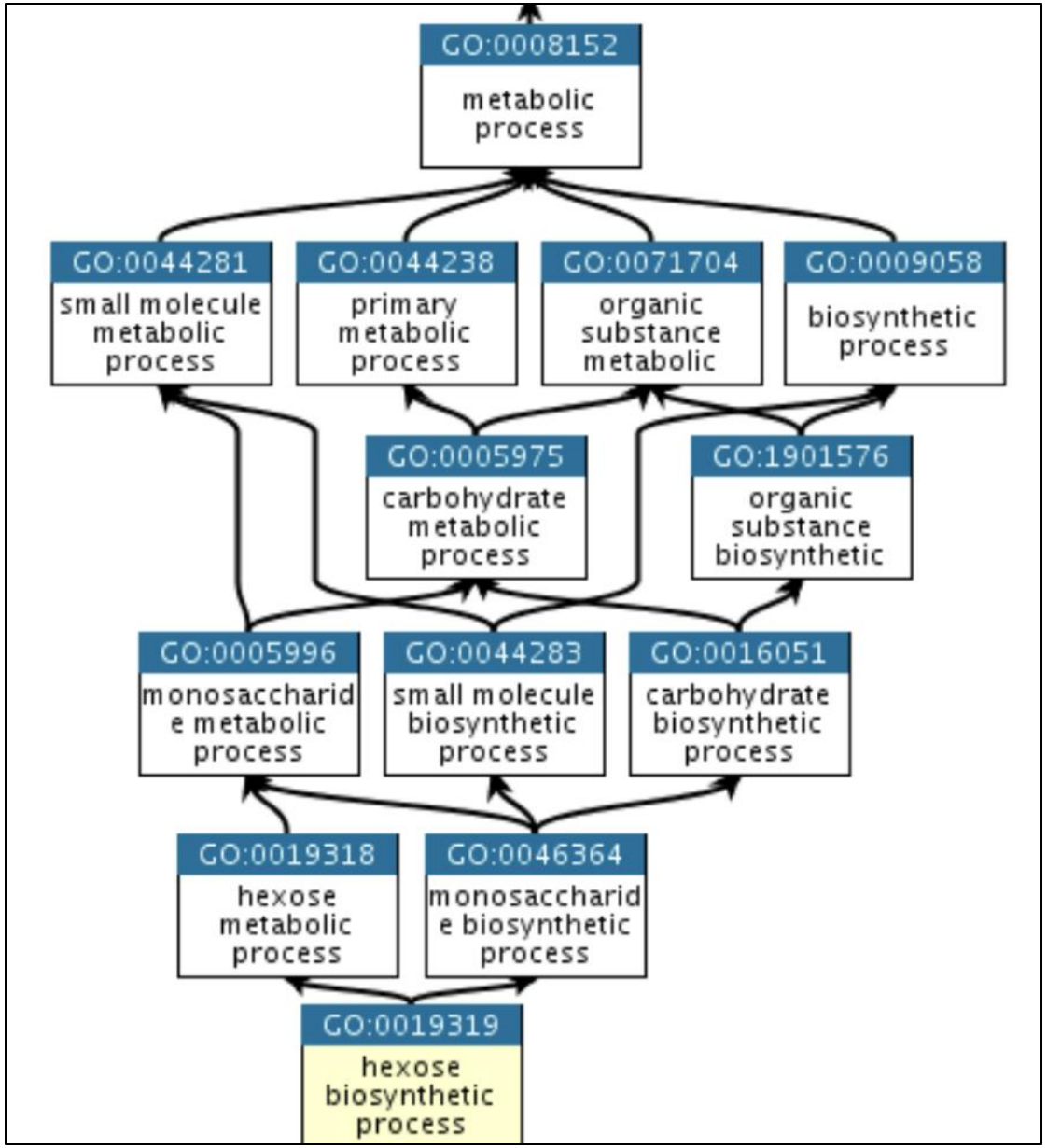
- **Fallibilism** – BFO is committed to tracking scientific research over time, which might change

- **Adequatism** – BFO is non-reductive, classes and relations motivated by research communities are not 'paraphrased away' for example

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

- 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.

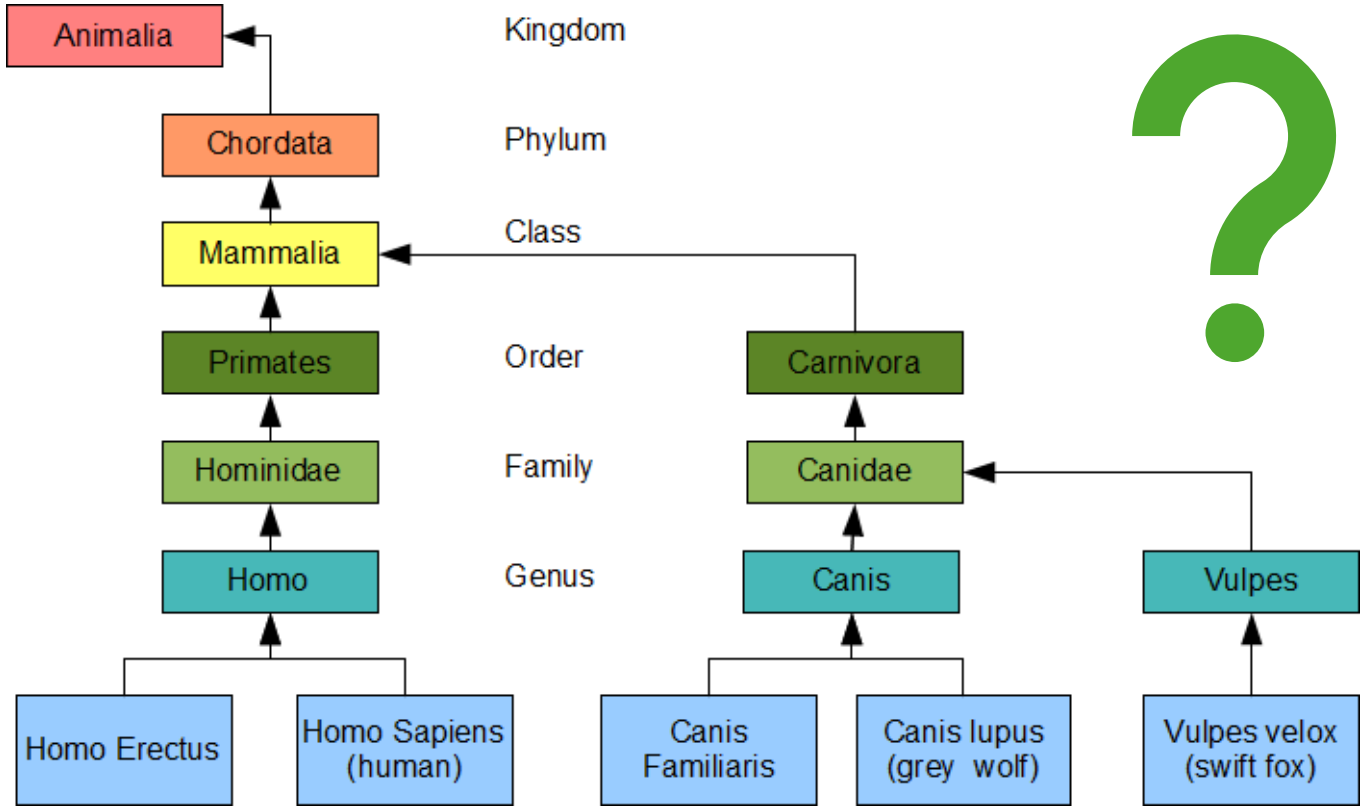
Open Biological and Biomedical Ontologies

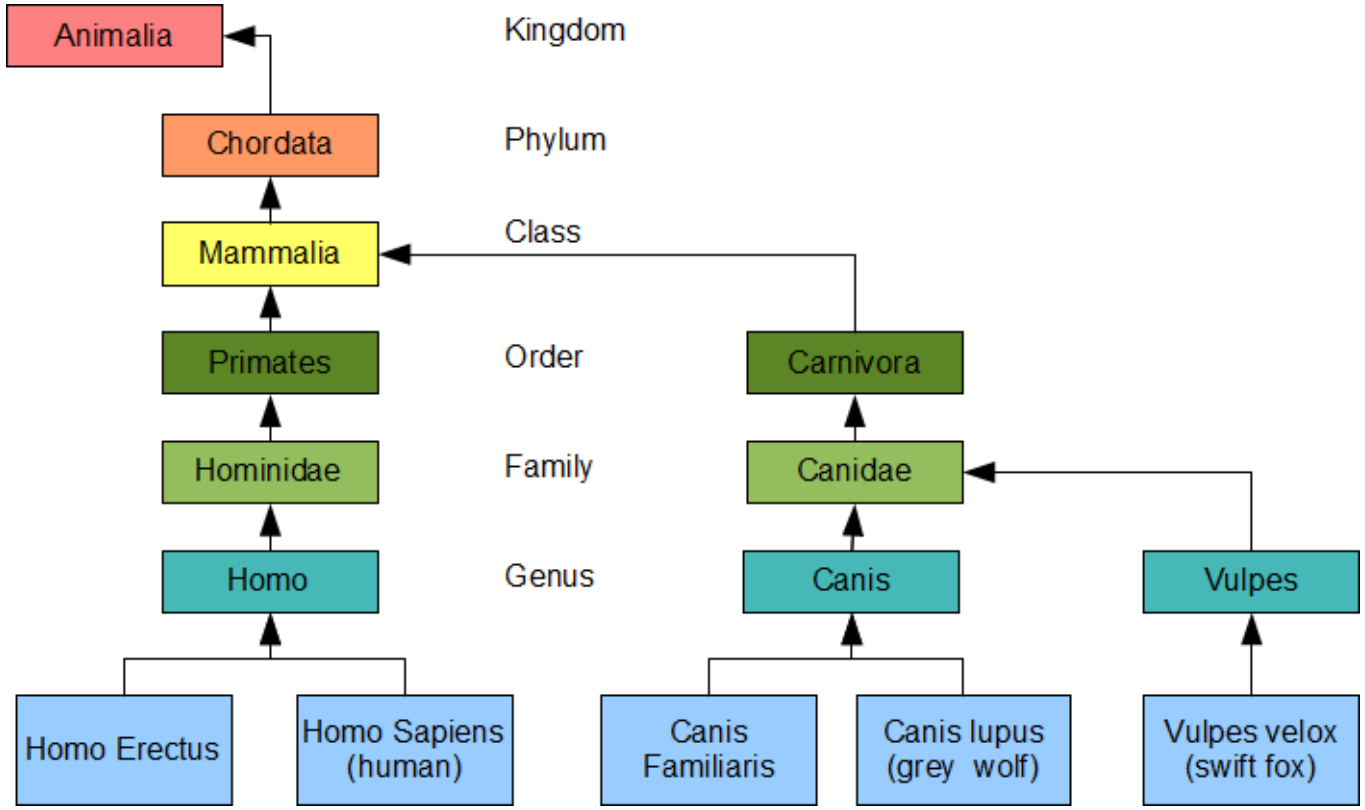
- In 2005, a consortium of biologists decided to create standards for ontology development

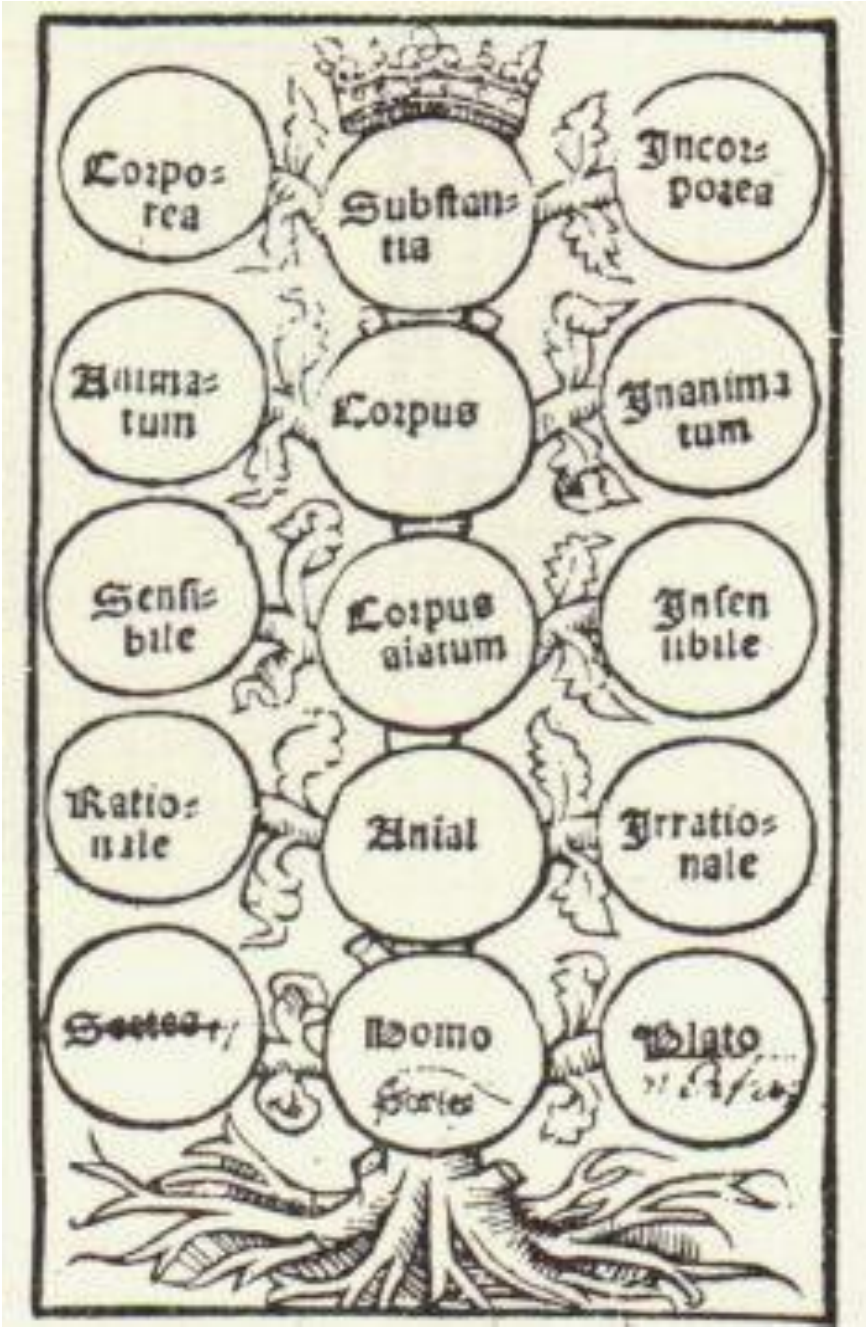
- Such as requiring ontologies be open-source, have documentation, include definitions for vocabulary terms **and…**

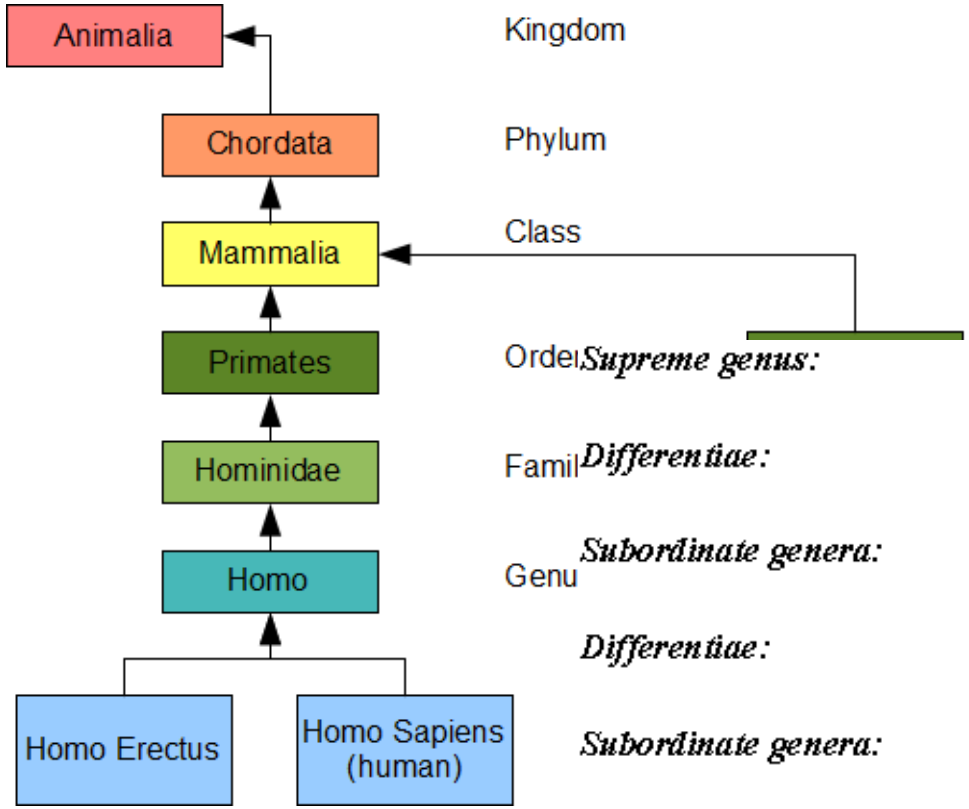
- **Align to a top-level ontology which provides a starting point for all ontology development…**

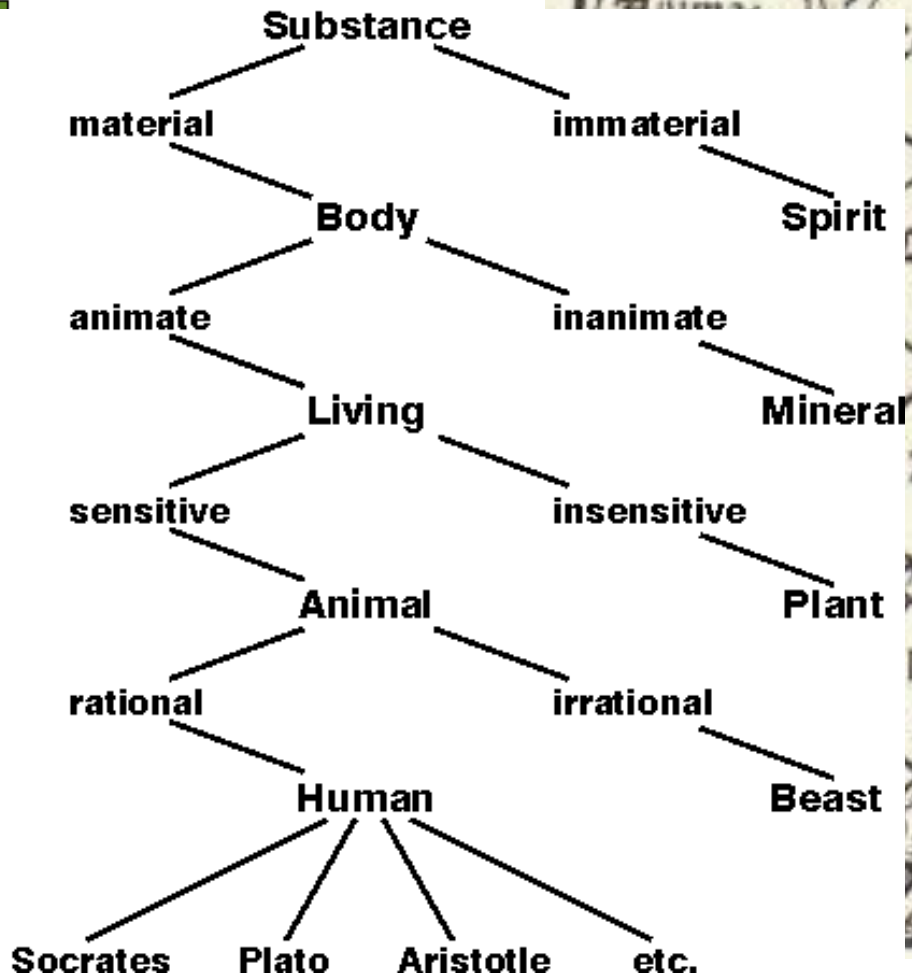
Overview
Open (principle 1)
Common Format (principle 2)
URI/Identifier Space (principle 3)
Versioning (principle 4)
Scope (principle 5)
Textual Definitions (principle 6)
Relations (principle 7)
Documentation (principle 8)
Documented Plurality of Users (principle 9)
Commitment To Collaboration (principle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

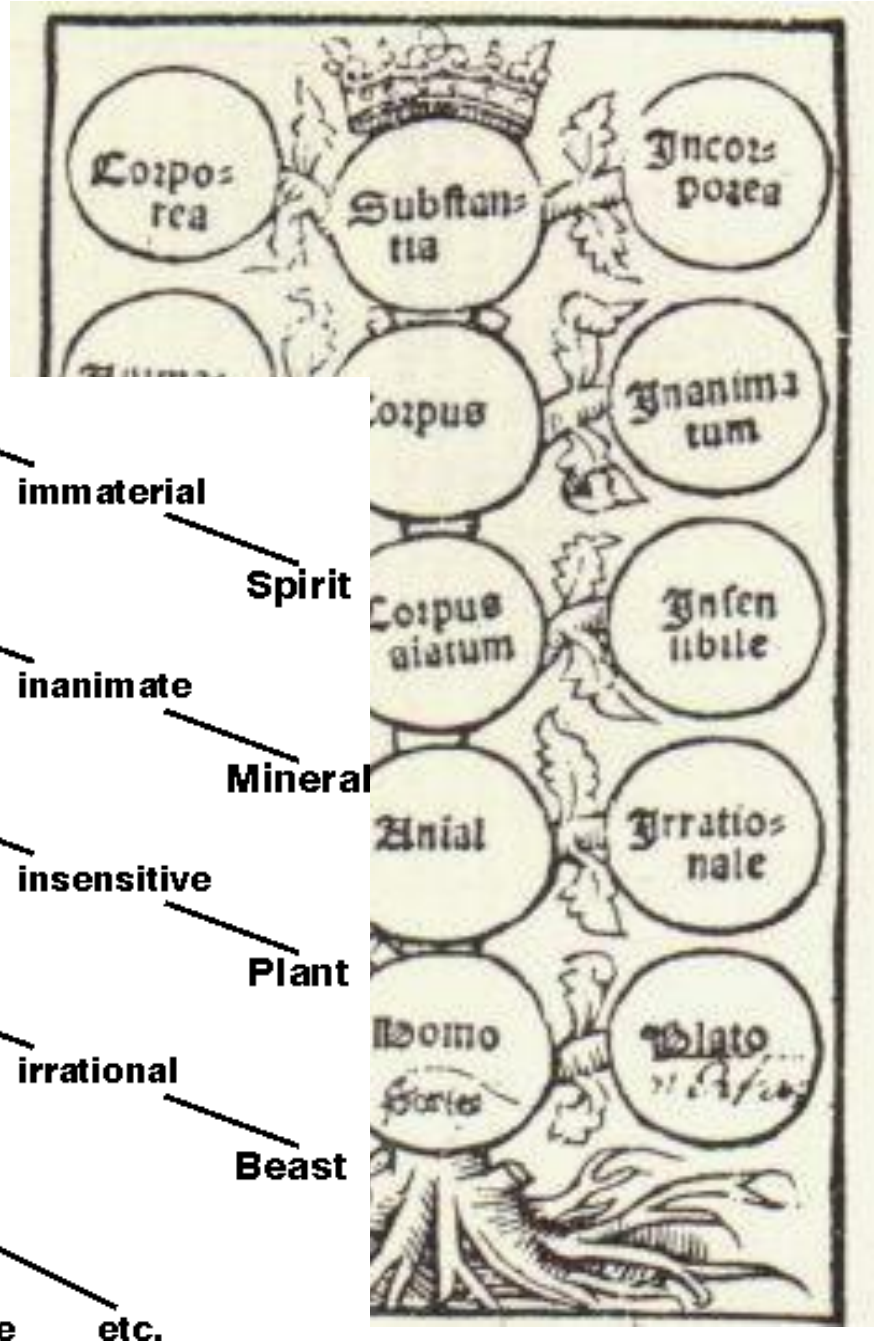

Animalia
Kingdom
Chordata
Phylum
Mammalia
Class
Primates
Order
Carnivora
Hominidae
Family
Canidae
Homo
Genus
Canis
Vulpes
Homo Erectus
Homo Sapiens (human)
Canis Familiaris
Canis lupus (grey wolf)
Vulpes velox (swift fox)
?

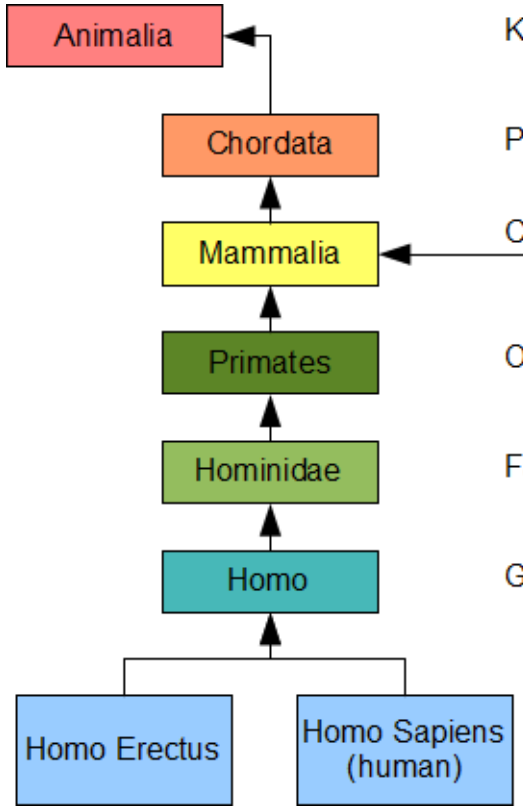

Animalia
Kingdom
Chordata
Phylum
Mammalia
Class
Primates
Order
Carnivora
Hominidae
Family
Canidae
Homo
Genus
Canis
Vulpes
Homo Erectus
Homo Sapiens (human)
Canis Familiaris
Canis lupus (grey wolf)
Vulpes velox (swift fox)


Corpo= rea
Subſtan= tia
Incor= porea
Animā= tum
Corpus
Inanima tum
Senſi= bile
Corpus aiatum
Inſen ſibile
Ratio= nale
Anial
Irratio= nale
Socrates
Homo
Plato


Animalia
Kingdom
Chordata
Phylum
Mammalia
Class
Primates
Ordei
Hominidae
Famil
Homo
Genu
Homo Erectus
Homo Sapiens (human)


Supreme genus:
Substance
Differentiae:
material
immaterial
Subordinate genera:
Body
Spirit
Differentiae:
animate
inanimate
Subordinate genera:
Living
Mineral
Differentiae:
sensitive
insensitive
Proximate genera:
Animal
Plant
Differentiae:
rational
irrational
Species:
Human
Beast
Individuals:
Socrates
Plato
Aristotle
etc.


Corpo-rea
Substan-tia
Incor-porea
Corpus
Inanima-tum
Corpus aiatum
Insen-sibile
Anial
Irratio-nale
Homo
Plato



Kingdom

Phylum

Class

Orde

Famil

Genu

Supreme genus:

Differentiae:

Subordinate genera:

Differentiae:

Subordinate genera:

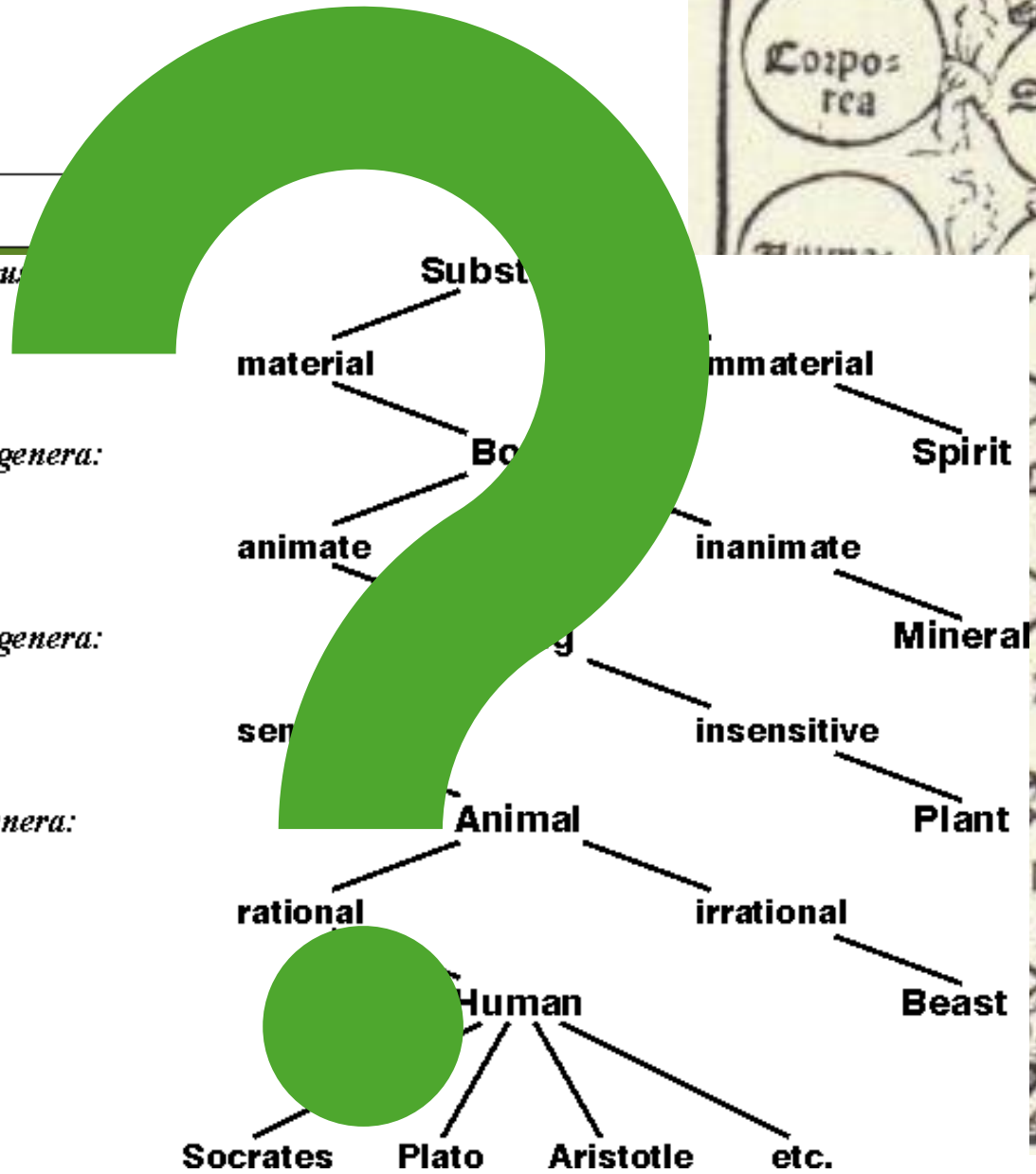
Differentiae:

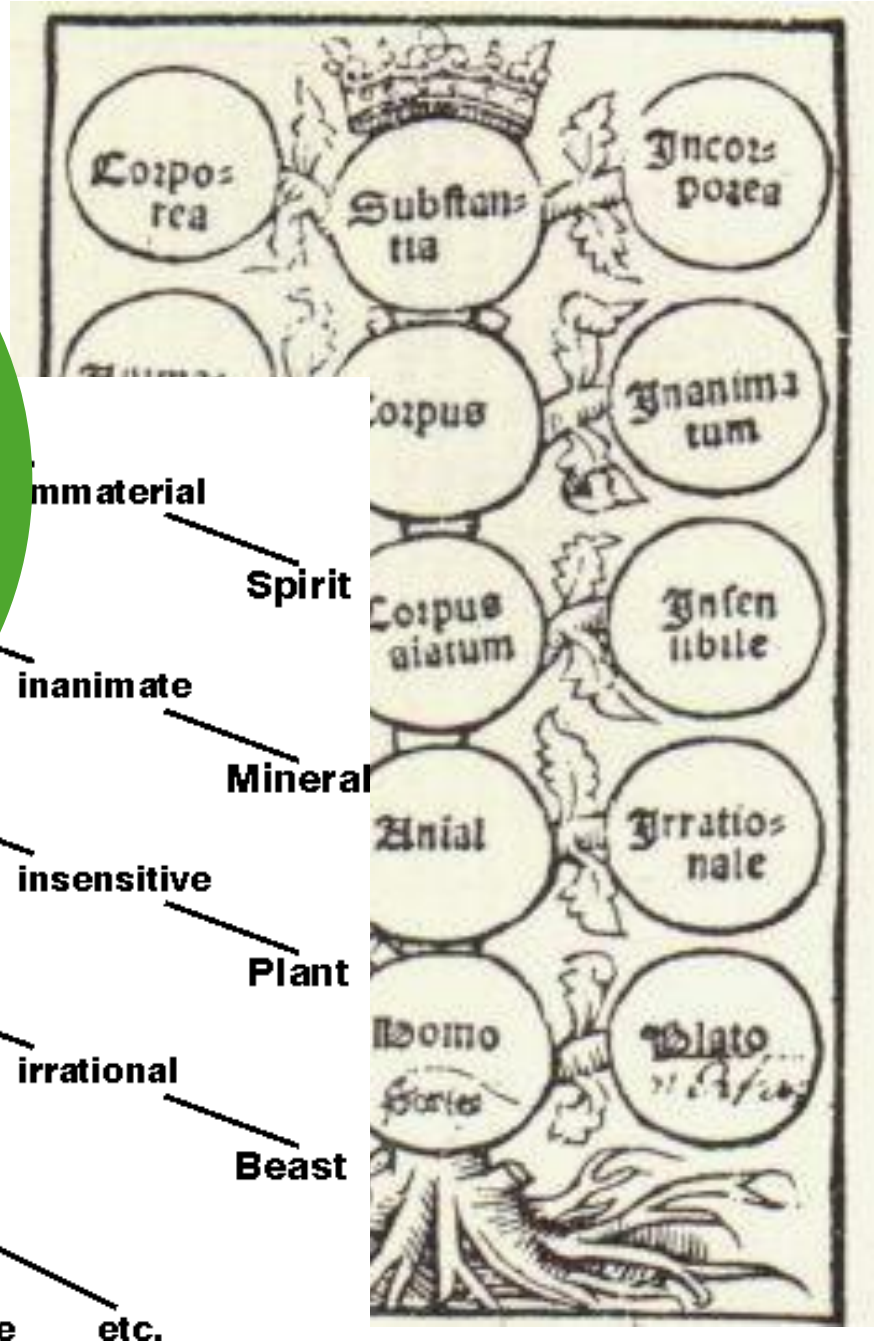
Proximate genera:

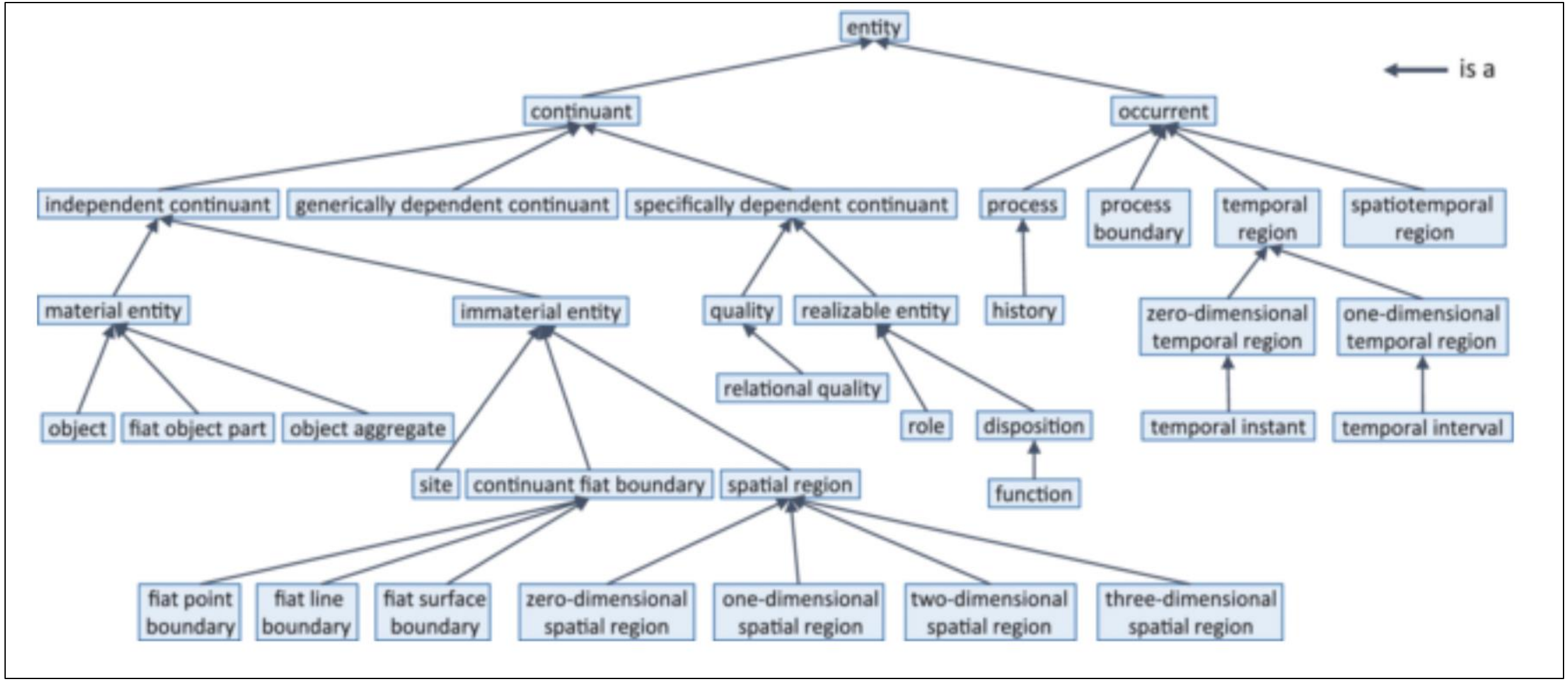
Differentiae:

Species:

Individuals:






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

Analogy

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

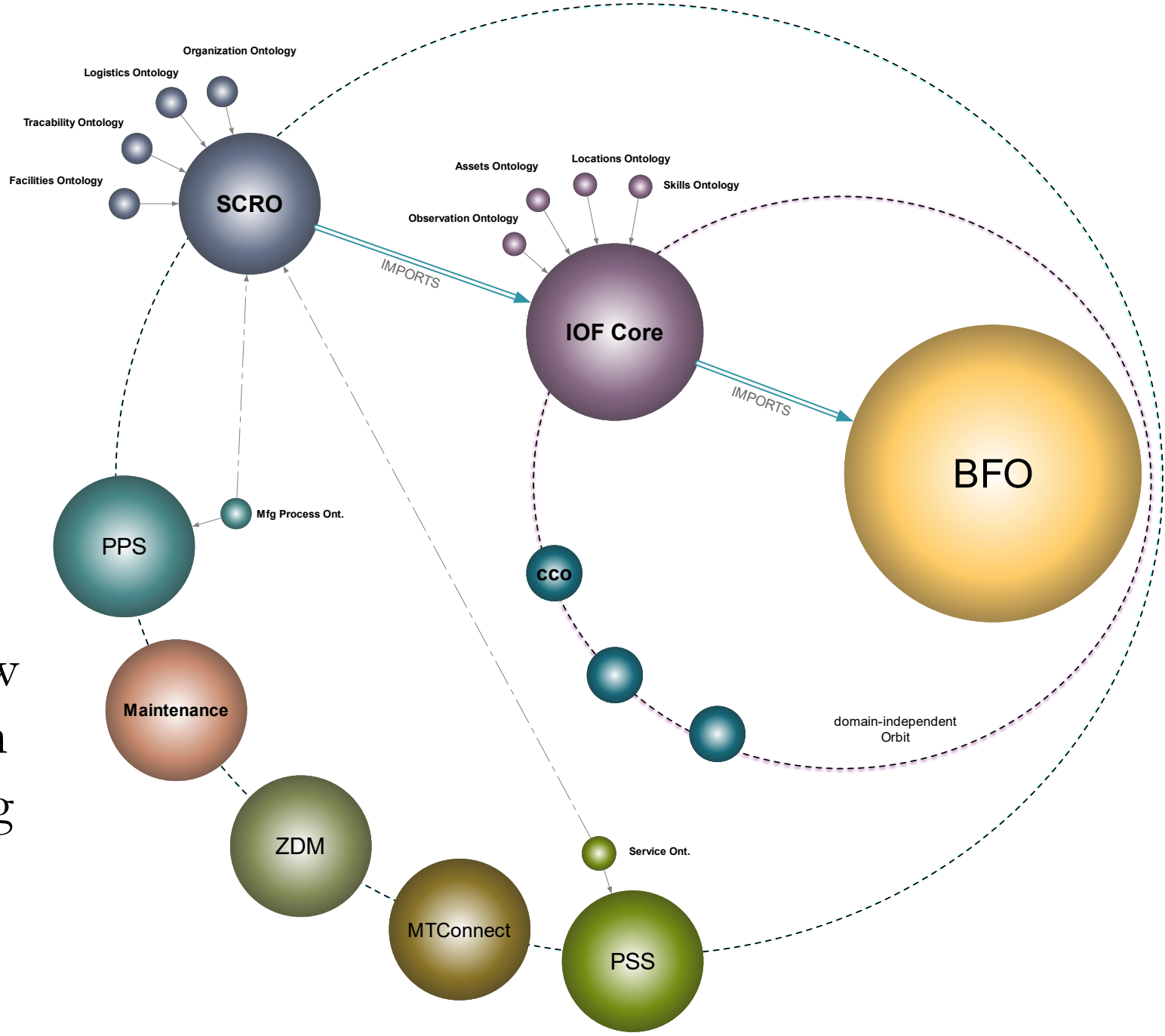
- You **could** create code that allows you to interact with, say, dataframes or you could **instead** start with Python and import a library like Pandas

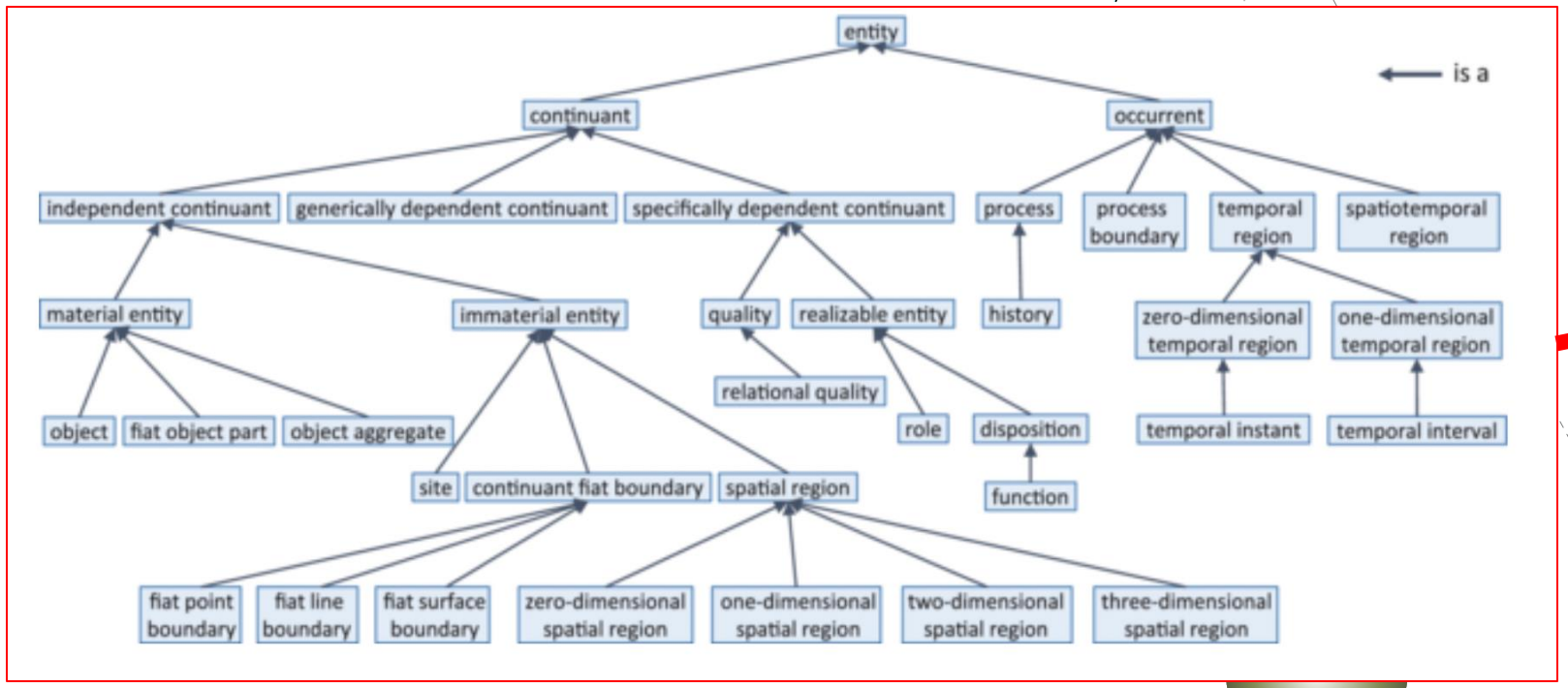
- You **could** create ontology elements that allow you to model artifacts and processes or you **could** instead start with BFO and import an extension

Hub & Spoke

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

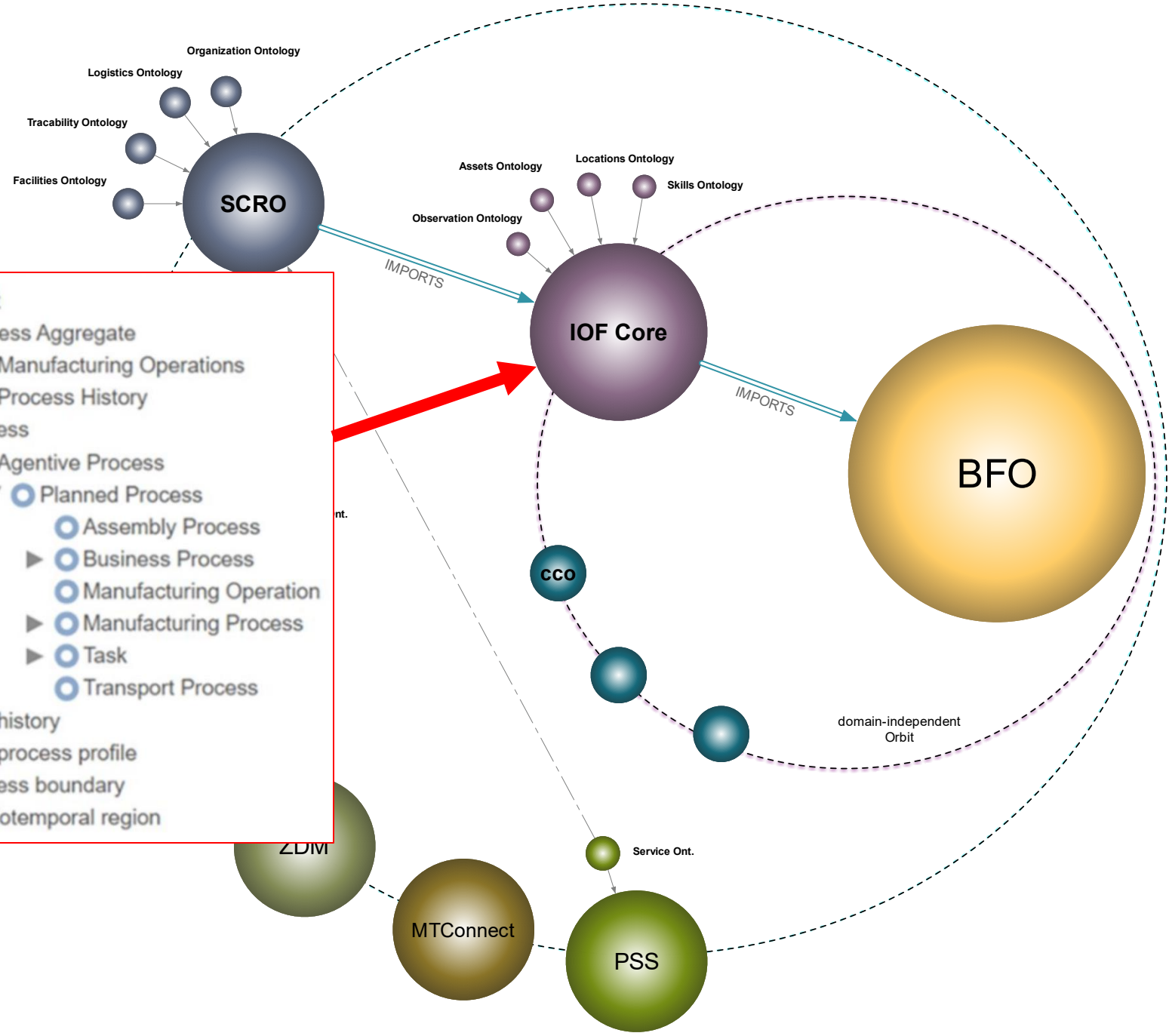
Ontologies are extended by **downward population**, new classes have parent classes in a hierarchy ultimately leading to a BFO class




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

Industrial Ontologies Foundry

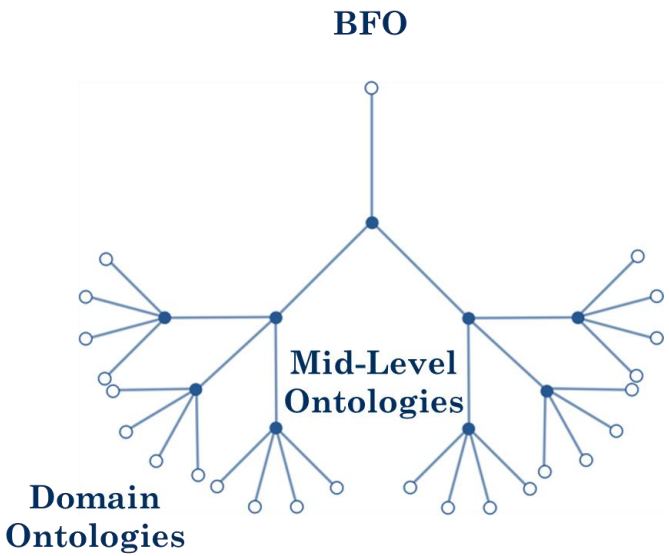
- IOF is an international standards group that operates under the auspices of the Open Applications Group (OAGi)

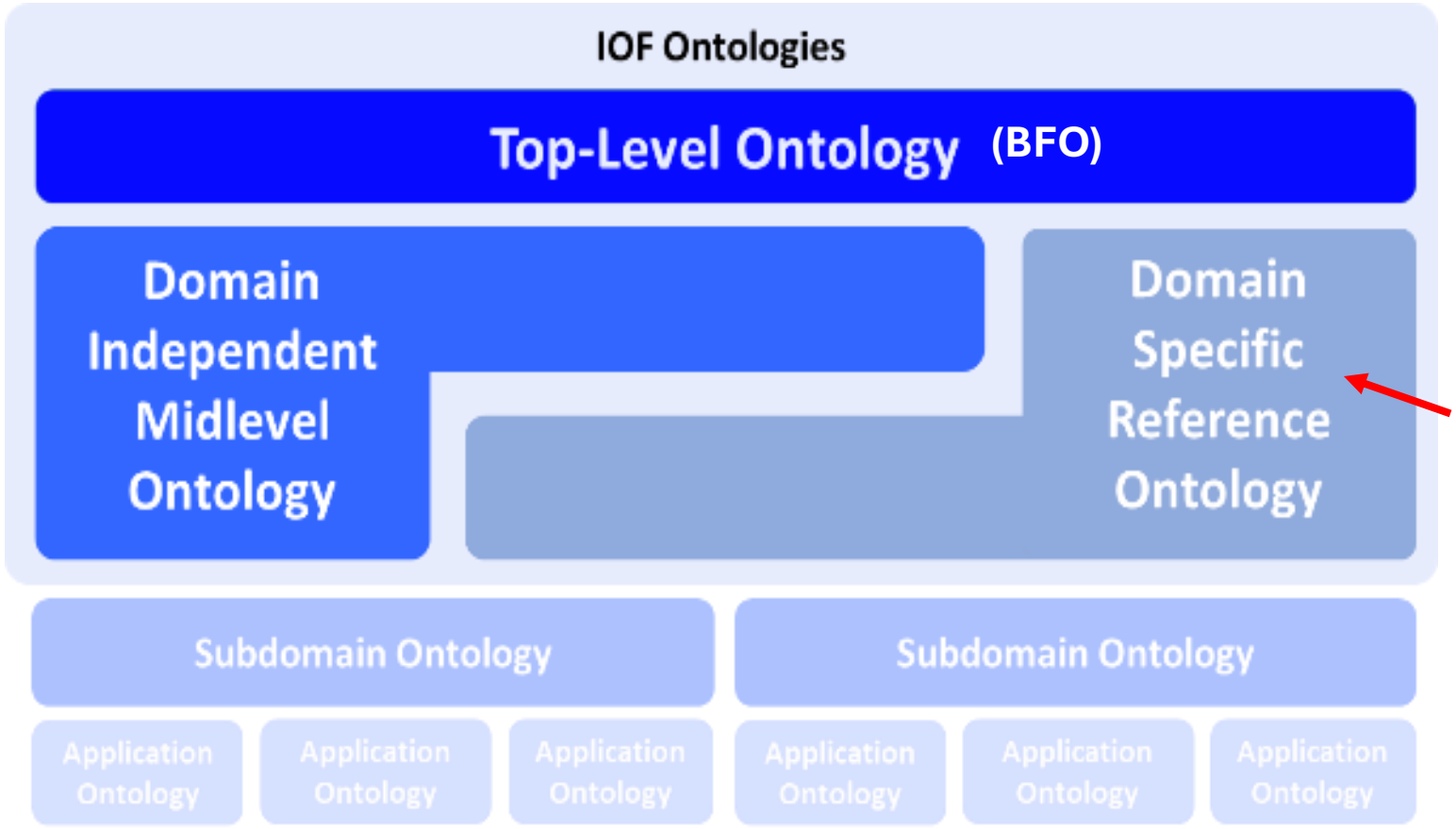
Mission:

- Create a suite of public and reusable reference ontologies covering the manufacturing domain
- Promote the use of ontologies in industrial applications
- Work with Government, Industry, Academic and Standards organizations to advance data interoperability in their respective fields

50+ Organizations

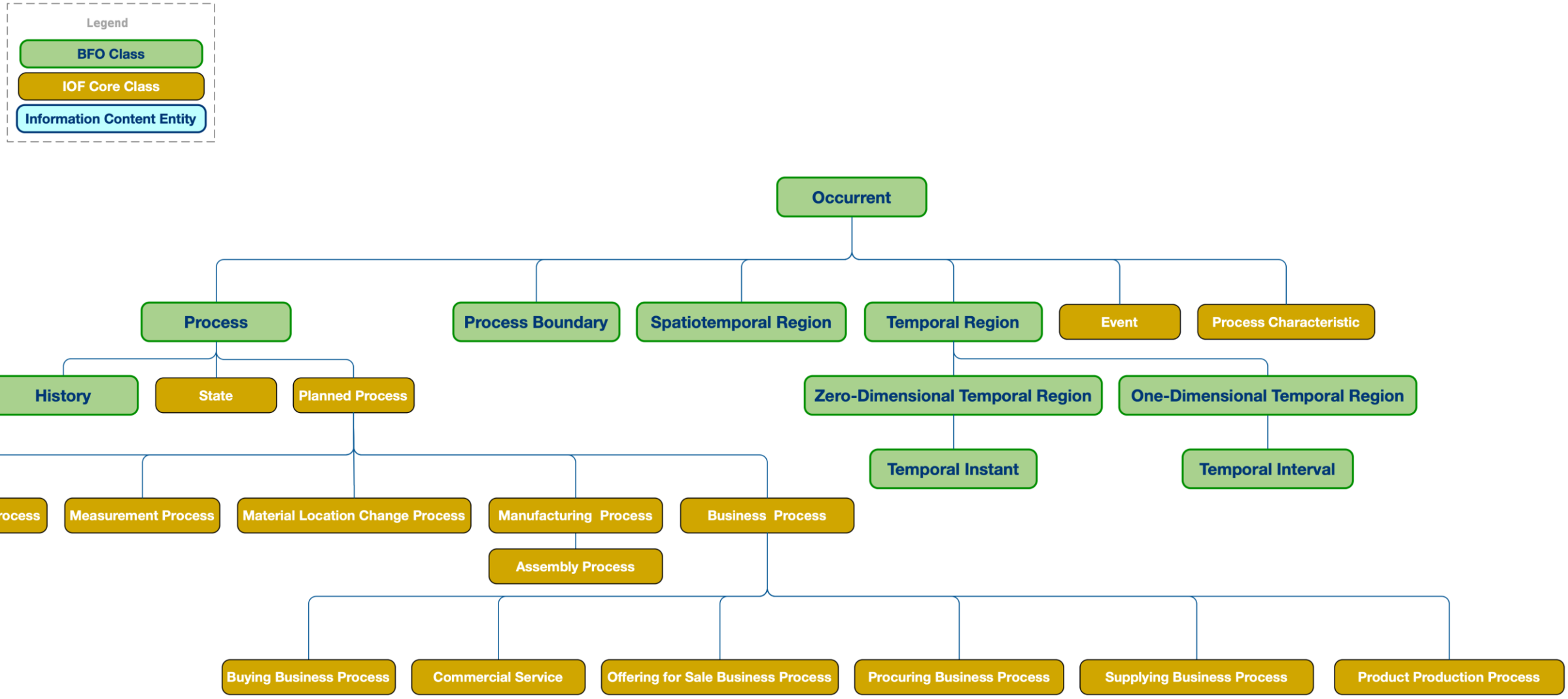
Hub-and-Spoke Architecture



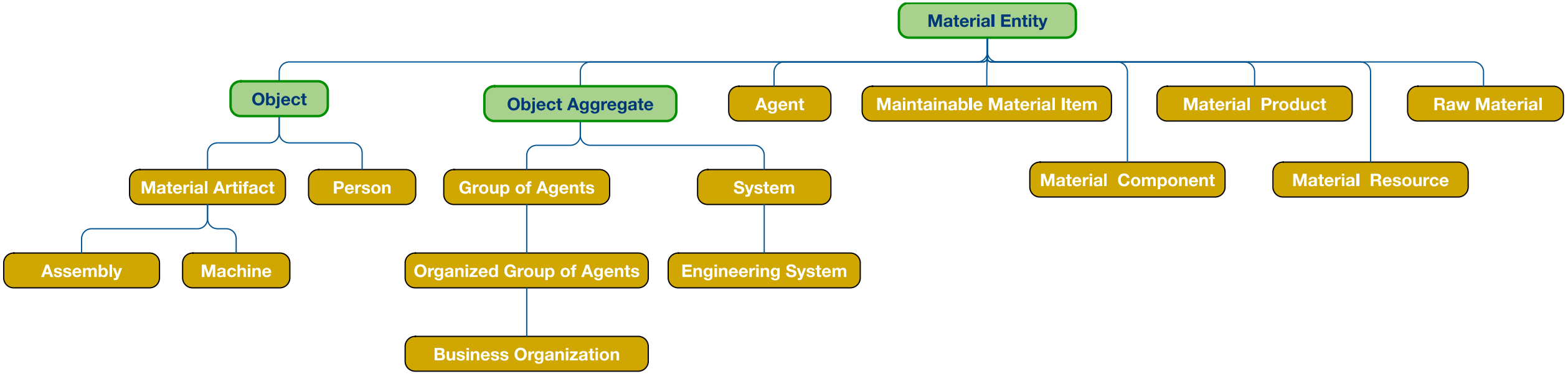


Supply chain
Maintenance
Production planning & scheduling
Engineering Design
Service Systems Engineering

IOF Core: Entities Existing Over Time



IOF Core: Entities with Material Parts

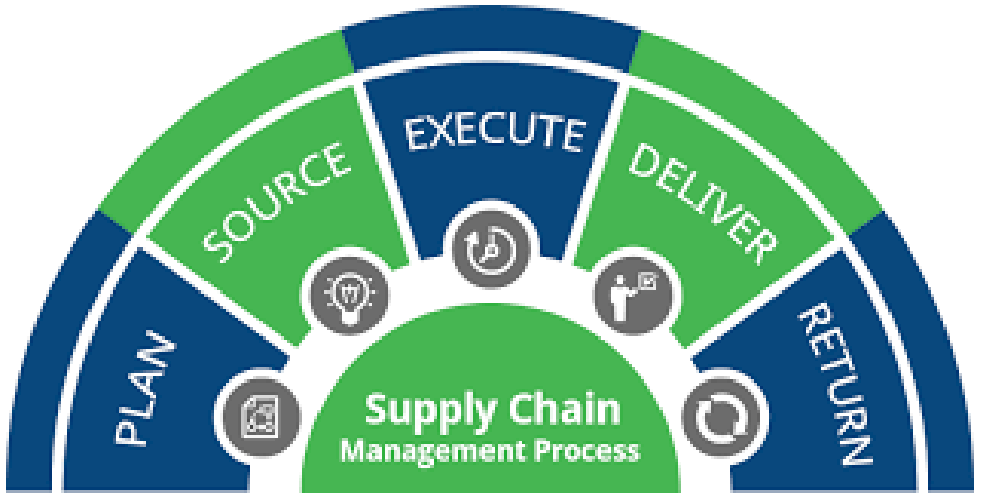


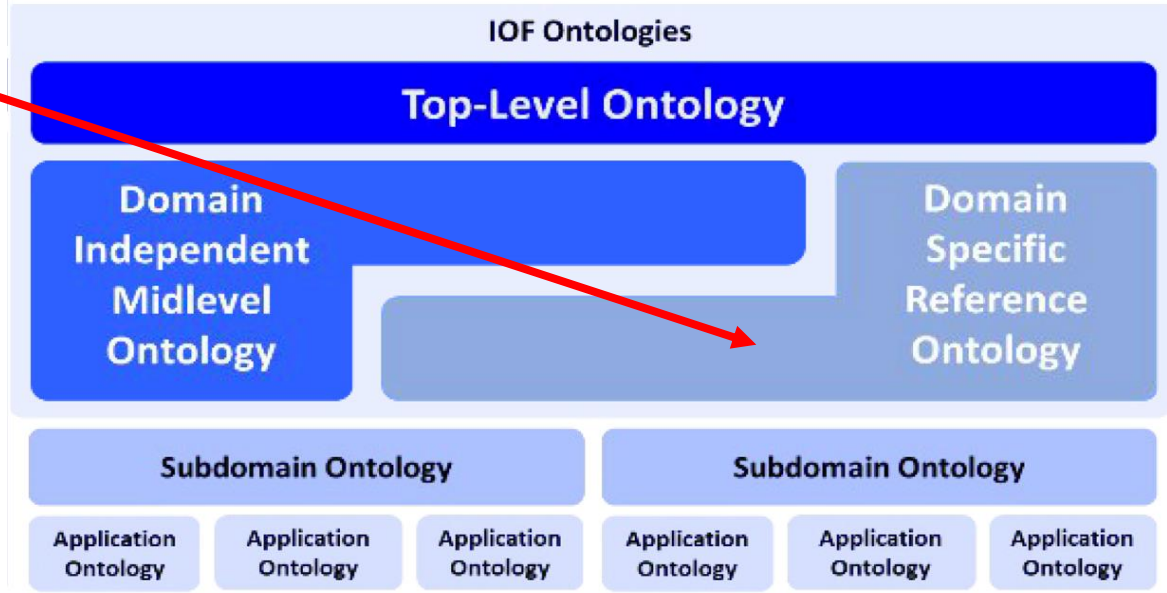
Supply Chain Core Ontology (SCRO)

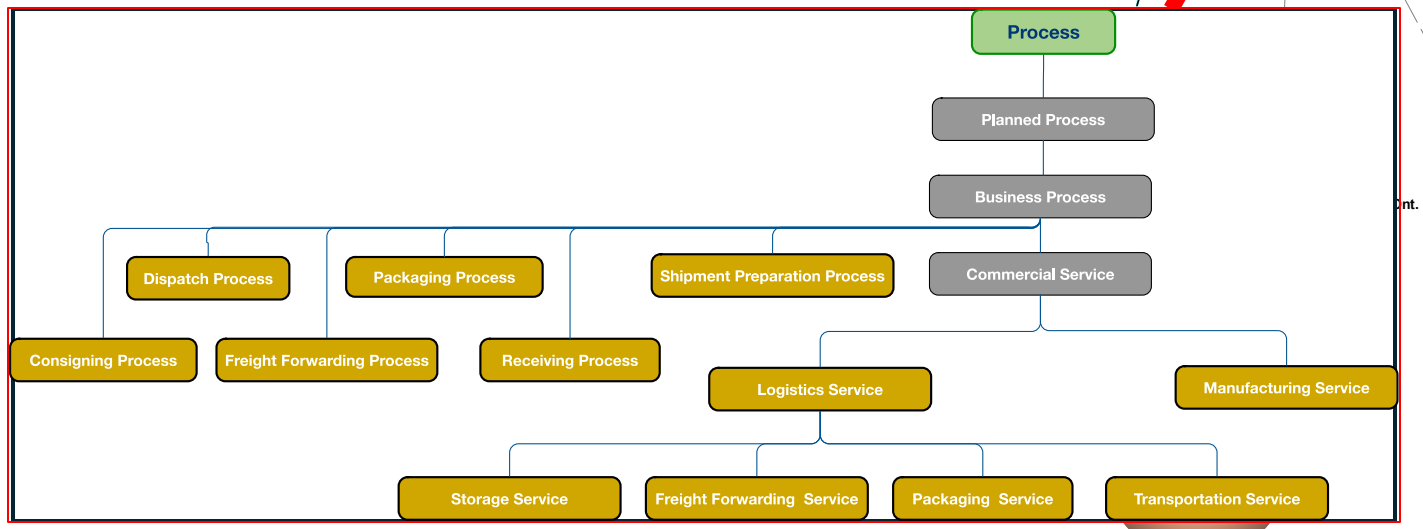
Objective:

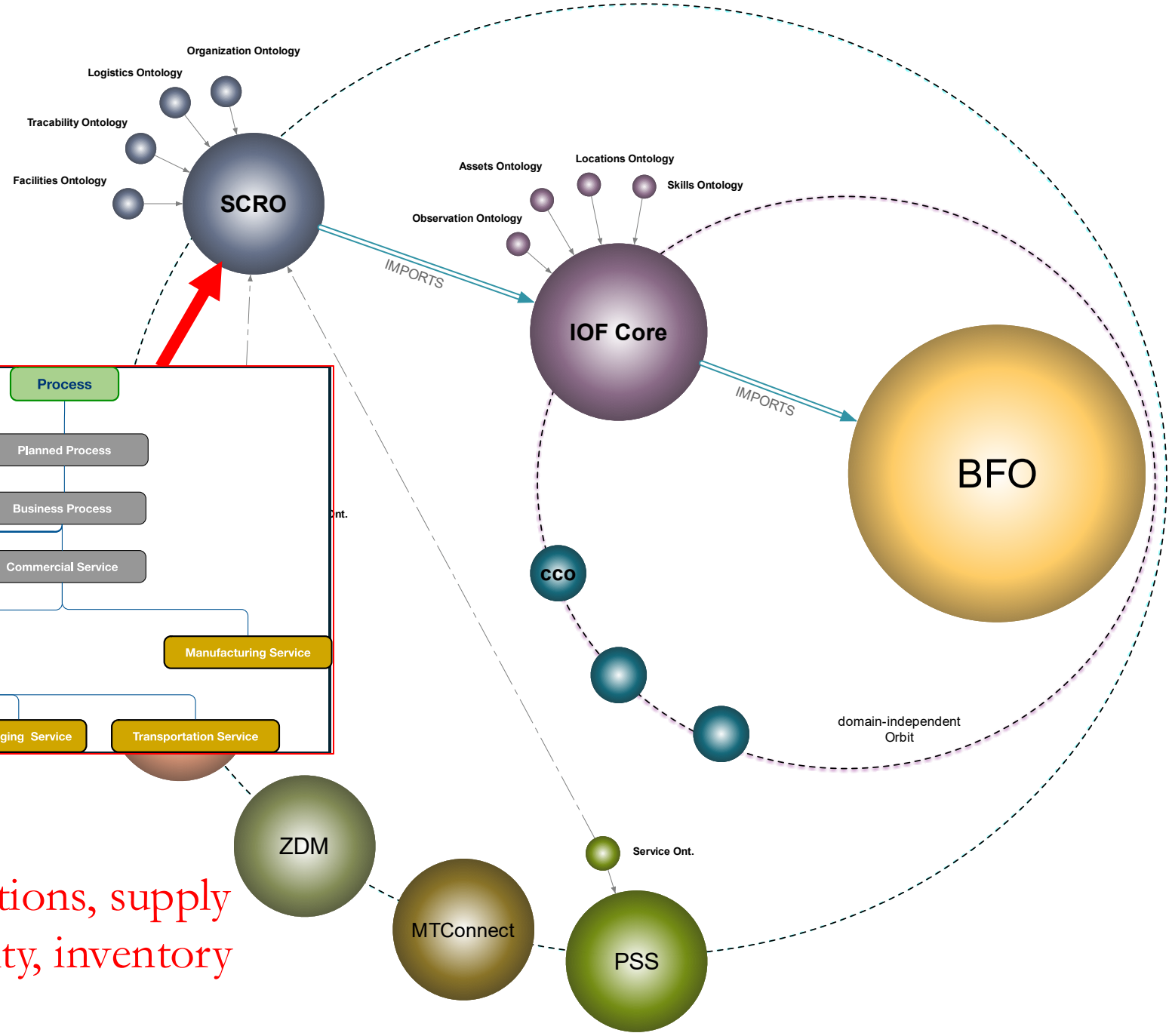
- Identify the requirements of reference ontologies (RO) in the supply chain domain,
- Develop SCRO and other lower-level ontologies in SC domain

Scope:





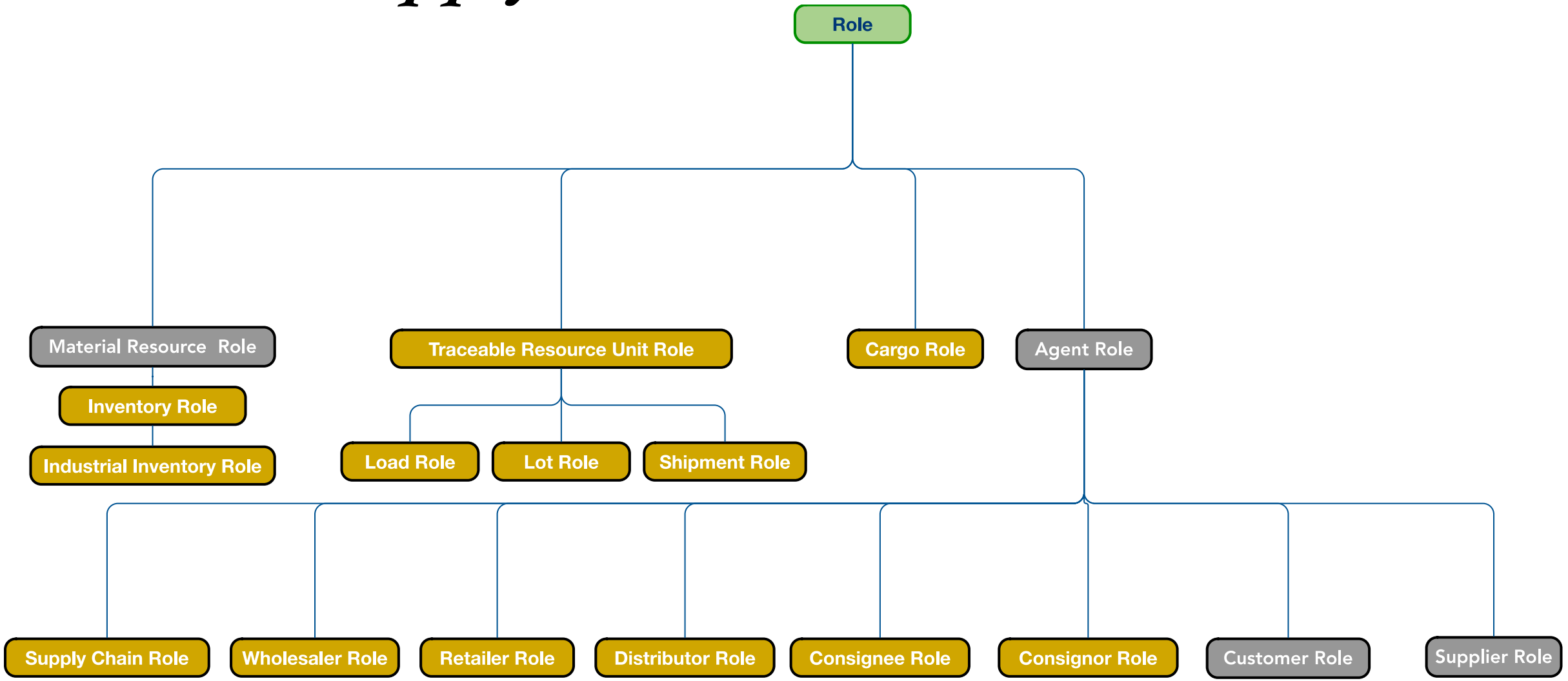




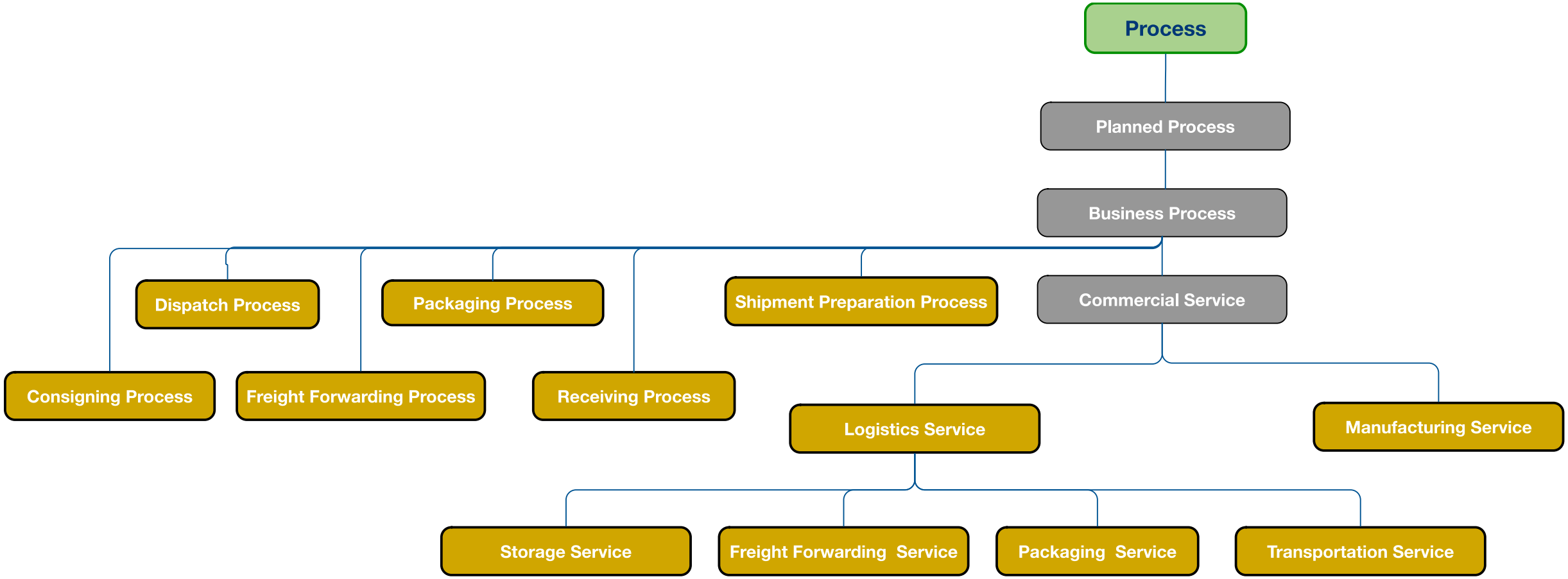
Scope

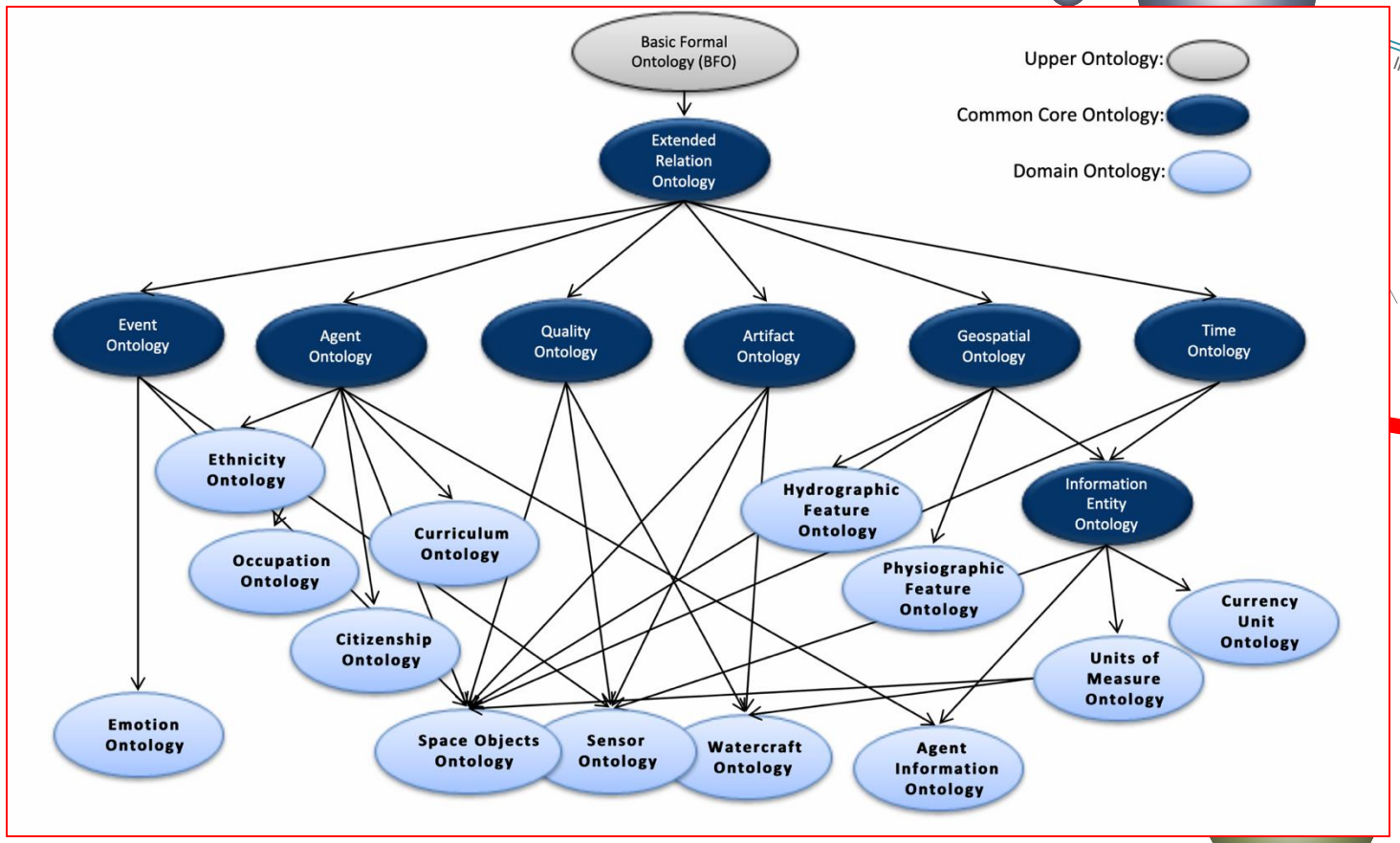
logistics and transportation, organizations, supply and service chains, facilities, traceability, inventory management

SCRO: Supply Chain Roles



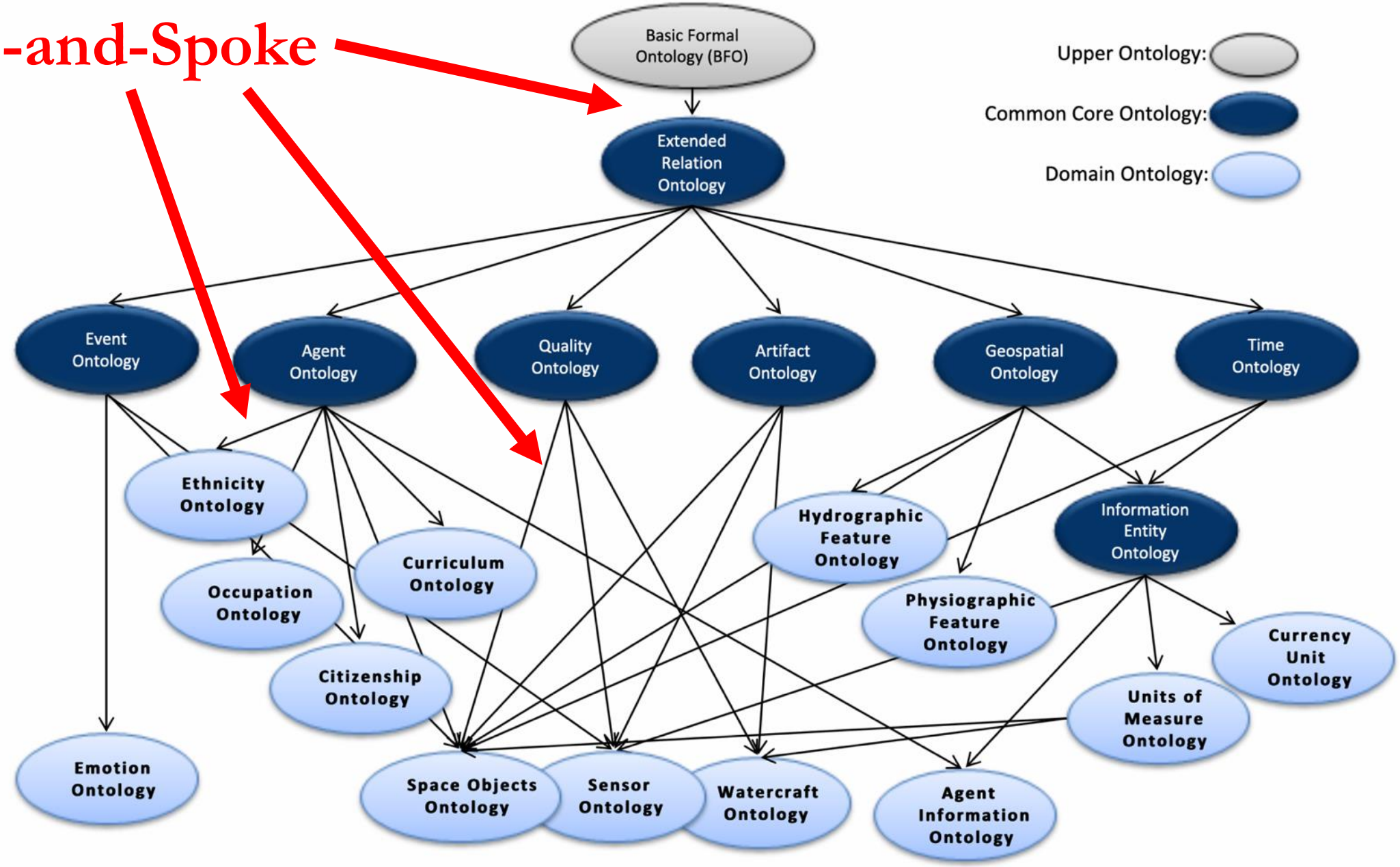
SCRO: Business Processes




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

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

Hub-and-Spoke



Methodological Convictions

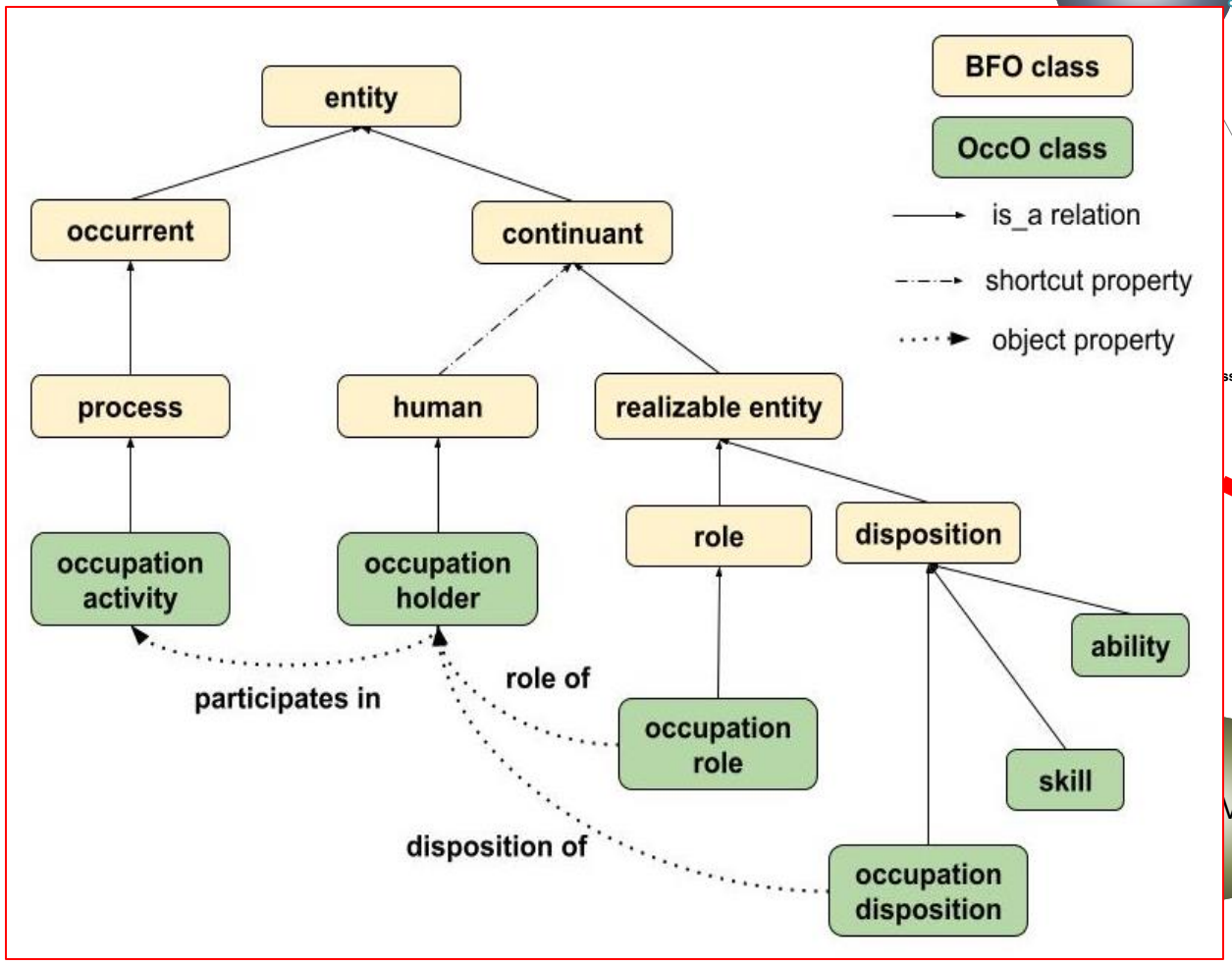
- **Realism** – BFO is designed to represent the world, rather than simply concepts about the world

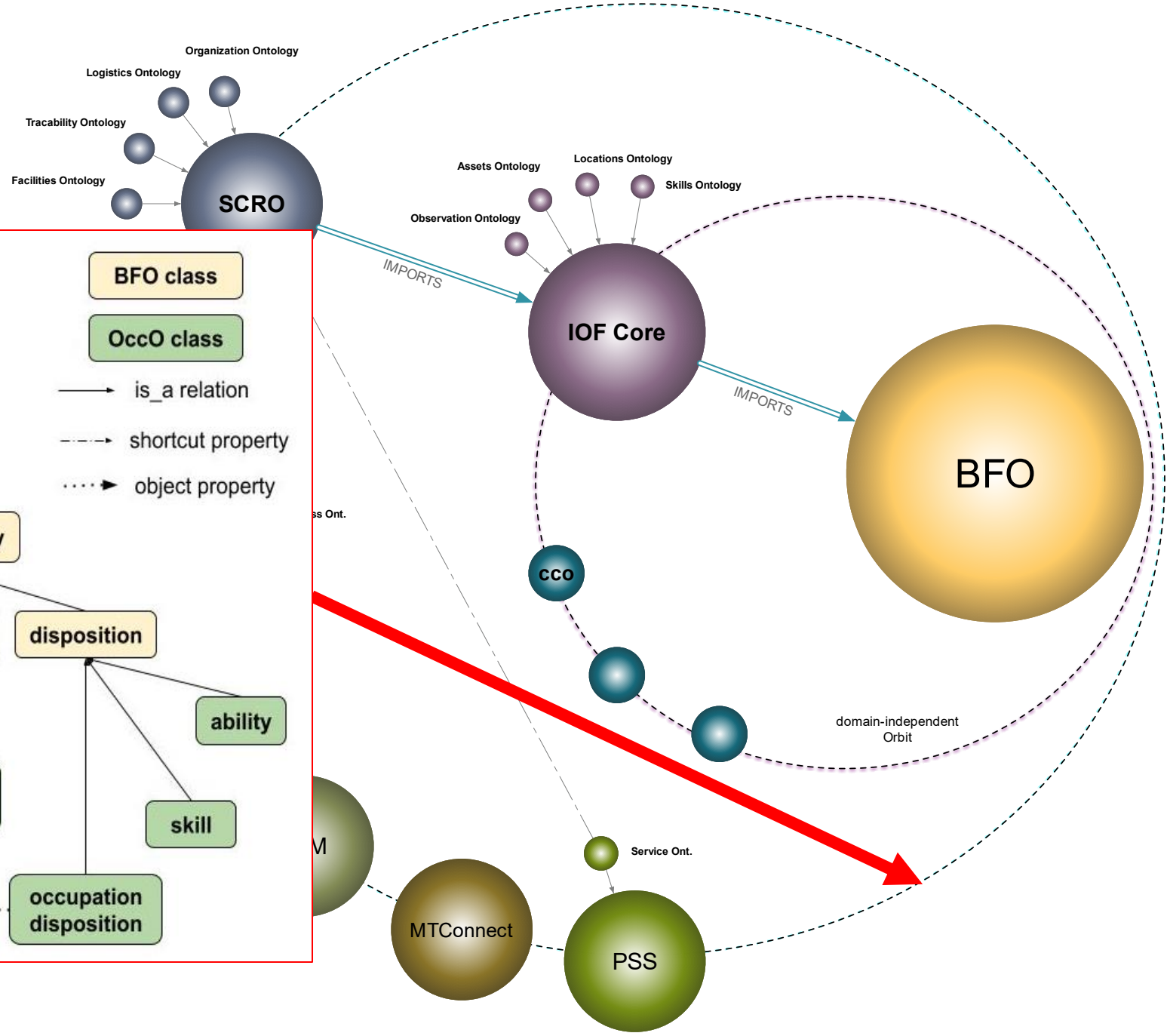
- **Hub & Spoke** – BFO is a hub from which spoke ontologies extend

- **Fallibilism** – BFO is committed to tracking scientific research over time, which might change

- **Adequatism** – BFO is non-reductive, classes and relations motivated by research communities are not 'paraphrased away' for example

The Occupation Ontology





51 jobs that don't exist anymore

Some of these jobs have transformed into new roles with new titles due to technological advances, while others are now common colloquial terms despite disappearing as actual jobs. Here are 51 jobs that are no longer around:

1. Leech collector

A leech collector was responsible for retrieving the blood-sucking worms from their natural habitat for doctors to use. Individuals with this job used the legs of animals or their own legs to lure leeches from creeks and rivers.

2. Knocker upper

Knocker uppers, or knocker-ups, were responsible for waking people up by making loud noises before electronic alarm clocks existed. People in the 1800s would hire these individuals to shoot peas at their windows or tap on the glass using a long pole to wake them up.

51 jobs that don't exist anymore

10 Disappearing Jobs That Won’t Exist in 10 Years: Professions That Won’t Guarantee Career Opportunities in 2024

from their natural habitat for doctors to use. Individuals with this job used the legs of animals or their own legs to lure leeches from creeks and rivers.

2. Knocker upper

Knocker uppers, or knocker-ups, were responsible for waking people up by making loud noises before electronic alarm clocks existed. People in the 1800s would hire these individuals to shoot peas at their windows or tap on the glass using a long pole to wake them up.

51 jobs that don't exist anymore

10 Disappearing Jobs That Won’t Exist in 10 Years: Professions That Won’t Guarantee Career Opportunities in 2024

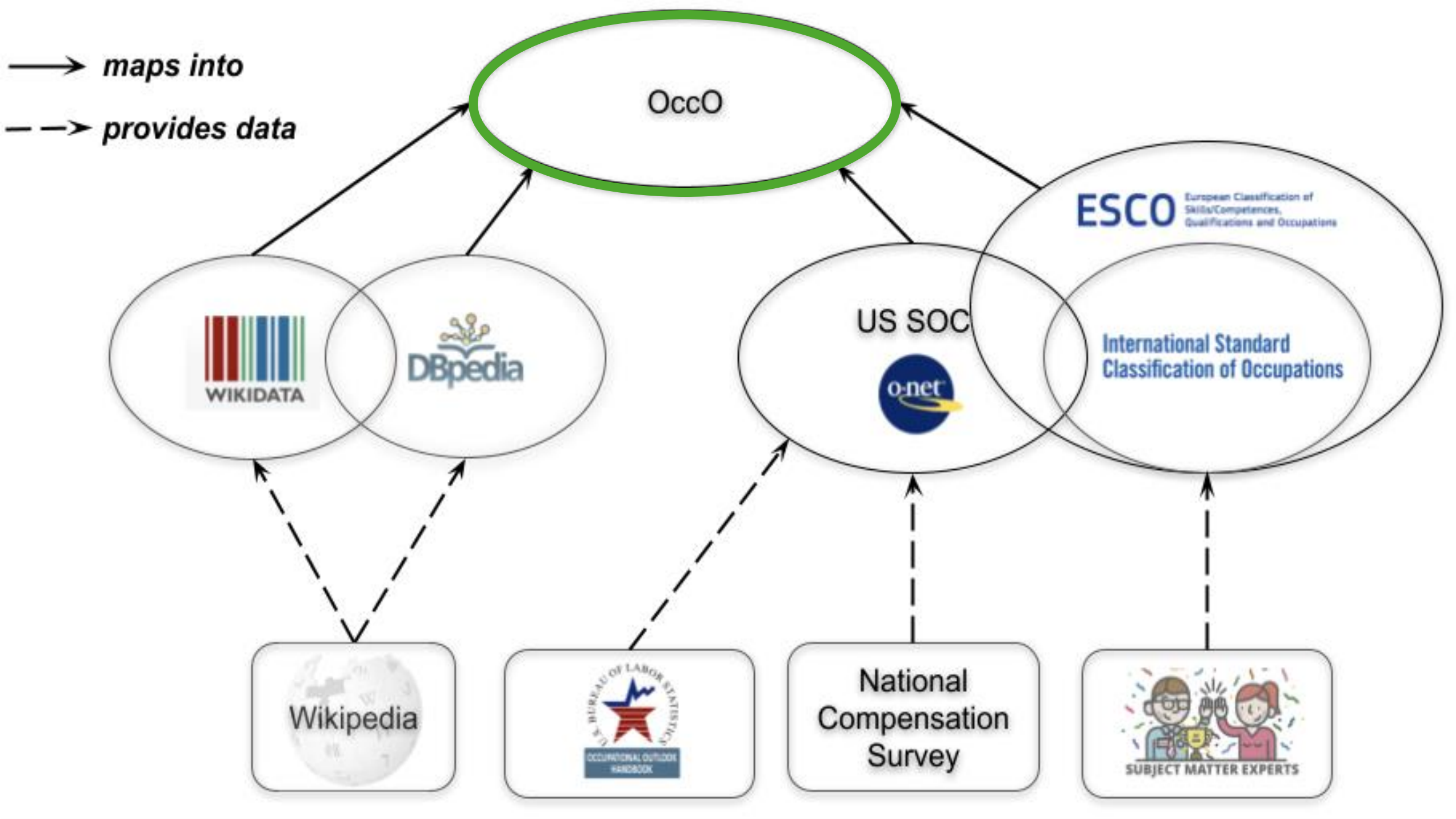
from their natural habitat for doctors to use. Individuals with this job used the

7 Jobs That Don't Exist Today but Will in the Next 5 Years Because of AI How AI will change the future of work.

using a long pole to wake them up.

Methodological Convictions

- **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
- **Fallibilism** – BFO is committed to tracking scientific research over time, which might change
- **Adequatism** – BFO is non-reductive, classes and relations motivated by research communities are not 'paraphrased away' for example


maps into
provides data
OccO
WIKIDATA
DBpedia
US SOC
o-net
ESCO
European Classification of Skills/Competences, Qualifications and Occupations
International Standard Classification of Occupations
Wikipedia
U.S. BUREAU OF LABOR STATISTICS
OCCUPATIONAL OUTLOOK HANDBOOK
National Compensation Survey
SUBJECT MATTER EXPERTS

ESCO

Description

Code

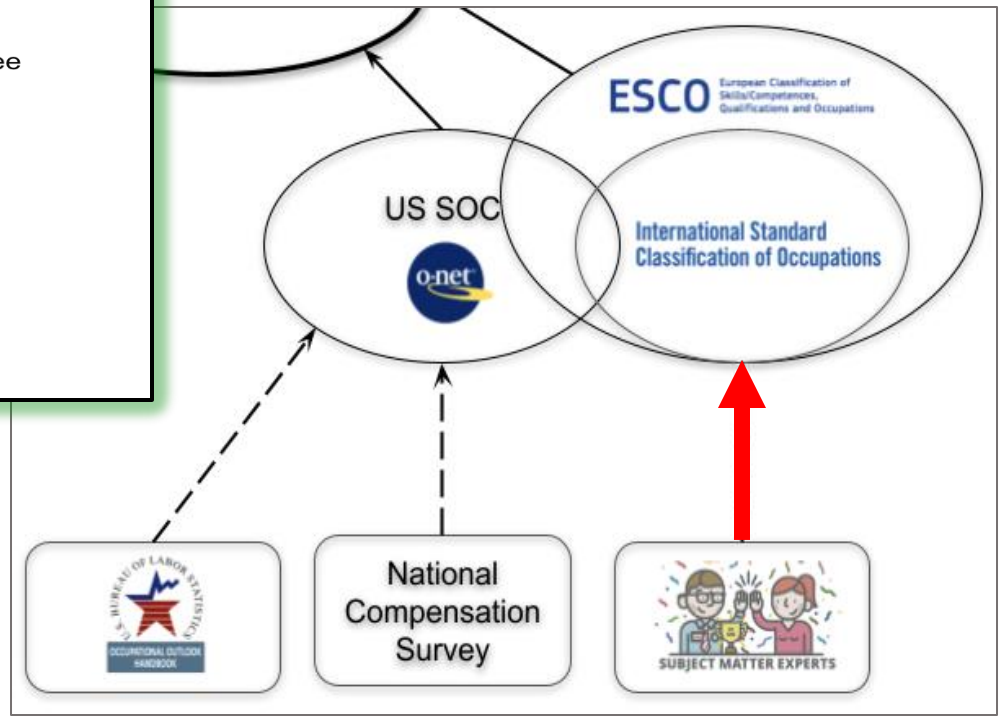
5132.1.1

Description

Barista's prepare specialised types of coffee using professional equipment in a hospitality/coffee shop/bar unit.

Alternative Labels

barista | coffee bartender | coffee maker | specialised bartender | specialised coffee bartender



Subject-matter experts - among other sources – inform the development of ISCO and ESCO standards

US SOC

35-3020 Fast Food and Counter Workers

This broad occupation is the same as the detailed occupation:

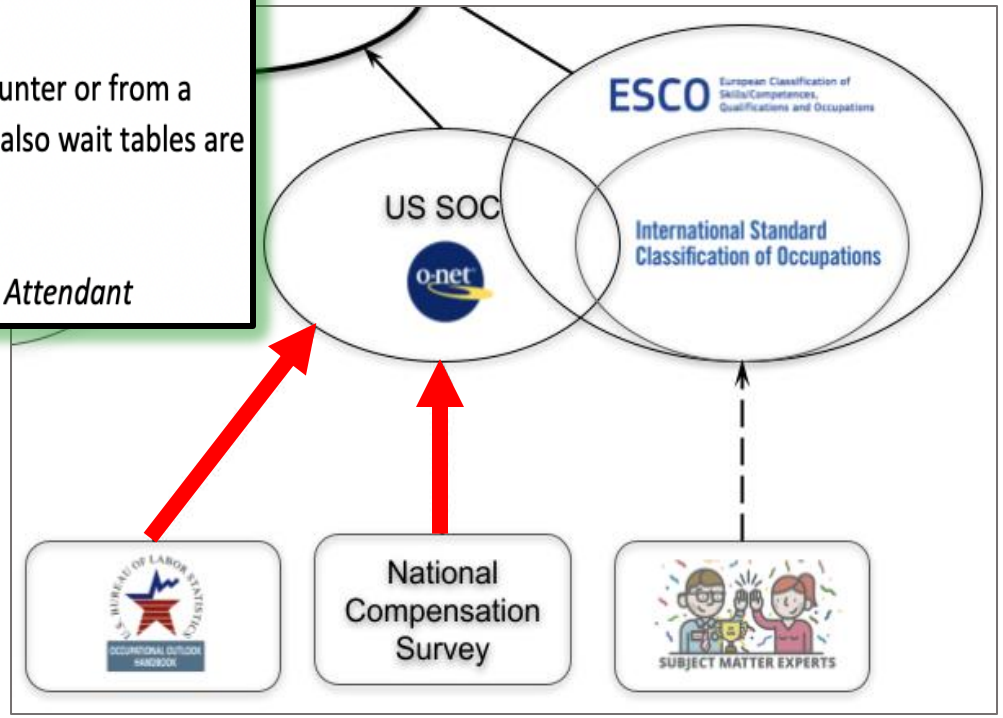
35-3023 Fast Food and Counter Workers

35-3023 Fast Food and Counter Workers

Perform duties such as taking orders and serving food and beverages. Serve customers at counter or from a steam table. May take payment. May prepare food and beverages. Counter attendants who also wait tables are included in "Waiters and Waitresses" (35-3031),

Illustrative examples: Barista, Cafeteria Server, Ice Cream Server, Mess Attendant, Snack Bar Attendant

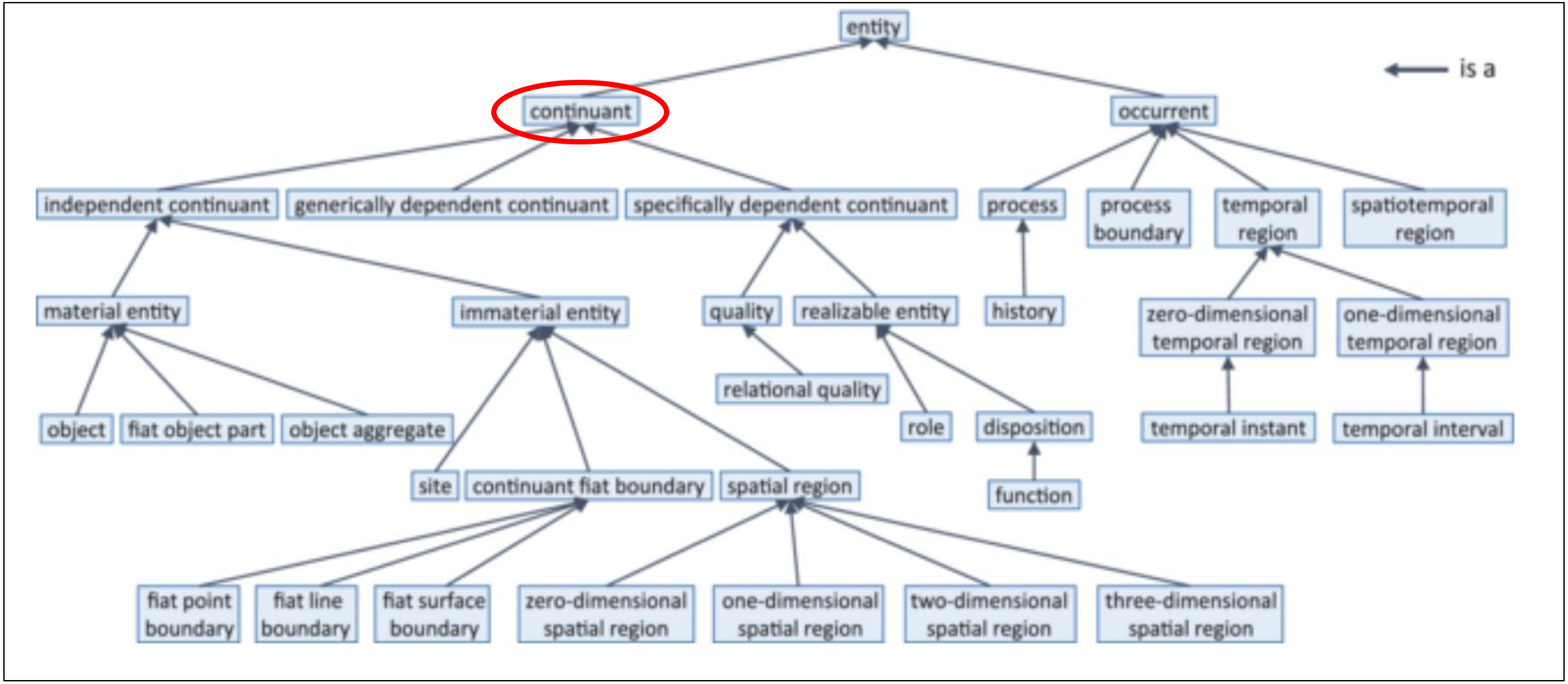
The National Compensation Survey and Occupation Outlook Handbook inform the development of US SOC/O*NET



Outline

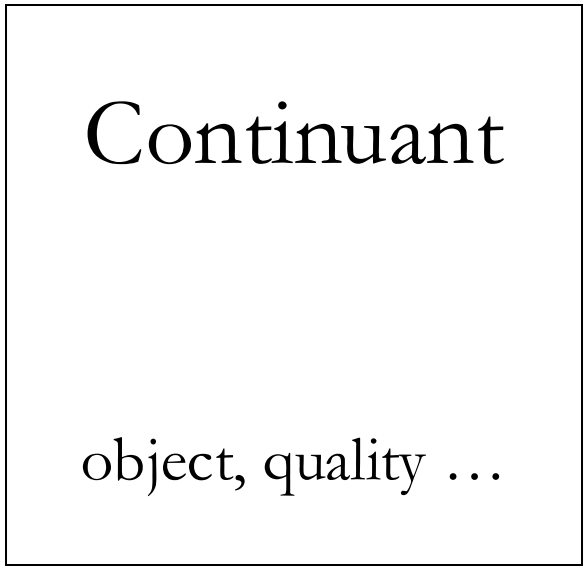
- **Module 1**: Motivation for Ontology Engineering
- **Module 2**: Motivation for Basic Formal Ontology
- **Module 3**: Theory of BFO
- **Module 4**: Building Ontologies with BFO
- **Module 5**: Exercises

Continuant

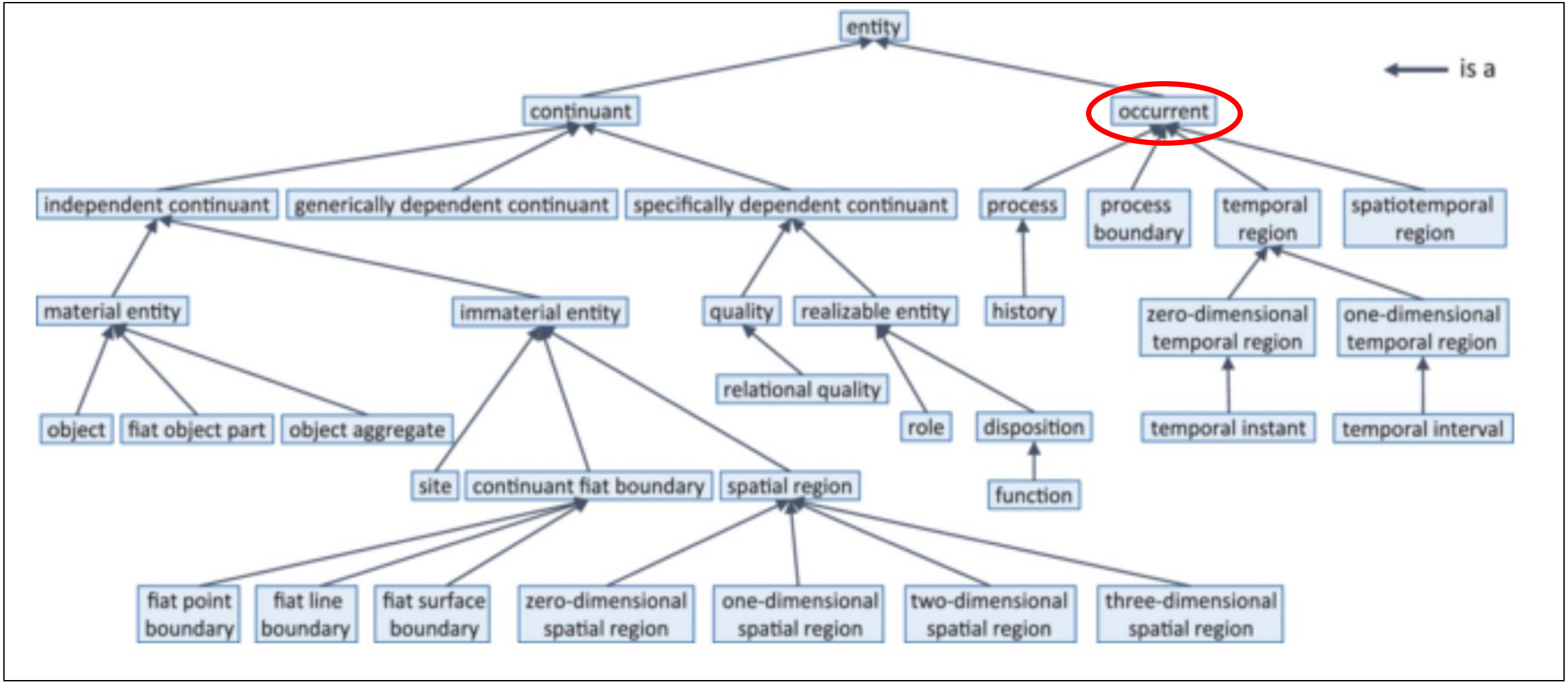

entity
is a
continuant
occurrent
independent continuant
generically dependent continuant
specifically dependent continuant
process
process boundary
temporal region
spatiotemporal region
material entity
immaterial entity
quality
realizable entity
history
zero-dimensional temporal region
one-dimensional 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

Continuant

- Continuants exist in time, wholly present whenever they exist at all; they are entities that lack temporal parts

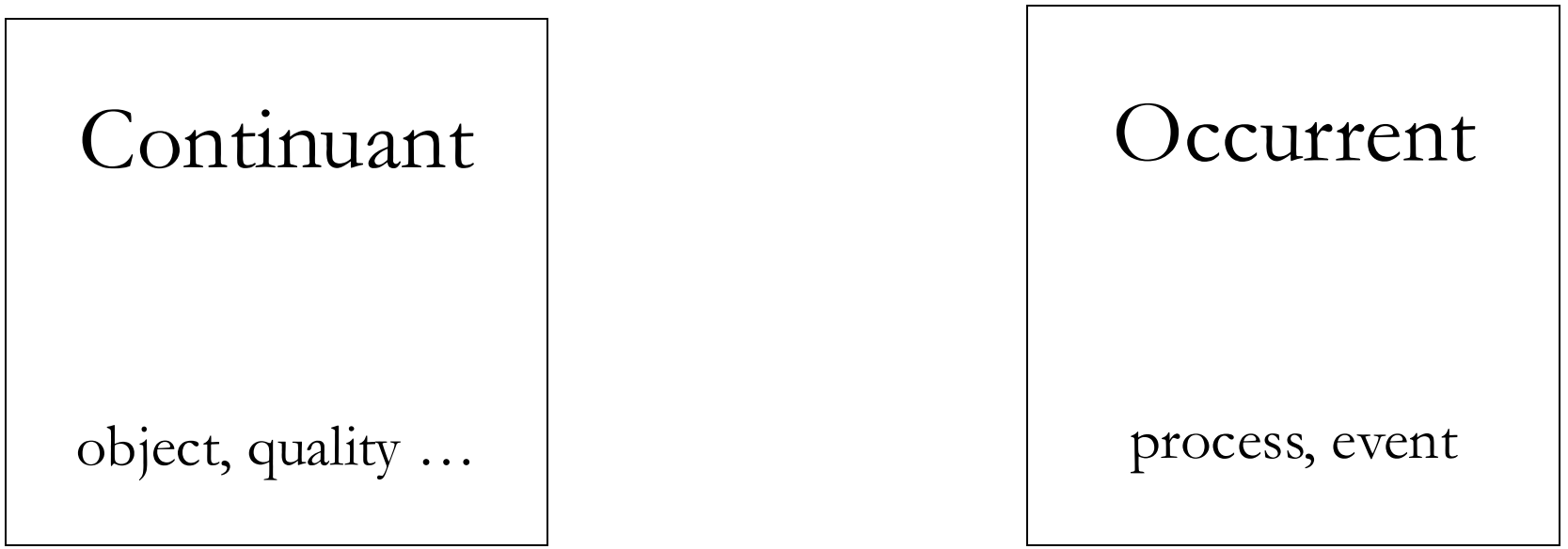


Occurrent


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

Occurrent

- Occurrents exist over time, in that they have temporal parts



Parthood

- Among the most important logical relationships is parthood

- Which in BFO comes in two flavors:
  - continuant parthood
  - occurrent parthood

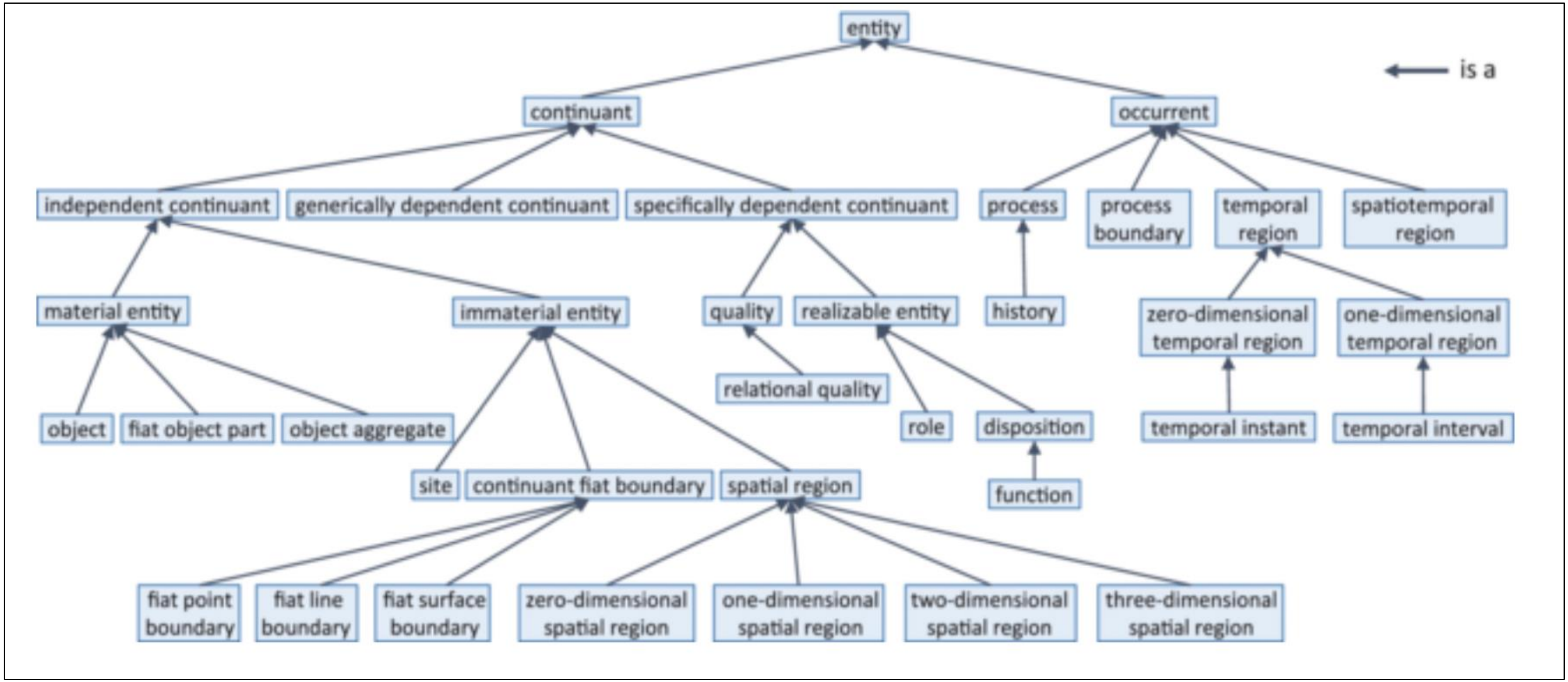
- Reflecting that the class Continuant is closed under parthood, and Occurrent is as well

No continuant may have or be part of any occurrent

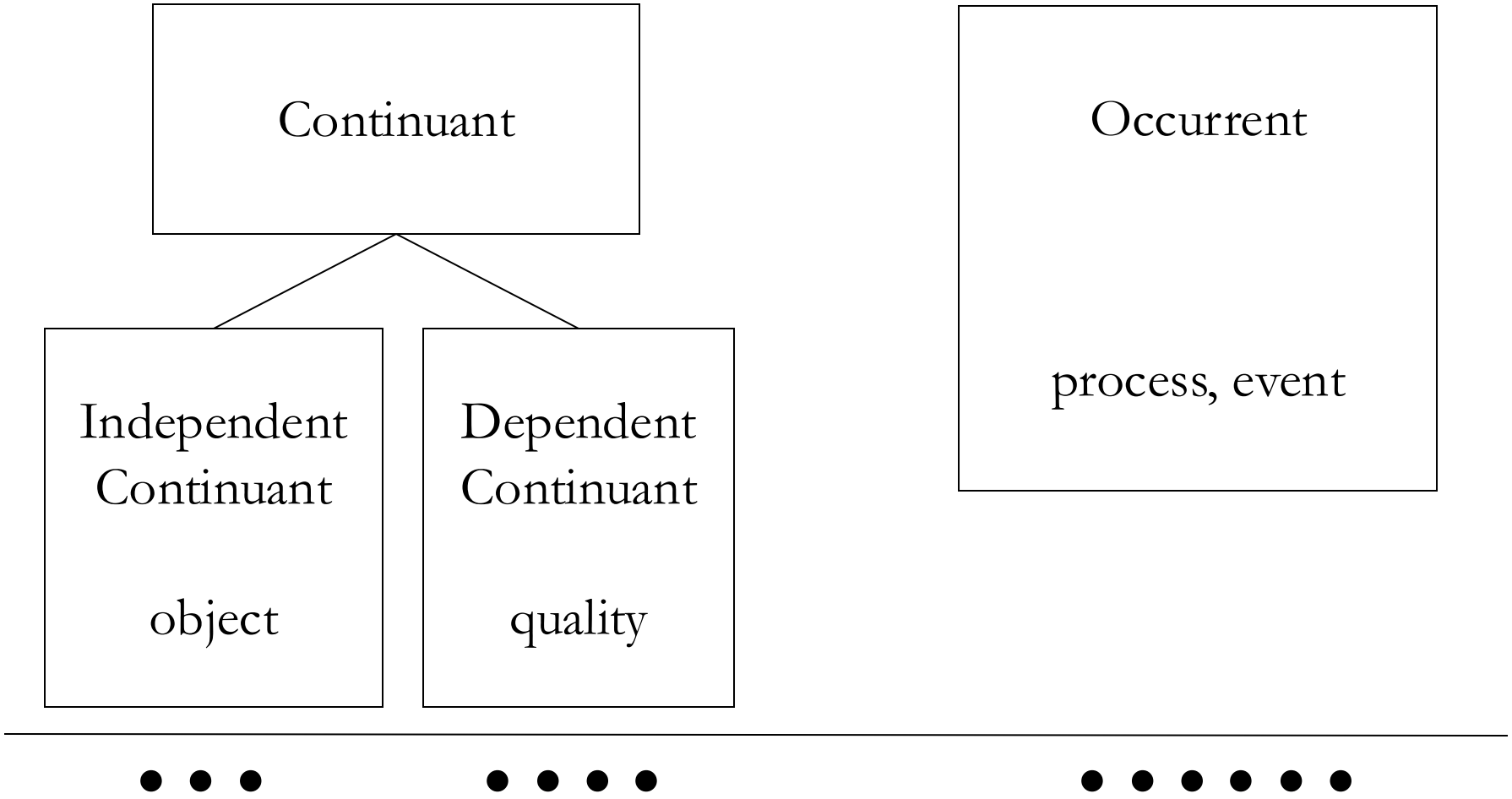
No occurrent may have or be part of any continuant

Classes represent collections of instances
For example: the class of *tables* falls under the class of *objects* and your dinner table would be an instance of the former

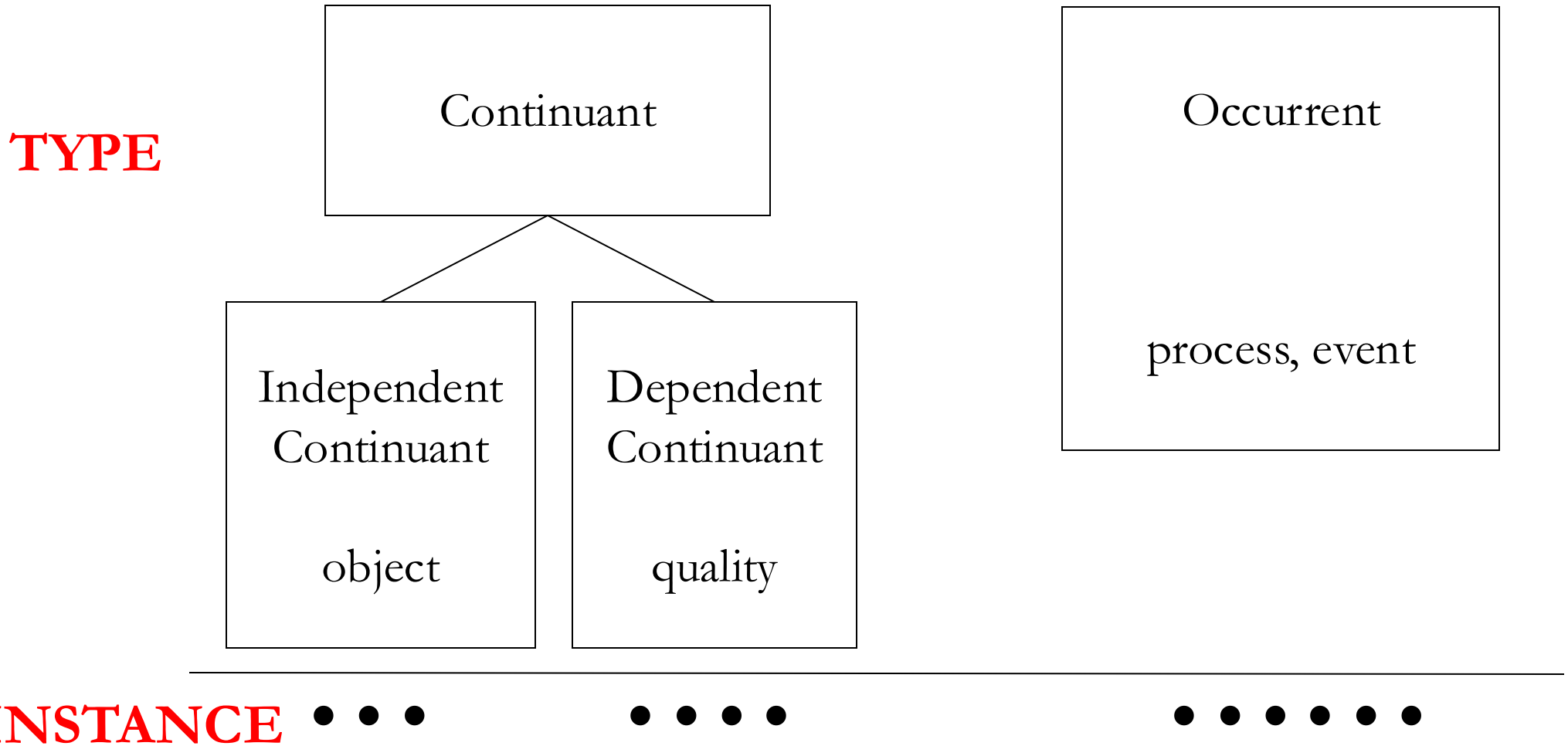
Class A *is_a* Class B means any instance of Class A is an instance of Class B



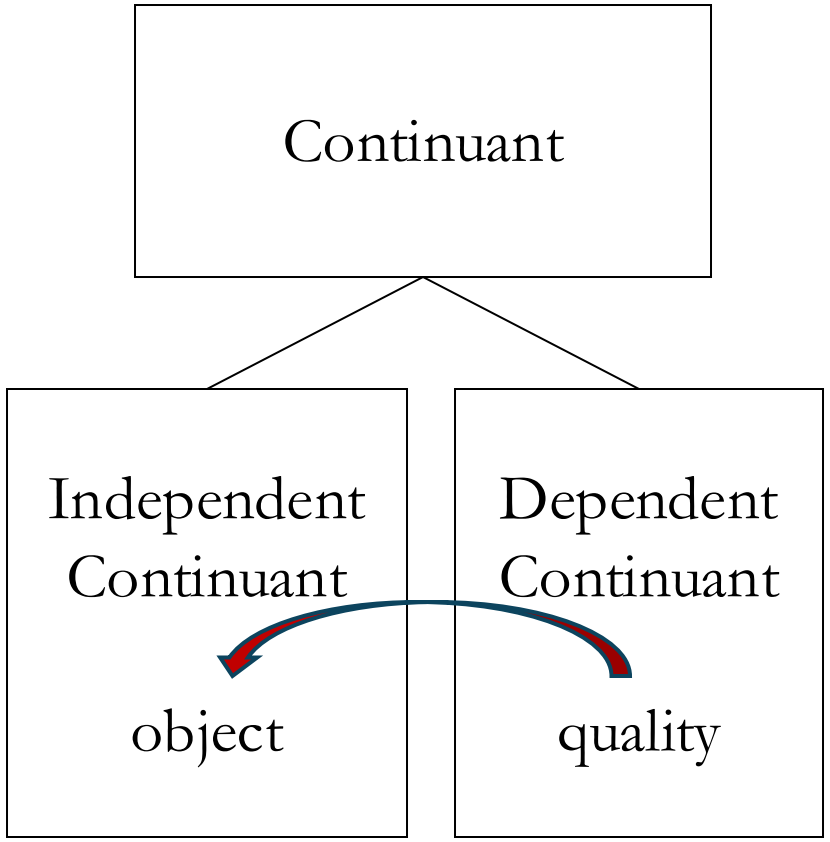
Types and Tokens



Types and Instances



(In)dependence



Occurrent

process, event

Some continuants depend for their existence on others

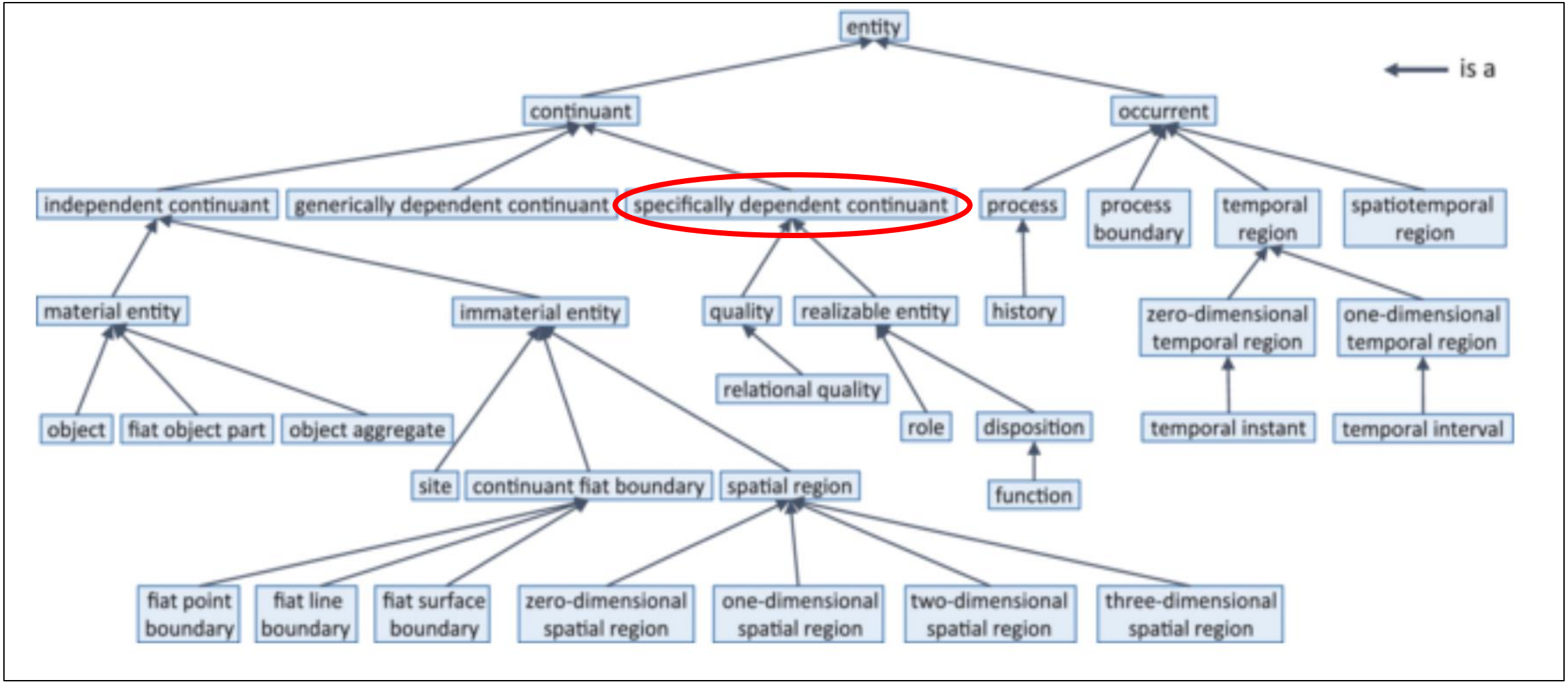
Dependence

- For certain entities, their existence depends on the existence of something else
- Other entities do not depend on any other entities for their existence
- The latter are categorized in BFO as **independent continuants**
- The former include **specifically dependent** and **generically dependent entities**, as well as **processes**

Dependence

- For certain entities, their existence depends on the existence of something else
- Other entities do not depend on any other entities for their existence
- The latter are categorized in BFO as **independent continuants**
- The former include **specifically dependent** and **generically dependent entities**, as well as **processes**

Specifically Dependent Continuant



Specifically Dependent Continuant

- These are continuants that in every case **specifically depend on** some independent contiuant for their existence

- For example, the mass of a tomato specifically depends on a given tomato, the shape of your smile depends on your face, and so on

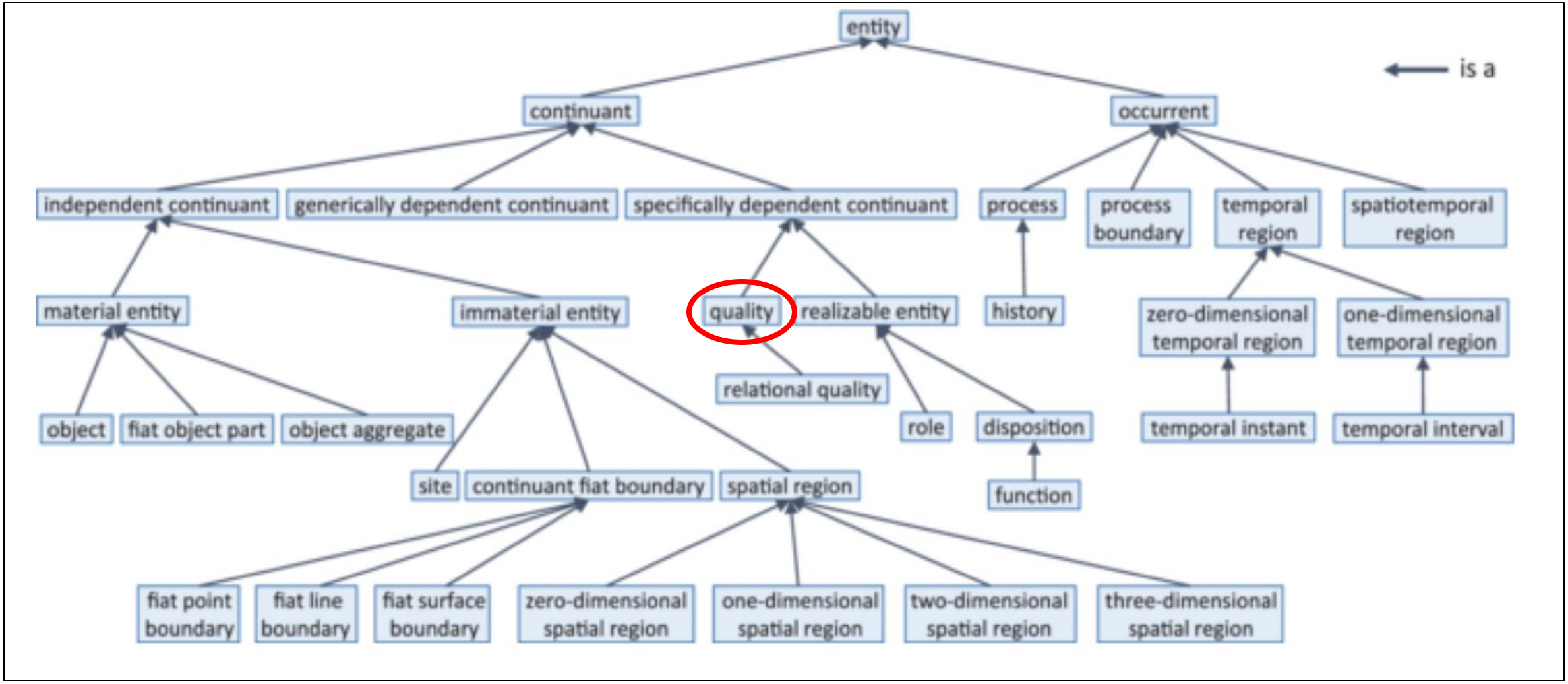
Specifically Dependent Continuant

- These are continuants that in every case **specifically depend on** some independent contiuant for their existence

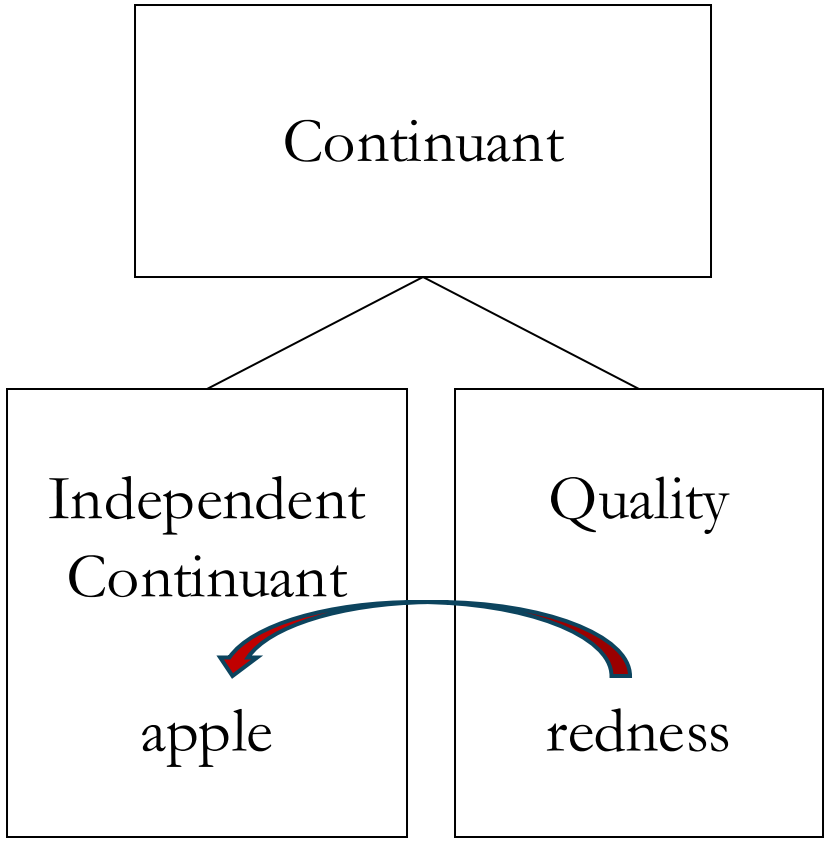
- For example, the mass of a tomato specifically depends on a given tomato, the shape of your smile depends on your face, and so on

- Importantly, SDCs cannot migrate across bearers, i.e. the specific shape of your smile **depends on you** and so cannot **specifically depend on** me

Quality


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

Qualities



Occurrent

process, event

Qualities inhere in independent continuants

Quality

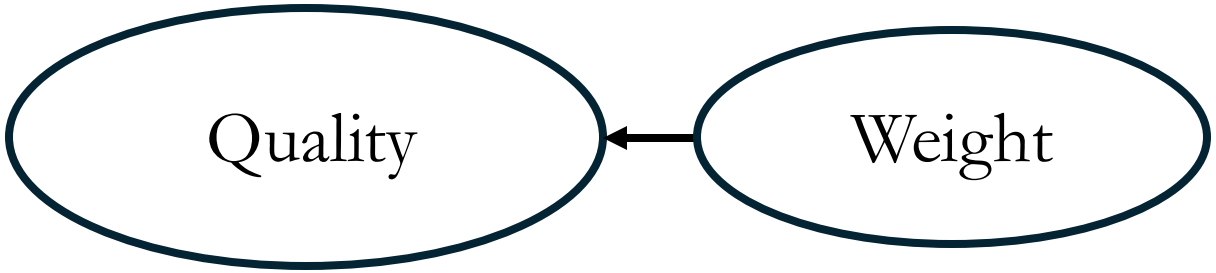
- In BFO, instances of Quality are said to manifest in full whenever they manifest at all

- For example, when an apple bears a redness quality, there is nothing more to that quality than the redness

- Similarly, the shape of the smile on your face is there for the world to see whenever it is there at all; there is nothing more to the shape than what is presented on your face

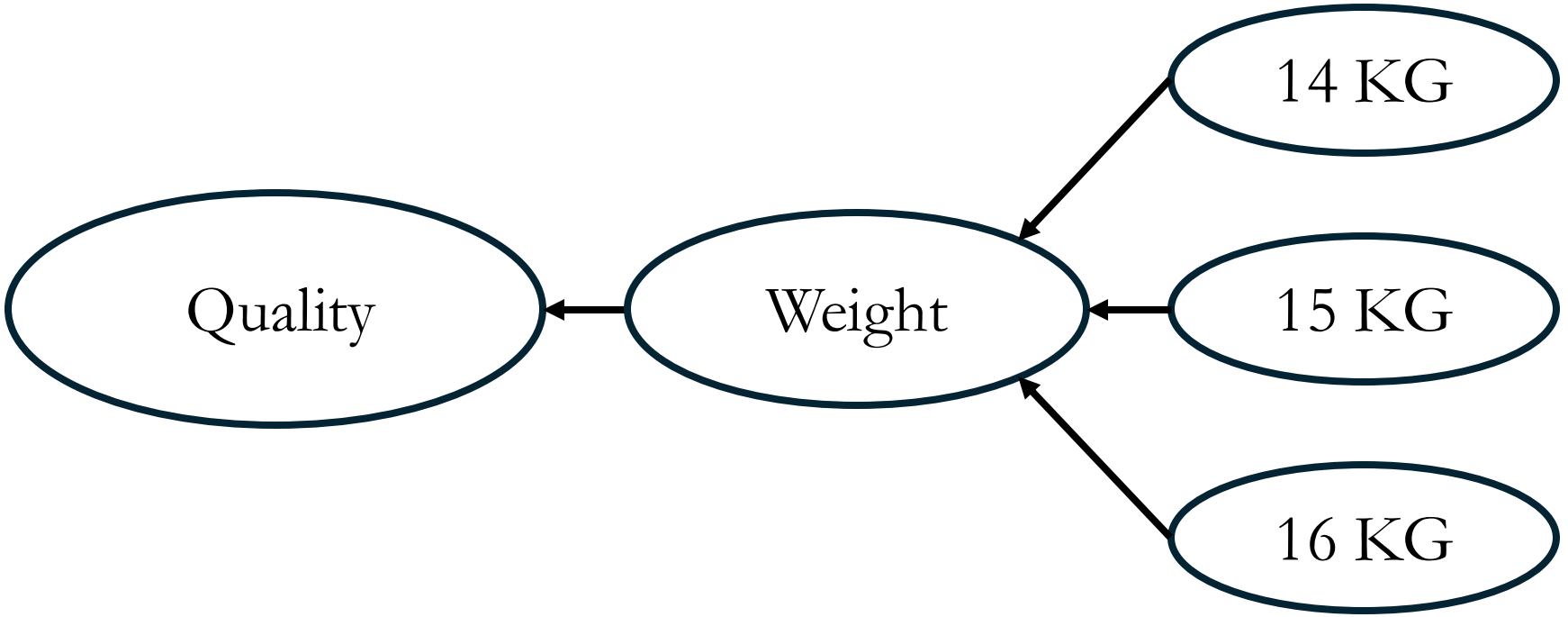
Subclasses of Quality

- That said, your various qualities and mine may be instances of the same subclass of the class Quality



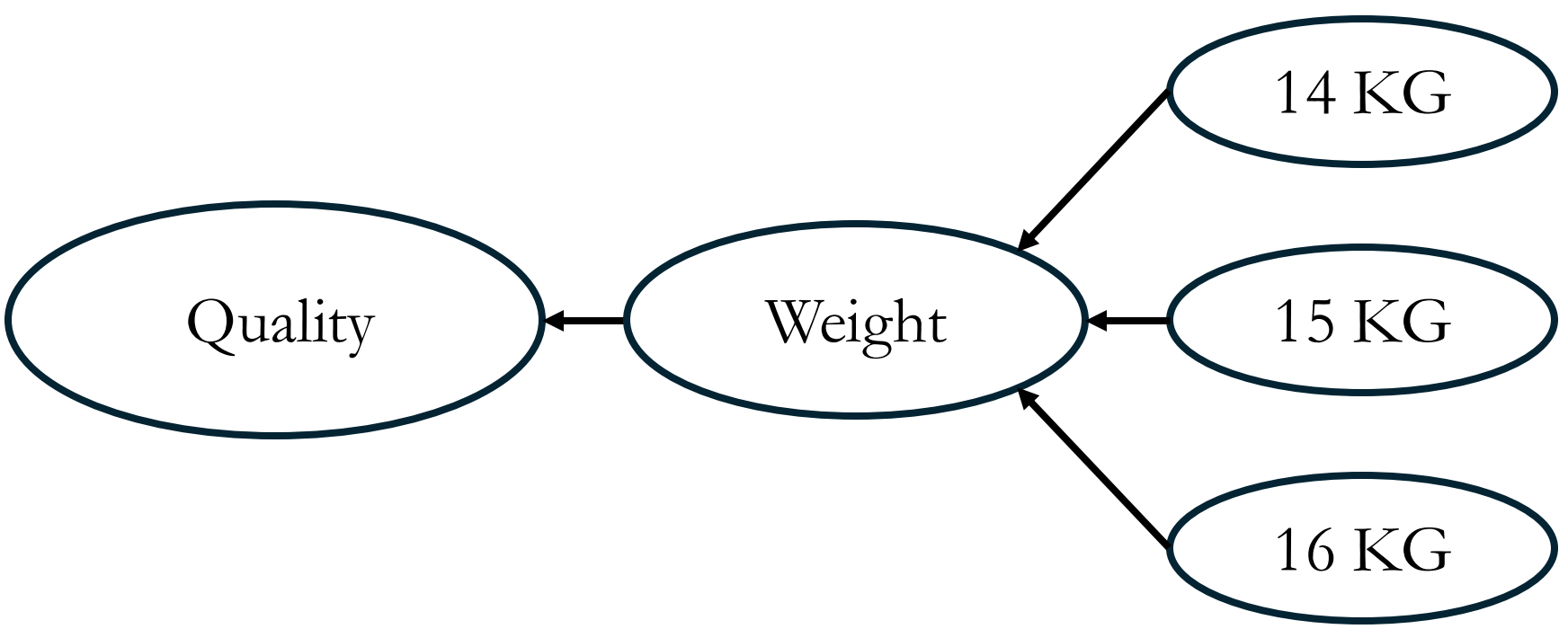
Subclasses of Quality

- That said, your various qualities and mine may be instances of the same subclass of the class Quality



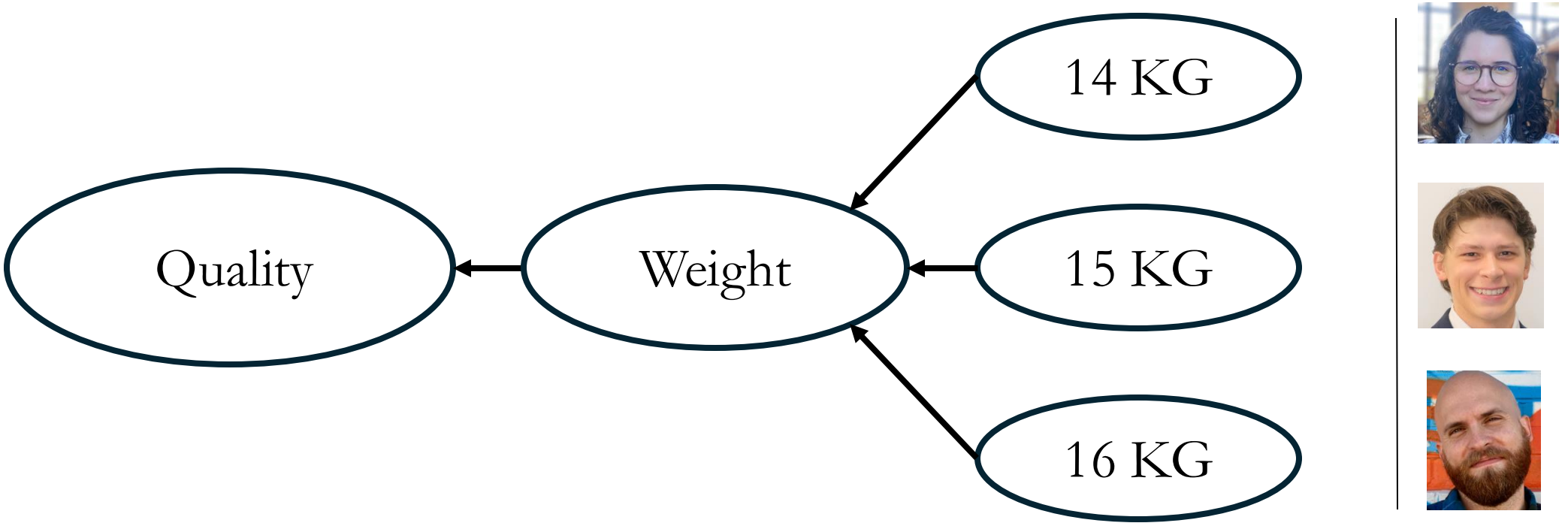
Subclasses of Quality

- That said, your various qualities and mine may be instances of the same subclass of the class Quality



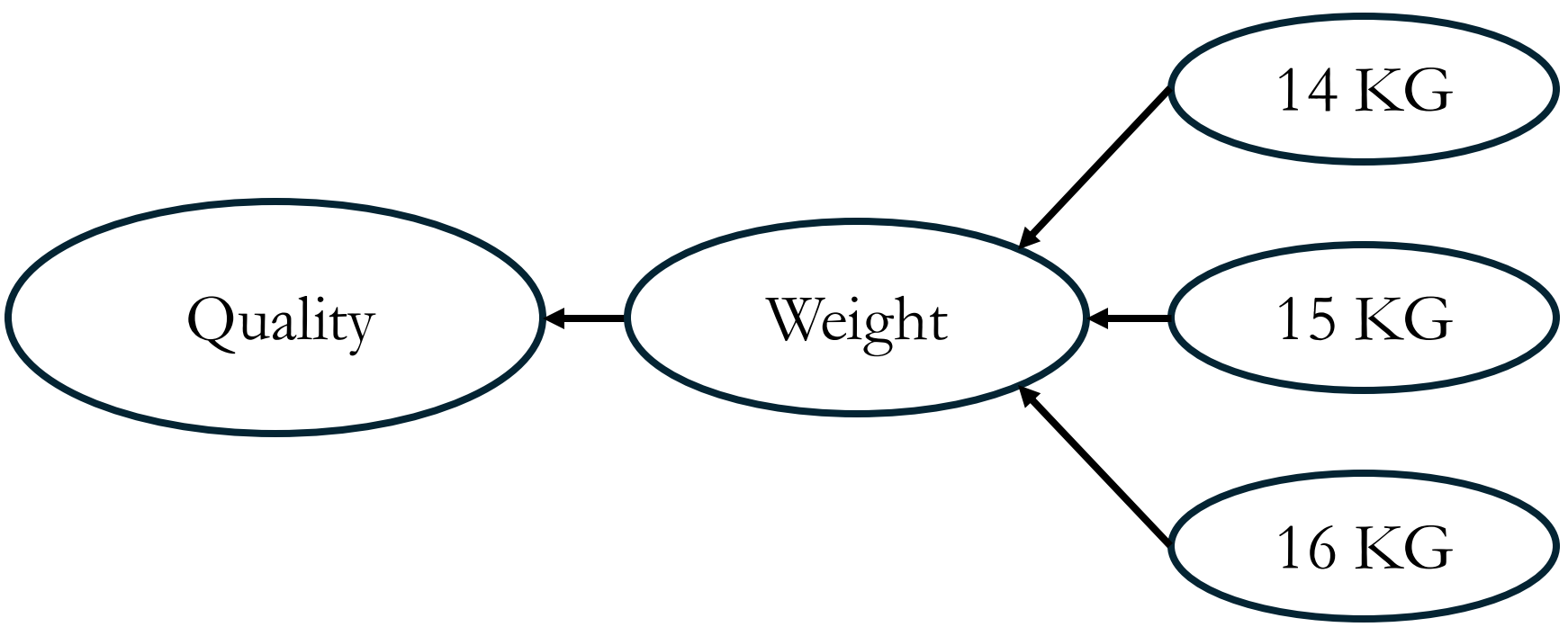
Determinates and Determinibles

- Certain instances of Quality may fall under different specializations of subclasses of Quality



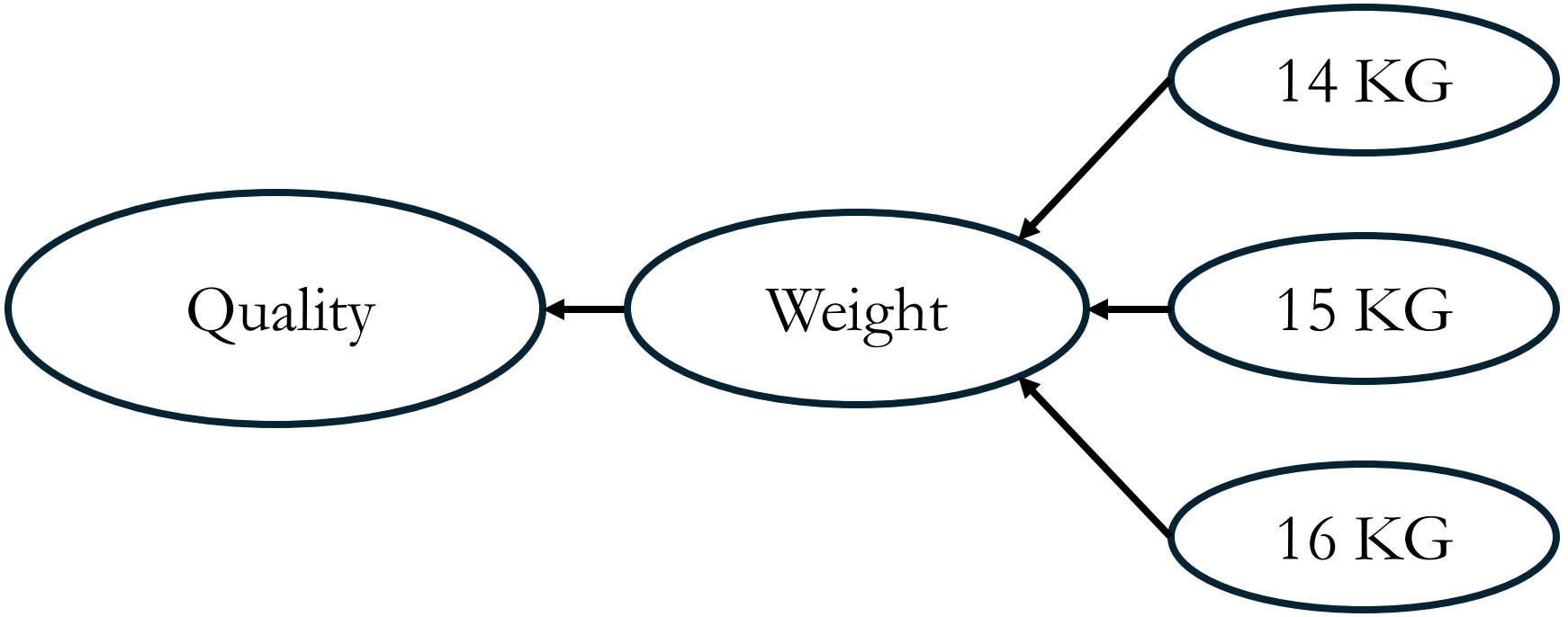
Determinates and Determinibles

- Certain instances of Quality may fall under different specializations of subclasses of Quality



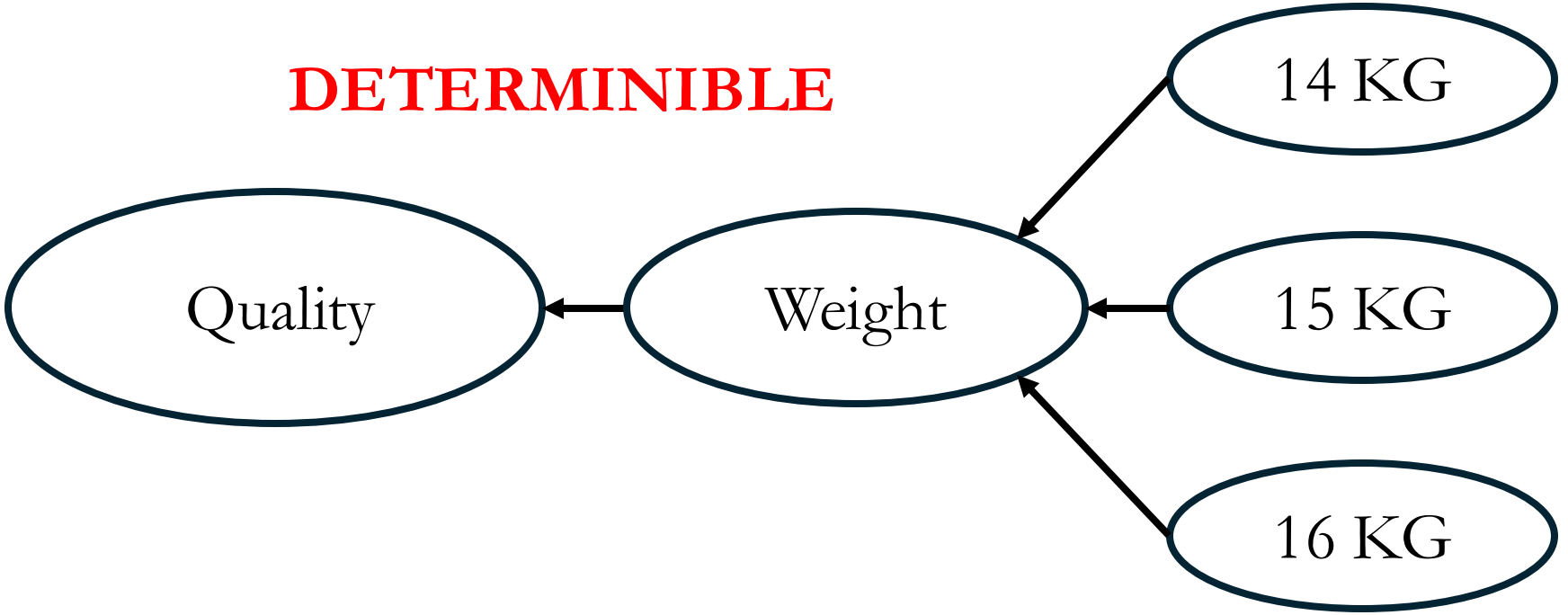
Determinates and Determinibles

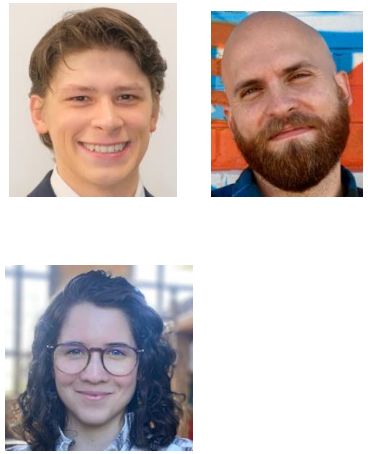
- Certain instances of Quality may fall under different specializations of subclasses of Quality



Determinates and Determinibles

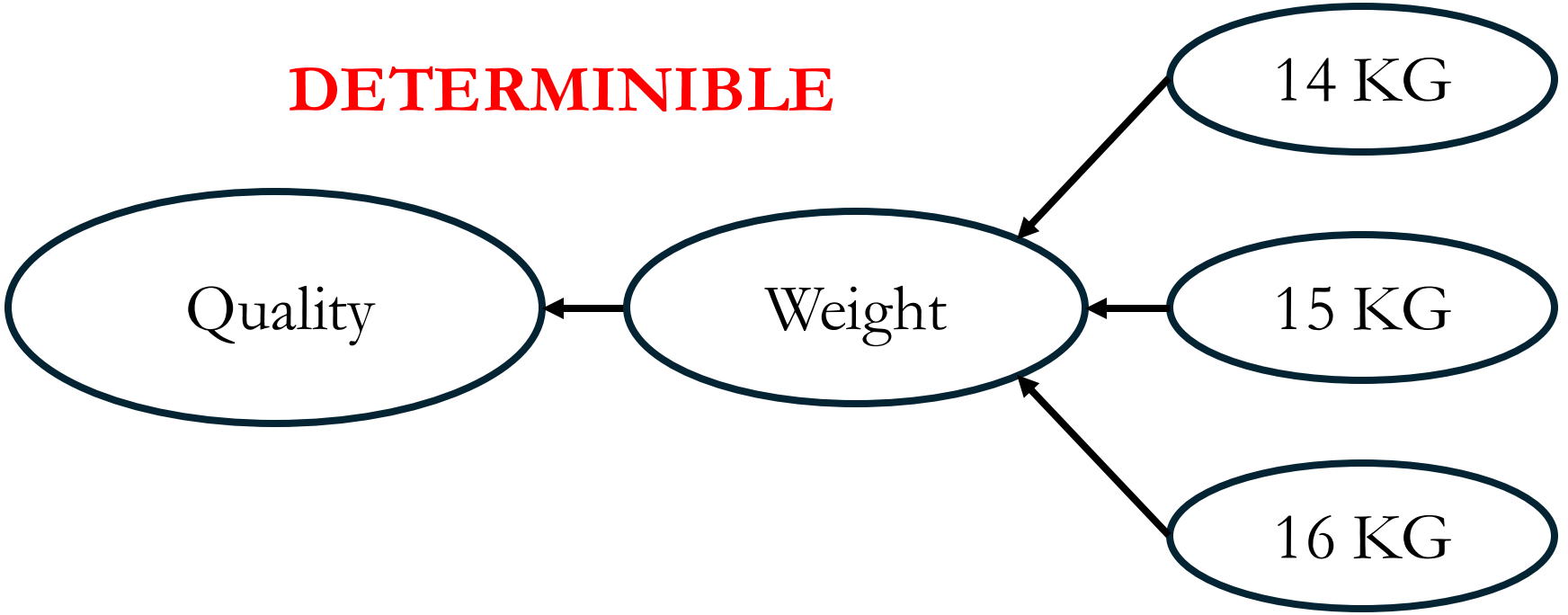
- We call the subclasses of Quality that remain the same throughout **determinibles** and those specializations that change **determinates**

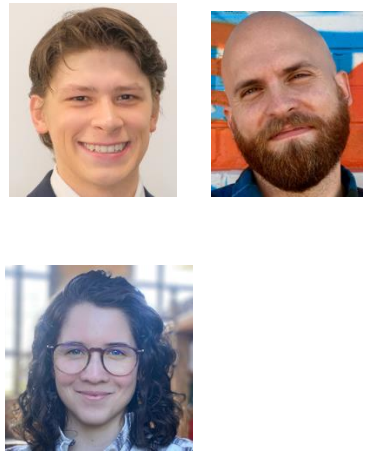




Determinates and Determinibles

- Even with determinate change, however, at **no point** does an instance of Quality migrate to a new bearer; rather, there are **distinct instances**





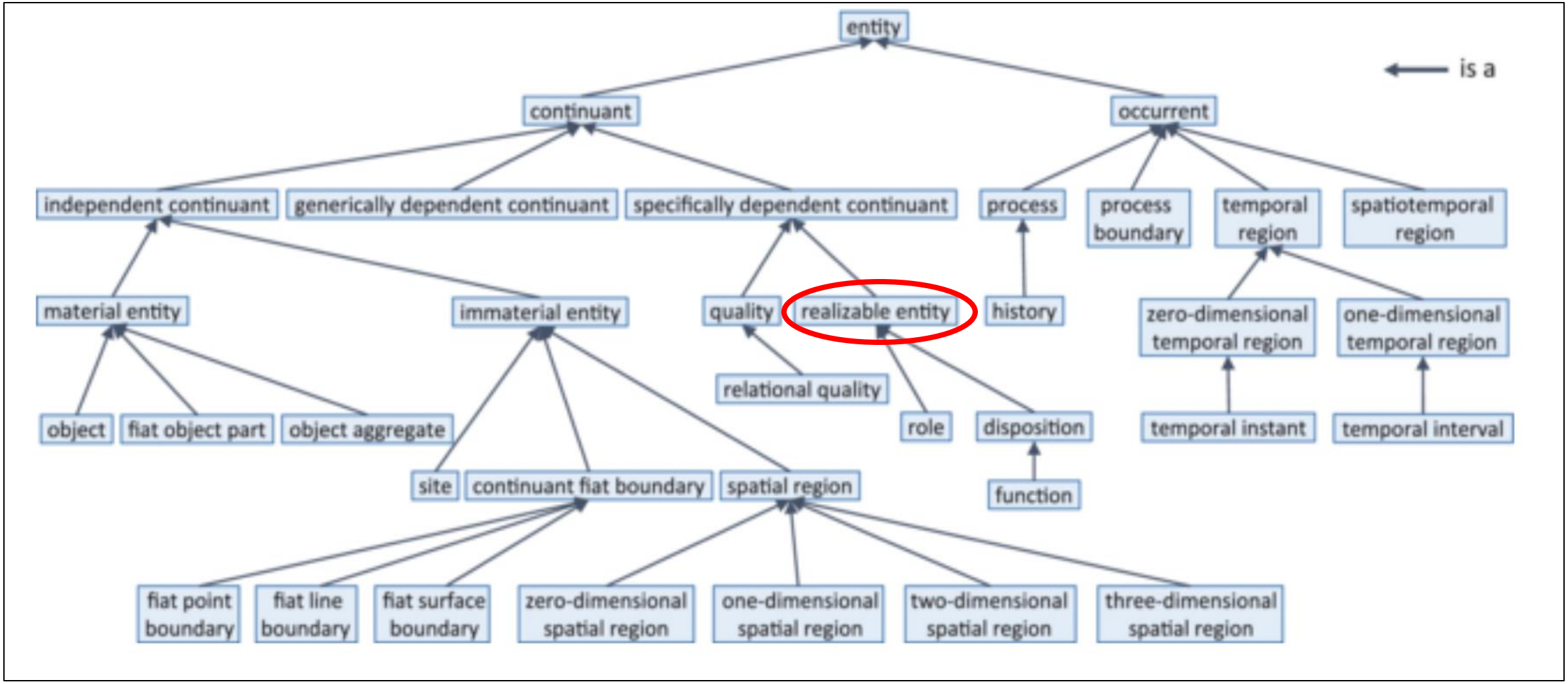
Determinates and Determinibles

- Traditionally, determinates exhibit some ordering relative to a given determinible

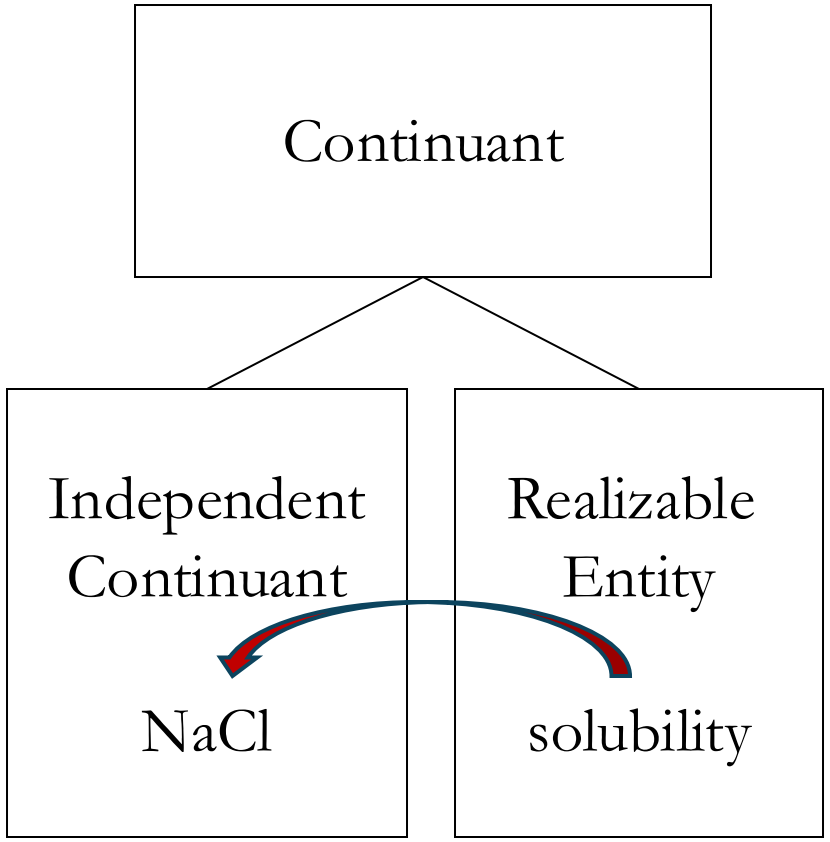
- If P is a determinate of determible Q, then:
  - P is more specific than Q
  - There is a strict partial ordering of determination between P and Q
  - Neither P nor Q can causally exclude one another
  - Any two detereminates P_1 and P_2 of Q are comparable

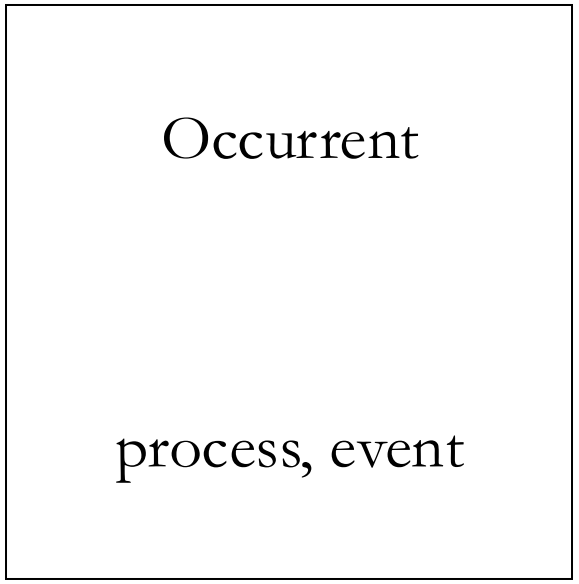
- Caveat: The preceding is not official BFO, but from observation

Realizable Entity

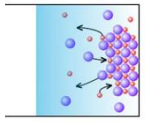


Realizable Entity





Not all dependent entities fully manifest when they exist



• • • • • •

Realizable Entity

- Attributes of some material bearer that only become manifest under certain conditions

- Put another way, realizable entities underwrite what bearers can do

Rule of Thumb

There is a portion of sodium chloride before you

- Suppose I ask "Does this portion exhibit a lattice structure?"
- You need only look at the salt to find an answer
- Suppose I ask "Is this portion soluble in unsaturated H_2O?"
- You cannot simply look at the salt to find an answer

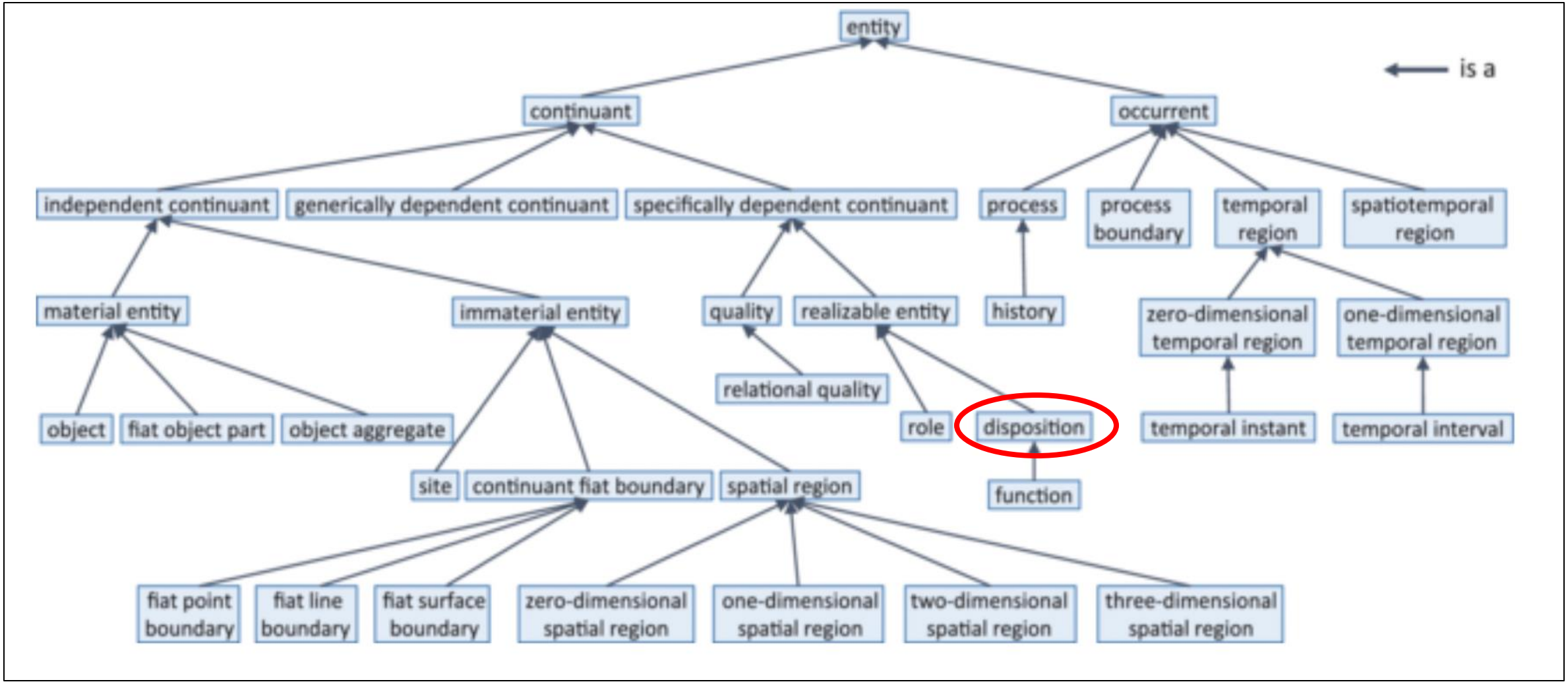
Modality

- Realizable Entities are how BFO represents **modality**

- The way the world is often differs from the way the world could be, could have been, and will be

- A yoga mat is black and you can see this; it could support a sleeping cat without you seeing it

Disposition

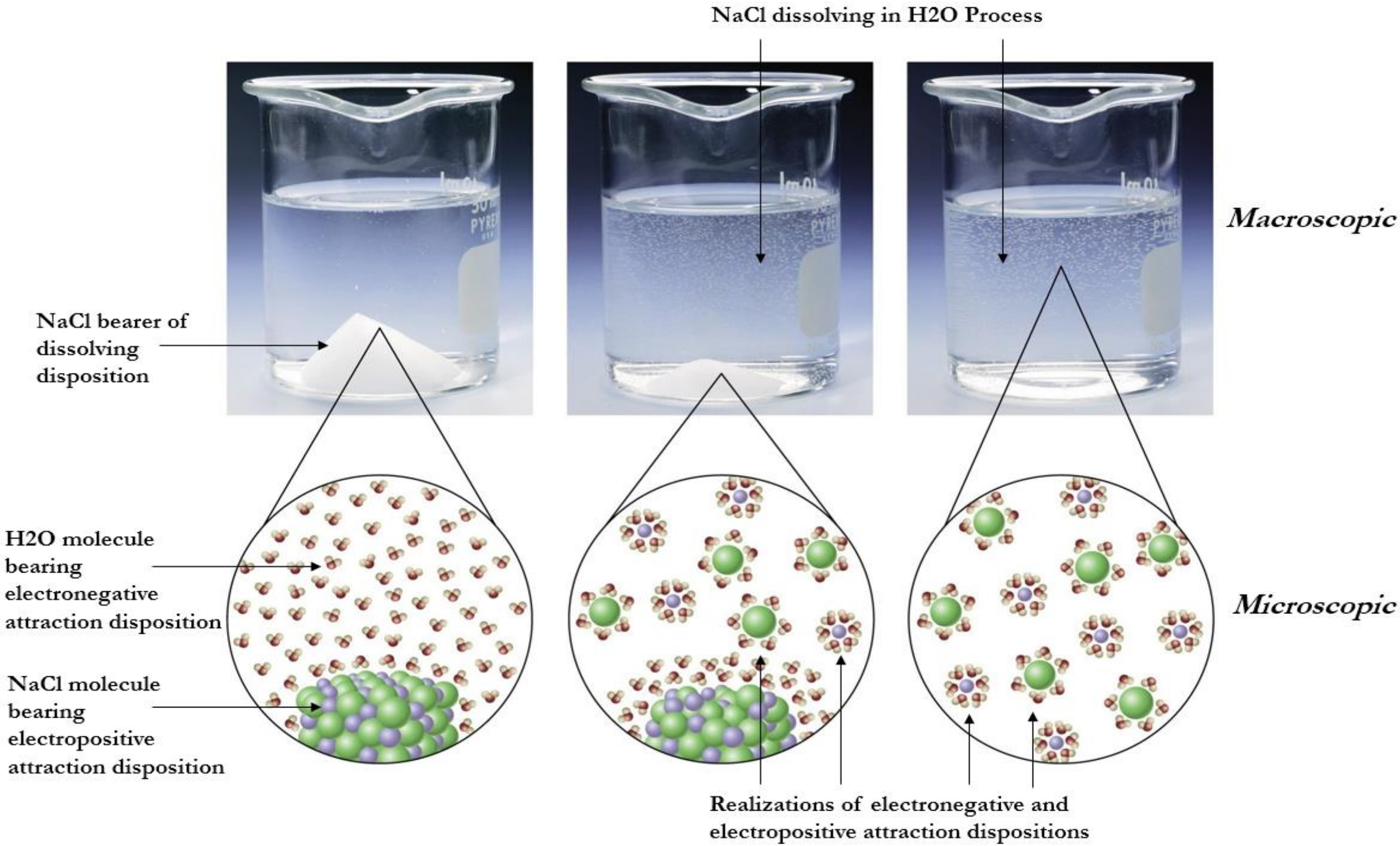


Disposition

- Attributes of some material bearer that only become manifest under certain conditions

Disposition

A realizable entity such that if it ceases to exist, then its bearer is physically changed, and its realization occurs when and because this bearer is in some special physical circumstances, and this realization occurs in virtue of the bearer's physical make-up


NaCl dissolving in H2O Process
Macroscopic
NaCl bearer of dissolving disposition
H2O molecule bearing electronegative attraction disposition
NaCl molecule bearing electropositive attraction disposition
Microscopic
Realizations of electronegative and electropositive attraction dispositions

Disposition

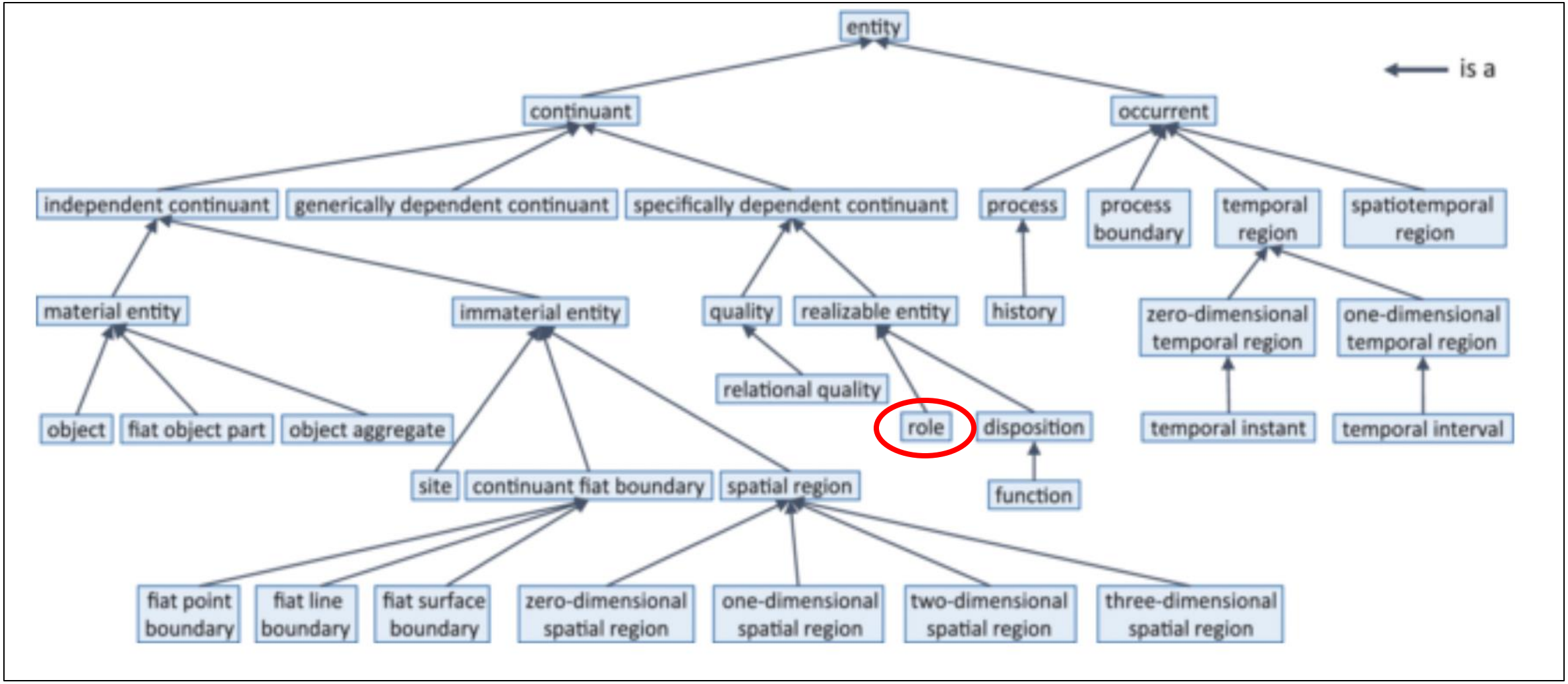
- Attributes of some material bearer that only become manifest under certain conditions

Disposition

A realizable entity such that if it ceases to exist, then its bearer is physically changed, and its realization occurs when and because this bearer is in some special physical circumstances, and this realization occurs in virtue of the bearer's physical make-up

INTERNALLY GROUNDED

Role


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

Role

- Attributes of some material bearer that only become manifest under certain conditions

Role

A realizable entity that exists because there is some single bearer that is in some special physical, social, or institutional set of circumstances in which this bearer does not have to be, and is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed.

Role

- Attributes of some material bearer that only become manifest under certain conditions

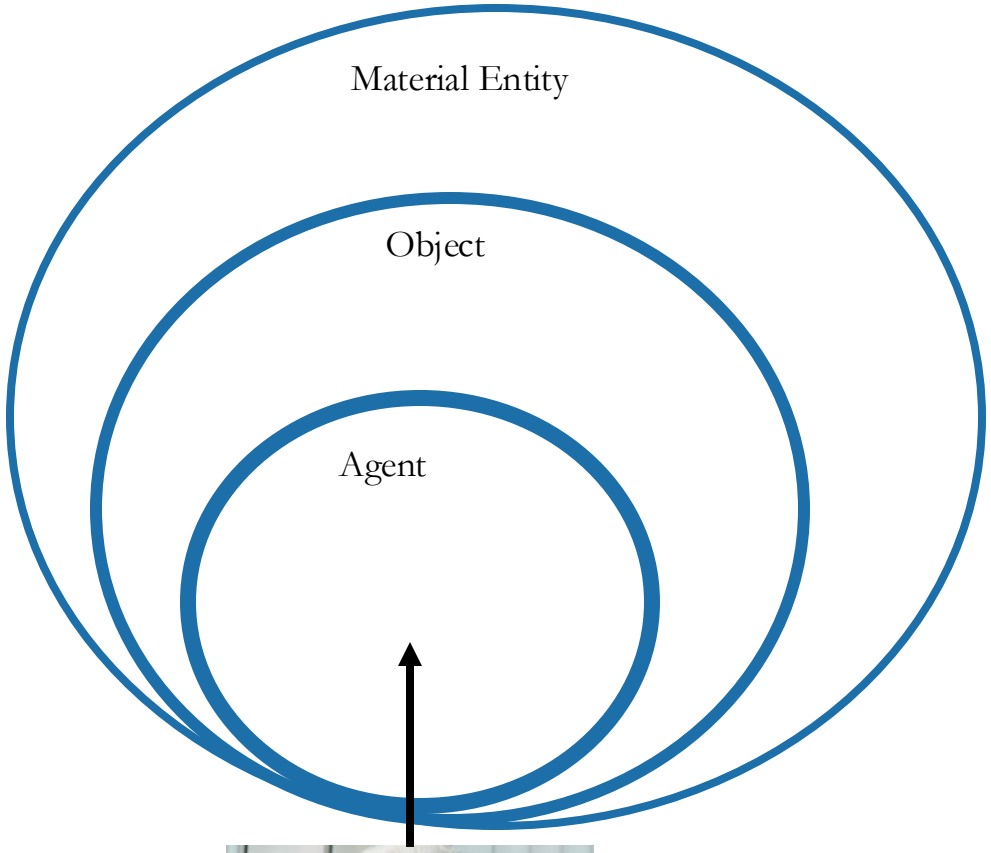
Role

A realizable entity that exists because there is some single bearer that is in some special physical, social, or institutional set of circumstances in which this bearer does not have to be, and is not such that, if it ceases to exist, then the physical make-up of the bearer is thereby changed.

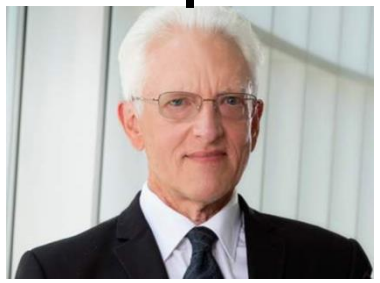
EXTERNALLY GROUNDED

Barry Smith instance_of Agent

CLASSES

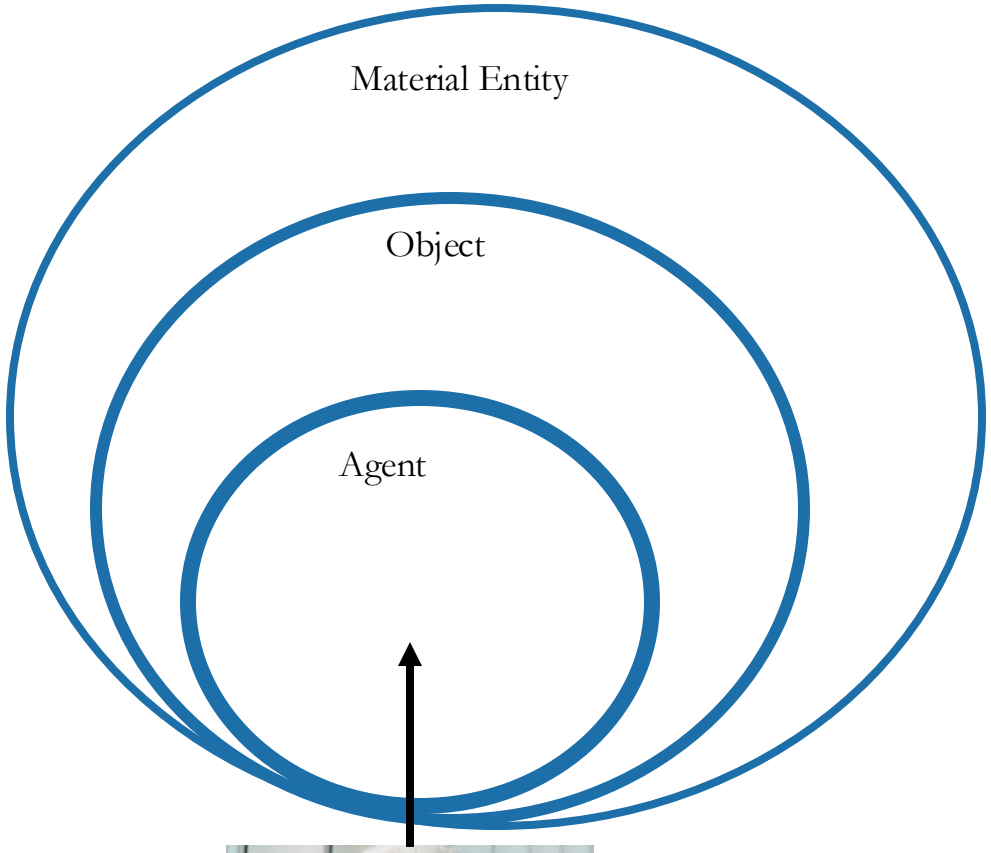


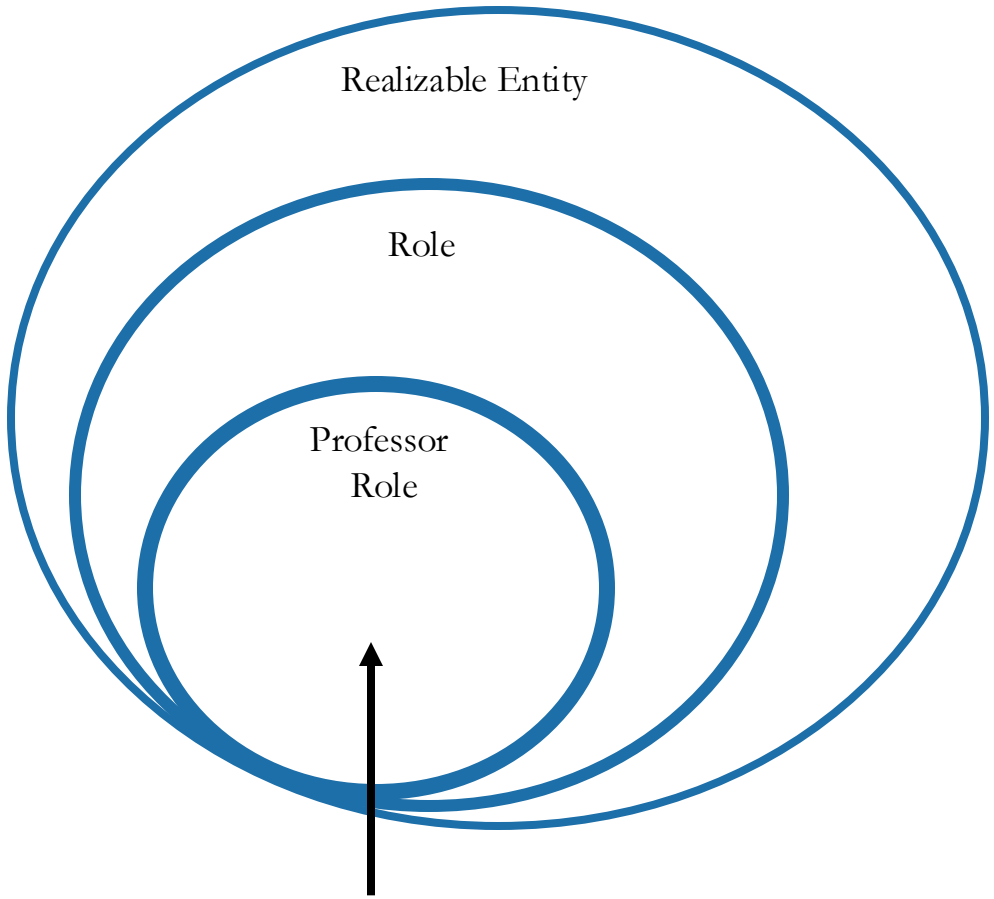
INSTANCES



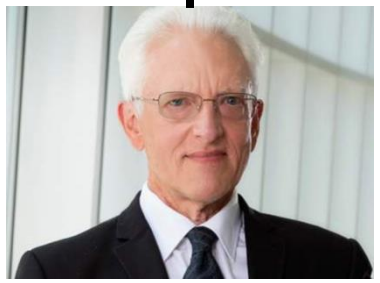
SUNY Professor instance_of Professor Role

CLASSES





INSTANCES

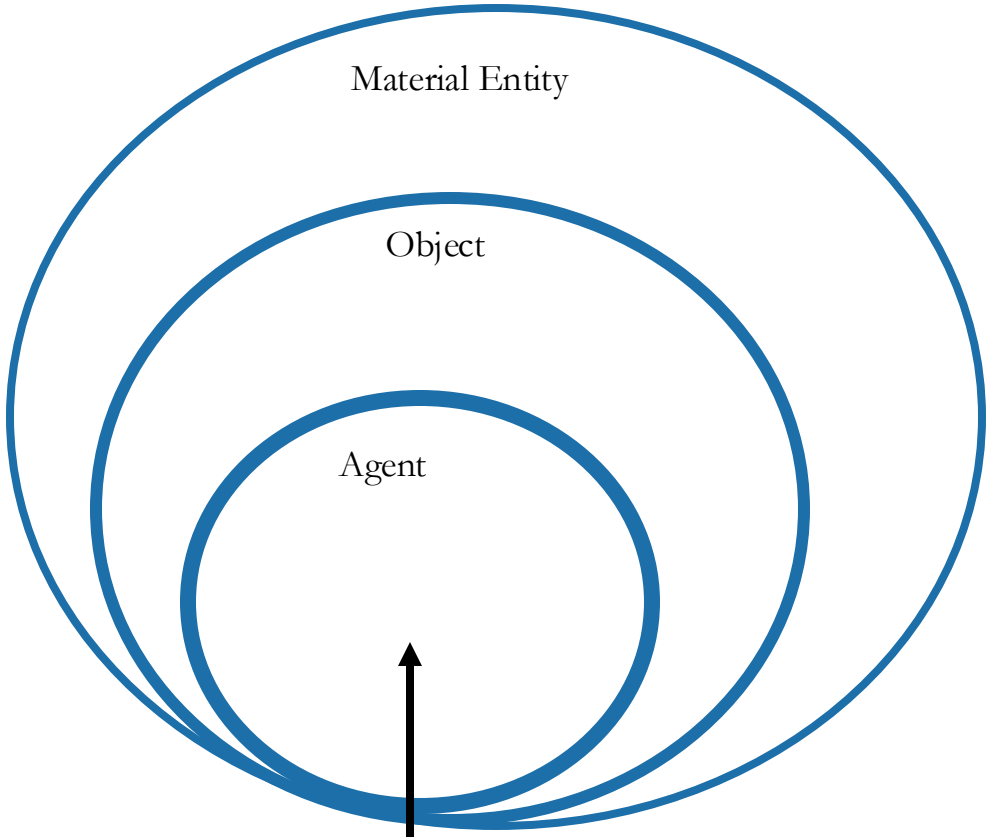


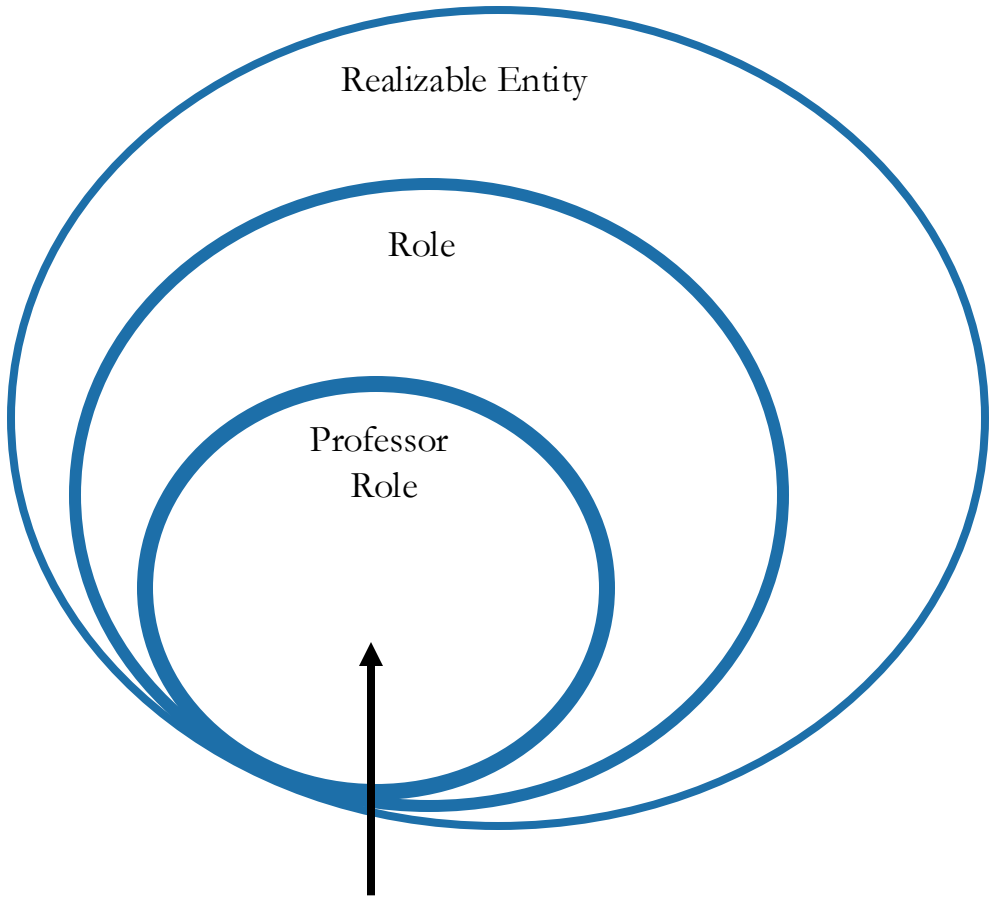
SUNY Distinguished Professor of Philosophy

Julian Park Chair

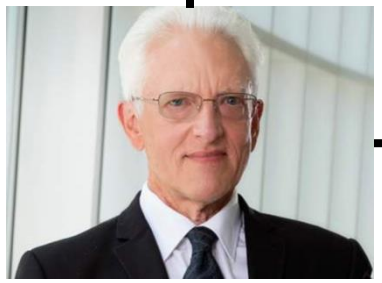
Barry Smith bearer_of SUNY Professor

CLASSES





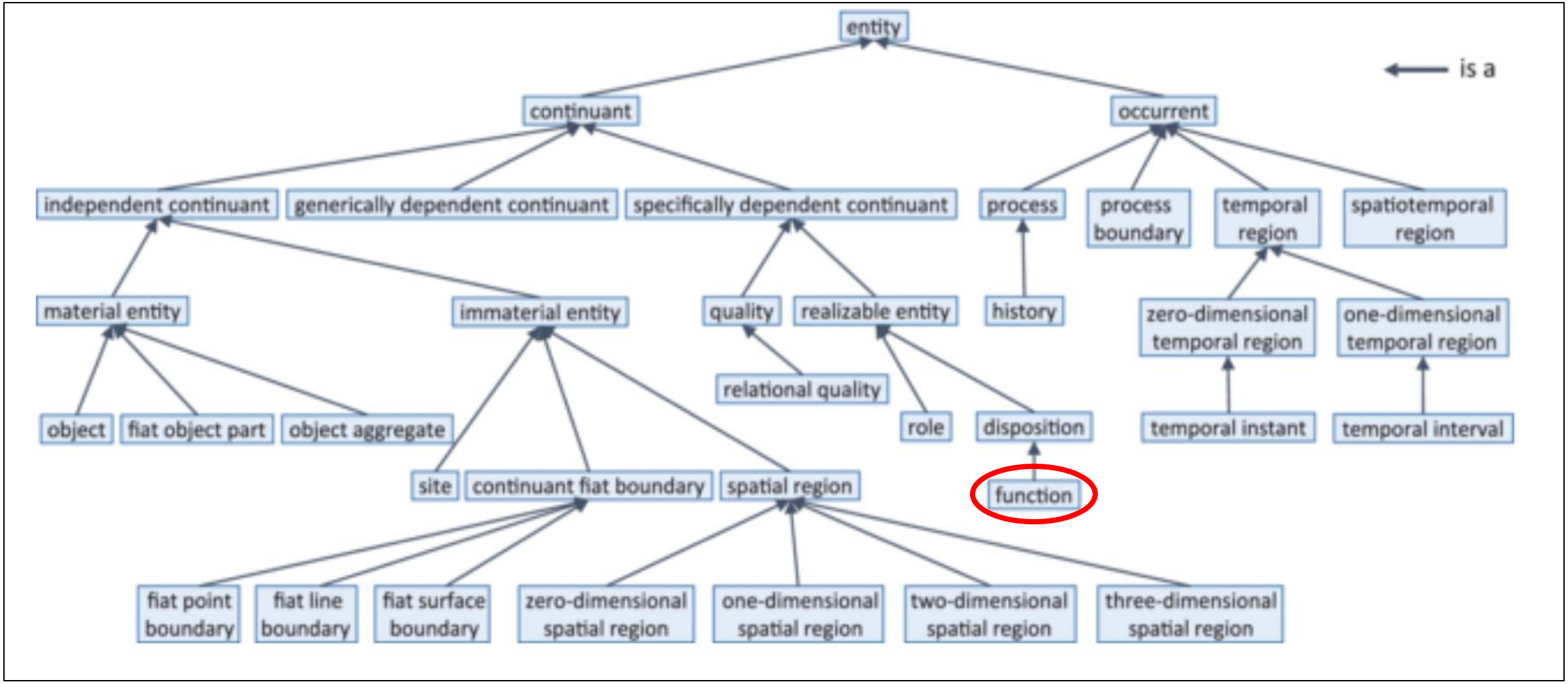
INSTANCES



SUNY Distinguished Professor of Philosophy

Julian Park Chair

Function


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

Function

- Attributes of some material bearer that only become manifest under certain conditions

Function

A disposition that exists in virtue of the bearer's physical make-up and this physical make-up is something the bearer possesses because it came into being, either through evolution (in the case of natural biological entities) or through intentional design (in the case of artefacts), in order to realize processes of a certain sort.

Function

- Attributes of some material bearer that only become manifest under certain conditions

Function

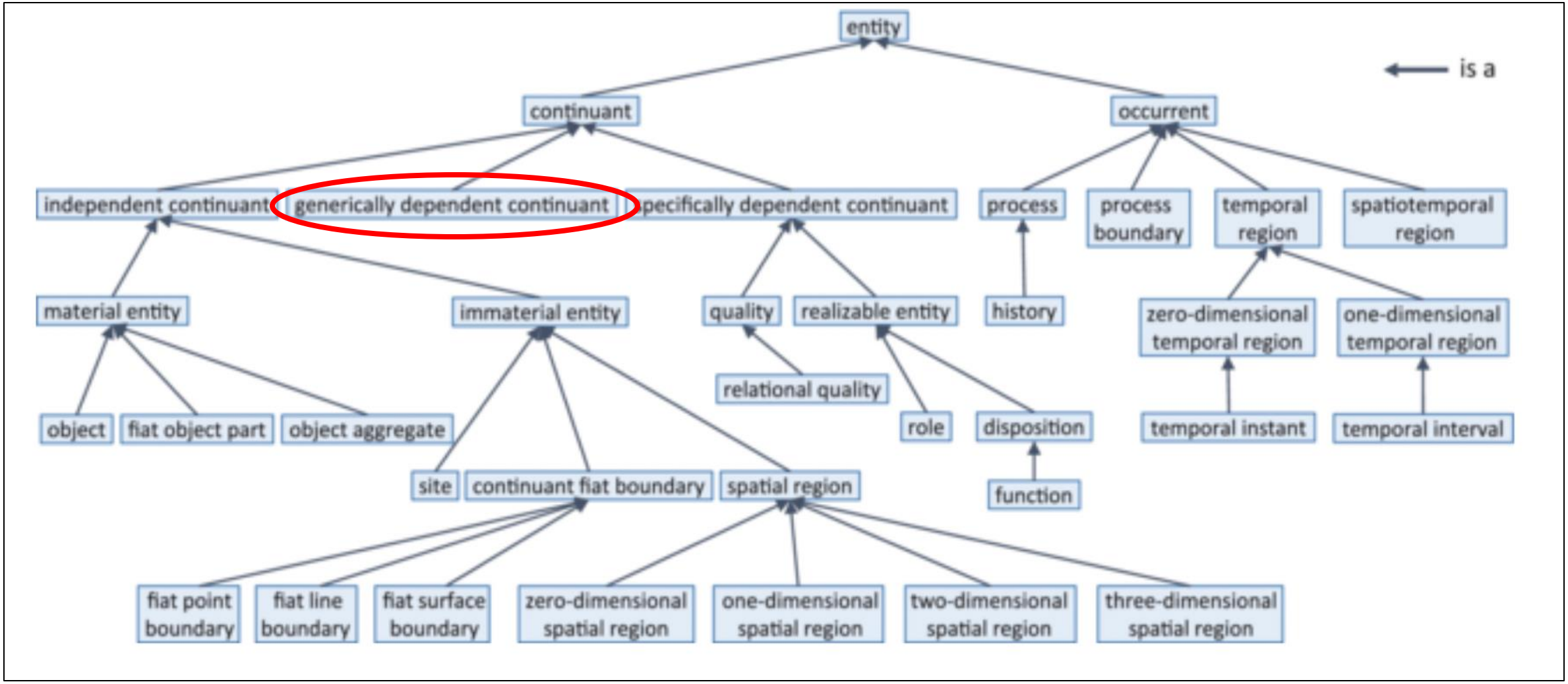
A disposition that exists in virtue of the bearer's physical make-up and this physical make-up is something the bearer possesses because it came into being, either through evolution (in the case of natural biological entities) or through intentional design (in the case of artefacts), in order to realize processes of a certain sort.

PURPOSE GROUNDED

Dependence

- For certain entities, their existence depends on the existence of something else
- Other entities do not depend on any other entities for their existence
- The latter are categorized in BFO as **independent continuants**
- The former include **specifically dependent** and **generically dependent entities**, as well as **processes**

Generically Dependent Continuant



Pattern Recognition

- We're disposed to recognize patterns with our perceptual faculties…

Pattern Recognition

- We're disposed to recognize patterns with our perceptual faculties…

- …and with our cognitive faculties…

Photo 51 crystallography
image by Rosalind

Double-helix hypothesized
by Watson and Crick

BFO 1.0

- Earlier versions of BFO did not permit dependent entities to migrate from bearer to bearer

- This is true in current versions of BFO for many cases, e.g. your smile is dependent on your face

- As mentioned, dependent continuants that cannot migrate fall under the class **Specifically Dependent Continuant**

Patterns

- A need arose to represent dependent entities that could migrate across bearers

- This need led to **generically dependent continuants**, continuants that are in some sense copyable, i.e. patterns

- For example, “Snow is white” and “Schnee ist weiß” may be used to express numerically identical content, i.e. the same pattern

Real Patterns

- Some patterns are necessarily **about** something; some patterns are not
- "Snow is white" expresses content that is **about** snow
- "cm" or "." are not necessarily **about** anything; they are nevertheless patterns
- Most **generically dependent entities** represented in BFO extensions are patterns that are **about** something

Aboutness

- **Information** is a pattern that is **about** something

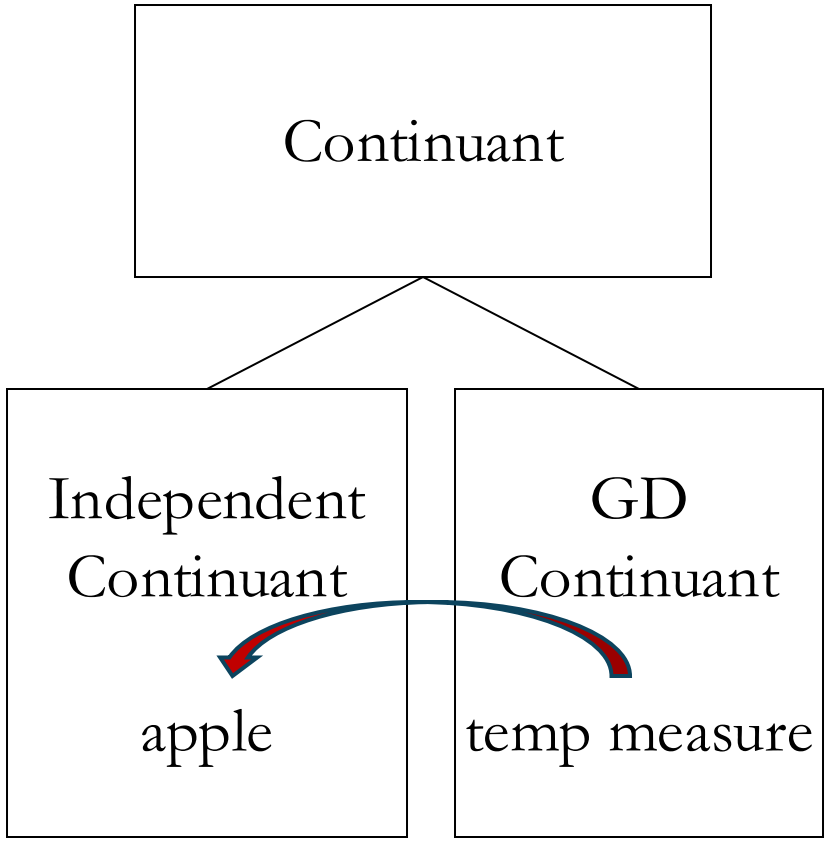
- In BFO extensions - such as the Information Artifact Ontology and the Information Entity Ontology - information is represented by the class **Information Content Entity**

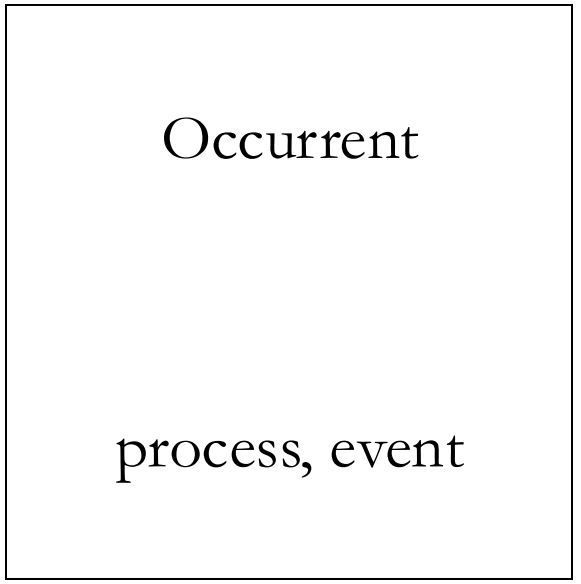
- Where the "is about" relation is understood to be primitive:

definition [language: en]

A primitive relationship between an Information Content Entity and some Entity.

Generically Dependent Continuant

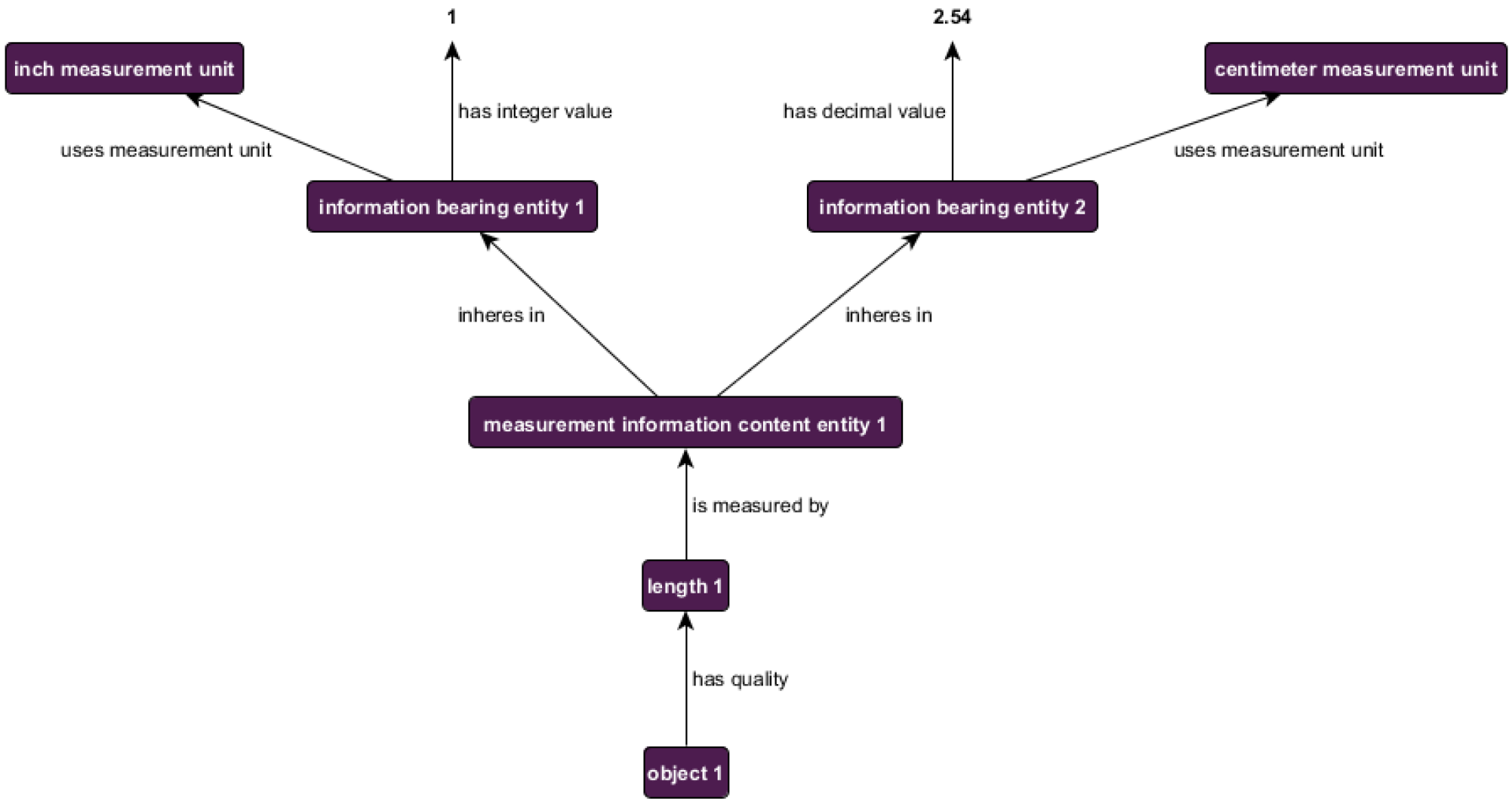




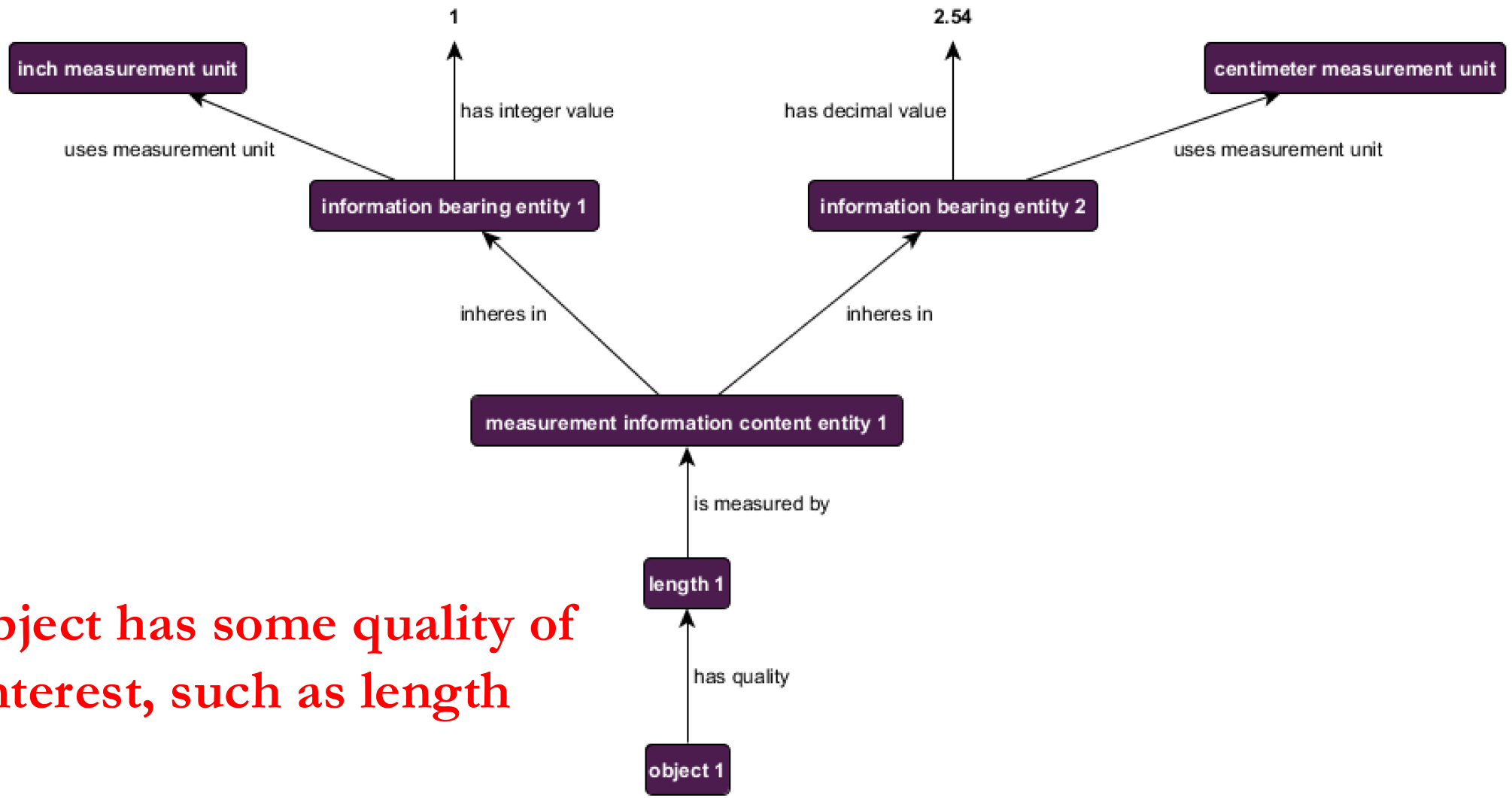
Many measures are about independent continuants

• • • • • •

CCO Measurement

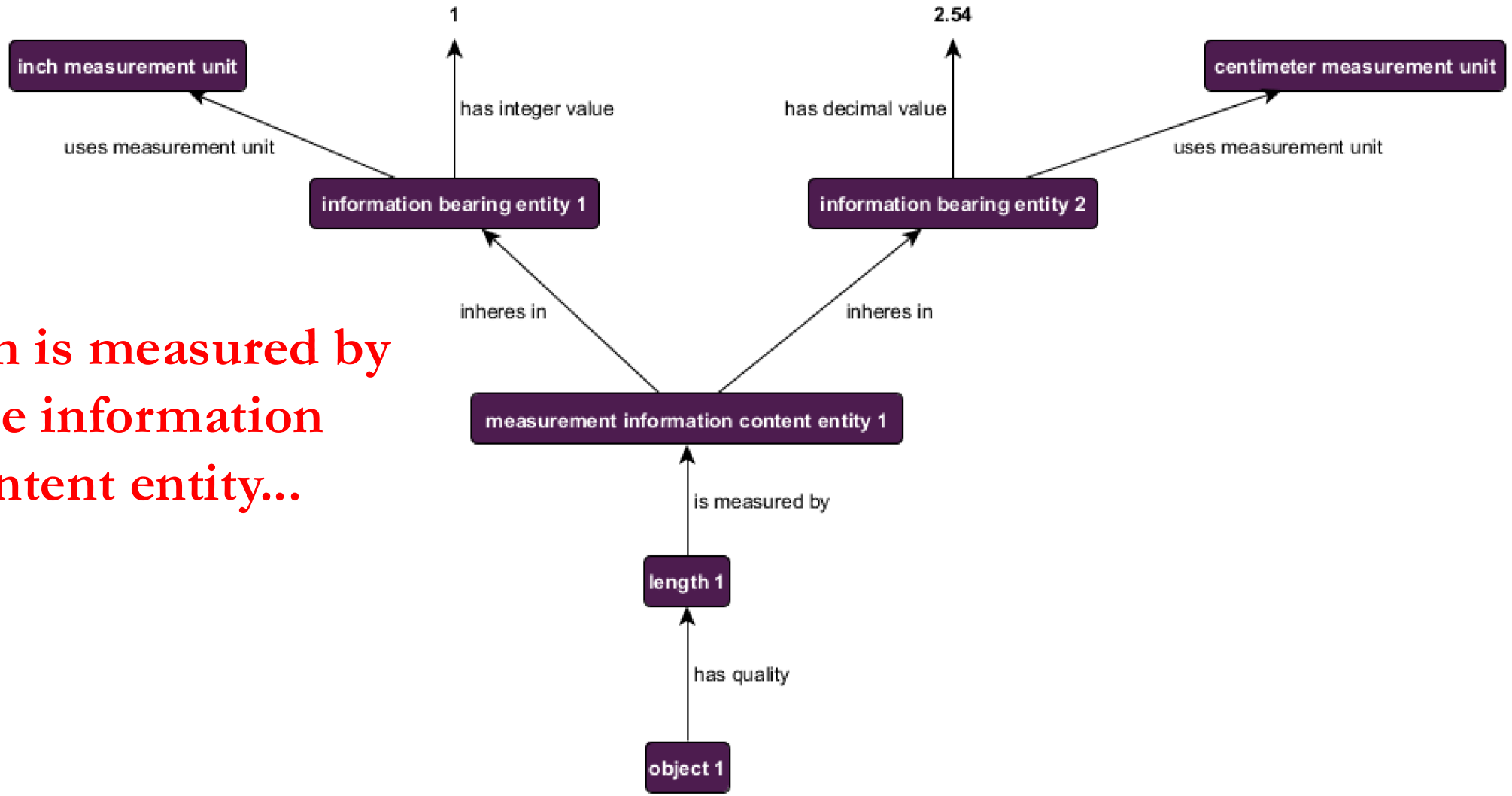


CCO Measurement



An object has some quality of interest, such as length

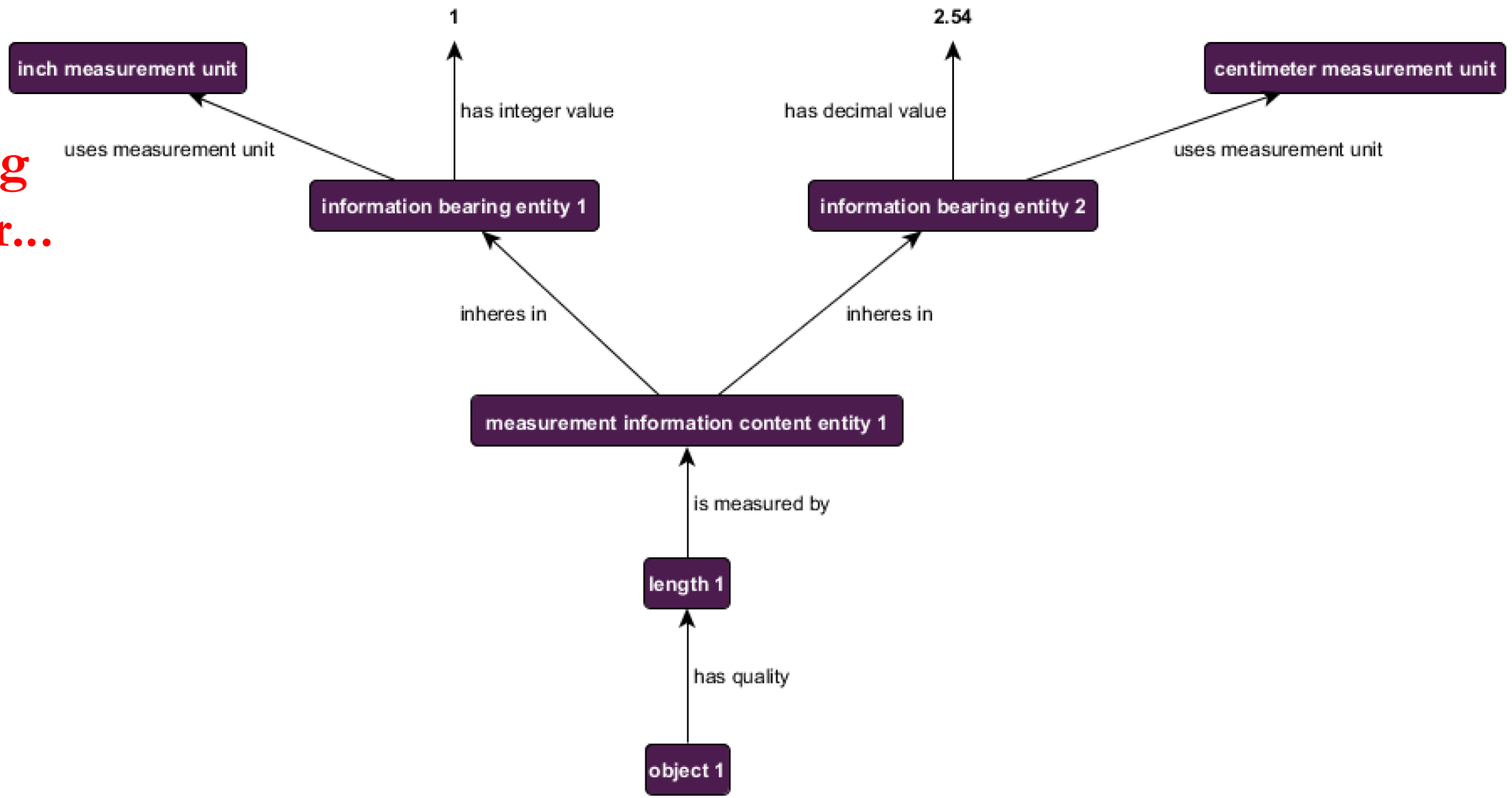
CCO Measurement



...which is measured by some information content entity...

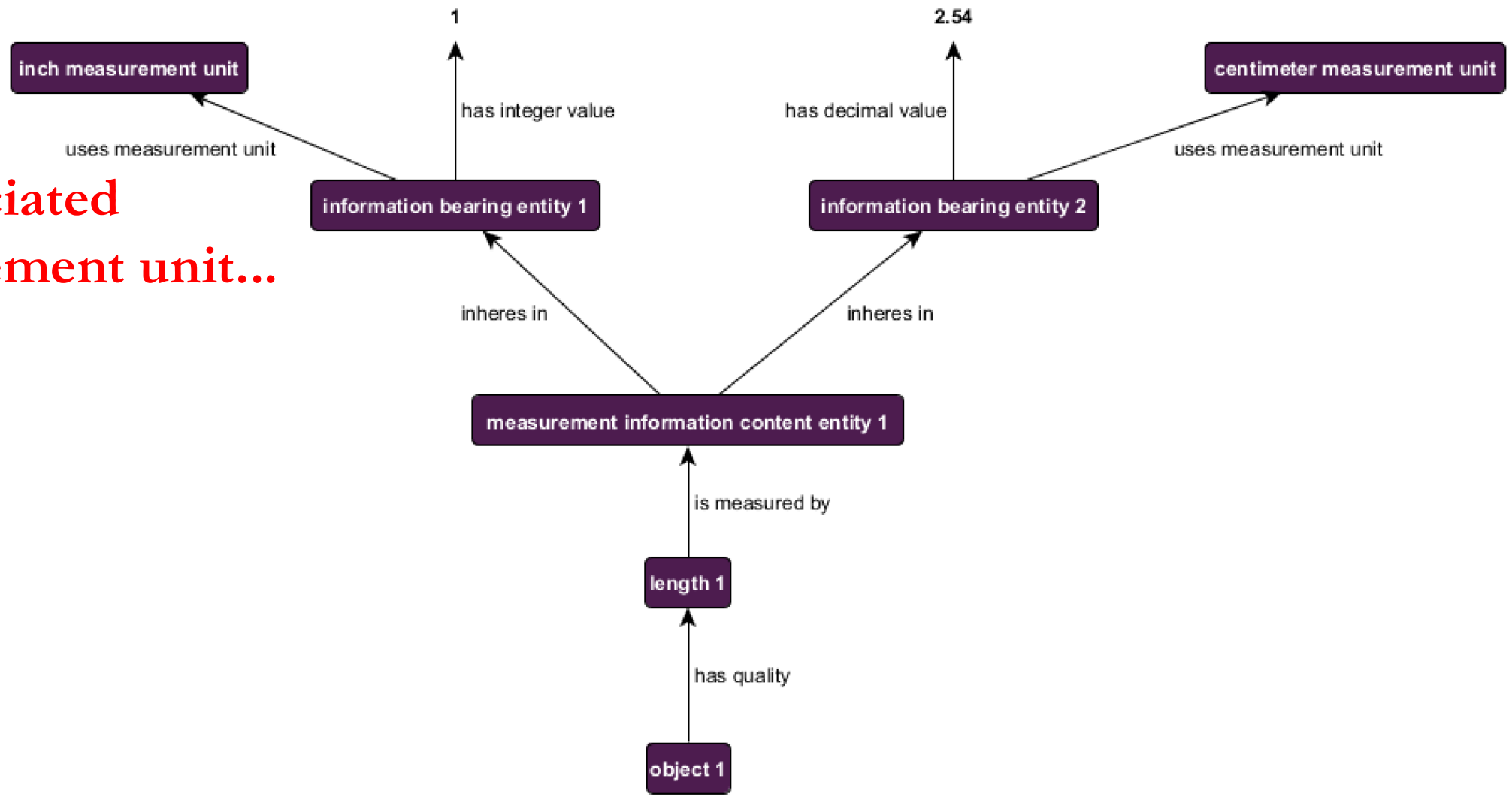
CCO Measurement

...inhering in a bearer...

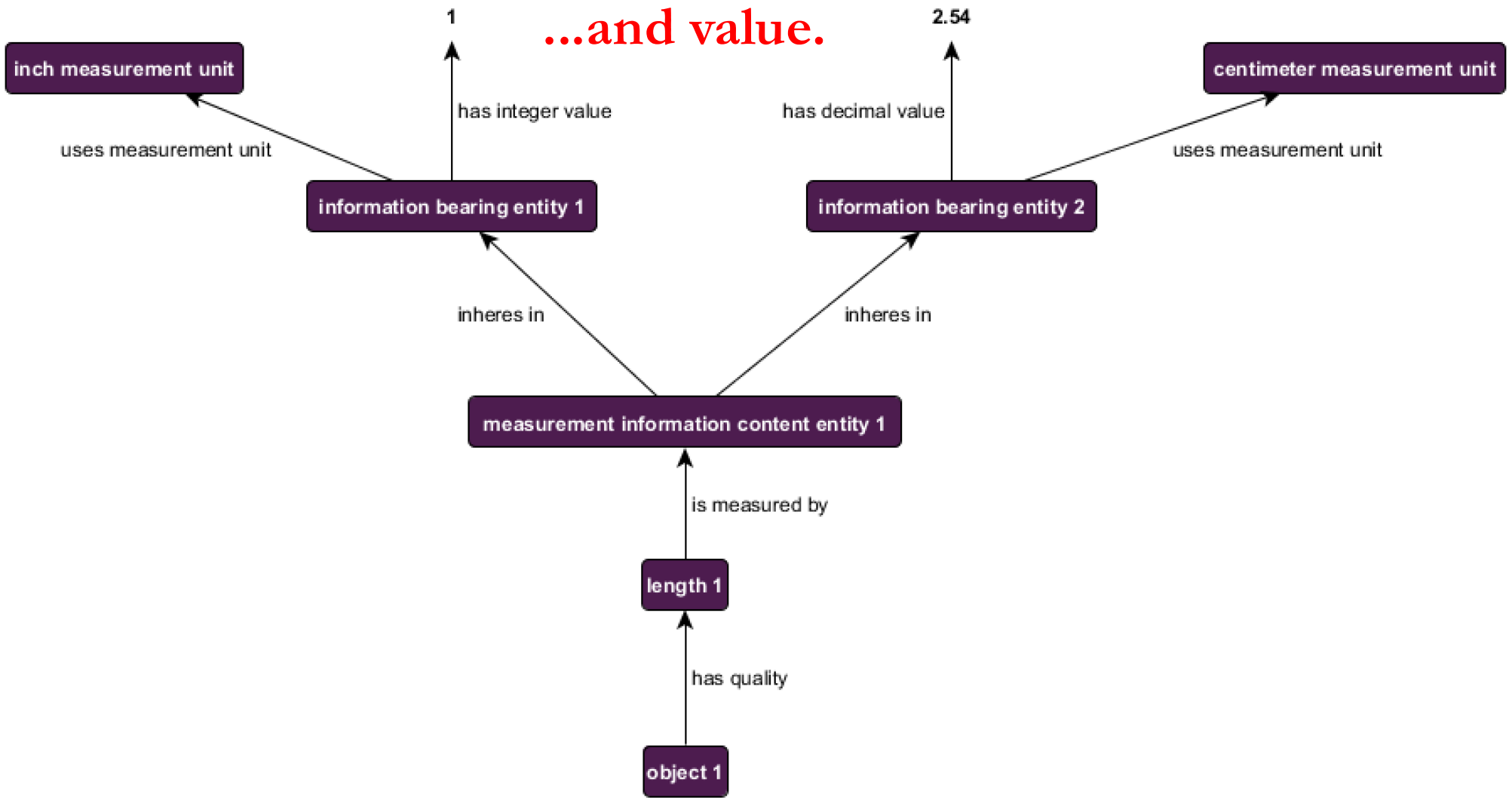


CCO Measurement

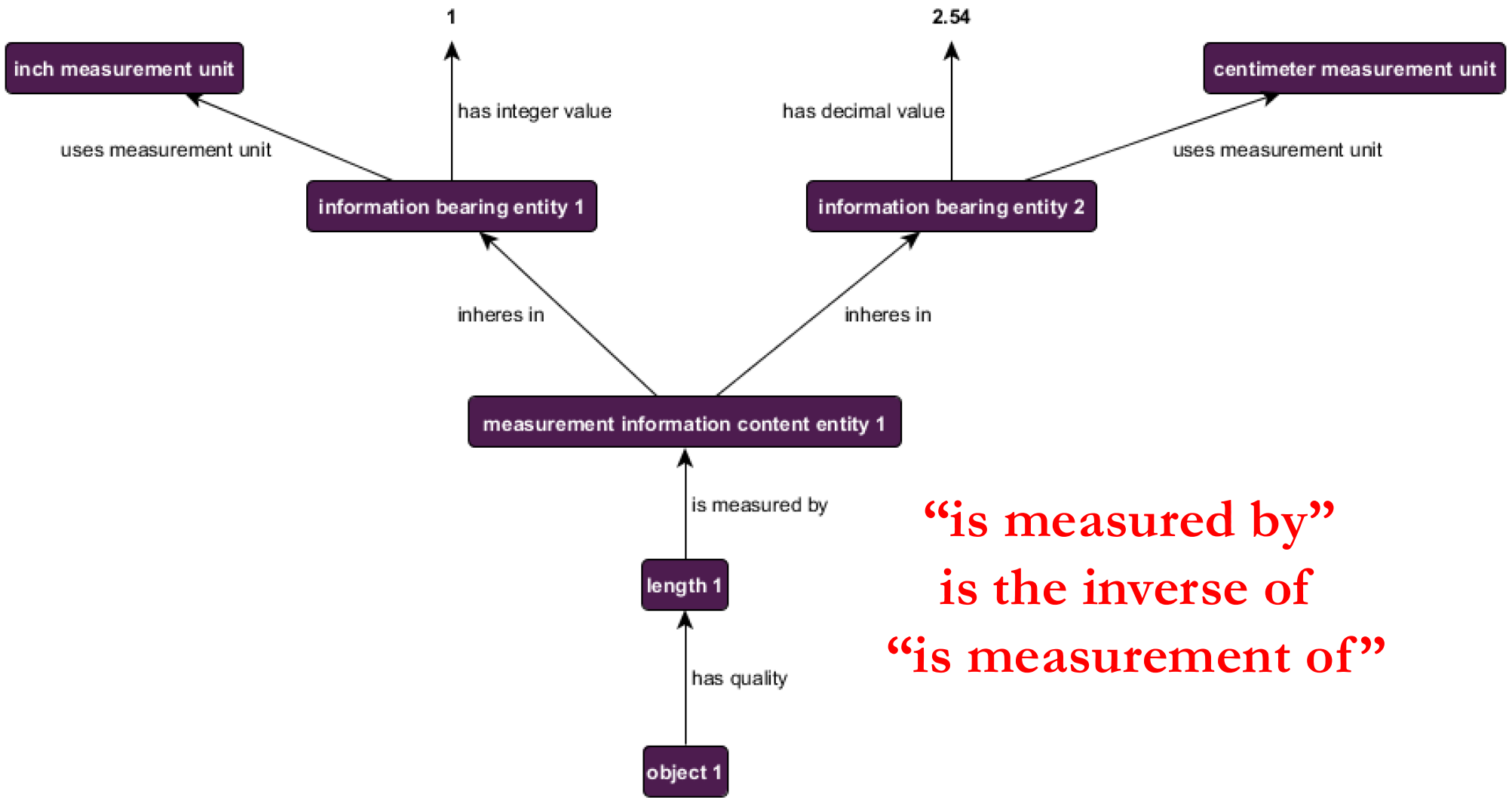
...with an associated measurement unit...



CCO Measurement

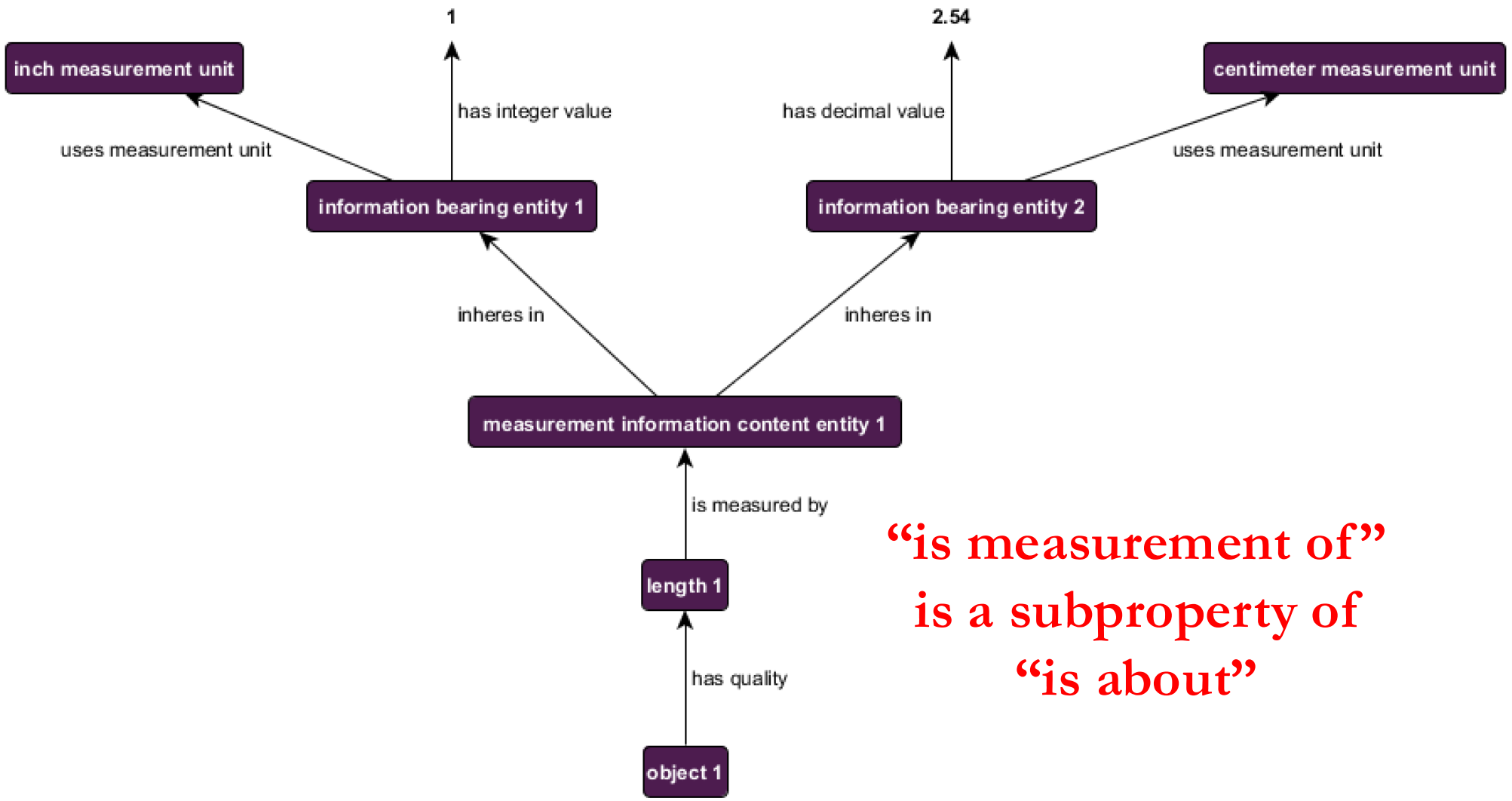


CCO Measurement



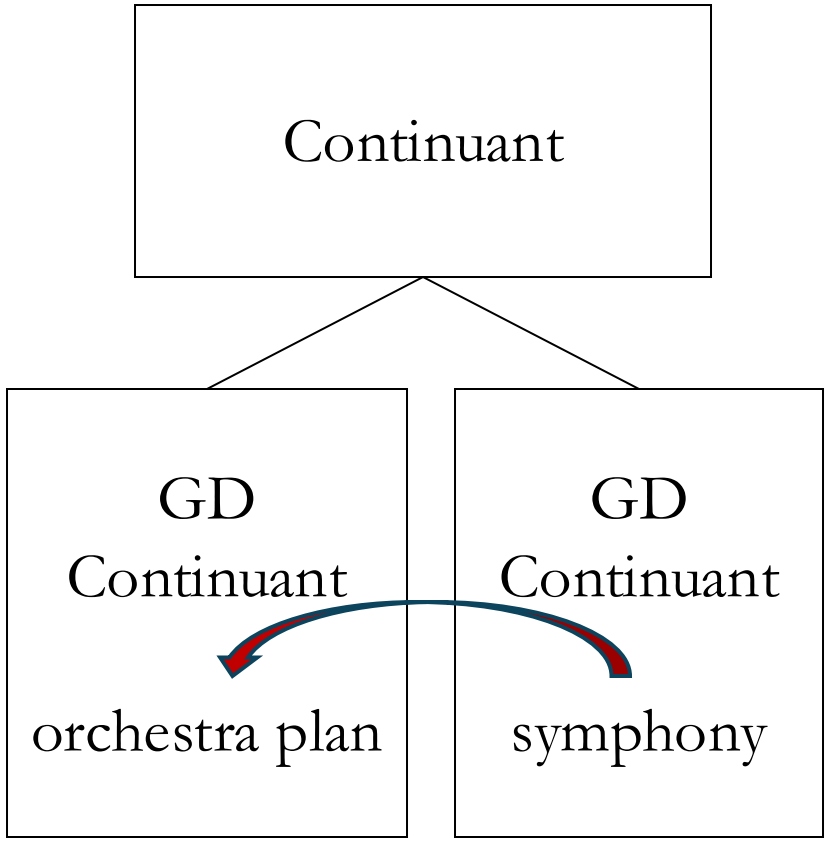
“is measured by”
is the inverse of
“is measurement of”

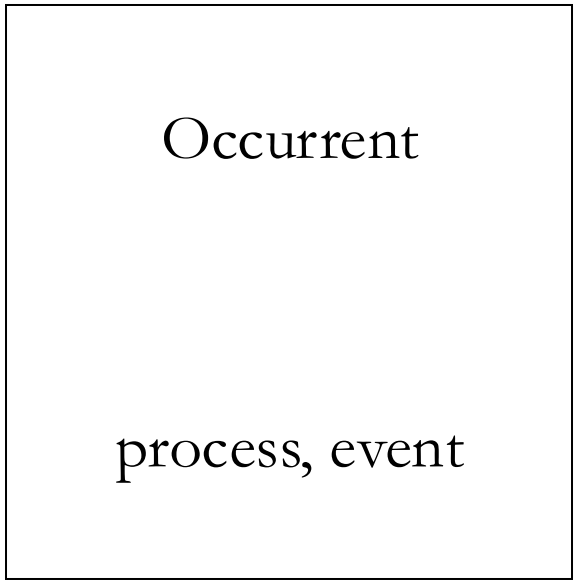
CCO Measurement



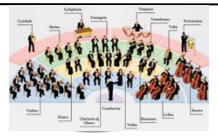
"is measurement of"
is a subproperty of
"is about"

Generically Dependent Continuant





GDCs may be about other GDCs



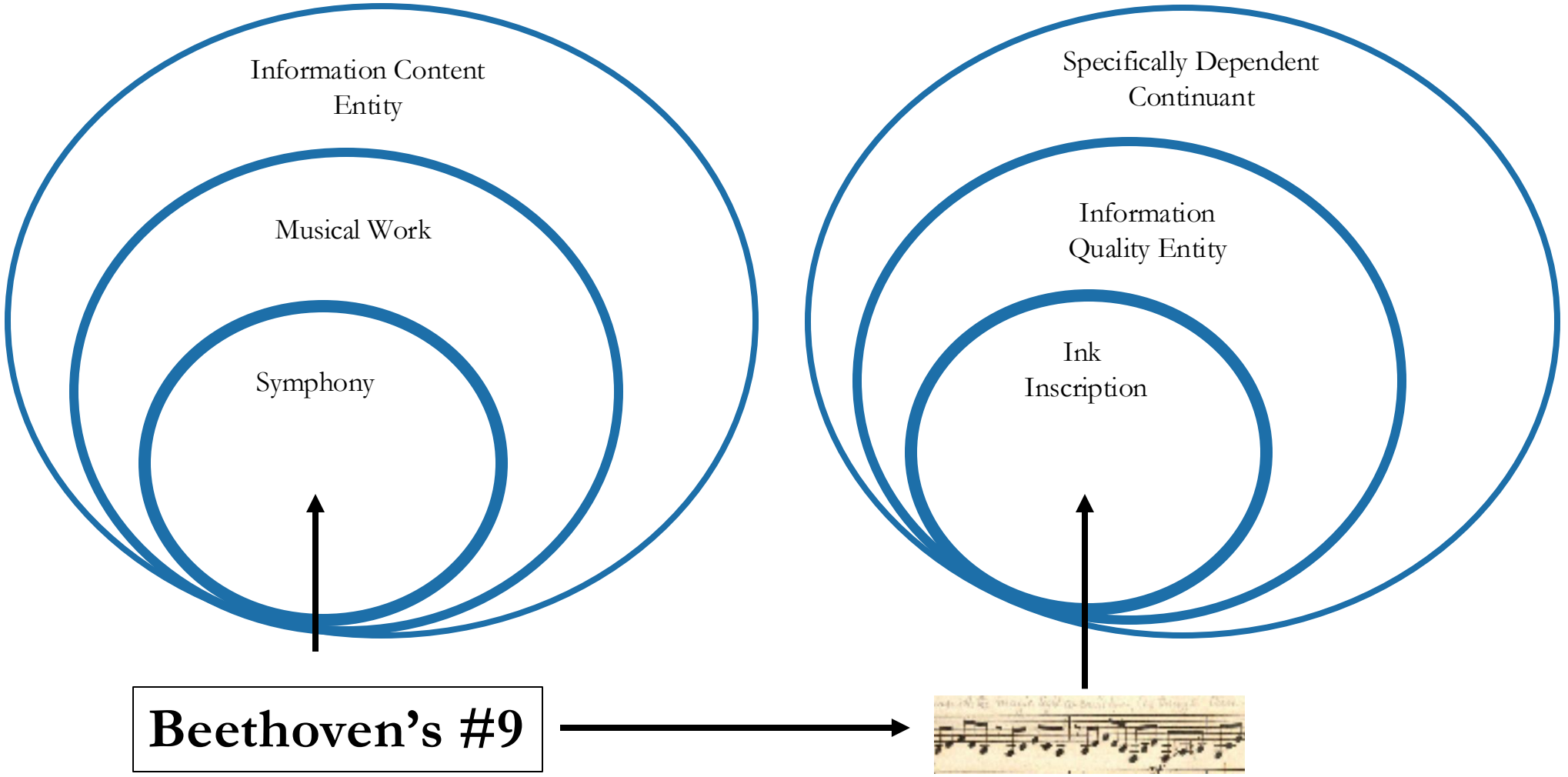
Beethoven's #9

• • • • • •

#9 Concretized in Ink Inscription

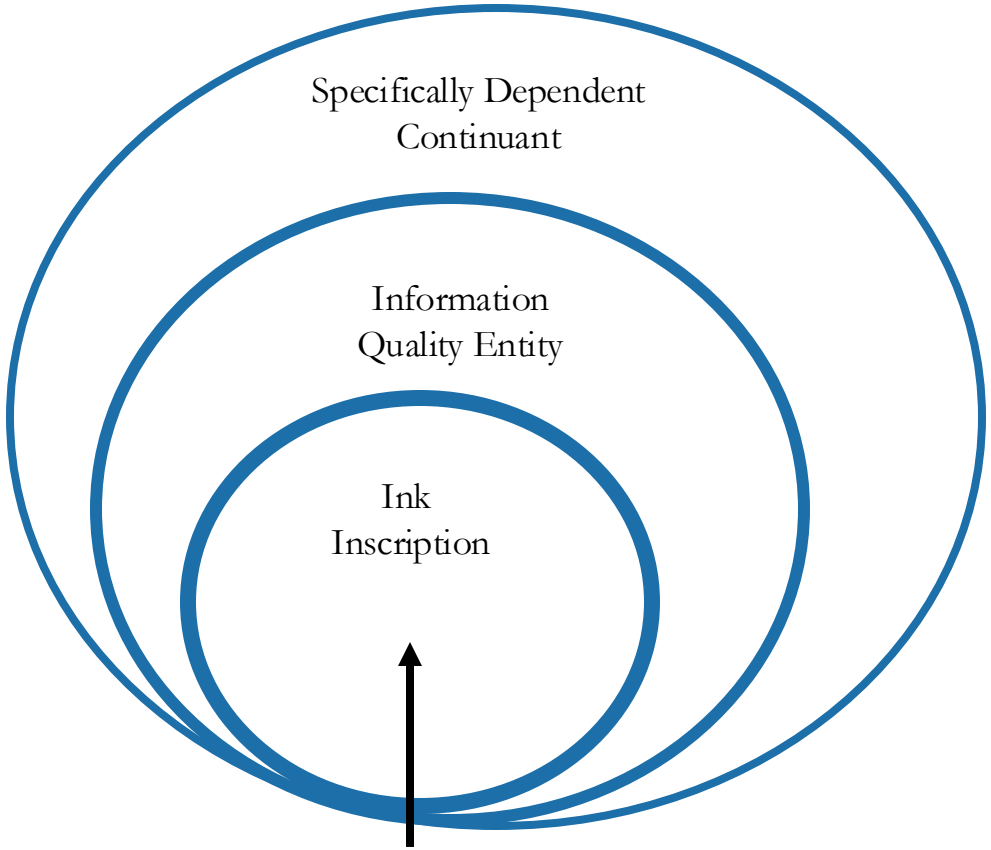
CLASSES

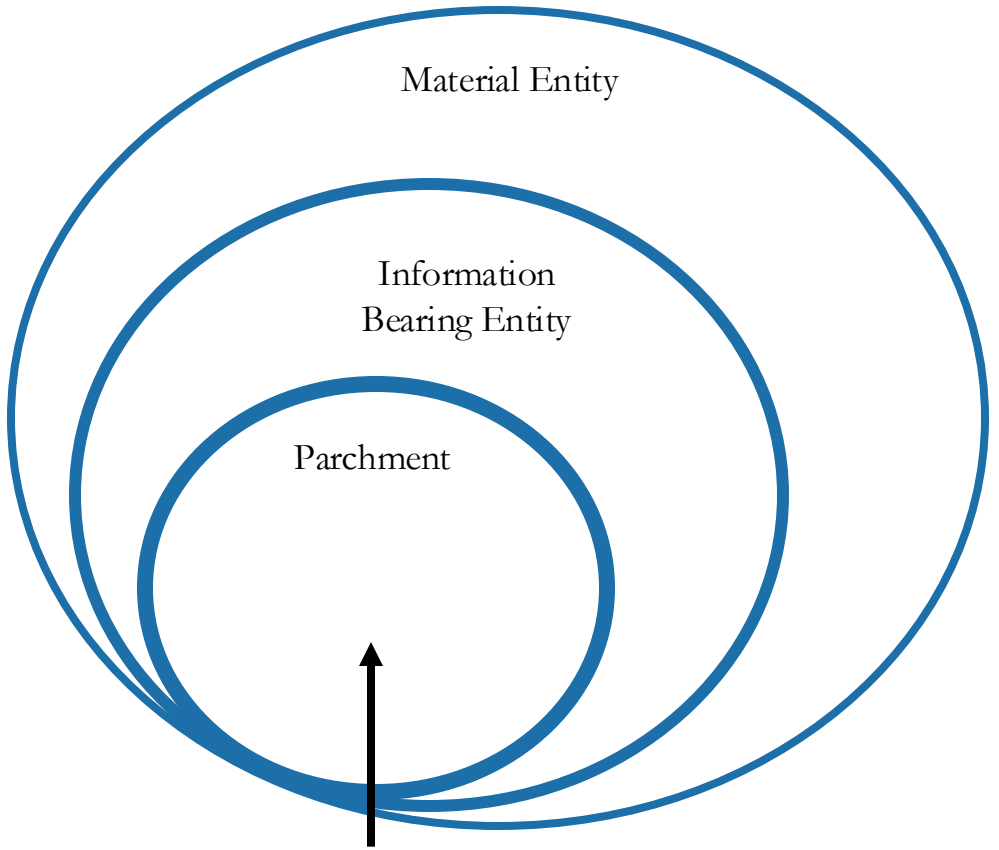
INSTANCES



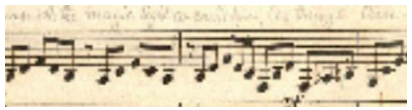
Ink Inscription inheres in Parchment

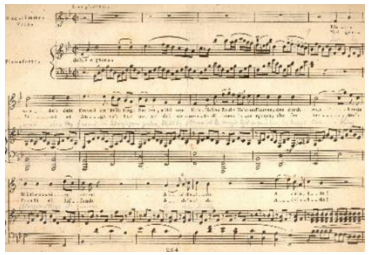
CLASSES





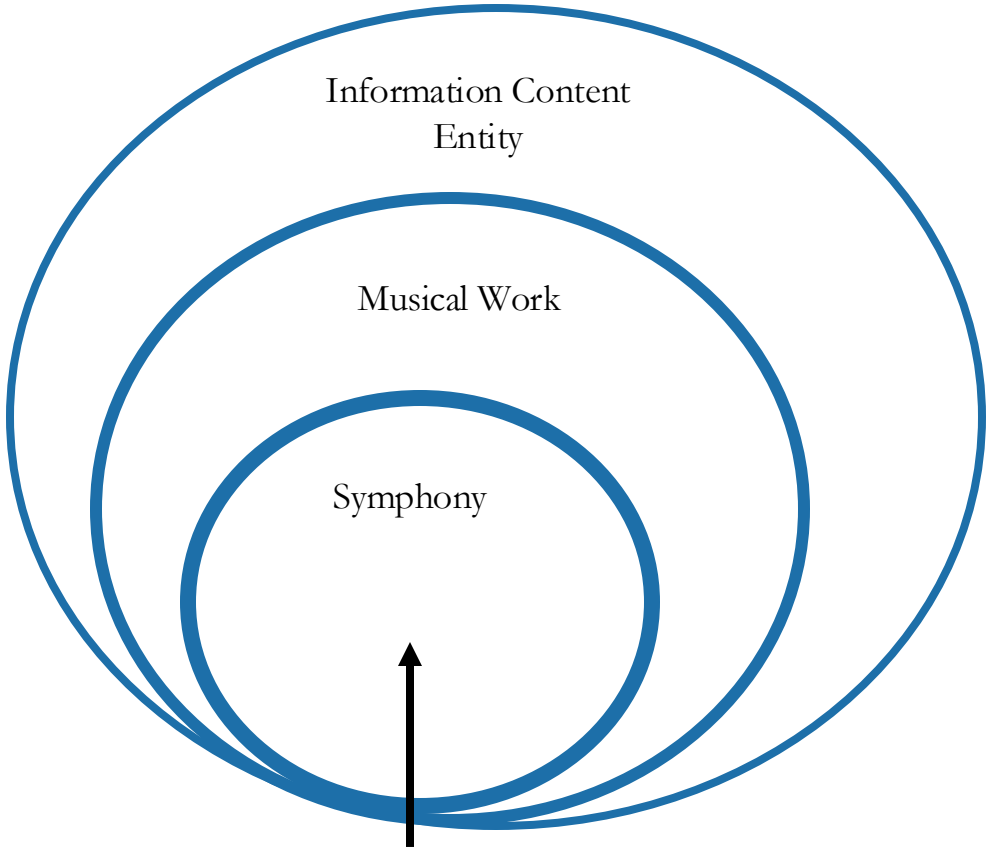
INSTANCES

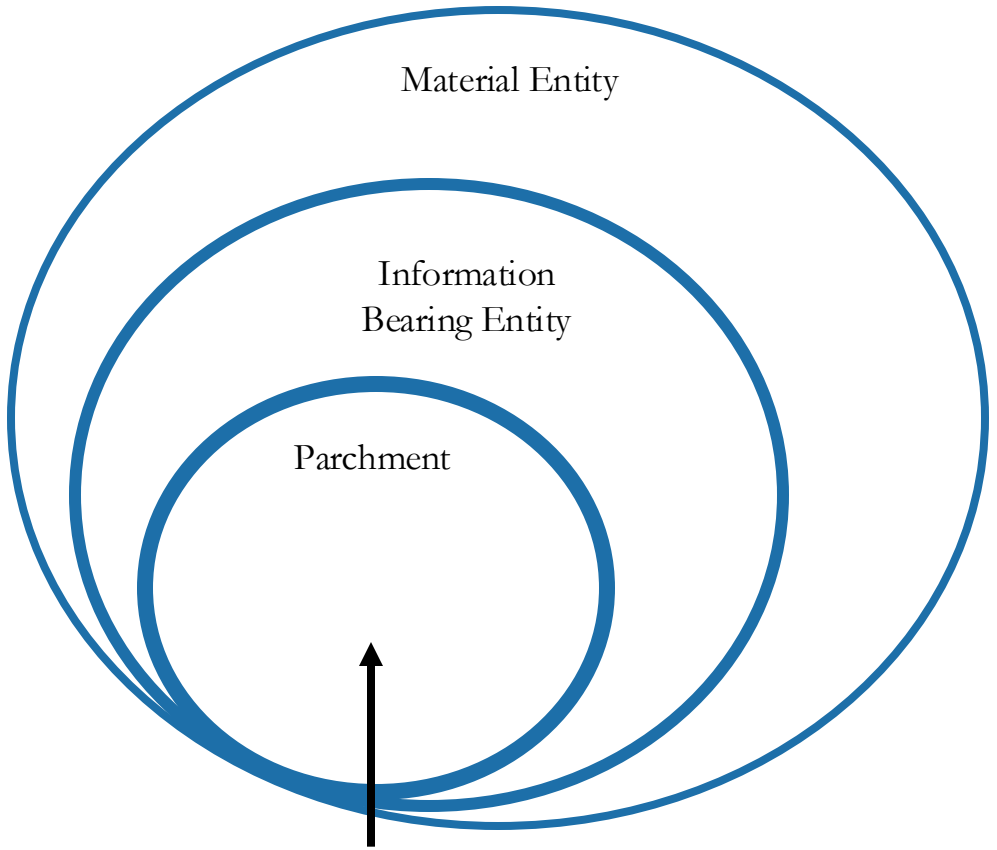




#9 Generically Dependent On Parchment

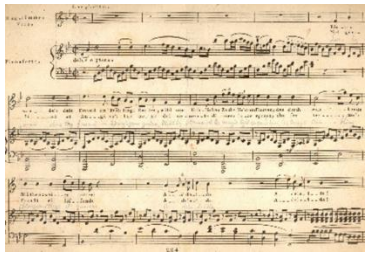
CLASSES





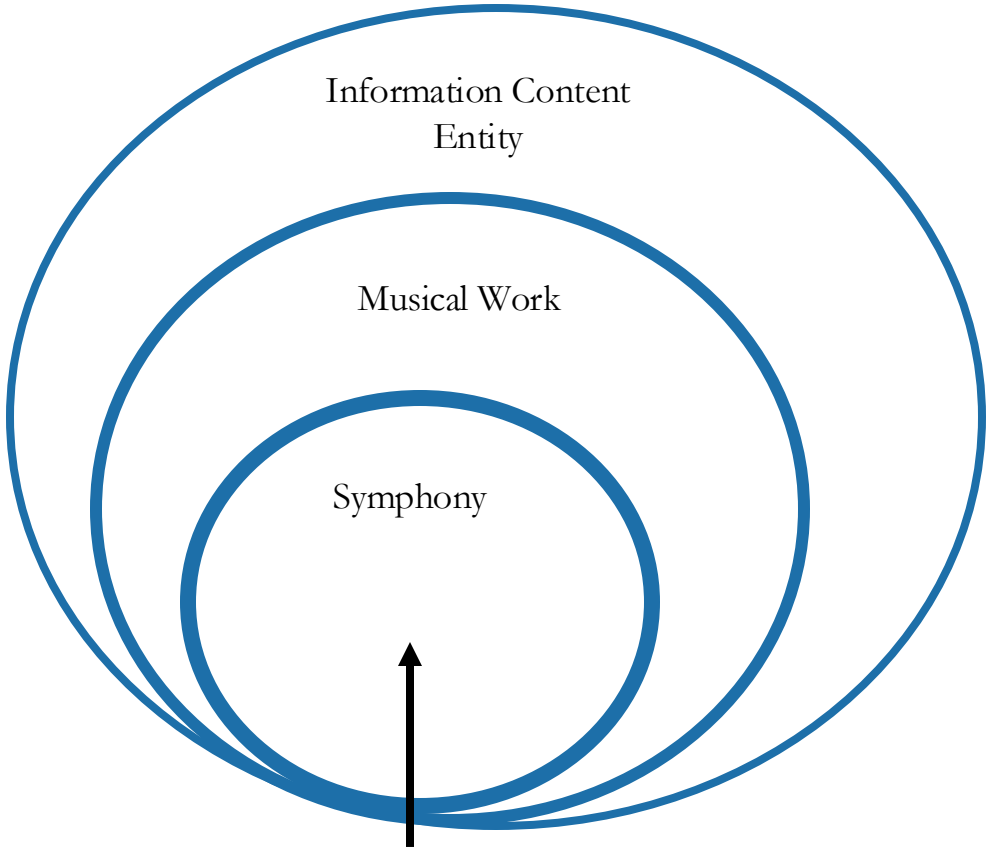
INSTANCES

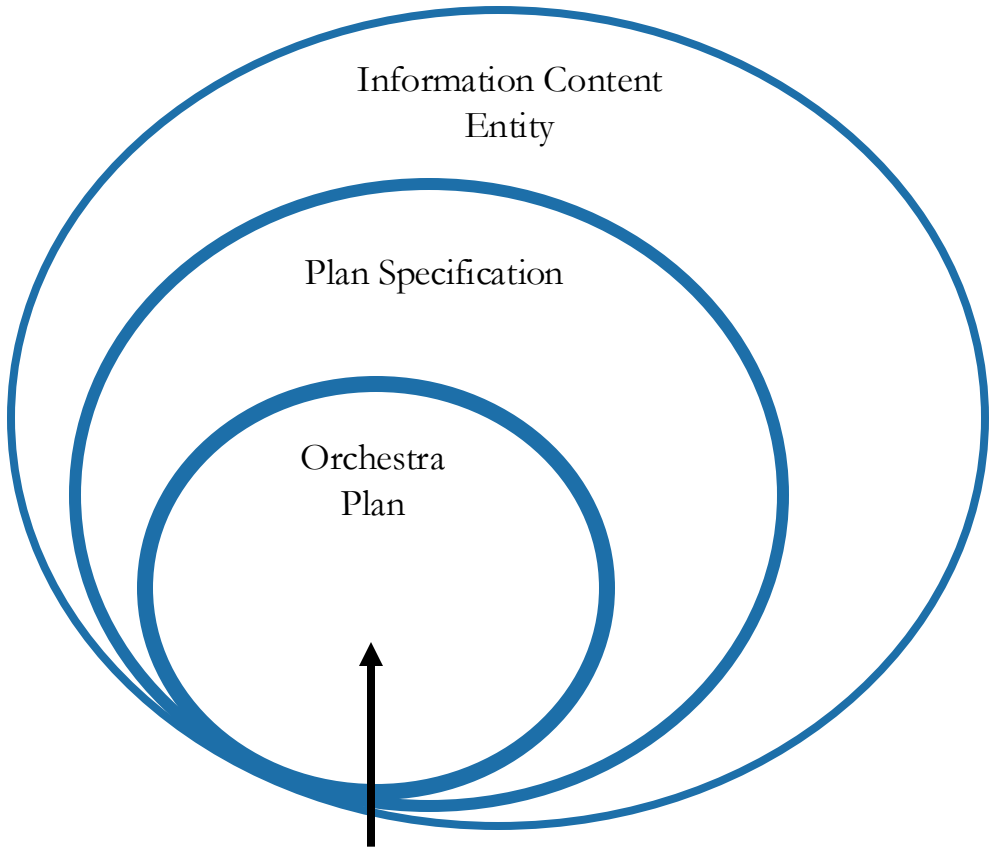
Beethoven's #9



#9 is about Orchestra Plan

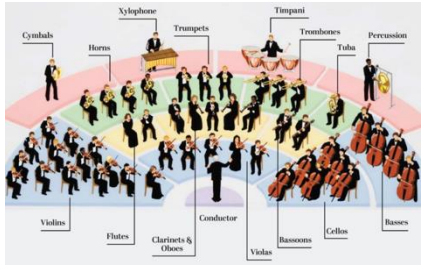
CLASSES





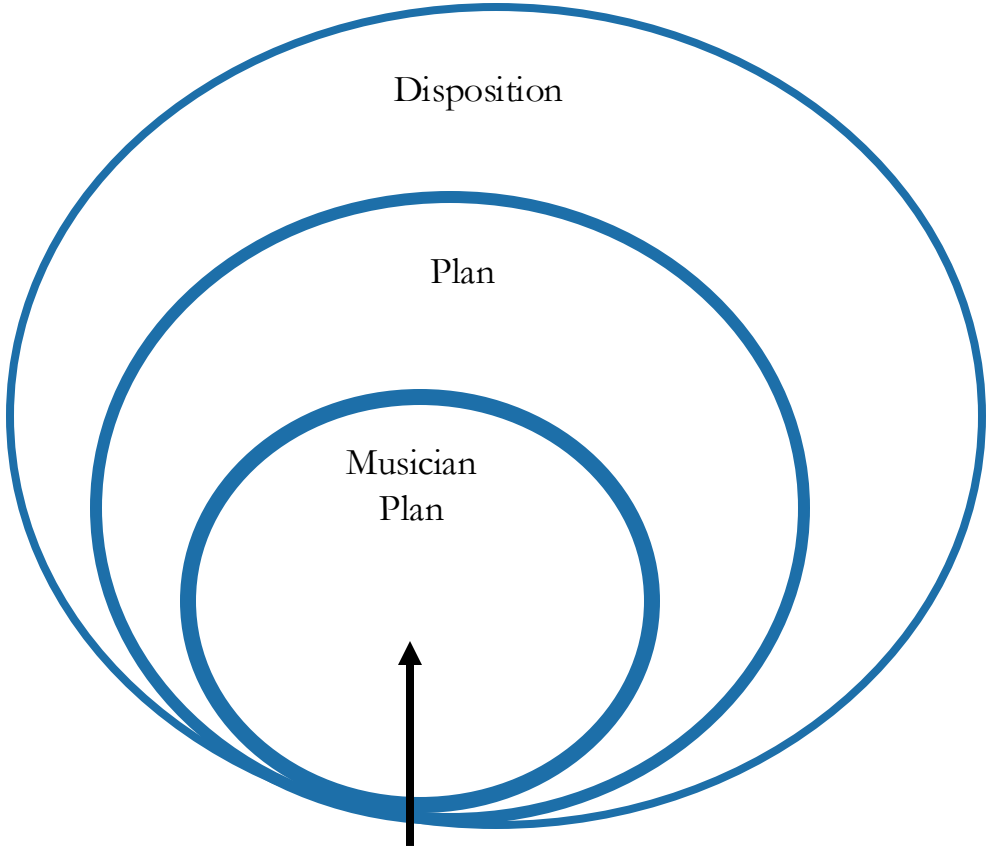
INSTANCES

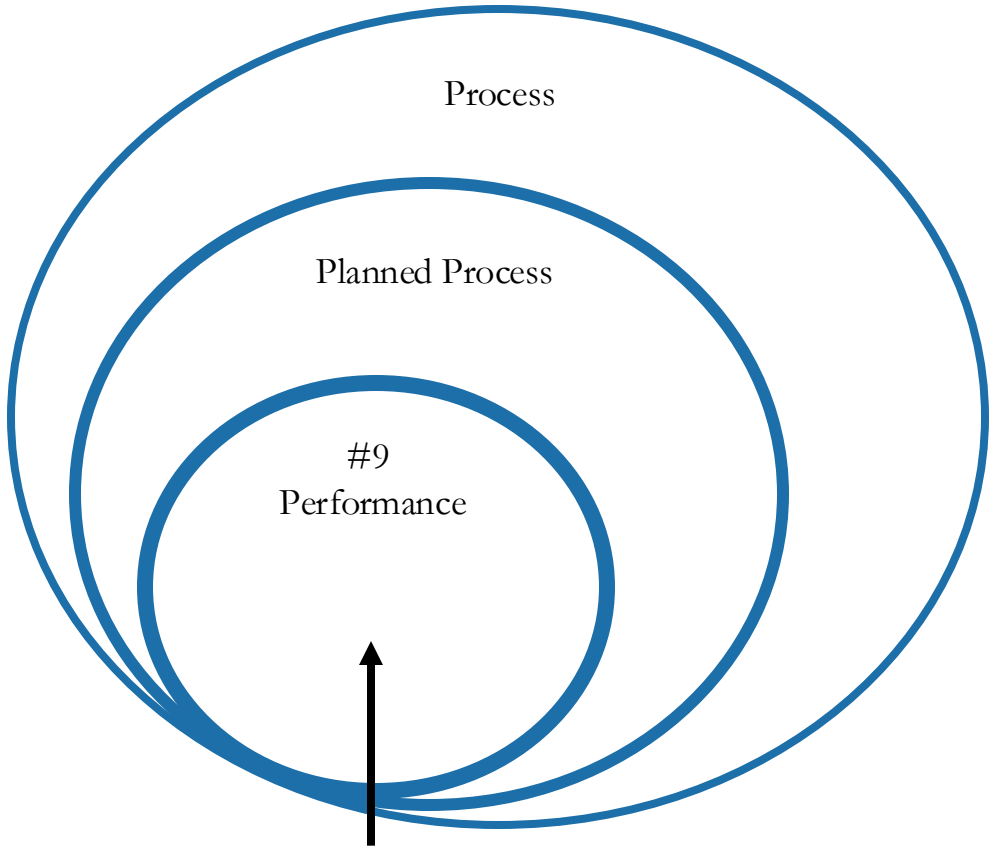
Beethoven's #9



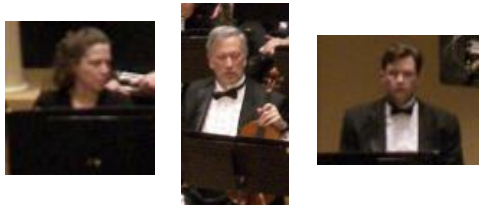
Musician Plan realized in #9 Performance

CLASSES





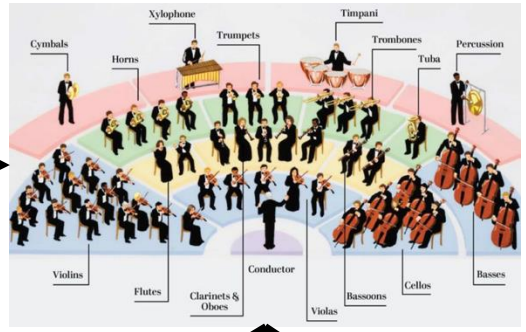
INSTANCES



Beethoven's #9th Symphony

Beethoven's #9

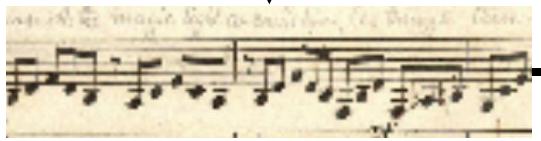
is about



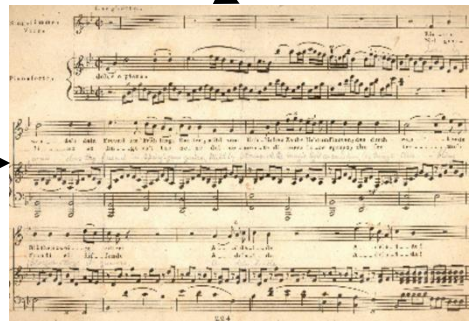
generically depends on

concretized in

concretized in

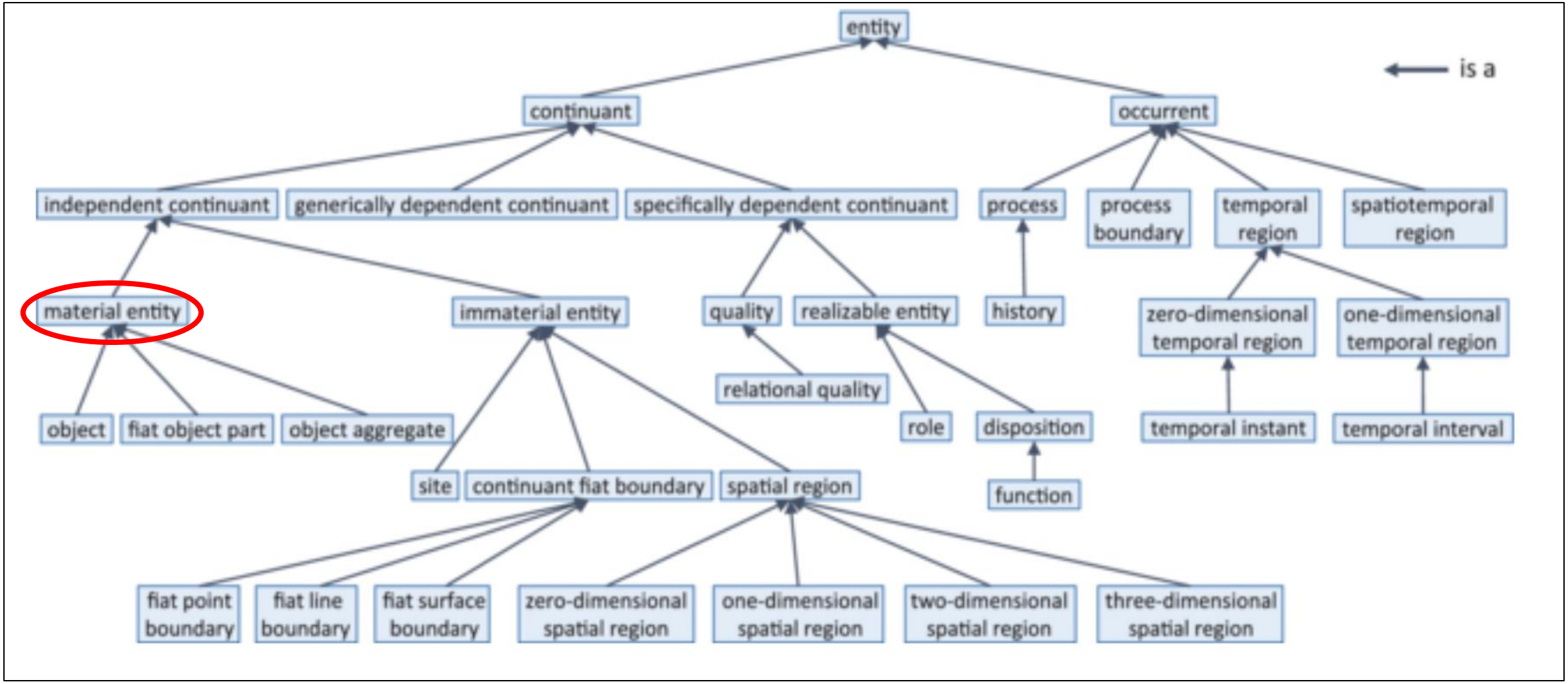


inheres in



has realization

Material Entity



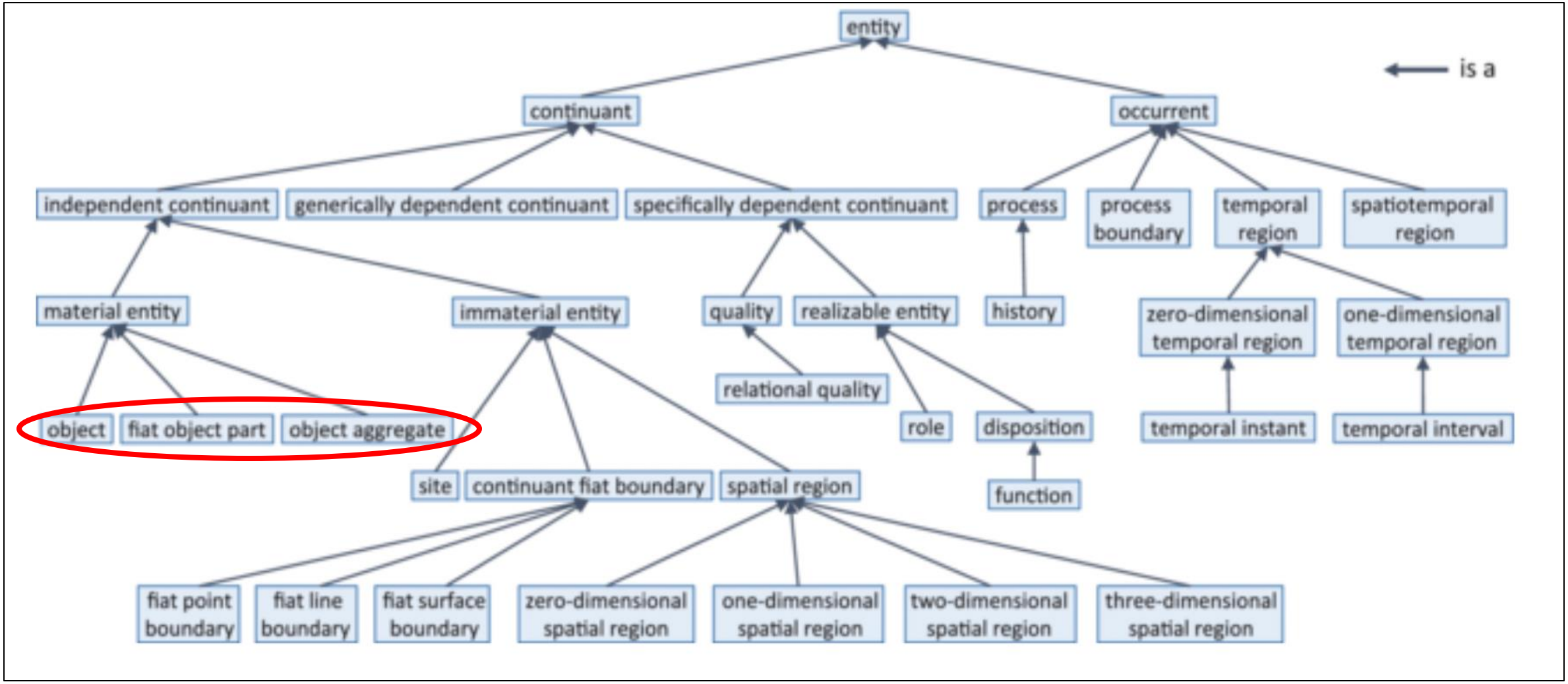
Material Entity

- Many independent continuants discussed thus far depend on instances falling under the class **Material Entity**, which includes all independent continuants having matter as part

- Apples, people, cars, blankets, viruses, tanks, etc. thus fall

- Subclasses include objects, object aggregates, and fiat object parts

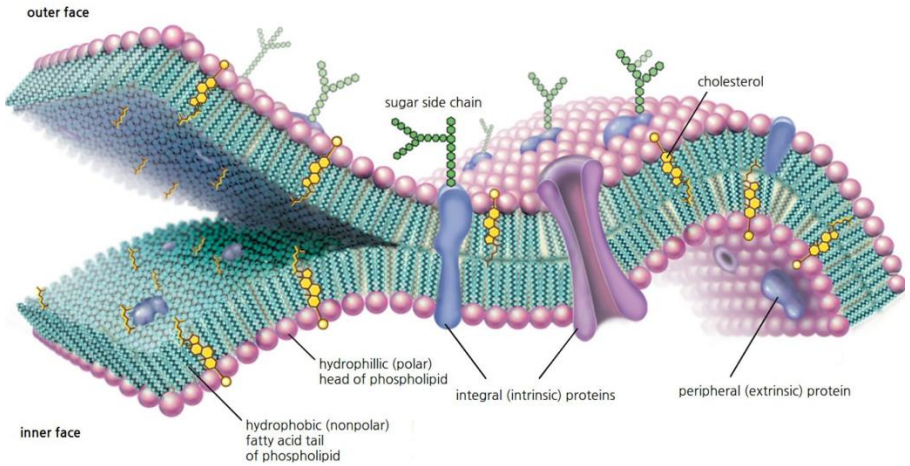
Subclasses of Material Entity



Object

- An object is a material entity that manifests **causal unity**, where its instances are maximal with respect to that causal unity

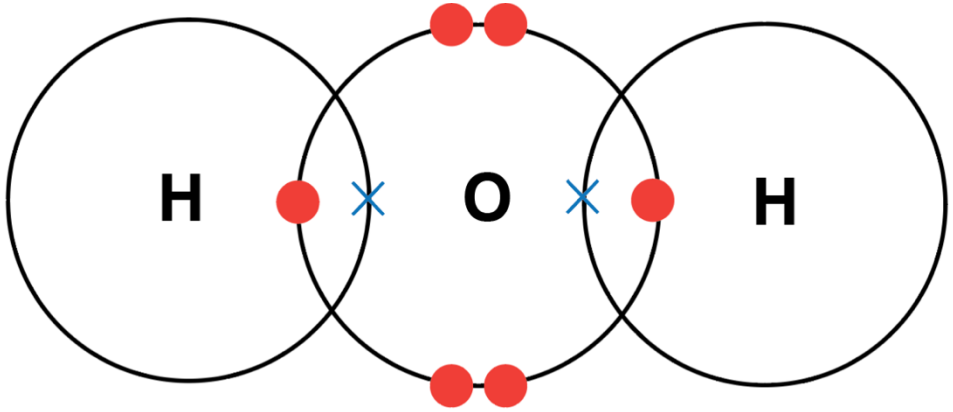
- Examples of causal unity:
  - Physical covering, e.g. interior of the object are covered by a connected membrane



Object

- An object is a material entity that manifests **causal unity**, where its instances are maximal with respect to that causal unity

- Examples of causal unity:
  - Physical covering, e.g. interior of the object are covered by a connected membrane
  - Internal forces, e.g. ionic bonds holding together molecules



Object

- An object is a material entity that manifests **causal unity**, where its instances are maximal with respect to that causal unity

- Examples of causal unity:
  - Physical covering, e.g. interior of the object are covered by a connected membrane
  - Internal forces, e.g. ionic bonds holding together molecules
  - Engineered assembly, e.g. mechanical assembly through screws or fasteners

Rule of Thumb

If moving a proper part of some material entity requires moving other material parts of that entity, there is likely causal unity between them

Object

- An object is a material entity that manifests causal unity, where its instances are **maximal** with respect to that causal unity

Object

- An object is a material entity that manifests causal unity, where its instances are **maximal** with respect to that causal unity

- To say x is maximal with respect to causal unity is to say x is:
  - causally unified by that causal unity

Object

- An object is a material entity that manifests causal unity, where its instances are **maximal** with respect to that causal unity

- To say x is maximal with respect to causal unity is to say x is:
  - causally unified by that causal unity
  - if x is part of some y and y is causally unified in precisely the same way, then x is identical to y

Object

- An object is a material entity that manifests causal unity, where its instances are **maximal** with respect to that causal unity

- To say x is maximal with respect to causal unity is to say x is:
  - causally unified by that causal unity
  - if x is part of some y and y is causally unified in precisely the same way, then x is identical to y

- For example, relative to causal unity by covering, your torso is not maximal, but the whole of you as an organism is maximal

Object Aggregate

- Defined such that any and all members of the aggregate are objects which do not share any parts in common, i.e. are pairwise disjoint

- For example, one can define the object aggregate that is all instruments in an orchestra, or all members of a band

- More generally, the "X aggregate" is intended to be a recipe that may be applied to other classes, e.g. "aggregate of roles"

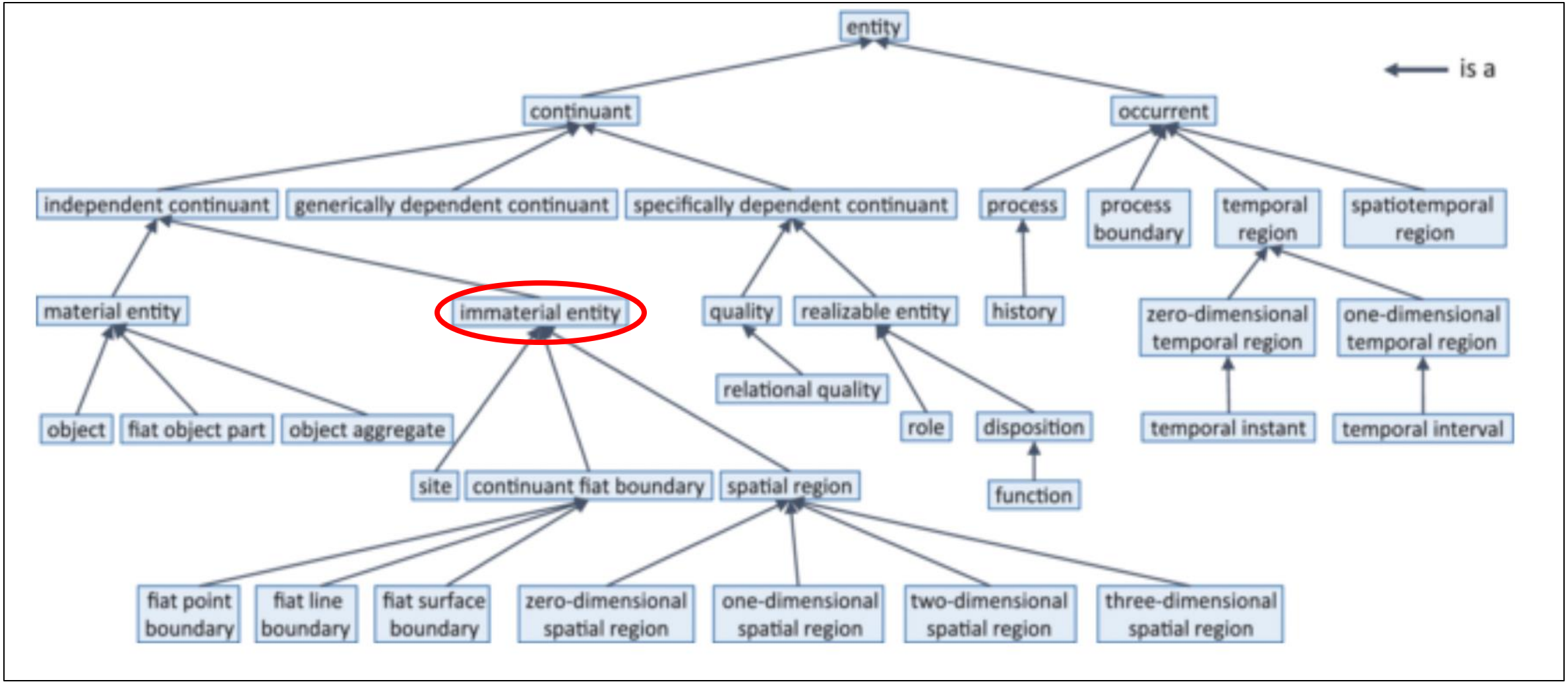
Fiat Object Part

- Certain parts of objects that are not themselves objects, warrant catergorization beyond merely being identified as parts

- For example, a so-called **bona fide** object part of the Earth, which would be an object, such as an island, may be divided into northern and southern **fiat** object parts

- Northern and southern portions of a given island exist regardless of whether we delineate them so

Immaterial Entity



Any entity that has a material entity as part is a material entity

But material entities may have immaterial entities as parts

Immaterial Entity

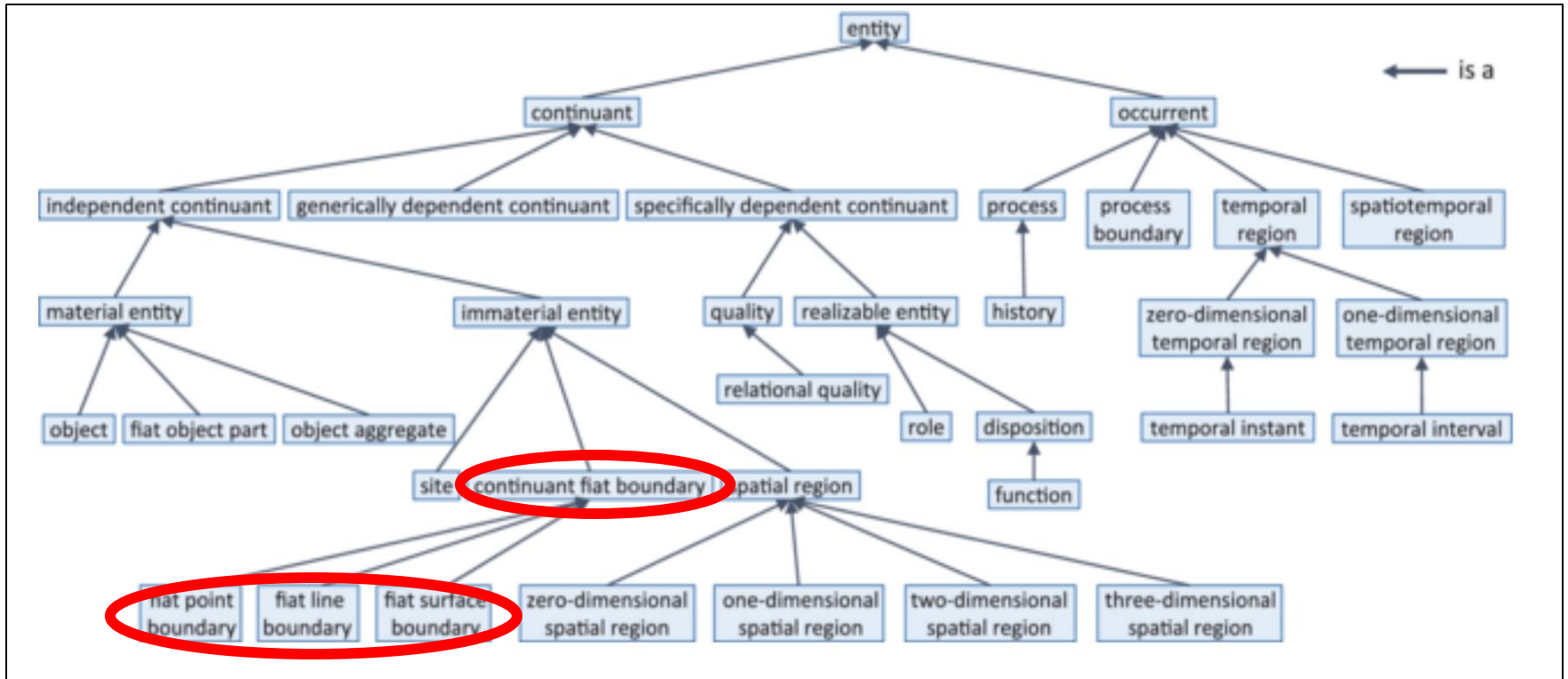
- Not all independent continuants have matter as parts

- Territorial boundaries, internal hulls of ships, interiors of capsules, etc. are not identical to whatever material is often associated with them

- For example, an archaeologist seeking the site through which a contemporary river used to flow, is not looking for the material the river used to flow through, for that is lost to time

Continuant Fiat Boundary

- *Continuant Fiat Boundary* $=_{\text{def}}$ An immaterial entity such that there is no time t when it has a spatial region as continuant part & whose location is determined in relation to some material entity



Continuant Fiat Boundary

- *Continuant Fiat Boundary* $=_{\text{def}}$ An immaterial entity such that there is no time t when it has a spatial region as continuant part & whose location is determined in relation to some material entity

- In BFO, **objects** are three-dimensional and have two-dimensional boundaries, e.g. surfaces

- There are no three-dimensional boundaries, because boundaries are always entities of some lower dimension

Dimension Constraint

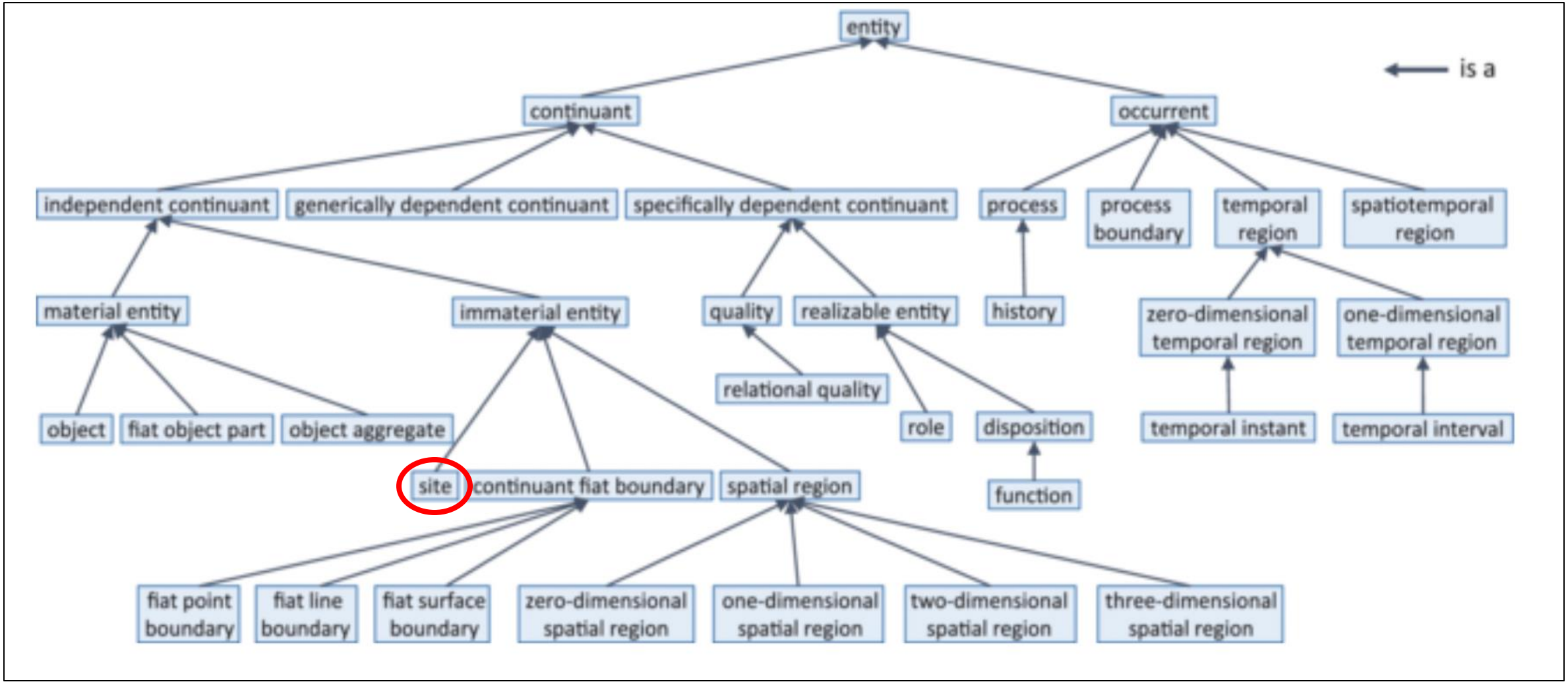
- x has a lower dimension than y
  - irreflexive
  - asymmetric
  - transitive

Dimension Constraint

- *x* has a lower dimension than *y*
  - irreflexive
  - asymmetric
  - transitive

If *x* is boundary of *y* then *x* has lower dimension than *y*

Site


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

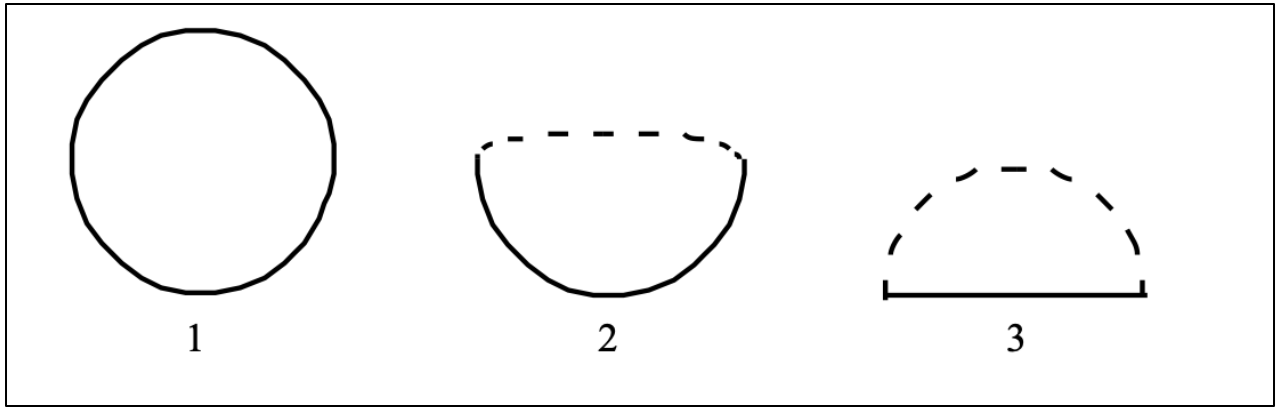
Site

- *Site* $=_{\text{def}}$ A three-dimensional immaterial entity whose boundaries either (partially or wholly) coincide with the boundaries of one or more material entities or have locations determined in relation to some material entity

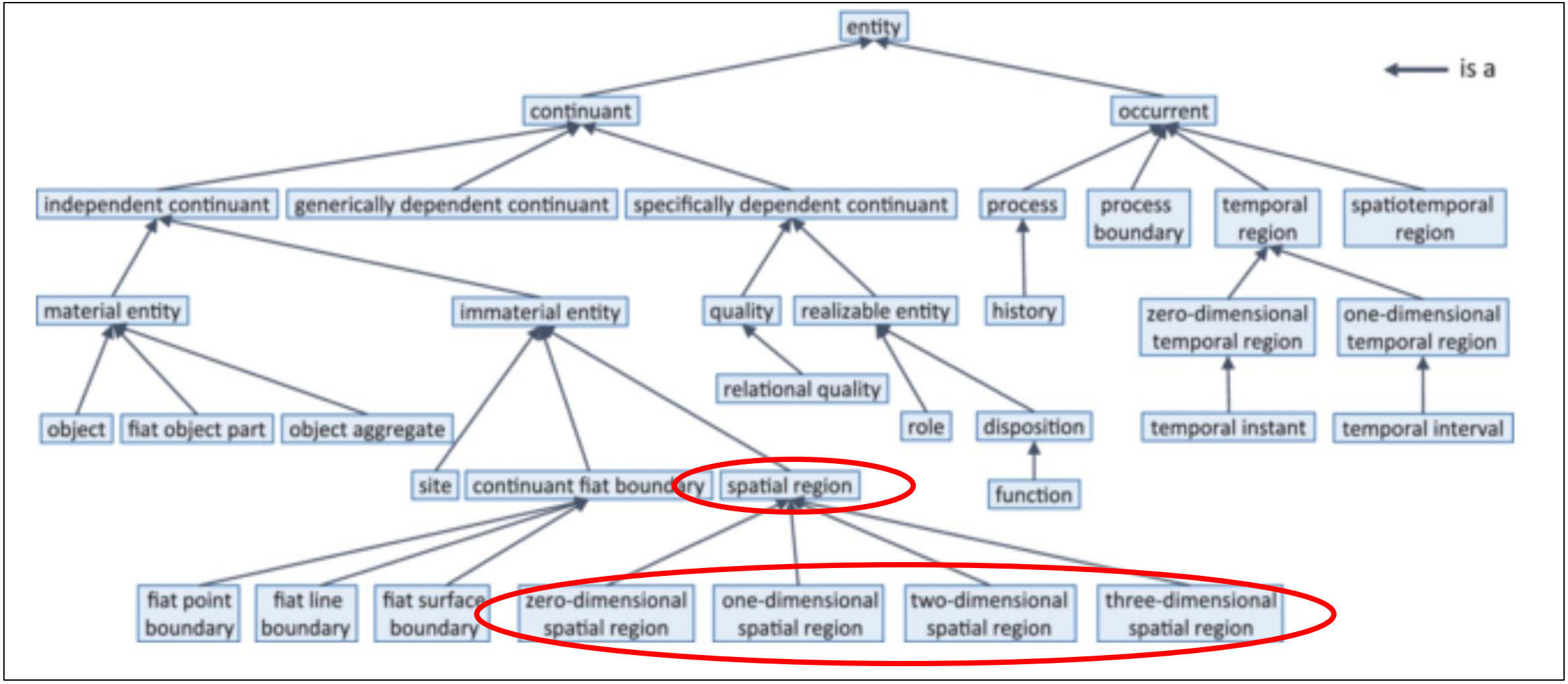
Site

- *Site* $=_{\text{def}}$ A three-dimensional immaterial entity whose boundaries either (partially or wholly) coincide with the boundaries of one or more material entities or have locations determined in relation to some material entity

- Examples:
  - A rabbit hole
  - The interior of your bedroom
  - The hold of a ship
  - The cockpit of an aircraft



Spatial Region



Spatial Regions

- *Spatial Region* $=_{\text{def}}$ A continuant that is continuant part of the spatial projection of a portion of spacetime at a given time

Spatial Regions

- *Spatial Region* $=_{\text{def}}$ A continuant that is continuant part of the spatial projection of a portion of spacetime at a given time

- *spatially projects onto* $=_{\text{def}}$ Holds between spatiotemporal region *s* and spatial region *r* at some time *t* such that *r* is the spatial extent of *s* at *t*

Spatial Regions

- *Spatial Region* $=_{\text{def}}$ A continuant that is continuant part of the spatial projection of a portion of spacetime at a given time

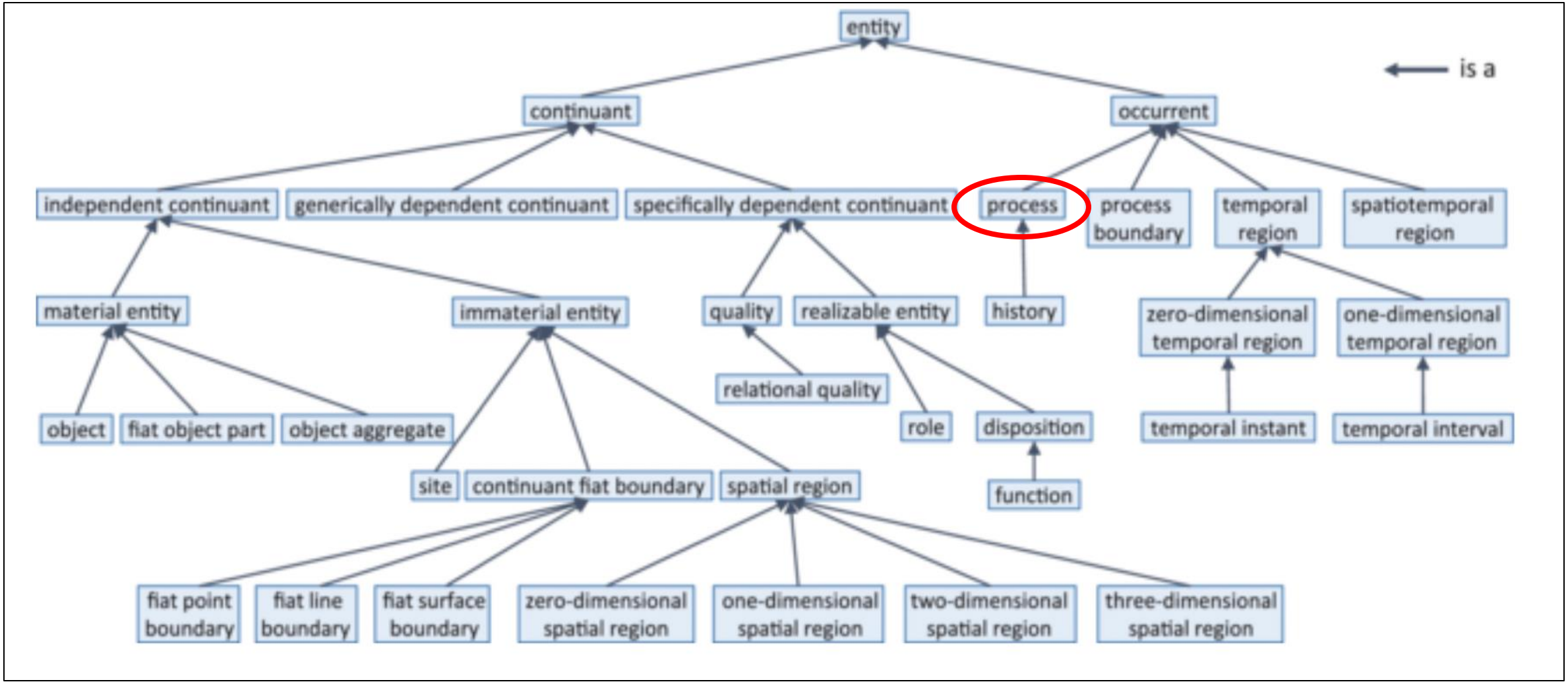
- *spatially projects onto* $=_{\text{def}}$ Holds between spatiotemporal region *s* and spatial region *r* at some time *t* such that *r* is the spatial extent of *s* at *t*

spatial projection is exact, i.e. there is no *r'* of which *r* is proper part such that *s* spatially projects onto *r'*

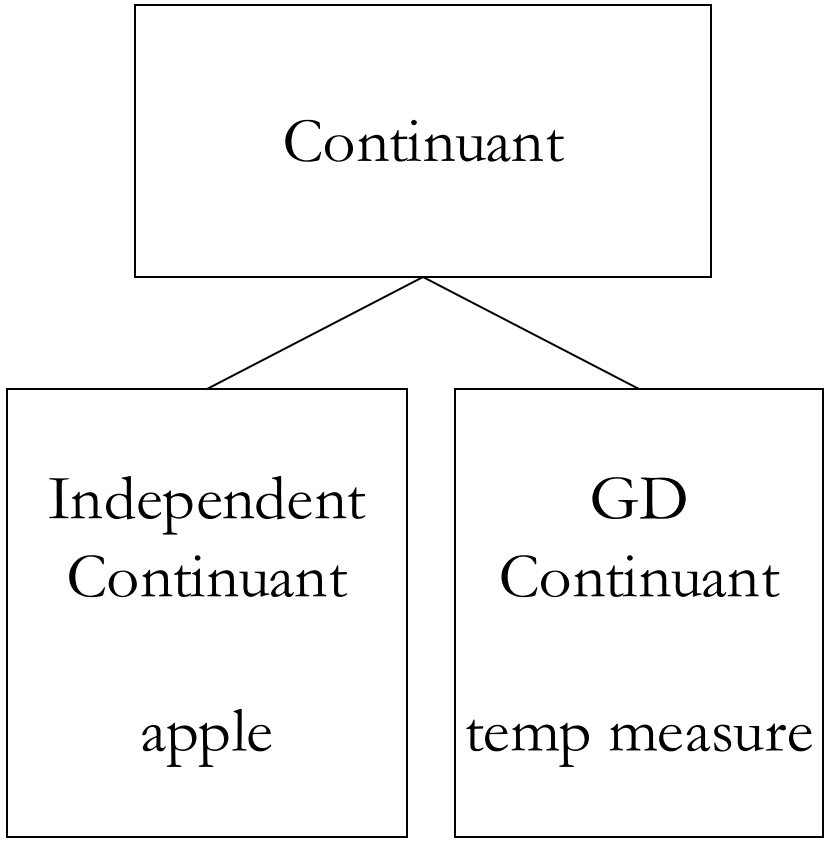
Dependence

- For certain entities, their existence depends on the existence of something else
- Other entities do not depend on any other entities for their existence
- The latter are categorized in BFO as **independent continuants**
- The former include **specifically dependent** and **generically dependent entities**, as well as **processes**

Process


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

Process



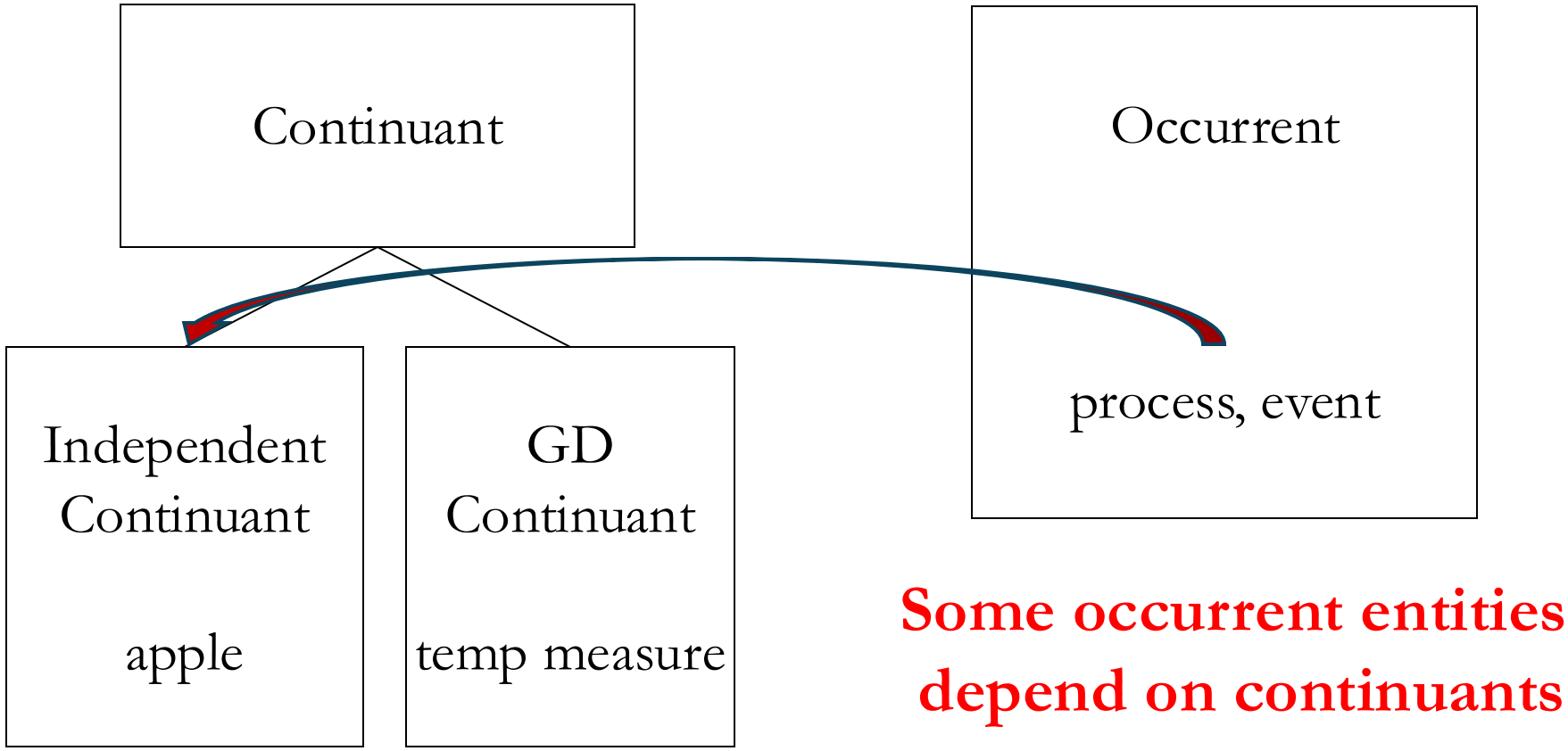
Occurrent

process, event

Some occurrent entities depend on continuants

• • • • • •

Process

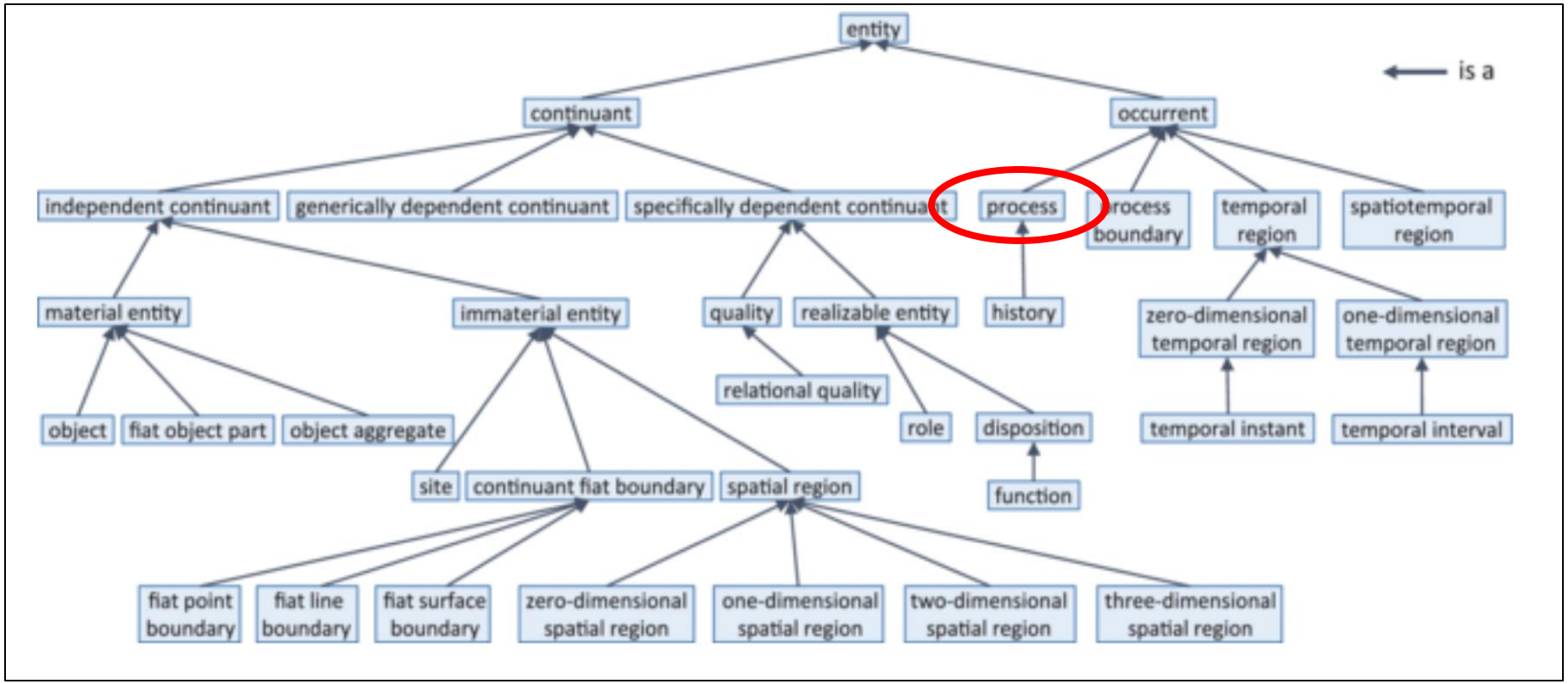

Continuant
Occurrent
Independent Continuant
apple
GD Continuant
temp measure
process, event
Some occurrent entities depend on continuants

Processes

- Are where happenings live…
- All processes in BFO have at least one **temporal part** and are such that there is some **material entity** which **participates in** the process
- **participates in** is a minimal relationship connecting specifically, generically, and independent continuants to **process**

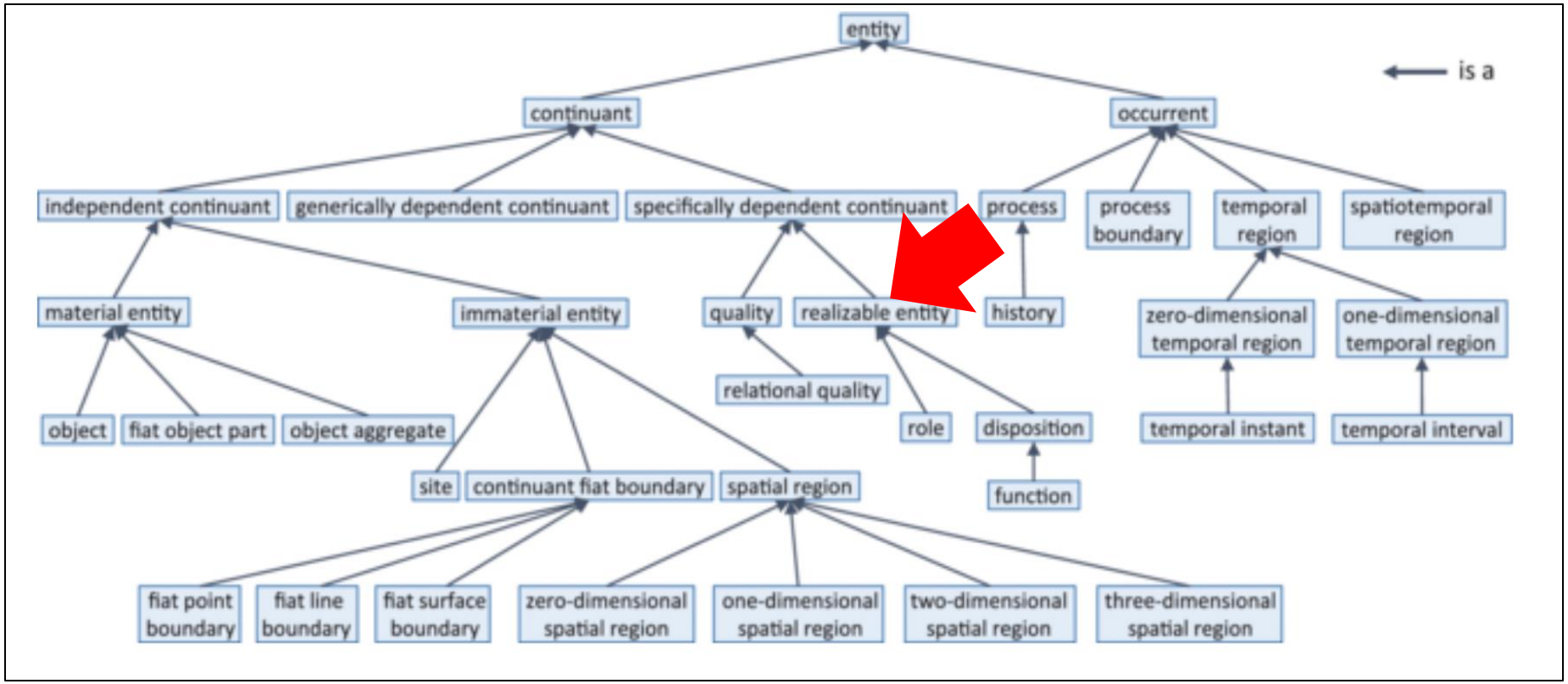
Dependency Chain

- A given **process** may have realization some realizable entity, which inheres in some independent continuant



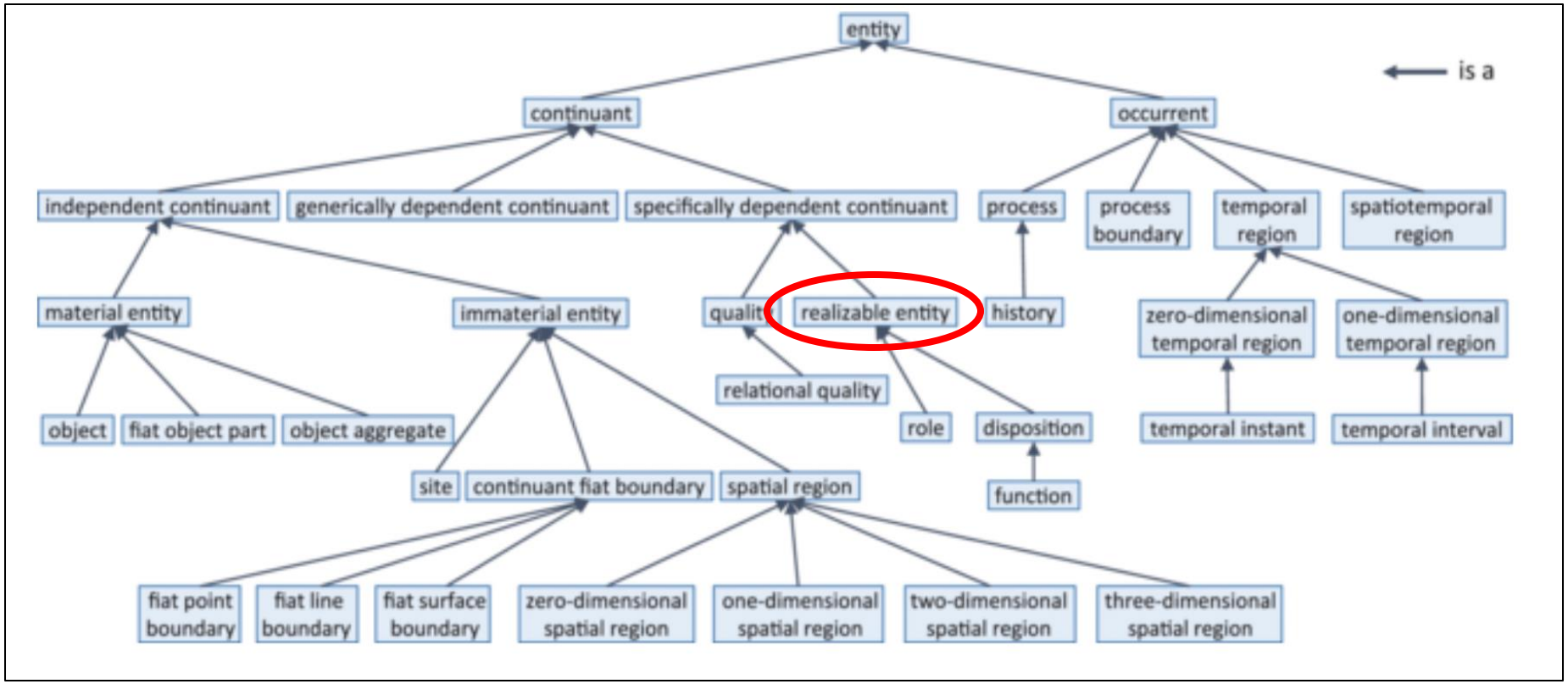
Dependency Chain

- A given **process** may **have realization** some realizable entity, which inheres in some independent continuant



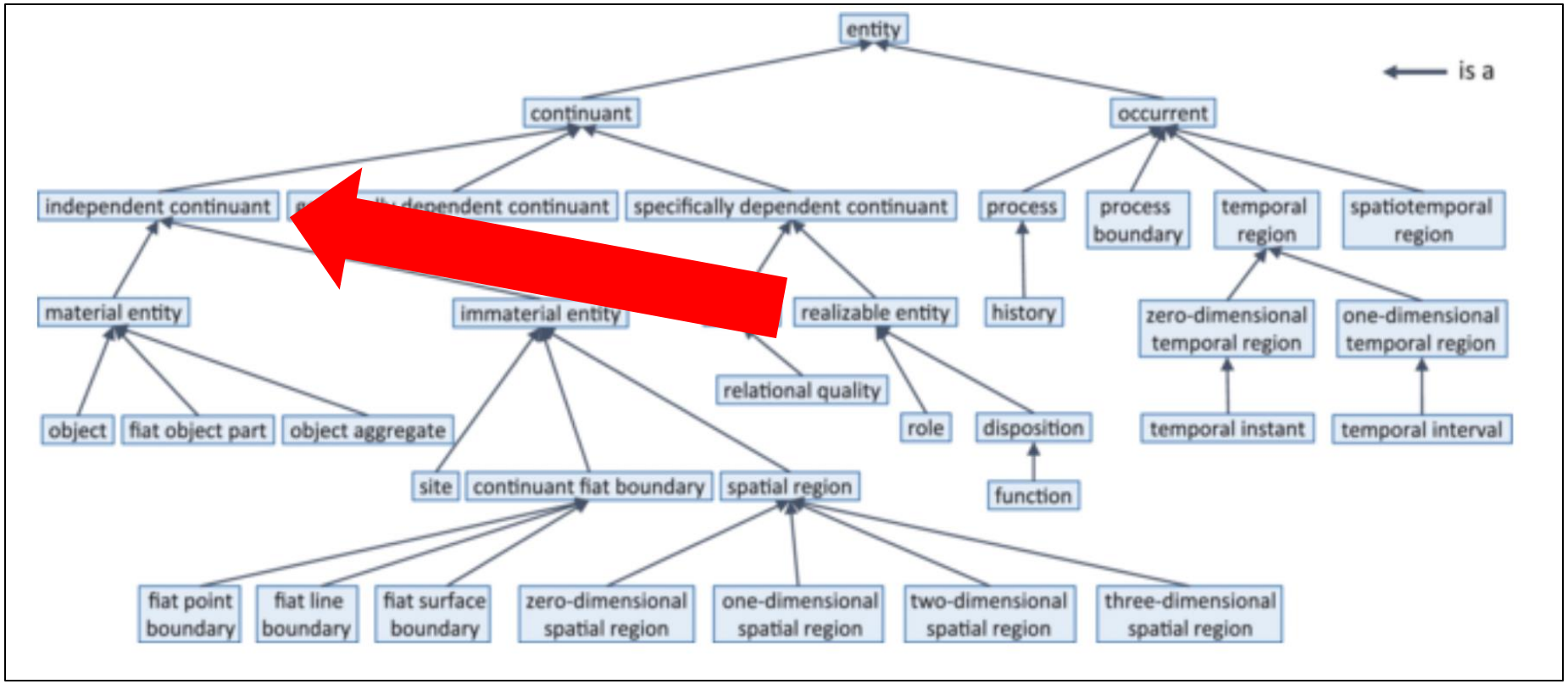
Dependency Chain

- A given **process** may **have realization** some **realizable entity**, which inheres in some independent continuant



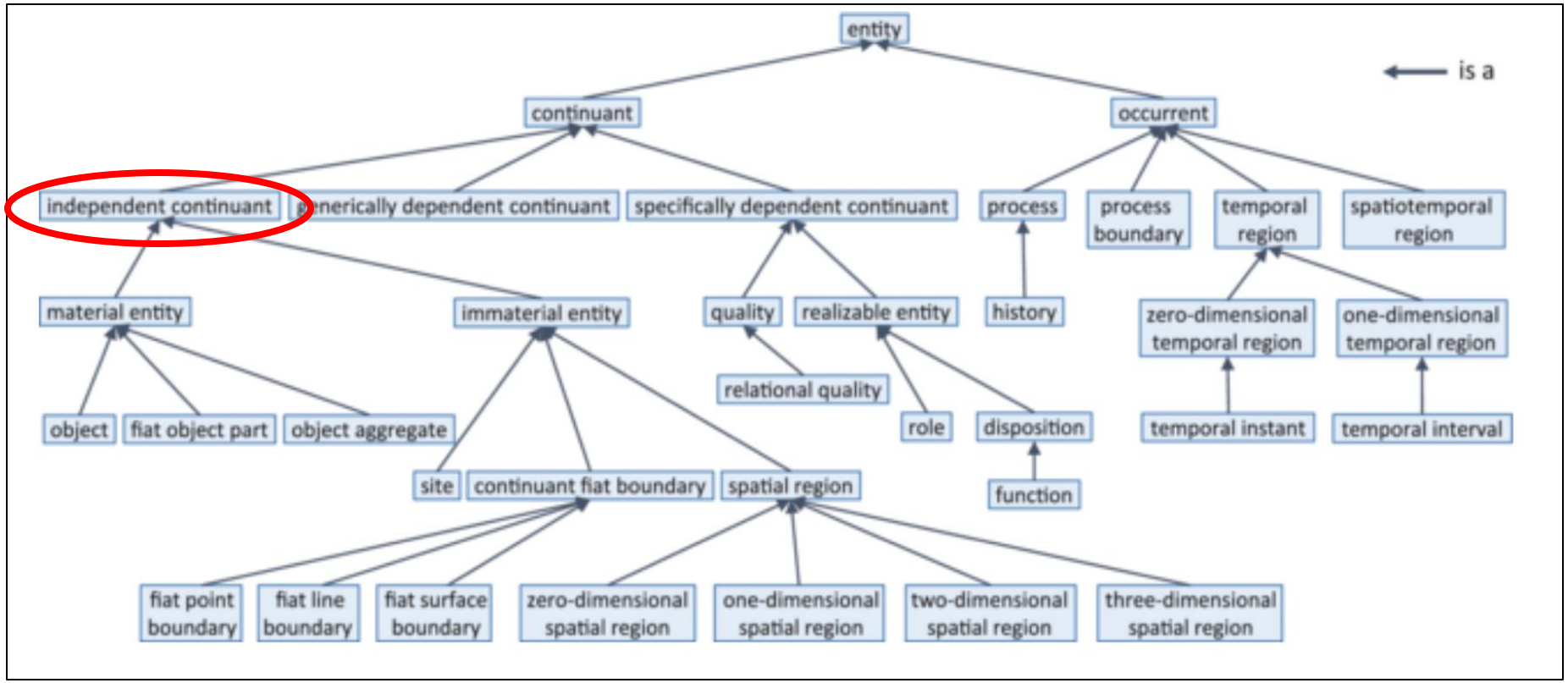
Dependency Chain

- A given **process** may **have realization** some **realizable entity**, which **inheres in** some independent continuant

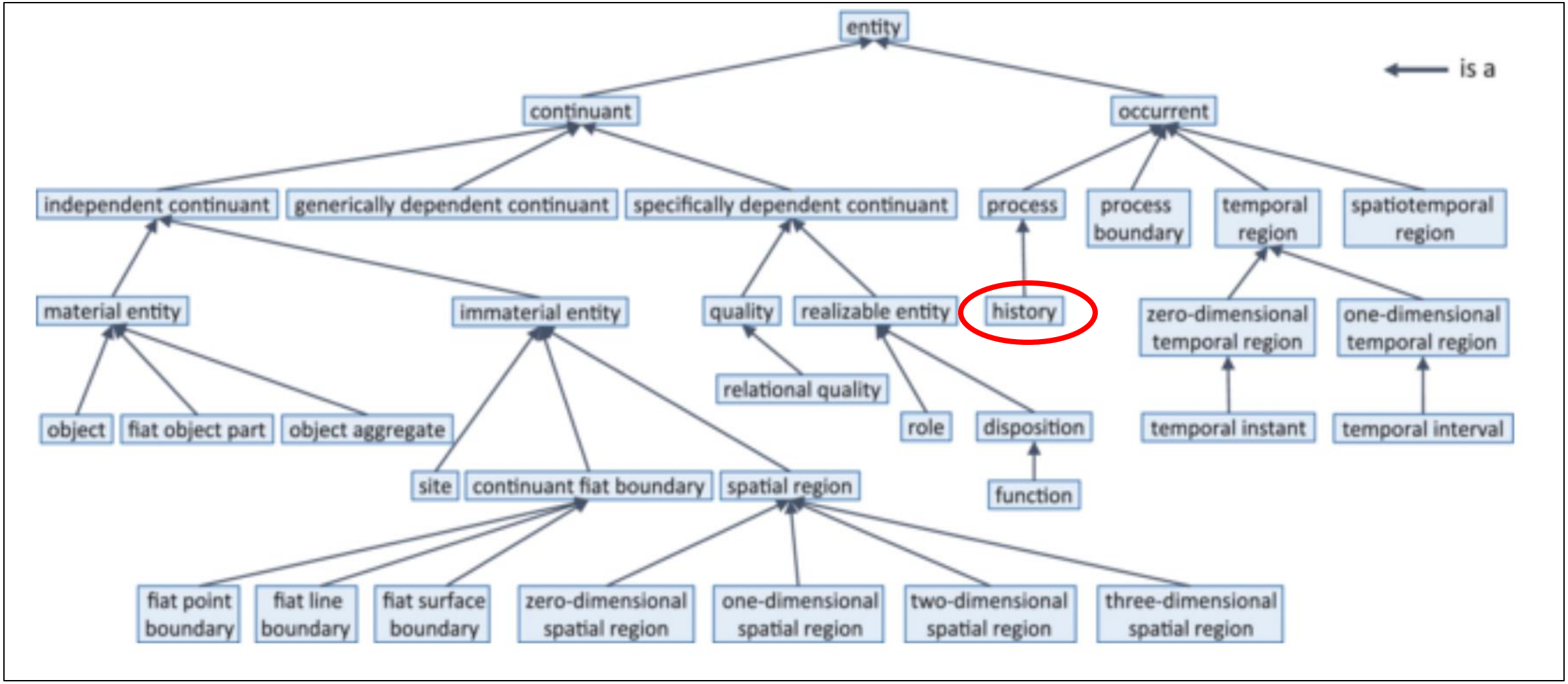


Dependency Chain

- A given **process** may **have realization** some **realizable entity**, which **inheres in** some **independent continuant**



History


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

History

- Is the sum total of all processes associated with a given material entity

- Every instance of history corresponds to one and only one instance of material entity; any instance of material entity corresponds to one and only one instance of history

- For example, the history that is my life is my history and mine alone, just as the history of the material entity that is this building belongs to the building

Change over Time

- In BFO, instances of material entities:

Change over Time

- In BFO, instances of material entities:
  - Have matter as parts

Change over Time

- In BFO, instances of material entities:
  - Have matter as parts
  - Gain or lose qualities,

Change over Time

- In BFO, instances of material entities:
  - Have matter as parts
  - Gain or lose qualities, parts,

Change over Time

- In BFO, instances of material entities:
  - Have matter as parts
  - Gain or lose qualities, parts, occupy different locations, etc.

Change over Time

- In BFO, instances of material entities:
  - Have matter as parts
  - Gain or lose qualities, parts, occupy different locations, etc. over the course of their history

Change over Time

- In BFO, instances of material entities:
  - Have matter as parts
  - Gain or lose qualities, parts, occupy different locations, etc. over the course of their history

- An apple in an orchard ripens, reddens, and sweetens, before spoiling, developing blotches, etc. on a fruit basket

Processes Do Not Change

- An intuitive understanding of change is the gain or loss of specifically dependent continuants

- In BFO, occurrents do not bear specifically dependent continuants, and so cannot – strictly speaking – gain or lose them

Processes are Changes

- As a consequence, characterizing:
  - increasing velocity of this vehicle
  - changing direction of this airplane
  - lowered volume of this alarm

- Are not understood in terms of properties of processes

- In BFO, processes do not change, they *are* changes

Participants Do Change

CASE 3: *A flower is red in the summer. As time passes, the color changes. In autumn the flower is brown.*
GOAL: *The example aims to show if and how the ontology models change in qualities/properties.*
FOCUS: *The change of the color of a flower.*

Participants Do Change

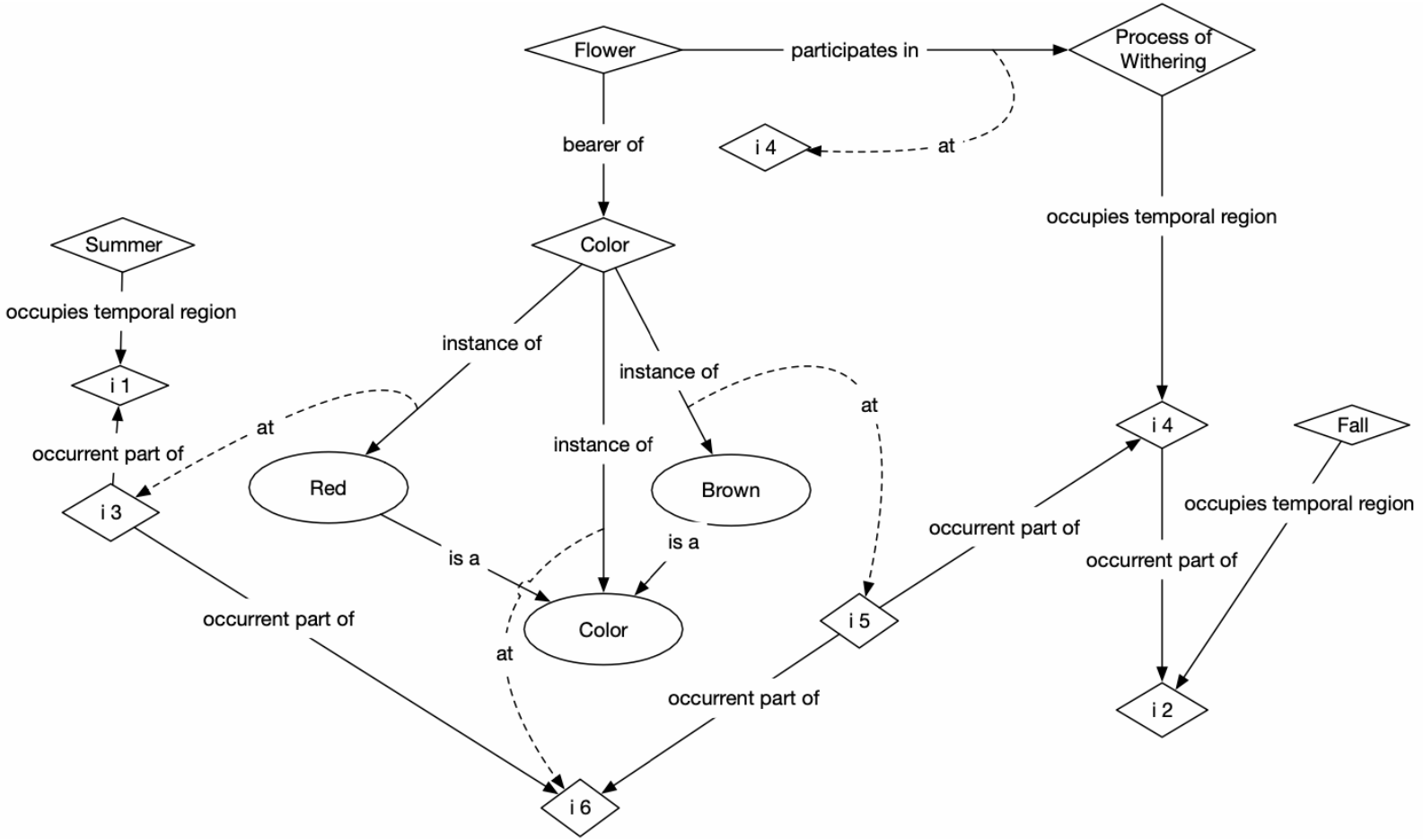


Figure 6: Petal Changing Color in Case 3

Participants Do Change

The flower participates in a withering process

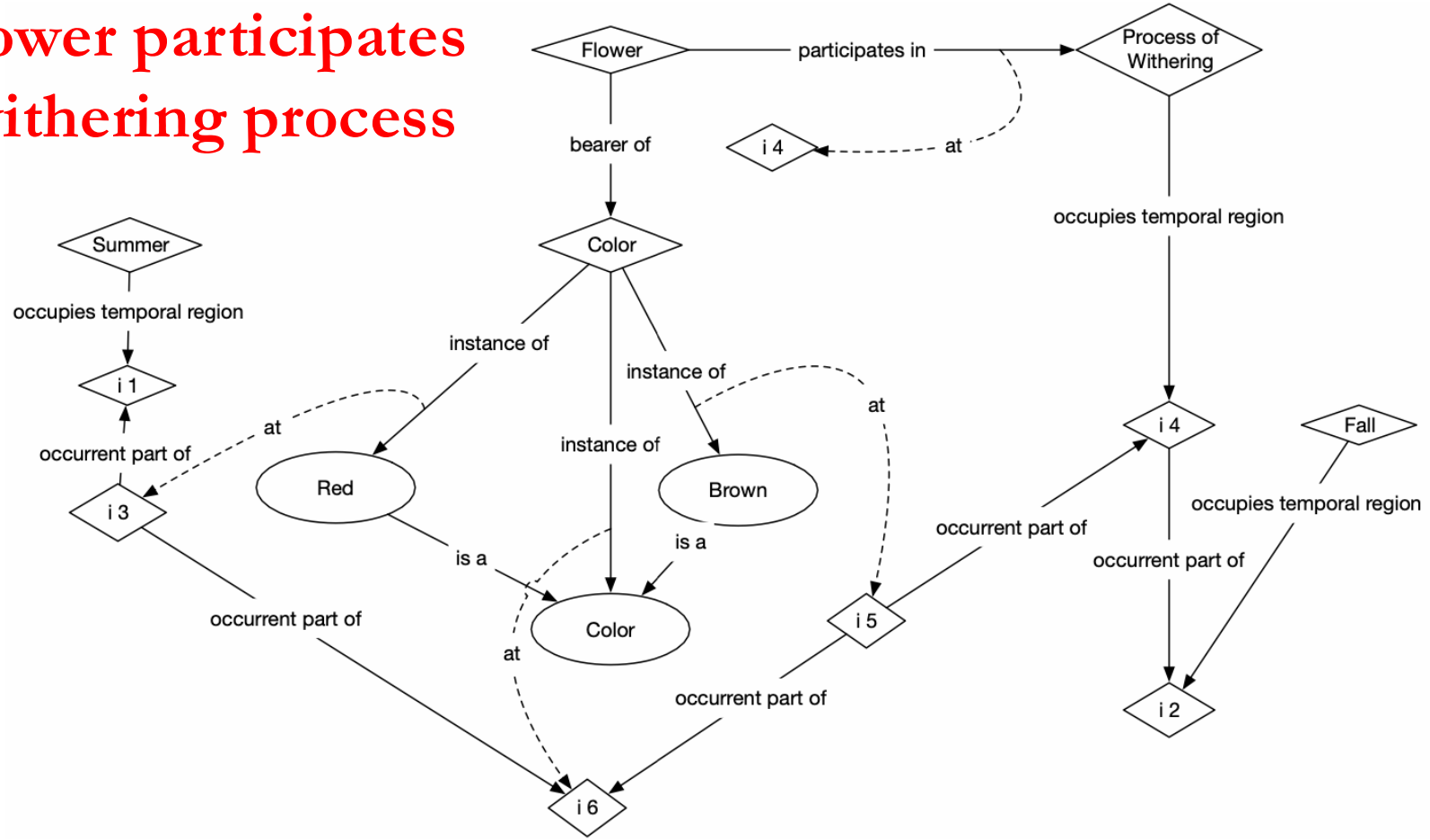


Figure 6: Petal Changing Color in Case 3

Participants Do Change

Bearing an instance of red over one interval

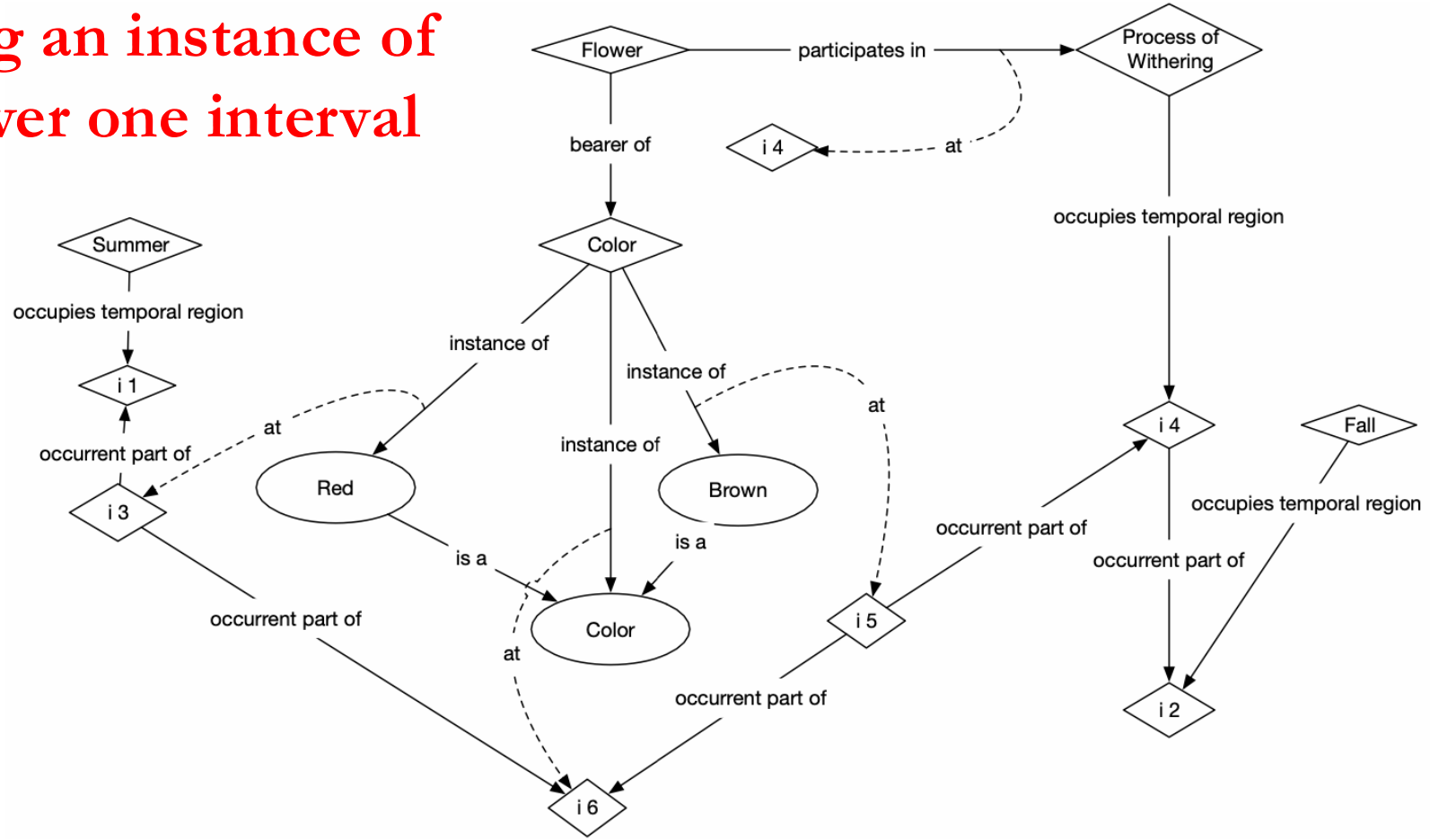


Figure 6: Petal Changing Color in Case 3

Participants Do Change

That is later an instance of brown over another

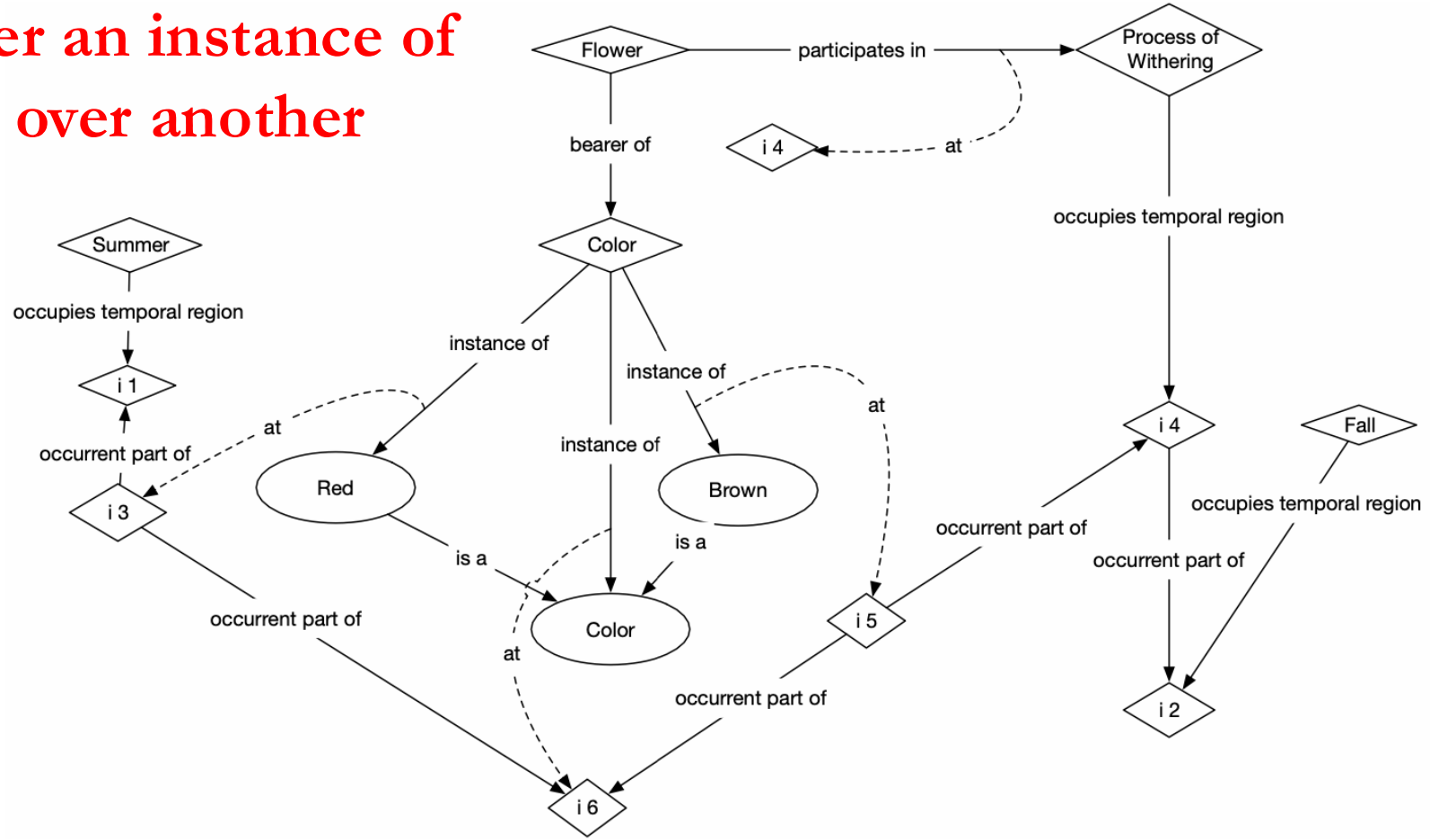


Figure 6: Petal Changing Color in Case 3

Participants Do Change

Recall: Determinates vs Determinibles

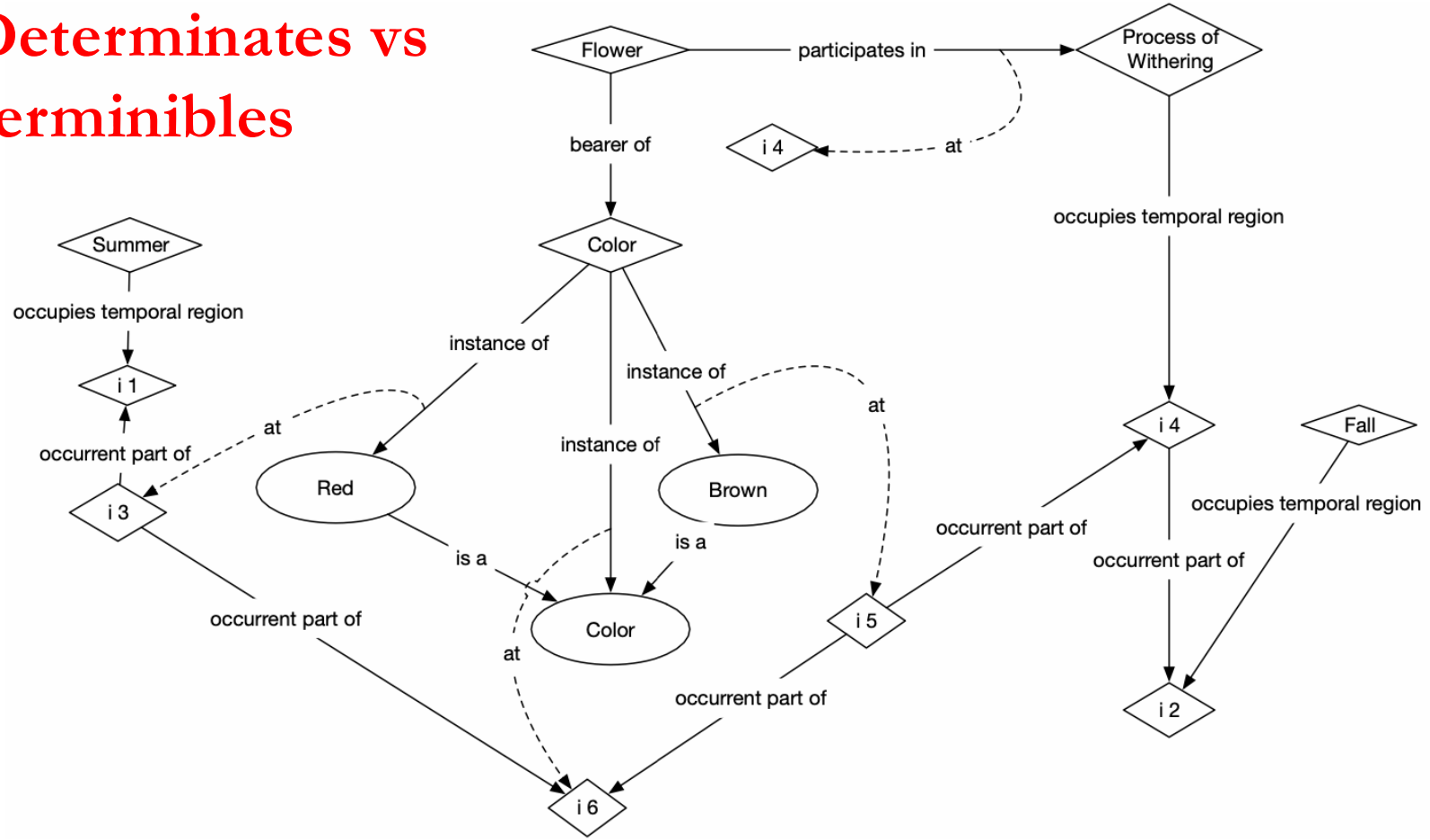
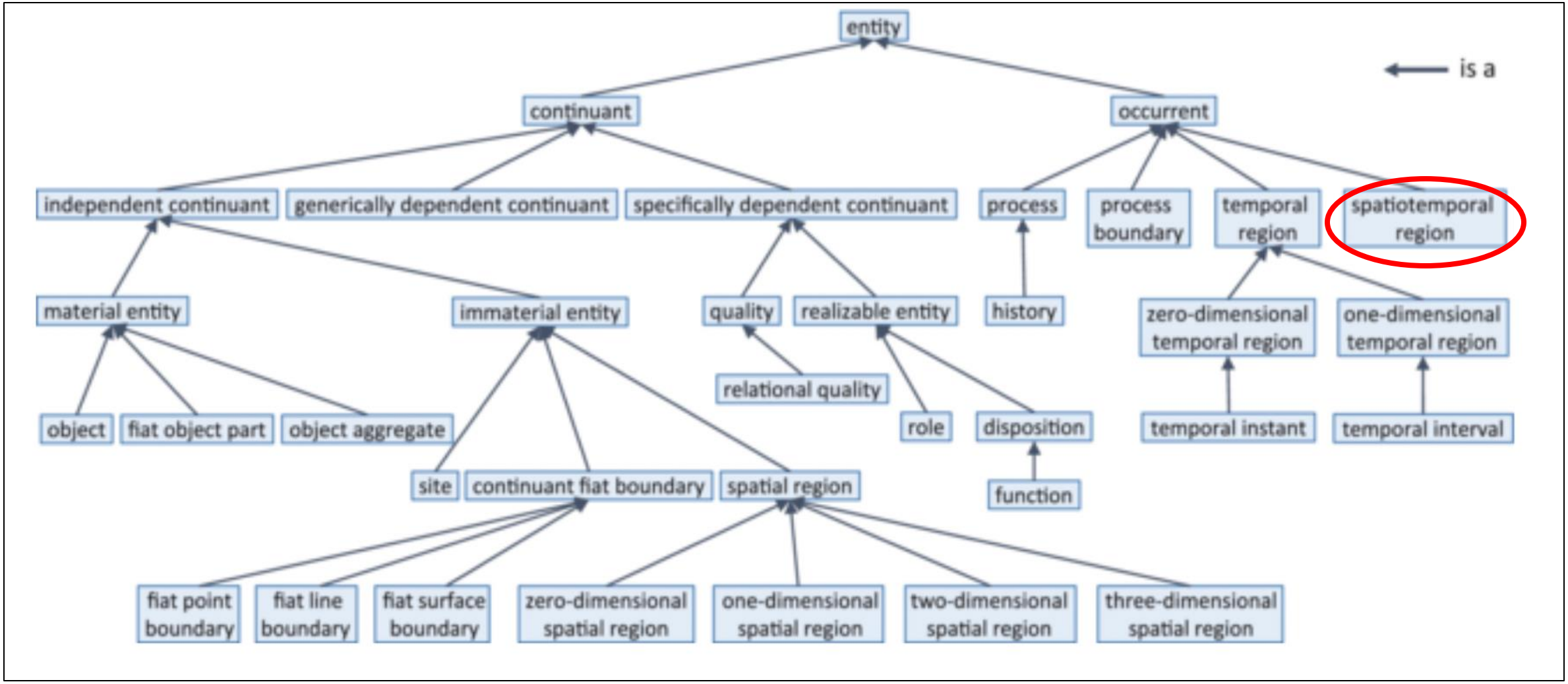


Figure 6: Petal Changing Color in Case 3

Spatiotemporal Region

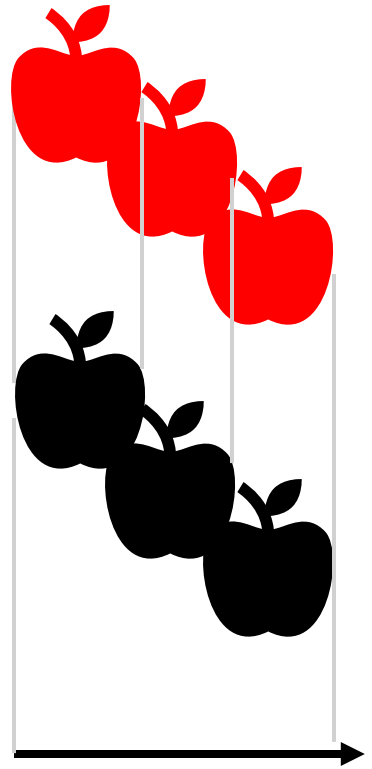


Spatiotemporal Region

- The history of a material entity occupies some **spatiotemporal region**
- Which is an occurrent part of the instance spacetime_R
- Spatiotemporal regions have both **spatial** and **temporal** extents

Spatiotemporal Region

- The apple occupies a spatial region *r*
- The history of that apple occupies a temporal region *t*
- The history of that apple occupies a spatiotemporal region *s*
  - *s* spatially projects onto *r*
  - *s* temporally projects onto *t*



Spatiotemporal Region

- The apple occupies a spatial region *r*
- The history of that apple occupies a temporal region *t*
- The history of that apple occupies a spatiotemporal region *s*
  - *s* spatially projects onto *r*
  - *s* temporally projects onto *t*

Spatial Regions

- *Spatial Region* $=_{\text{def}}$ A continuant that is continuant part of the spatial projection of a portion of spacetime at a given time

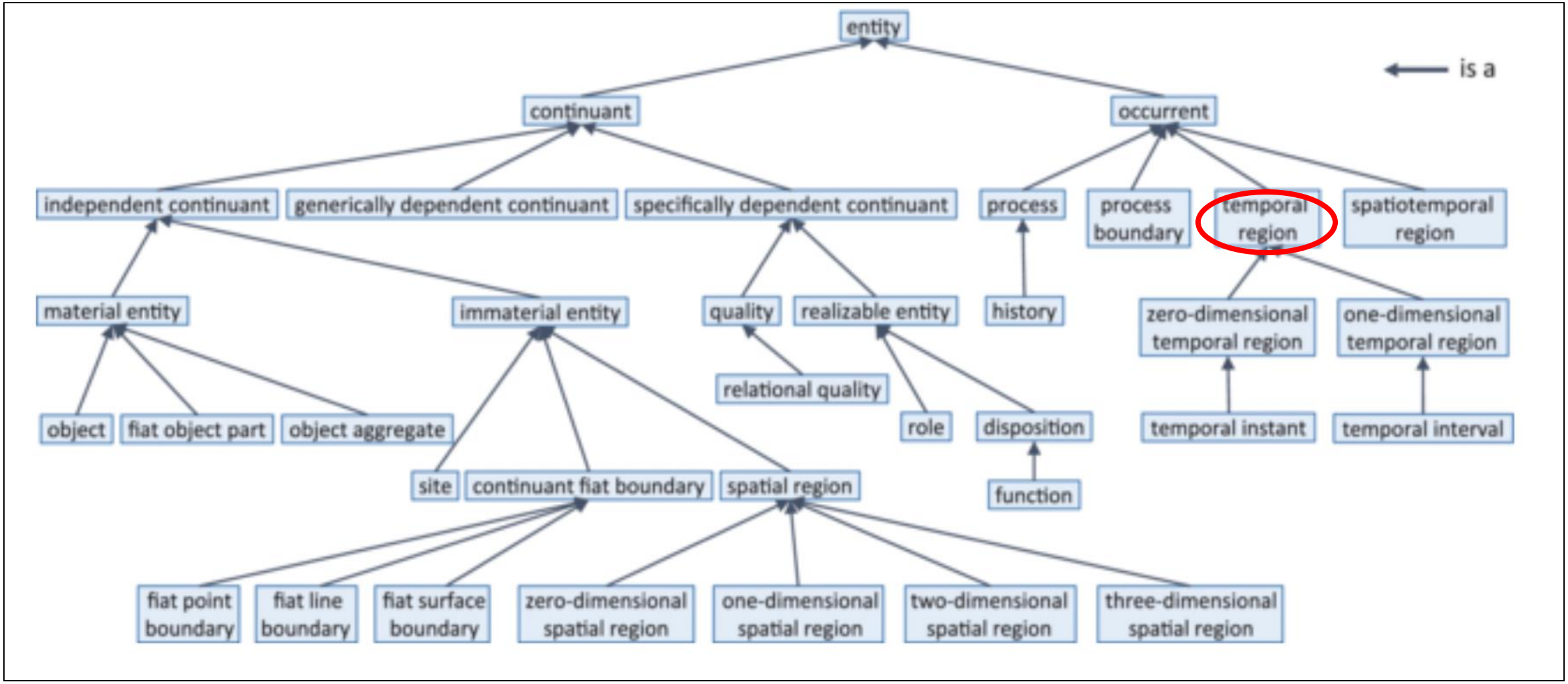
- *spatially projects onto* $=_{\text{def}}$ Holds between spatiotemporal region *s* and spatial region *r* at some time *t* such that *r* is the spatial extent of *s* at *t*

Spatiotemporal regions are useful and described in terms of spatial regions, so spatial regions are useful

Temporal Region

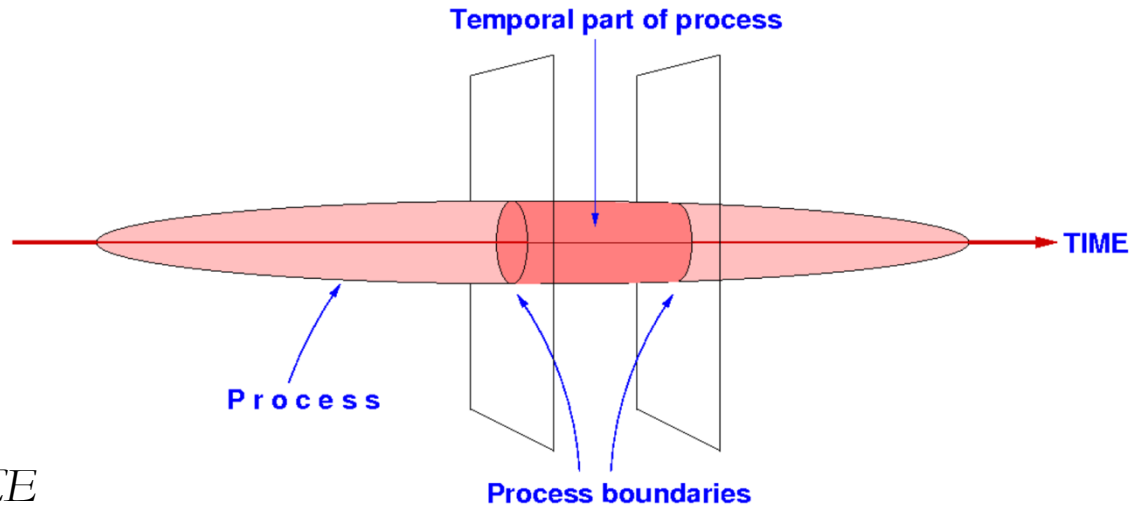
- The apple occupies a spatial region *r*
- The history of that apple occupies a temporal region *t*
- The history of that apple occupies a spatiotemporal region *s*
  - *s* spatially projects onto *r*
  - *s* temporally projects onto *t*

Temporal Region



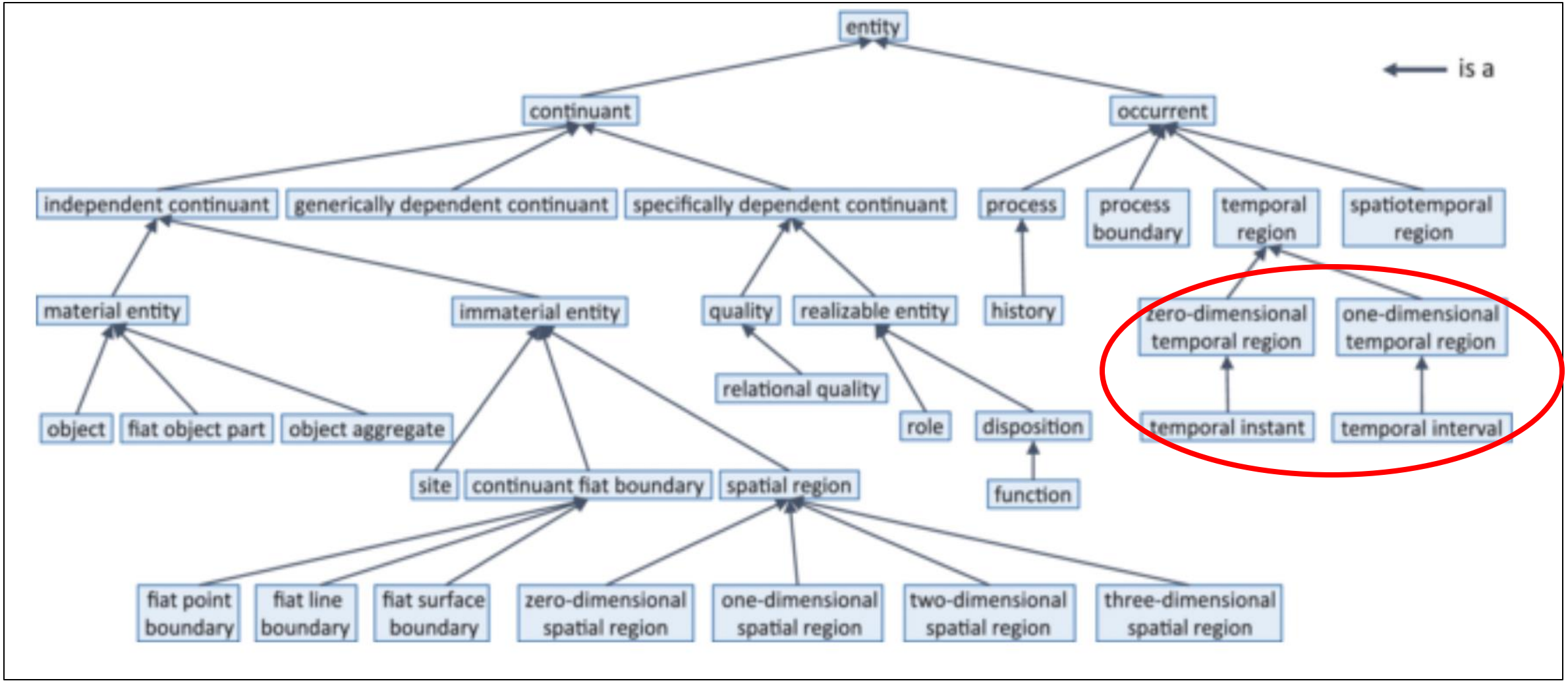
Temporal Region

- BFO does not distinguish between processes and events
- The process of baking of an apple pie has proper parts, such as cutting apples, preparing pastry crust, etc.
- Proper process parts may be further divided, e.g. cutting of specific apples



** Image from Galton, 2016: Processes and Events in BFO and DOLCE*

Dimensions of Temporal Region



Spatiotemporal Relationships

Entities are **located_at** spatial regions

Entities **exist_at** temporal regions

Spatiotemporal Relationships

Entities are **located_at** spatial regions

Partial: If x is located at r then x is located at least at r

Entities **exist_at** temporal regions

Partial: If x exists at t then x exists at least at t

Spatiotemporal Relationships

Processes **occupy** spatiotemporal regions

Spatiotemporal regions **project on** spatial and temporal regions

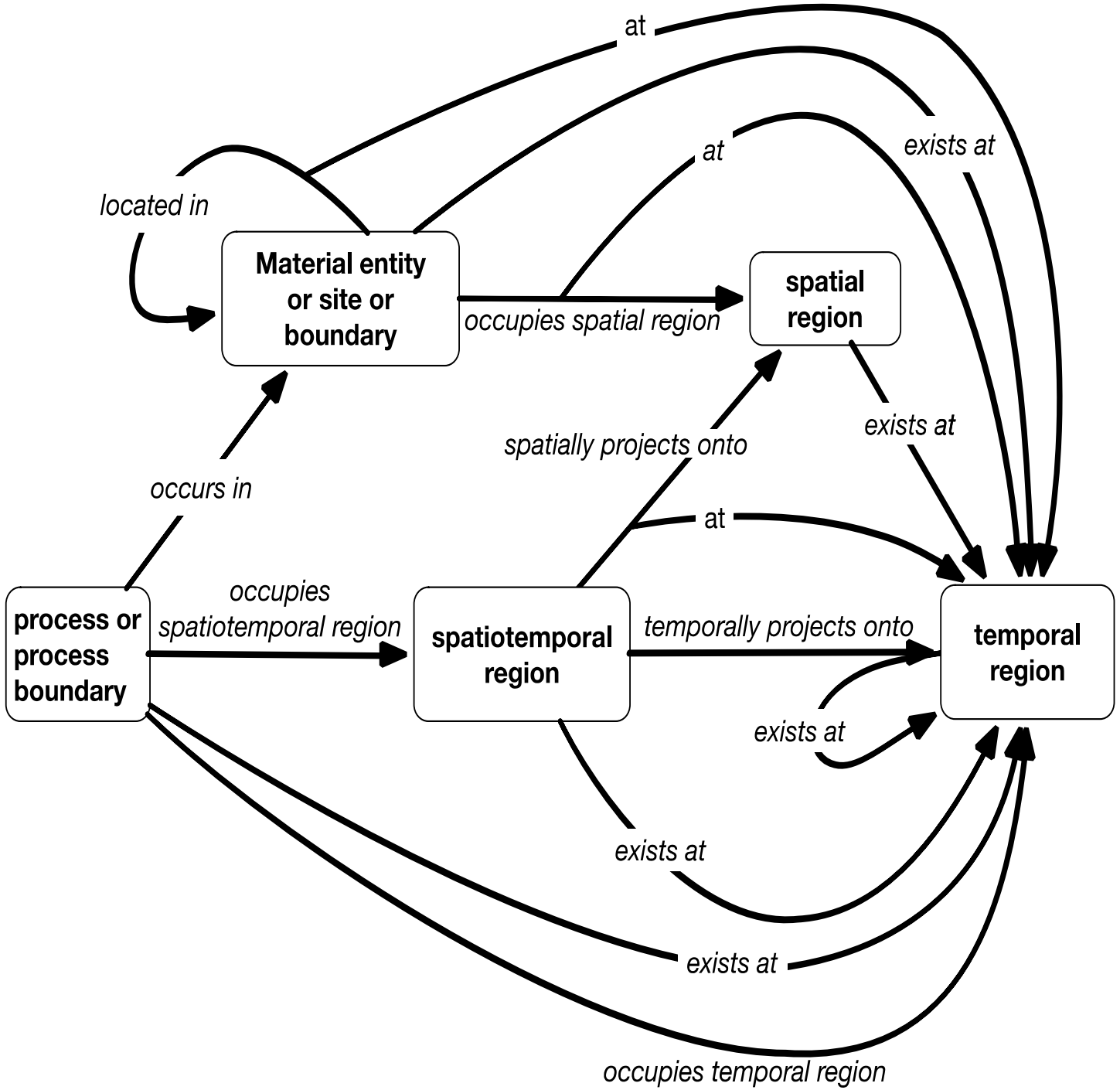
Spatiotemporal Relationships

Processes **occupy** spatiotemporal regions

Exact: If p occupies temporal region t then p occupies only t

Spatiotemporal regions **project on** spatial and temporal regions

Exact: If s projects on temporal region t then s projects on only t


at
located in
at
exists at
Material entity or site or boundary
occupies spatial region
spatial region
spatially projects onto
exists at
occurs in
at
process or process boundary
occupies spatiotemporal region
spatiotemporal region
temporally projects onto
temporal region
exists at
exists at
exists at
occupies temporal region

Outline

- **Module 1**: Motivation for Ontology Engineering
- **Module 2**: Motivation for Basic Formal Ontology
- **Module 3**: Theory of BFO
- **Module 4**: Building Ontologies with BFO
- **Module 5**: Exercises

avenue
avenue
avenue

It’s how you tell it

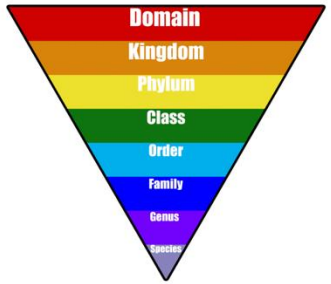
It’s how you tell it

We aim to integrate heterogenous datasets at scale, support interpersonal understanding, mission applications, data quality and governance

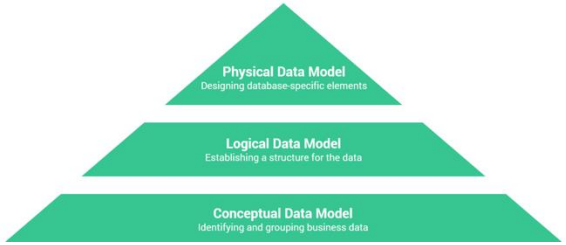
It’s how you tell it

But we tend to focus on “it”

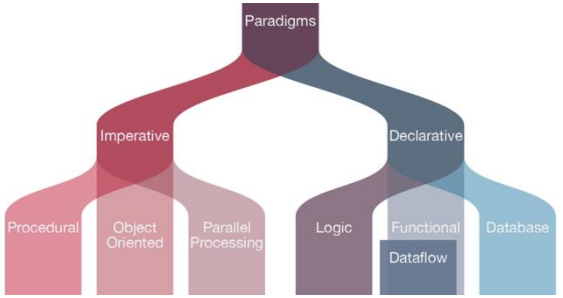
Bag of Words



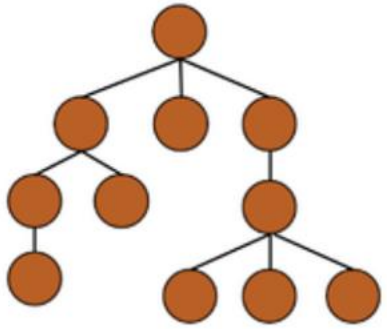
Taxonomies



Data Models

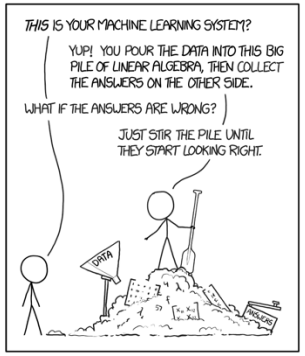


Code

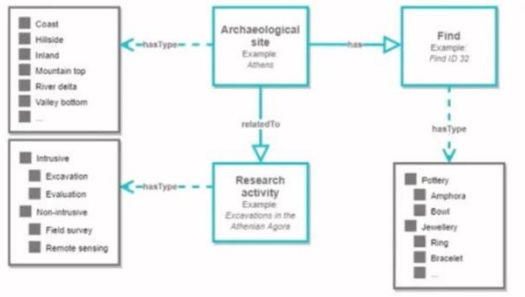


Ontology

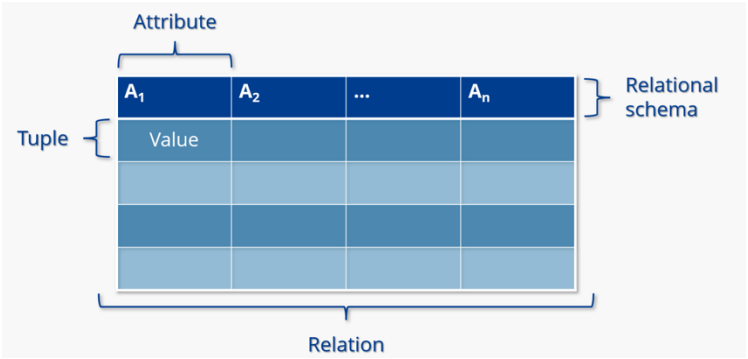
It's how you tell it



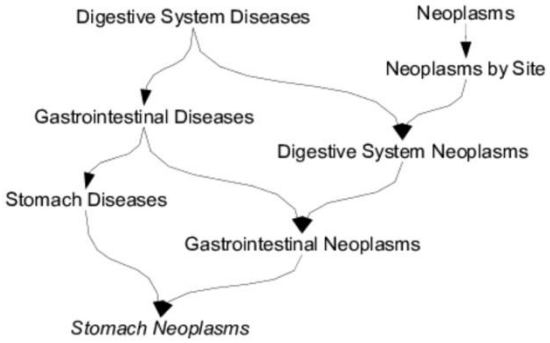
ML Algorithms



Controlled Vocabulary



Relational Database



Thesaurus

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

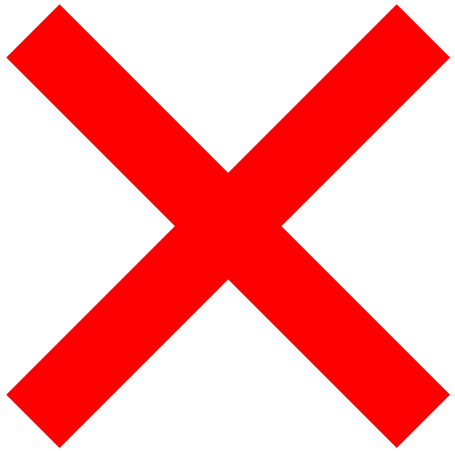
Building a knowledge graph sounds tricky enough – but doing so from scratch without any source code sounds like a mission impossible. That's exactly what I did even though I am not a full-blown developer and don't write code as my job on a daily basis, which means that you can do it too.

just another information silo

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.

Building Knowledge Graphs Using Python

Zulqarnain Shahid Iqbal · Follow
10 min read · Aug 26, 2024

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

Build Knowledge Graph From TextData using LangChain | Under 2min

Mahimai Raja J · Follow
5 min read · Feb 4, 2024

How to build your own Knowledge Graph using JanusGraph and Gremlin

Ayush Lall · Follow
10 min read · Oct 4, 2021

Building a Knowledge Base from Texts: a Full Practical Example

Implementing a pipeline for extracting a Knowledge Base from texts or online articles

Fabio Chiusano · Follow
Published in Generative AI · 12 min read · May 24, 2022

Make Knowledge Graph RAG with LlamaIndex from own obsidian notes

Haiyang(Ocean) Li · Follow
6 min read · Sep 28, 2023

Building Knowledge Graphs Using Python

Zulqarnain Shahid Iqbal · Follow
10 min read · Aug 26, 2024

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

Wolfa… …Live Data Concepts
May 26, 202…

Build Knowledge Graph Fr… TextData using LangChain | U… 2min

Mahimai Raja J · Follow
5 min read · Feb 4, 2024

…build your own Knowledge …h using JanusGraph and …emlin

…h Lall · Follow
…ad · Oct 4, 2021

Building a Knowledge Base … Texts: a Full Practical Exa…

Implementing a pipeline for extracting a Knowledge…om texts or online articles

Fabio Chiusano · Follow
Published in Generative AI · 12 min read · May 24, 2022

Mak… …ledge Graph RAG with Llamali… …om own obsidian notes

Haiyang(Ocean) Li · Follow
6 min read · Sep 28, 2023

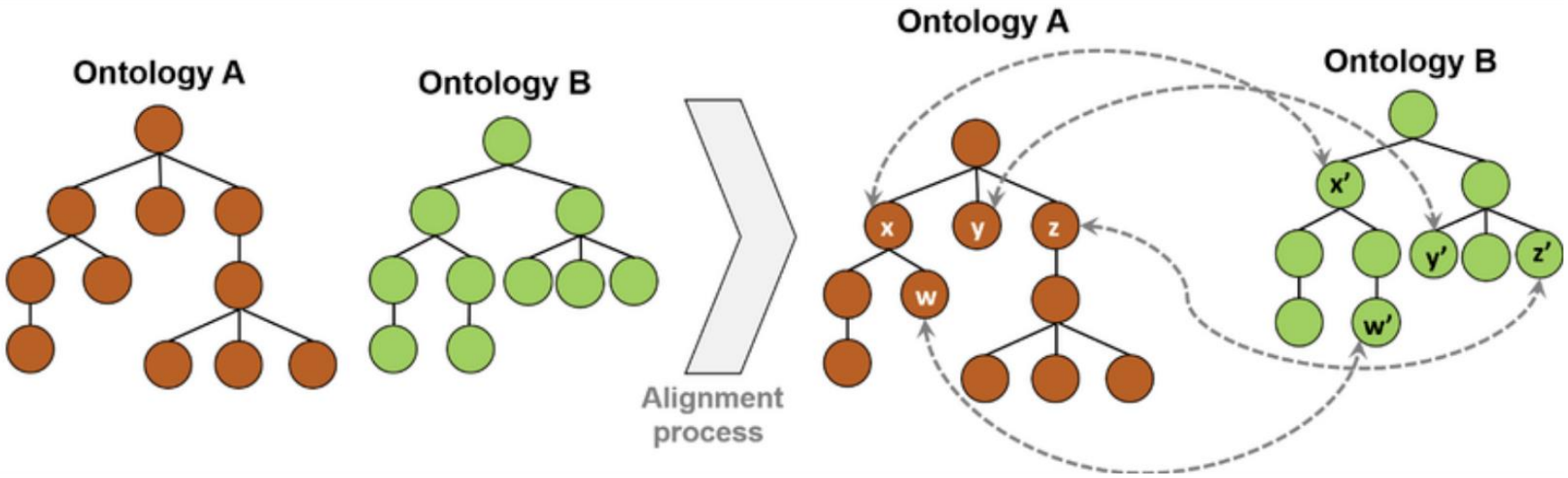
It's **how** you tell it

These aims require focusing on "how"

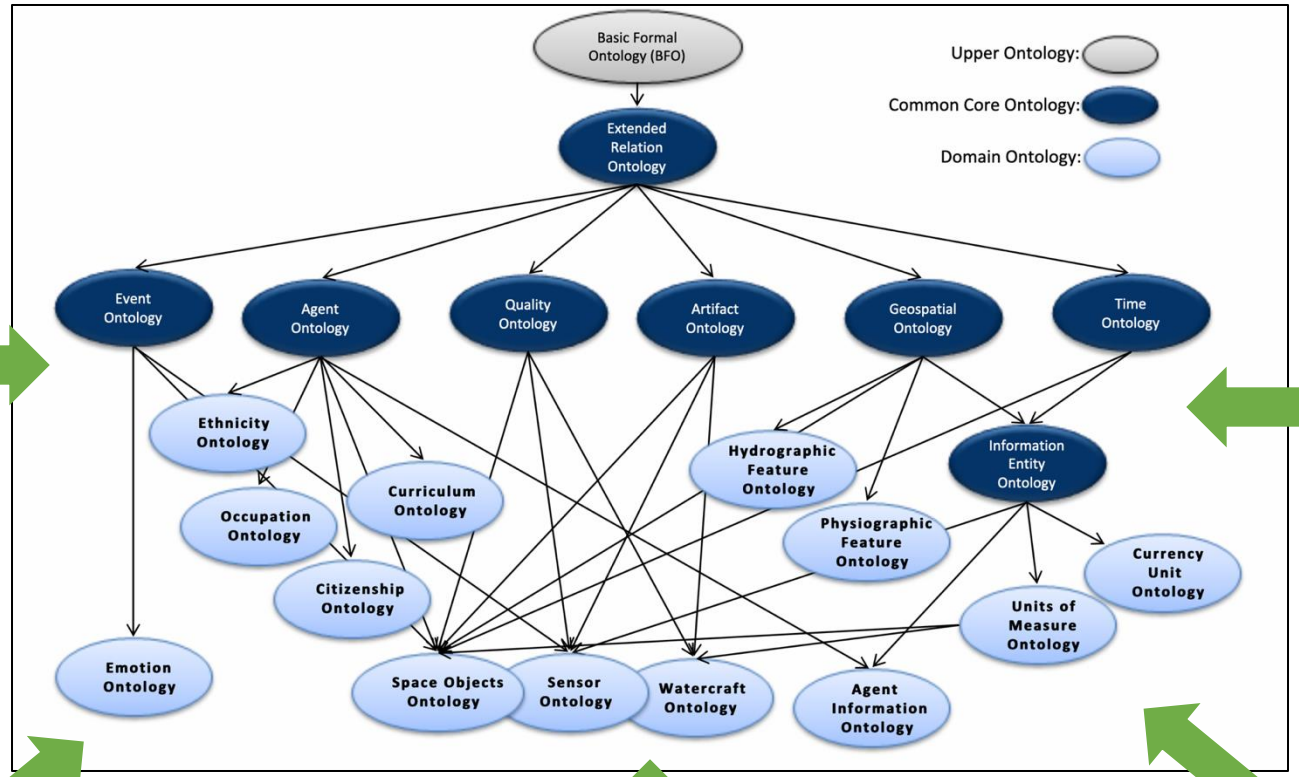
Caveat: Mono-Ontology Myth

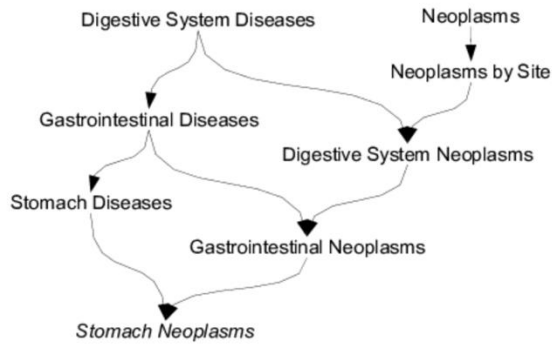
- Insisting on a single ontology standard used by everyone **is unwise**

- 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

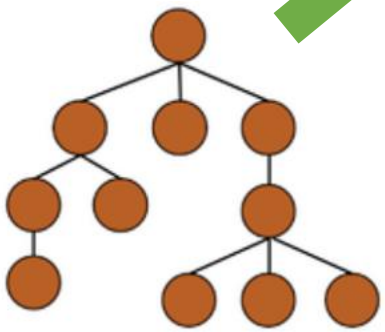


Bag of Words

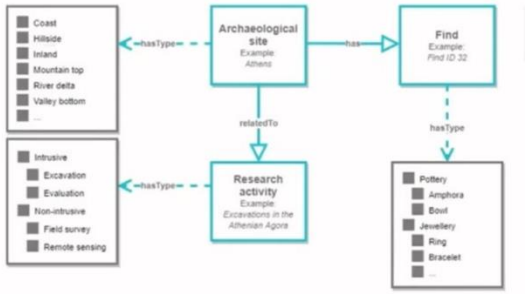




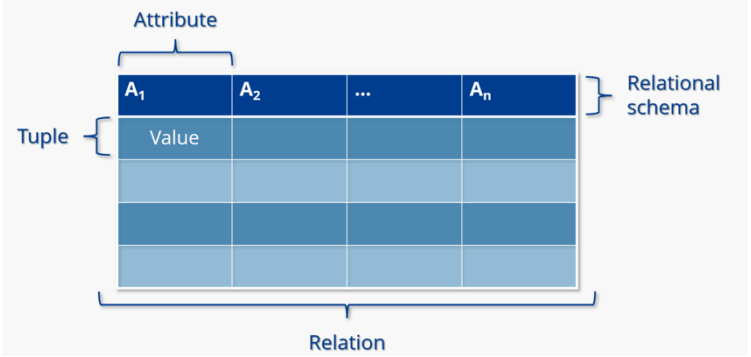
Thesaurus



Ontology

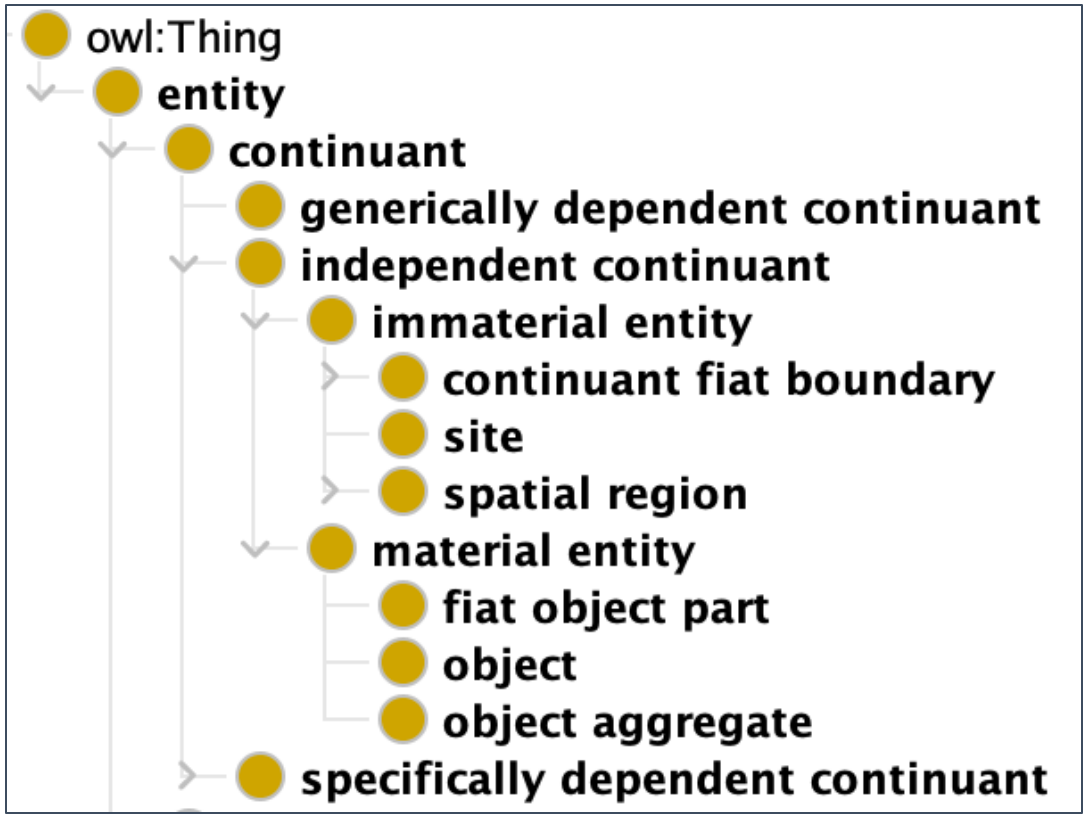


Controlled Vocabulary

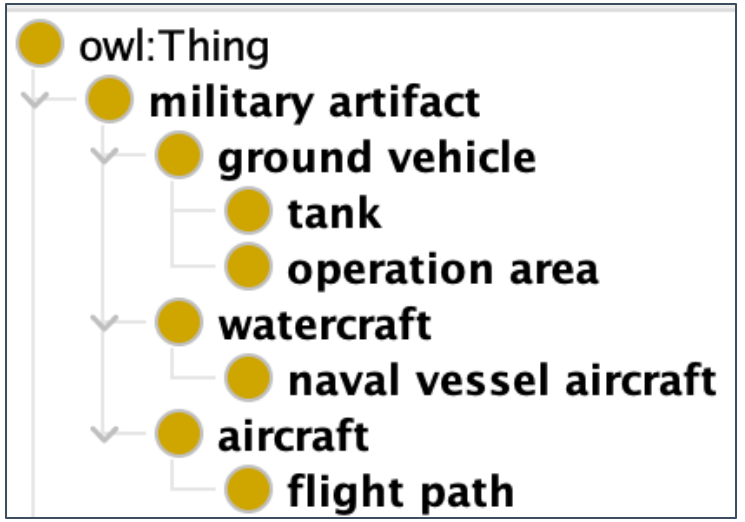


Relational Database

Generating Implicit Hierarchy

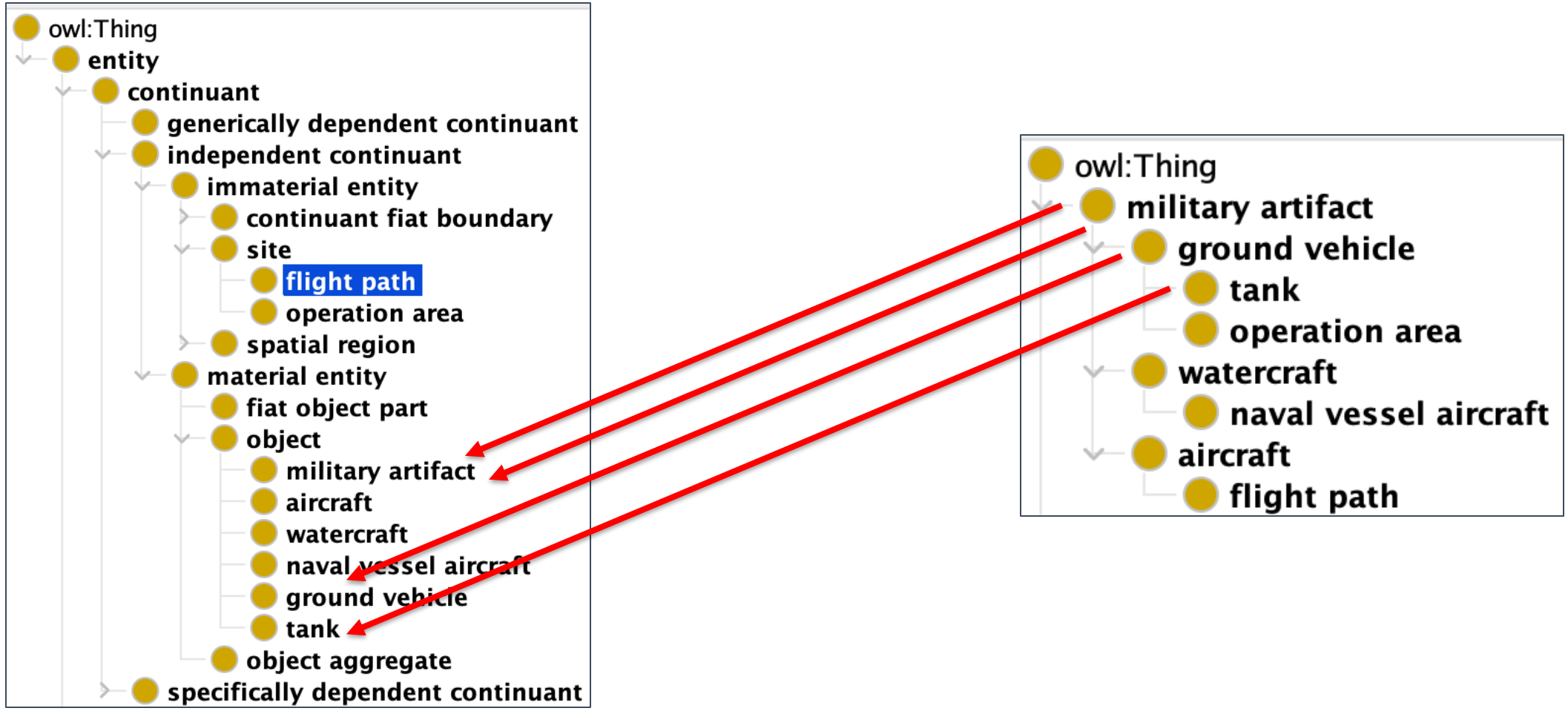


≠

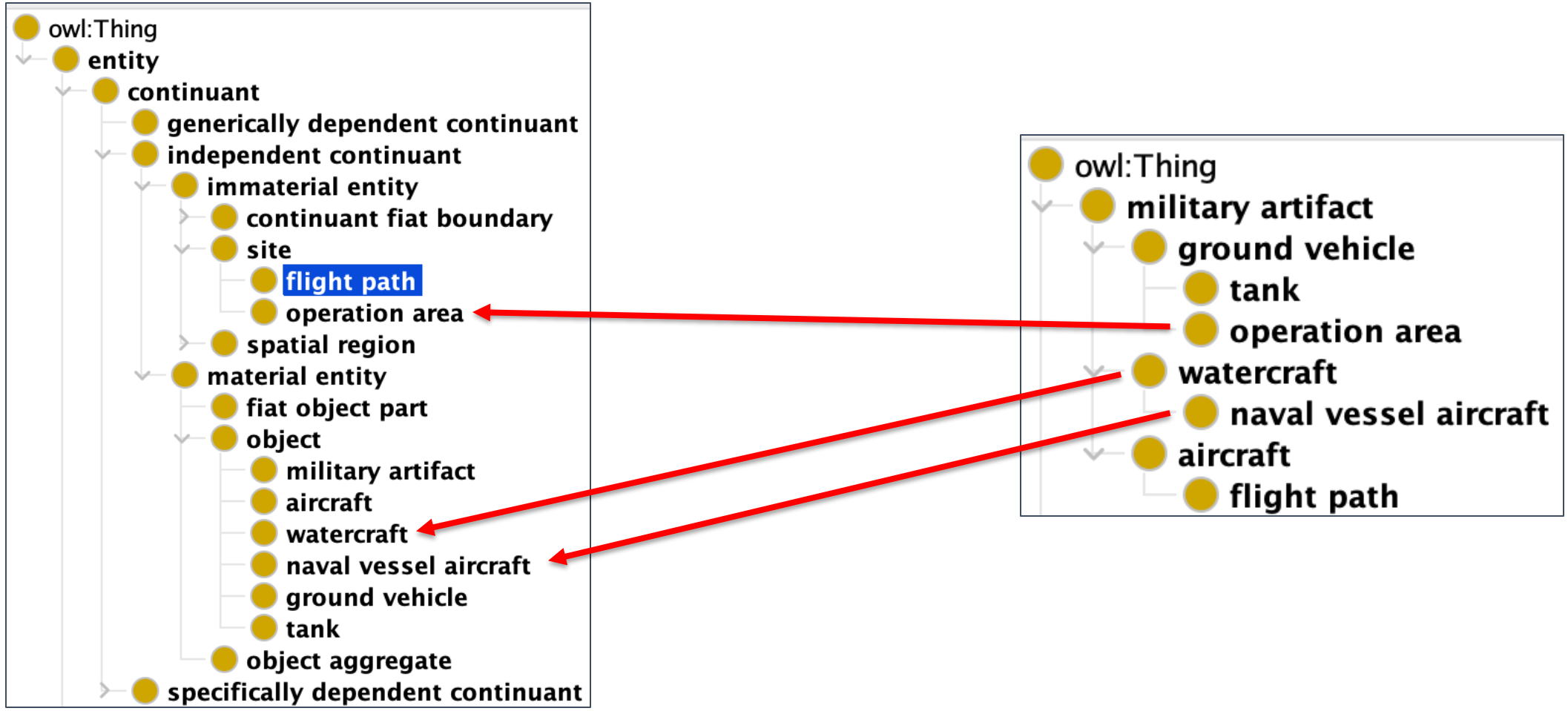


Suppose there is a need to maintain an application ontology that is not aligned to BFO

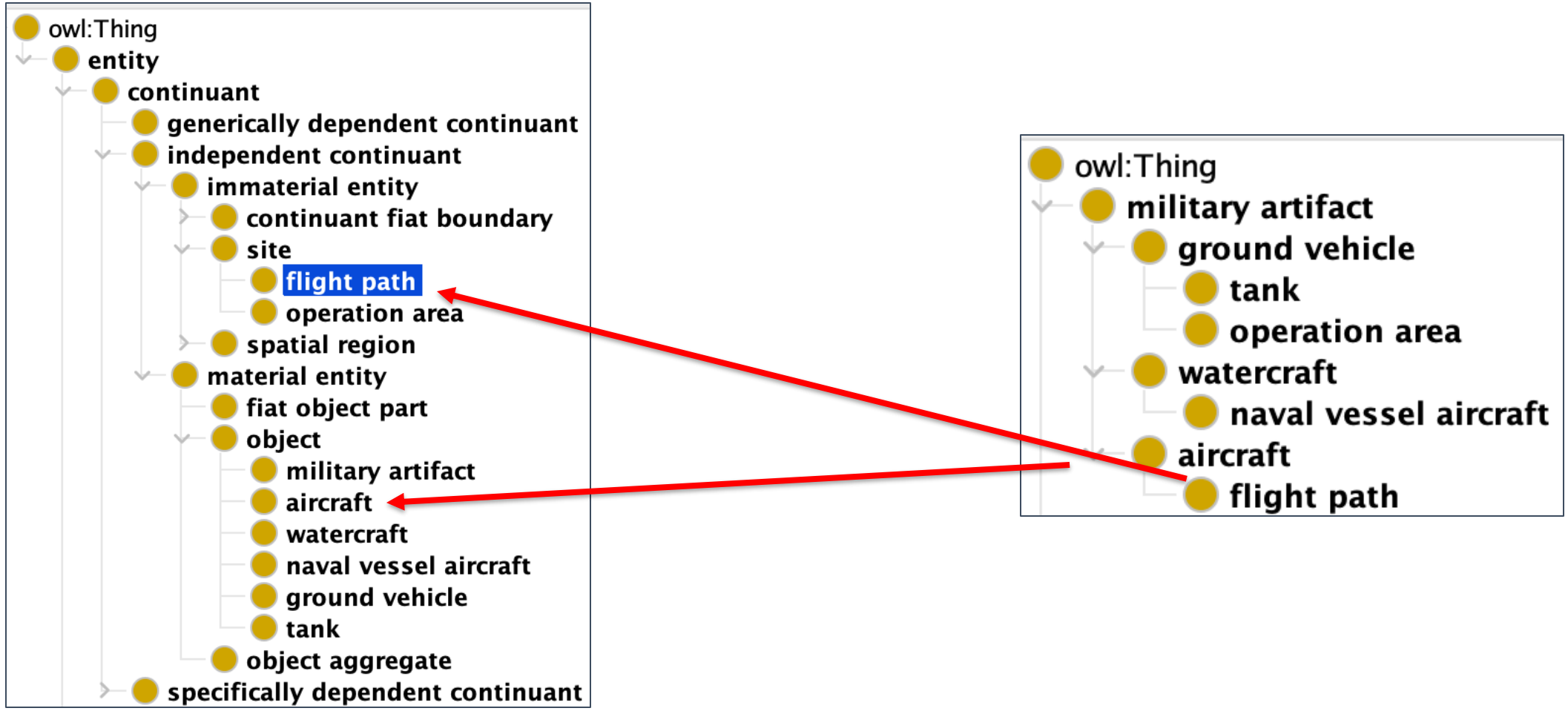
Generating Implicit Hierarchy



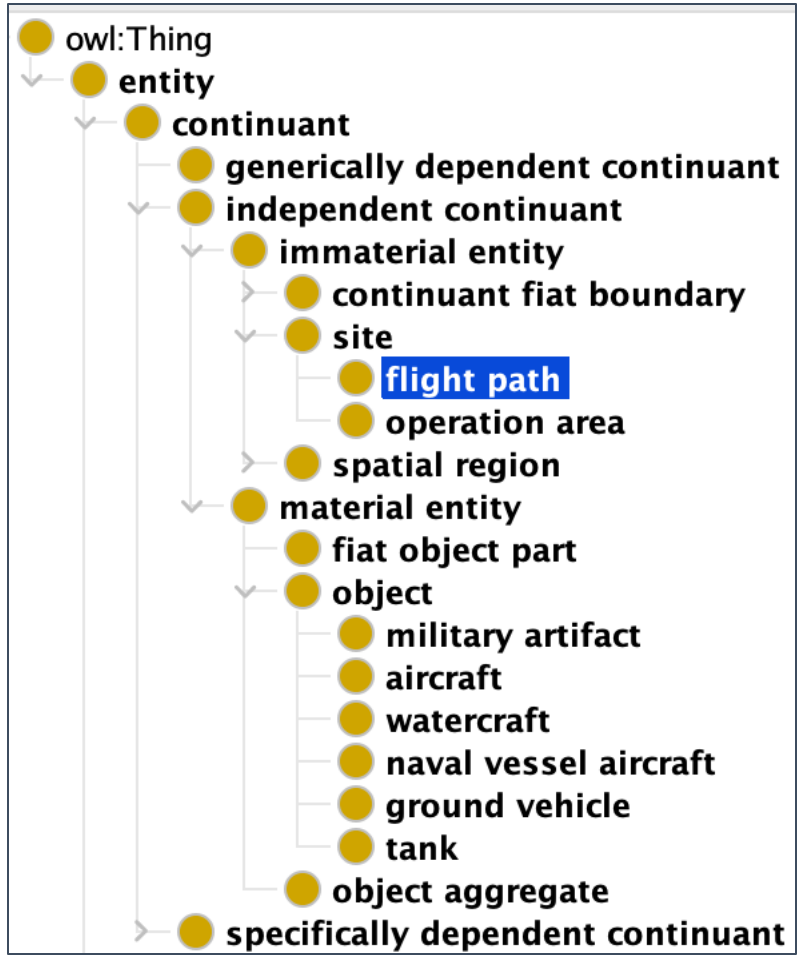
Generating Implicit Hierarchy



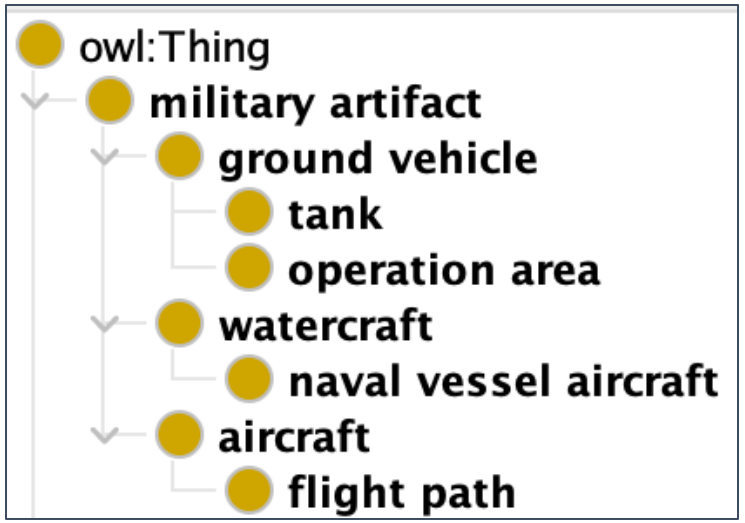
Generating Implicit Hierarchy



Generating Implicit Hierarchy



≠



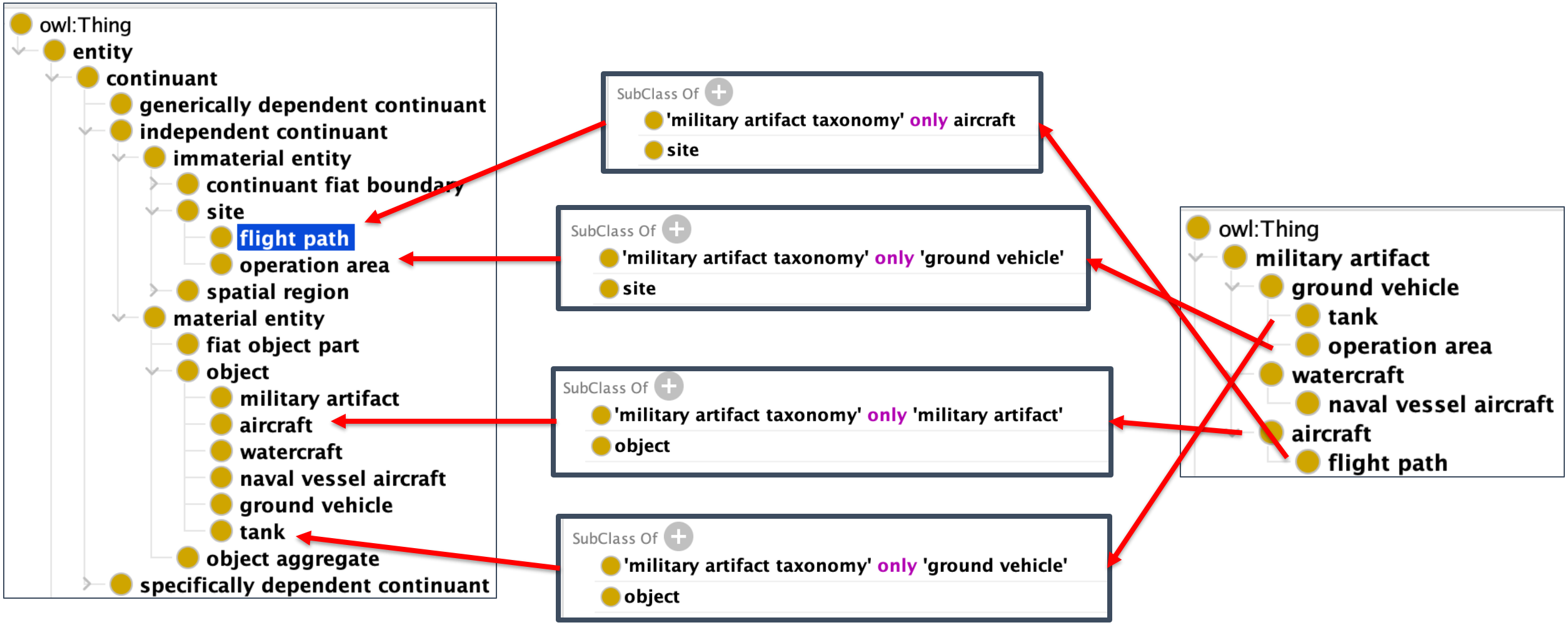
military taxonomy relation

- 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

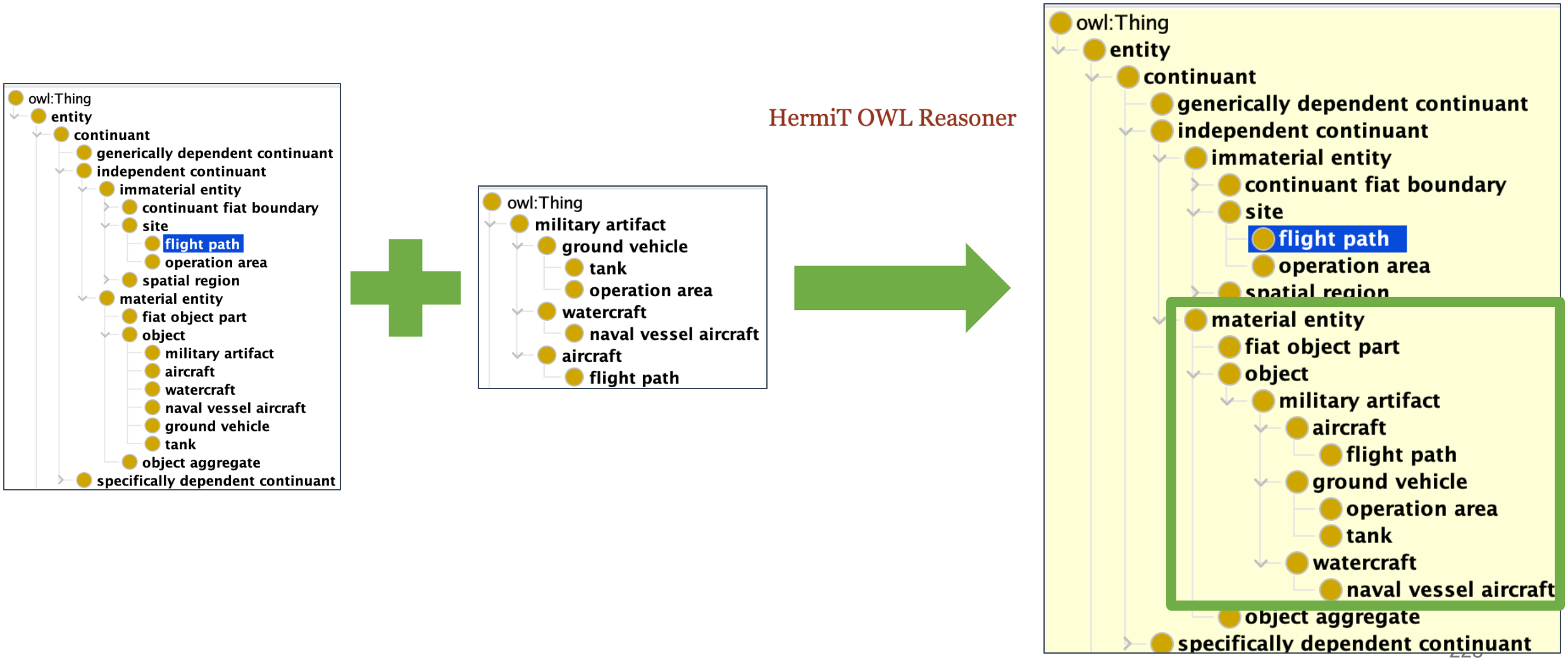
- To simulate the **subclass of** relation, we assert that **military taxonomy** is **reflexive** and **transitive**

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

Generating Implicit Hierarchy



Generating Implicit Hierarchy



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

- 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

Real-World Ontology Engineering

- 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

CONFIGURATION MANAGEMENT

Guidance

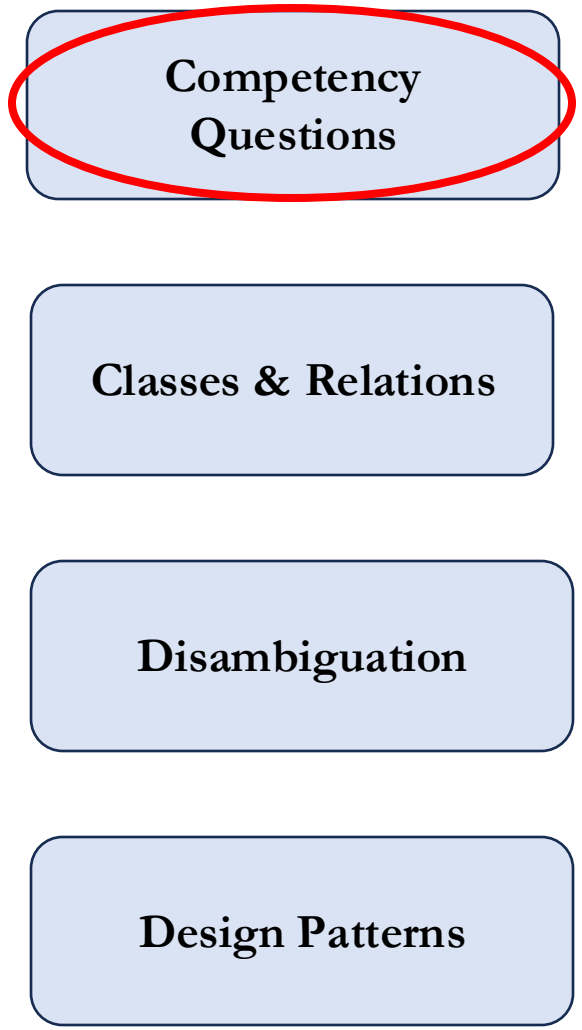
- Competency Questions
- Classes & Relations
- Disambiguation
- Design Patterns

Guidance

- Competency questions are **used to guide ontology development** and **generate unit tests** to ensure ontologies are sufficiently well-developed

- Identify a preliminary list of competency questions **first**

- They will help you scope your project



Type of OCQ	Purpose	Examples
Scoping CQ (SCQ)	Define the domain and scope of the ontology	Which predators eat rabbits? What information is clinically relevant for social interaction assessment?
Validation CQ (VCQ)	Verify the accuracy of the content	Is ruby a type of chocolate? What is the Base of ThinAndCrispyPizza?
Foundational CQ (FCQ)	Align entities with a foundational ontology	Is water bottle classified as a Material Entity in the BFO foundational ontology? Is coffee something that cannot be counted, or only in specific quantities?
Relationship CQ (RCQ)	Investigate the characteristics of relationships	What is the domain and range of the eating relationship? If a body contains a heart and a heart contains a cell, does the body contain the cell?
Metaproperty CQ (MpCQ)	Classify entities based on metaproperties	Is each instance of a coffee bean necessarily (at all times of its existence) an instance of a coffee bean? Does a thesis defense have a definite endpoint?

Keet, M, Kahn, Z. 2023 *On the Roles of Competency Questions in Ontology Engineering*
http://www.meteck.org/files/EKAW24positionPaperCQs.pdf

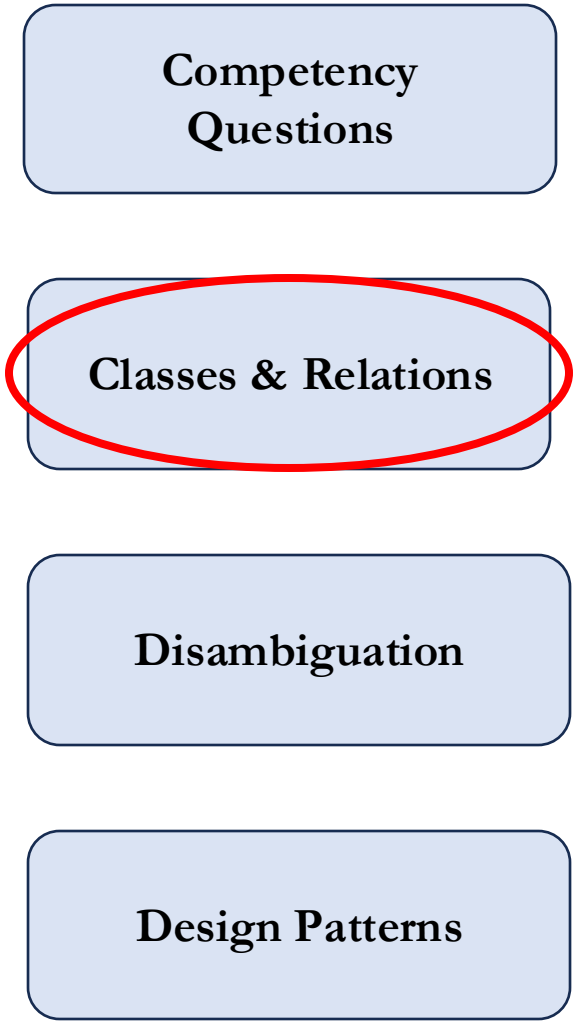
At what speed does a patrol boat move in knots over an hour?

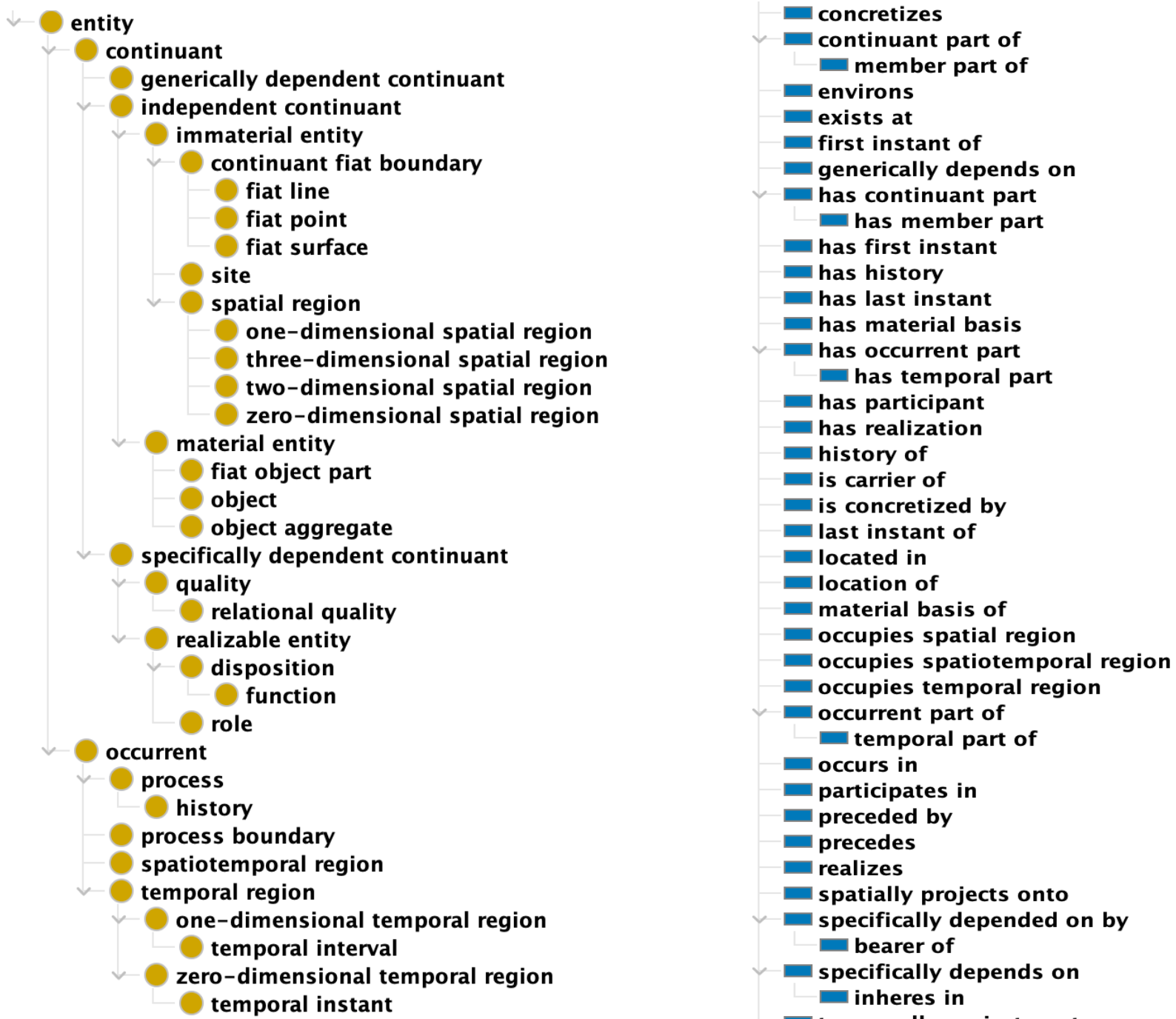
Classes & Relations

- Using competency questions as guidance, list the classes and relations you will need to represent to answer the questions

- Create this list through the lens of, say, Basic Formal Ontology (BFO) and/or Common Core Ontologies classes and relations

- I illustrate using BFO




entity
continuant
generically dependent continuant
independent continuant
immaterial entity
continuant fiat boundary
fiat line
fiat point
fiat surface
site
spatial region
one-dimensional spatial region
three-dimensional spatial region
two-dimensional spatial region
zero-dimensional spatial region
material entity
fiat object part
object
object aggregate
specifically dependent continuant
quality
relational quality
realizable entity
disposition
function
role
occurrent
process
history
process boundary
spatiotemporal region
temporal region
one-dimensional temporal region
temporal interval
zero-dimensional temporal region
temporal instant
concretizes
continuant part of
member part of
environs
exists at
first instant of
generically depends on
has continuant part
has member part
has first instant
has history
has last instant
has material basis
has occurrent part
has temporal part
has participant
has realization
history of
is carrier of
is concretized by
last instant of
located in
location of
material basis of
occupies spatial region
occupies spatiotemporal region
occupies temporal region
occurrent part of
temporal part of
occurs in
participates in
preceded by
precedes
realizes
spatially projects onto
specifically depended on by
bearer of
specifically depends on
inheres in
temporally projects onto

Rules of Thumb

- When identifying classes, describe:

1. Material entities within scope, i.e. **Material Entity**
2. Qualities these material entities have, i.e. **Quality**
3. What these material entities could do, i.e. **Realizable Entity**
4. What these material entities actually do, i.e. **Process**
5. Where these material entities and boundaries are located, i.e. **Immaterial Entity**
6. When these entities exist, i.e. **Temporal Region**
7. Information we use to talk about 1-6, i.e. **Generically Depedent Continuant**

https://github.com/BFO-ontology/BFO-2020

Classes

- Material Entities –
- Qualities –
- Processes –
- Realizables –
- Sites & Boundaries –
- Temporal Region –
- Information –

At what speed does a patrol boat move in knots over an hour?

Classes

- Material Entities – **Patrol boat**
- Qualities –
- Processes –
- Realizables –
- Sites & Boundaries –
- Temporal Region –
- Information –

At what speed does a patrol boat move in knots over an hour?

Classes

- Material Entities – Patrol boat
- Qualities –
- Processes – **Act of motion**
- Realizables –
- Sites & Boundaries –
- Temporal Region –
- Information –

At what speed does a patrol boat move in knots over an hour?

Classes

- Material Entities – Patrol boat
- Qualities –
- Processes – Act of motion, **speed?**
- Realizables –
- Sites & Boundaries –
- Temporal Region –
- Information – **speed?**

At what speed does a patrol boat move in knots over an hour?

Classes

- Material Entities – Patrol boat
- Qualities –
- Processes – Act of motion, speed*
- Realizables –
- Sites & Boundaries –
- Temporal Region –
- Information – speed*

use * to note ambiguity then move on; we will revisit

At what speed does a patrol boat move in knots over an hour?

Classes

- Material Entities – Patrol boat
- Qualities –
- Processes – Act of motion, speed*
- Realizables –
- Sites & Boundaries –
- Temporal Region –
- Information – speed*, **knots measurement**

At what speed does a patrol boat move in knots over an hour?

Classes

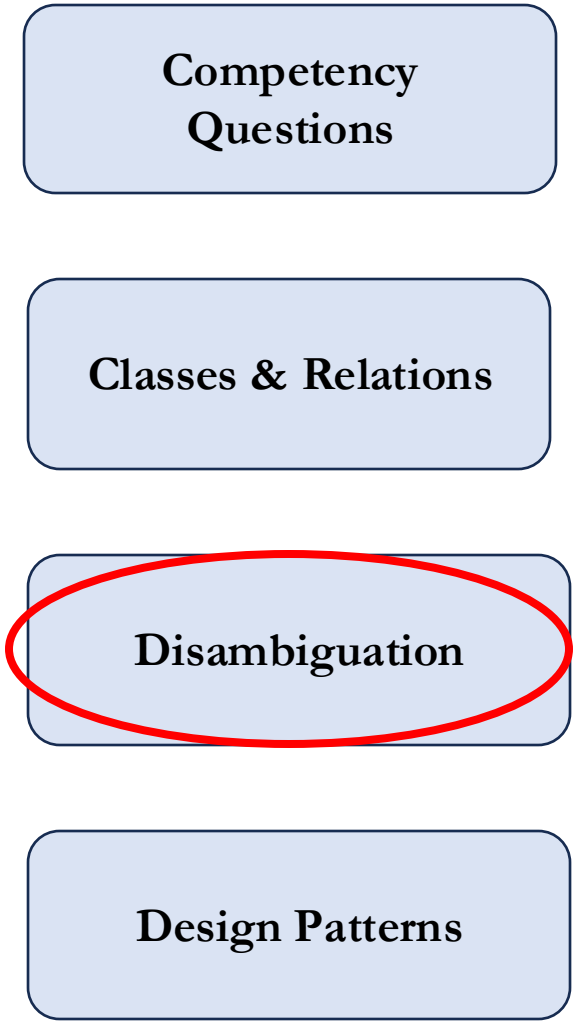
- Material Entities – Patrol boat
- Qualities –
- Processes – Act of motion, speed*
- Realizables –
- Sites & Boundaries –
- Temporal Region – **hours***
- Information – speed*, knots measurement, **hours***

use * to note ambiguity then move on; we will revisit

At what speed does a patrol boat move in knots over an hour?

Disambiguate

- Logic is **demanding**, in part because it is **complete**
- We make explicit the implicit semantics within data, which requires disambiguating
- It is easier to stitch meaning together having cut it from whole cloth, than it is from disparate meanings

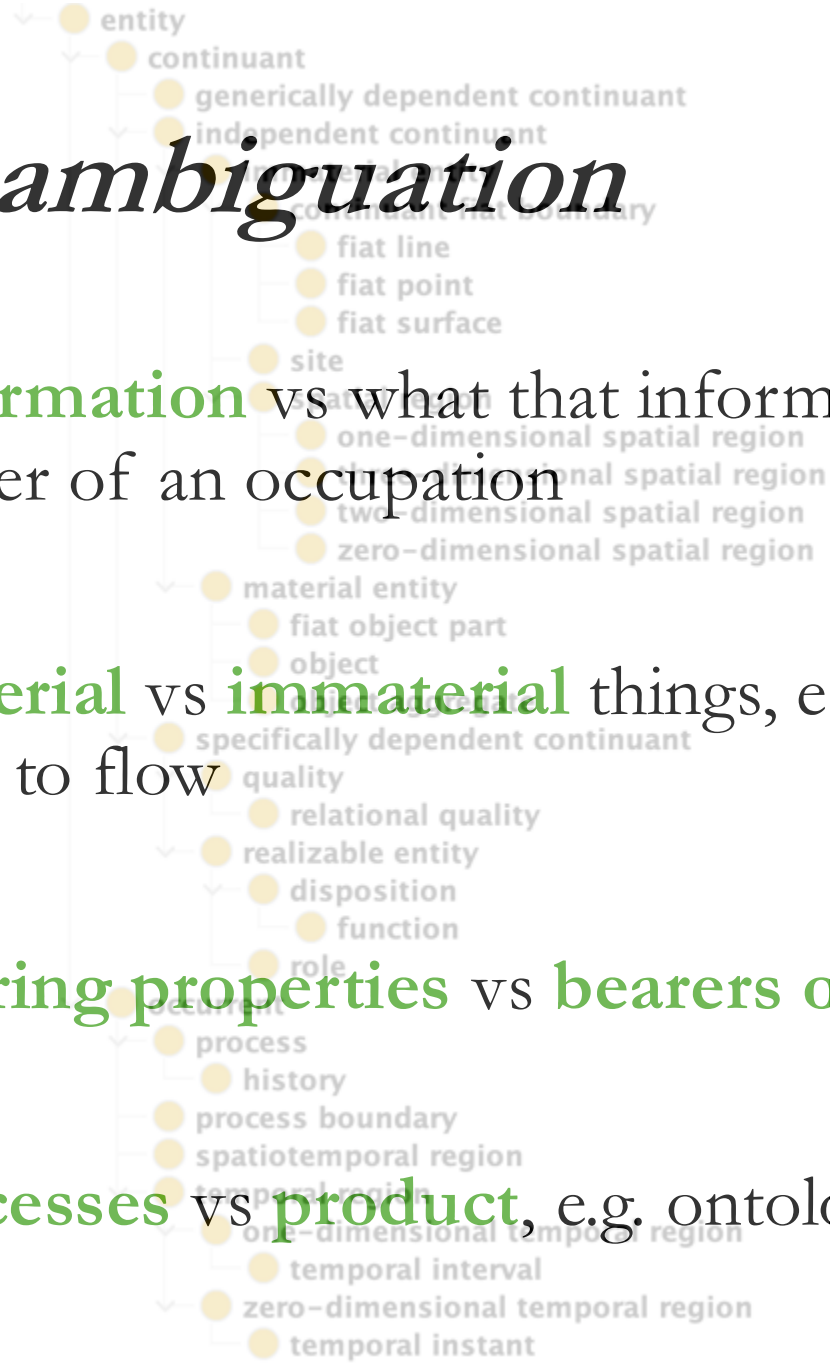


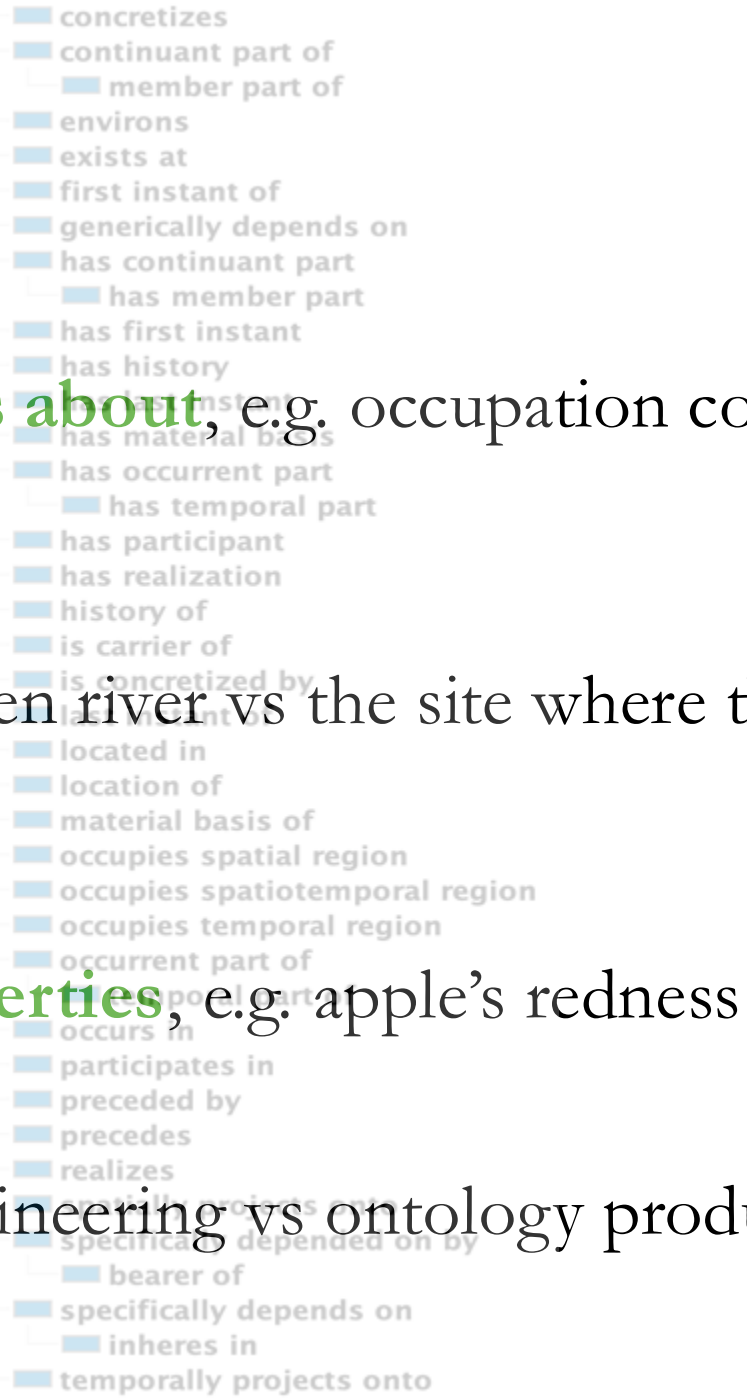
Disambiguation

- **Information** vs what that information **is about**, e.g. occupation code vs a holder of an occupation
- **Material** vs **immaterial** things, e.g. a given river vs the site where the river used to flow
- **Bearing properties** vs **bearers of properties**, e.g. apple's redness vs the apple
- **Processes** vs **product**, e.g. ontology engineering vs ontology produced

Disambiguation

- **Information** vs what that information **is about**, e.g. occupation code vs a holder of an occupation
- **Material** vs **immaterial** things, e.g. a given river vs the site where the river used to flow
- **Bearing properties** vs **bearers of properties**, e.g. apple's redness vs the apple
- **Processes** vs **product**, e.g. ontology engineering vs ontology produced





Revisiting Ambiguity

- “speed” as a process vs information about a process

Revisiting Ambiguity

- "speed" as a process vs information about a process

- Speed is the magnitude of a change in position over time

INFORMATION

Revisiting Ambiguity

- "speed" as a process vs information about a process

- Speed is the changing of position over time

PROCESS

Revisiting Ambiguity

- "speed" as a process vs information about a process

At what speed does a patrol boat move in knots over an hour?

WHICH DO WE CARE ABOUT FOR THIS COMPETENCY QUESTION?

Simplify

- Material Entities – Patrol boat
- Qualities –
- Processes – Act of motion, speed*
- Realizables –
- Sites & Boundaries –
- Temporal Region – hours*
- Information – speed*, knots measurement, hours*

At what speed does a patrol boat move in knots over an hour?

Simplify

- Material Entities – Patrol boat
- ~~Qualities –~~
- Processes – Act of motion, speed*
- ~~Realizables –~~
- ~~Sites & Boundaries –~~
- Temporal Region – hours*
- Information – ~~speed*,~~ knots measurement, ~~hours*~~

simplify the list

At what speed does a patrol boat move in knots over an hour?

Relations

- Material Entities – Patrol boat
- Processes – Act of motion, speed
- Temporal Region – hours
- Information – knots measurement

and reflect on relationships among the listed entities

At what speed does a patrol boat move in knots over an hour?

Rules of Thumb

- When identifying relations, describe:

1. Qualities to material entities, i.e. **inheres in**
2. Realizables to material entities, i.e. **inheres in**, **has material basis**
3. Processes to material entities, i.e **participates in**
4. Realizables to processes, i.e. **has realization**
5. Immaterial location of material entity, i.e. **located in**
6. When any such entities exist, i.e. **exists at**, **datatype property**
7. When any such entities carry information, e.g. **generically depends on**

https://github.com/BFO-ontology/BFO-2020

Relations

- Material Entities – **Patrol boat**
- Processes – **Act of motion**, speed
- Temporal Region – hours
- Information – knots measurement

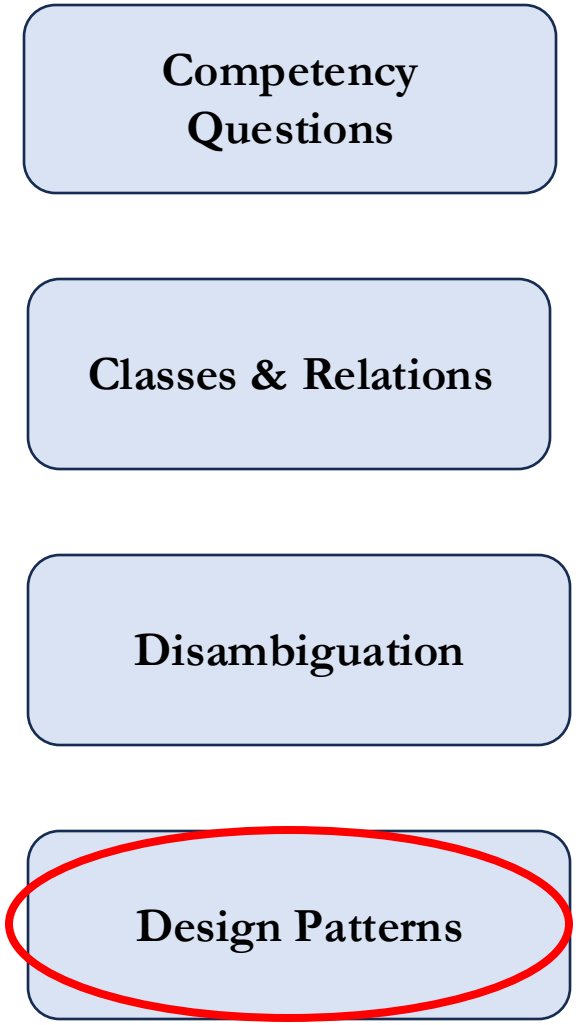
patrol boats participate in processes

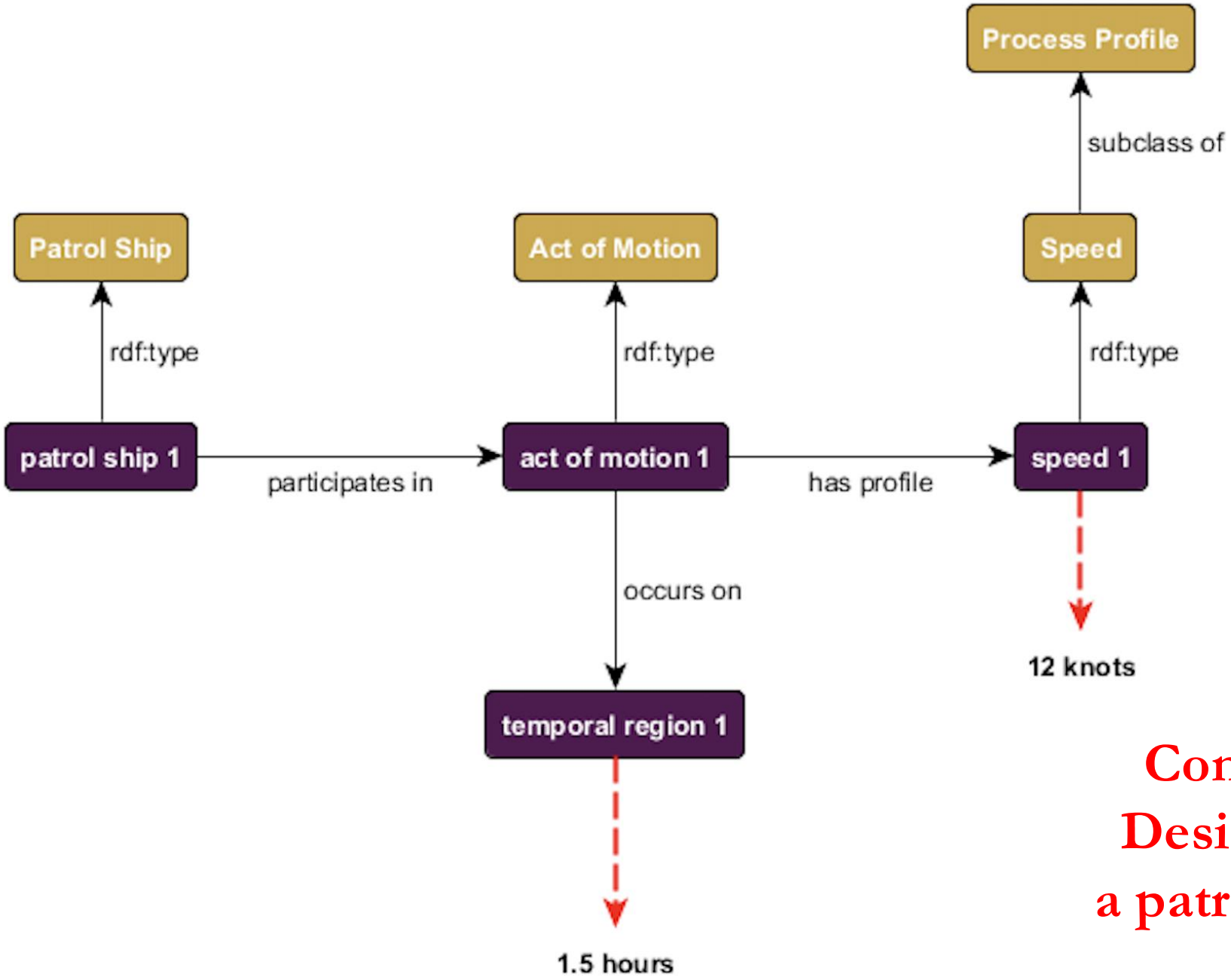
https://github.com/BFO-ontology/BFO-2020

Design Patterns

- Classes and relations identified, turn next to constructing visual representations reflecting the competency questions

- If you have completed the preceding steps, this should be relatively straightforward





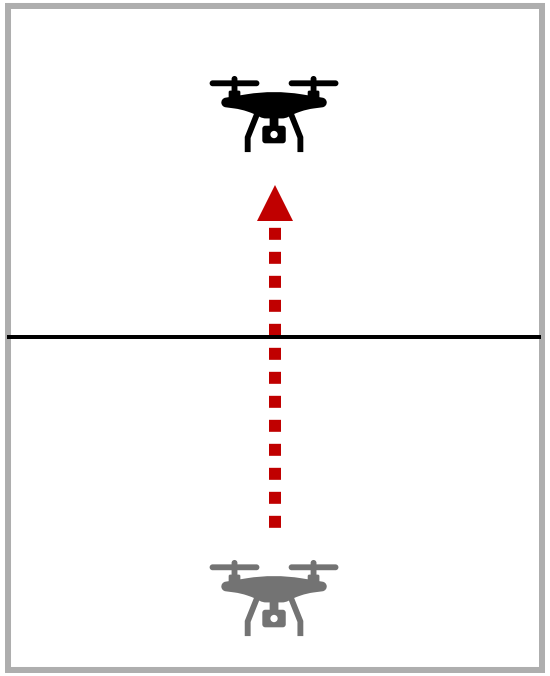
Common Core Ontologies Design Pattern representing a patrol ship traveling 12 knots over 1.5 hours

I HEAR YOU WONDERING, HOW WOULD I USE THIS IN A REAL WORLD APPLICATION?

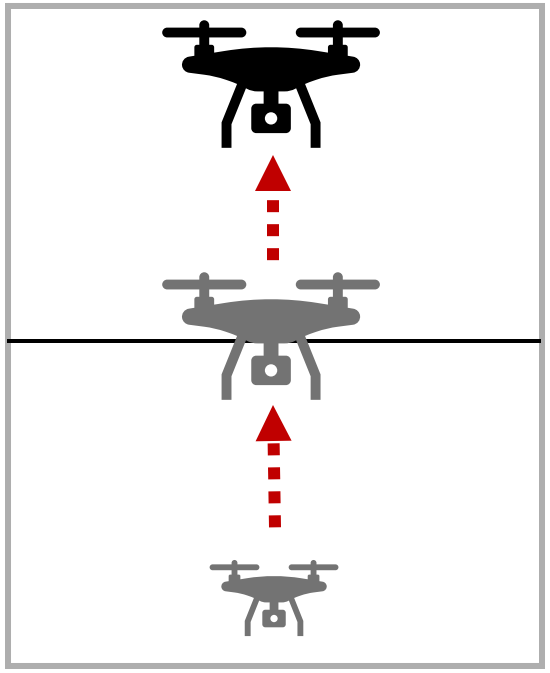
I HEAR YOU WONDERING, HOW WOULD I USE THIS IN A REAL WORLD APPLICATION?

WELL I'M GLAD YOU THOUGHT THAT.

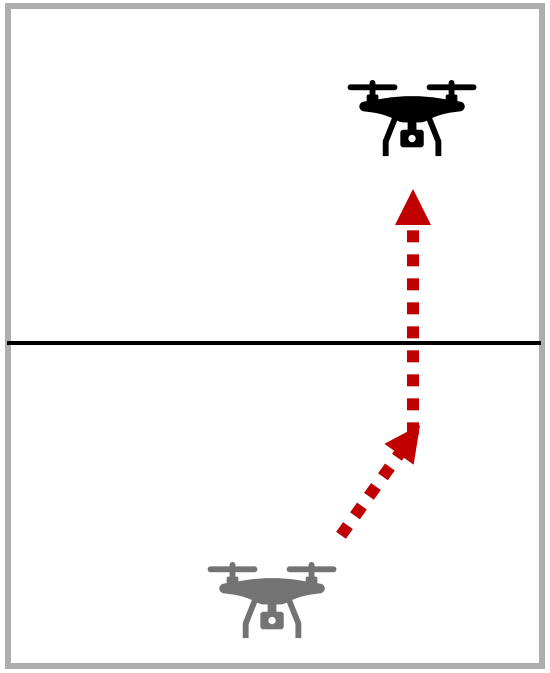
Competency Question



Flat, Linear Path



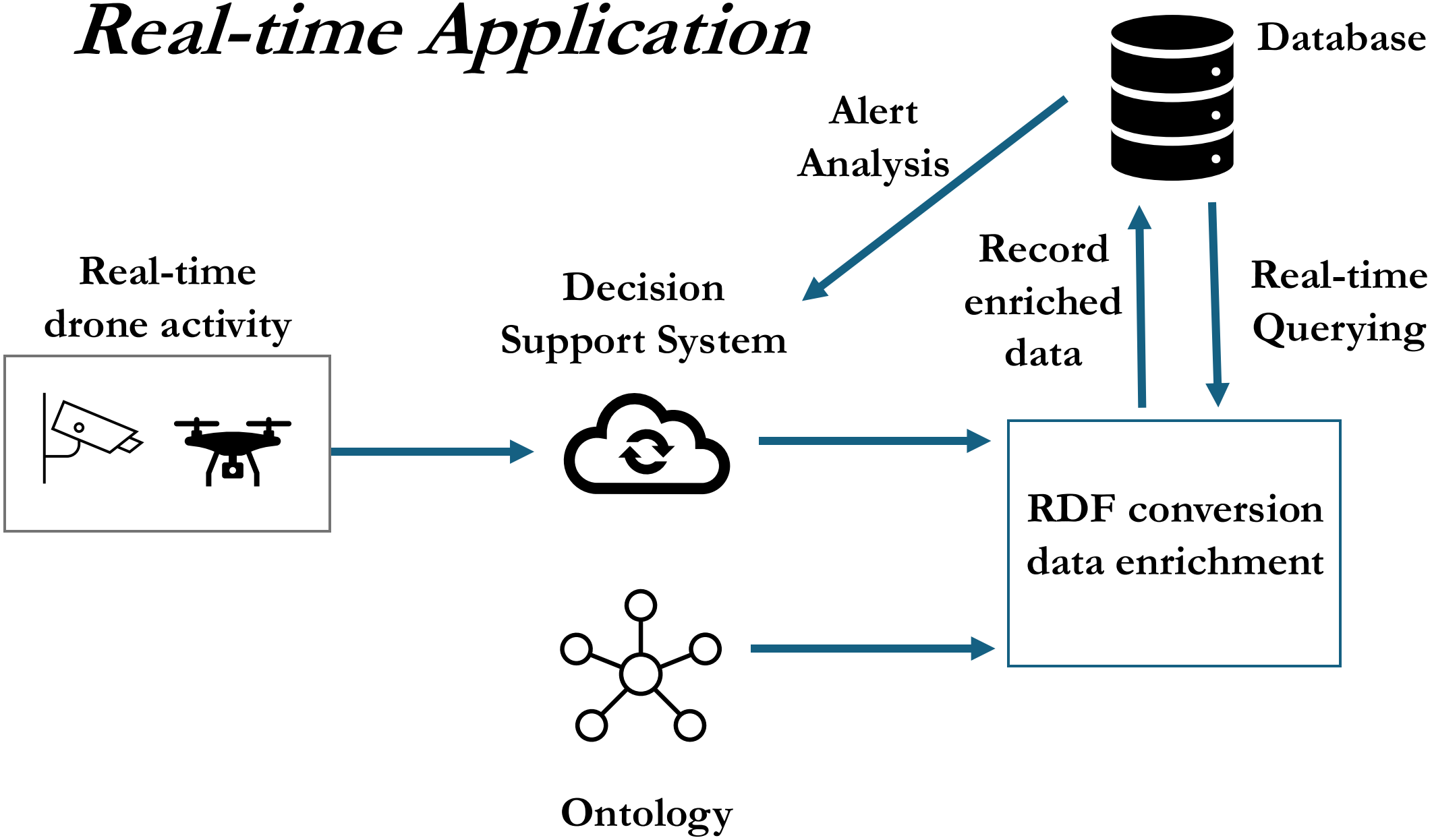
Climbing Linear Path



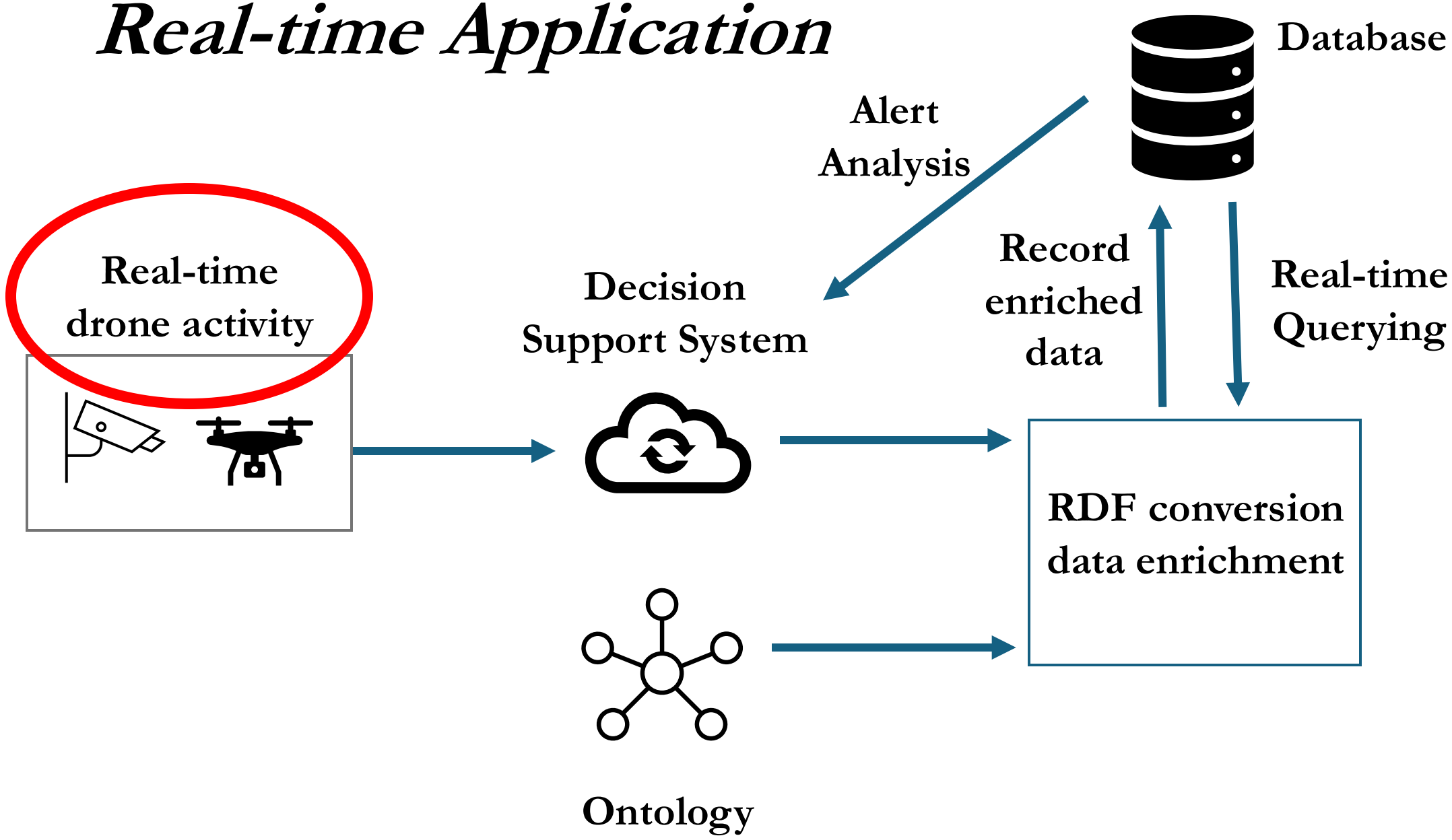
Flat Non-Linear Path

Has a drone cross the US-MZ border?

Real-time Application



Real-time Application

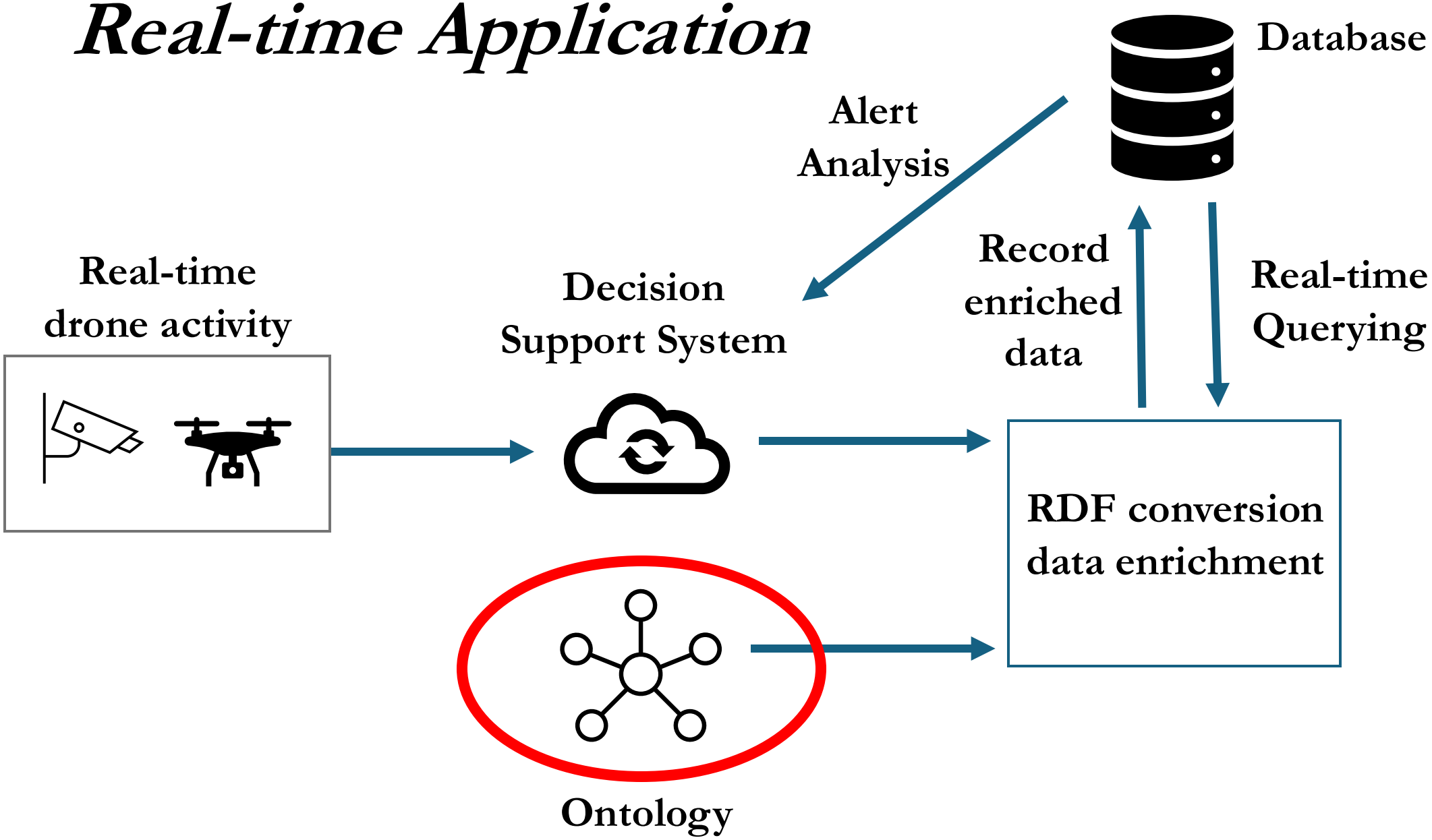


Sensor Data

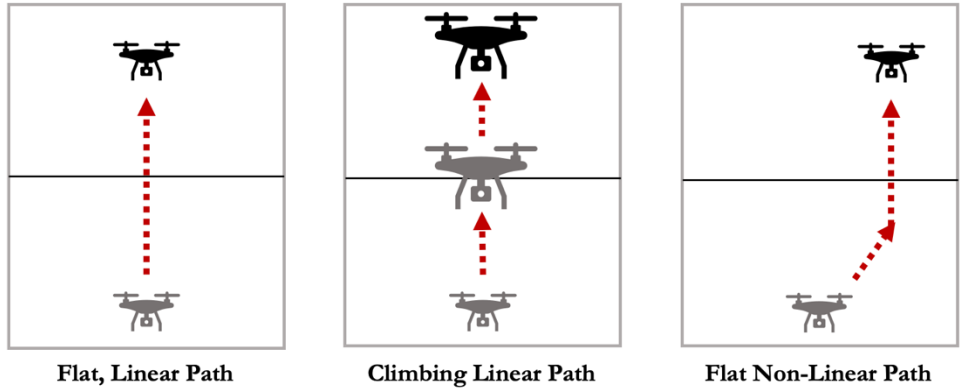
- Sample sensor data tracking an object at the AZ-MX border, formatted in XML:

```
<?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?

Ontology Design

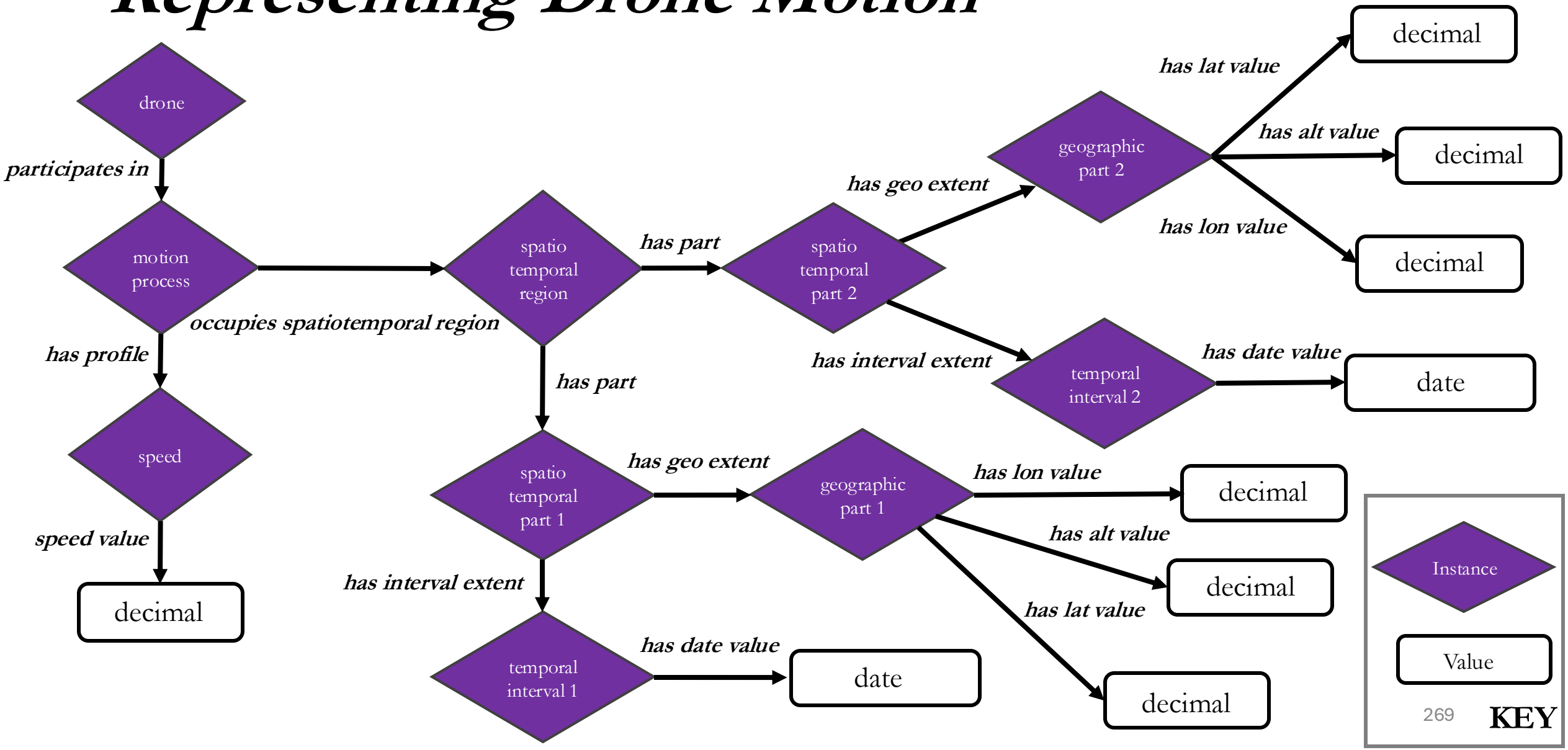
- Addressing the competency question requires ontologically representing sensor data relevant to the question

- For our example, we will need representations of:

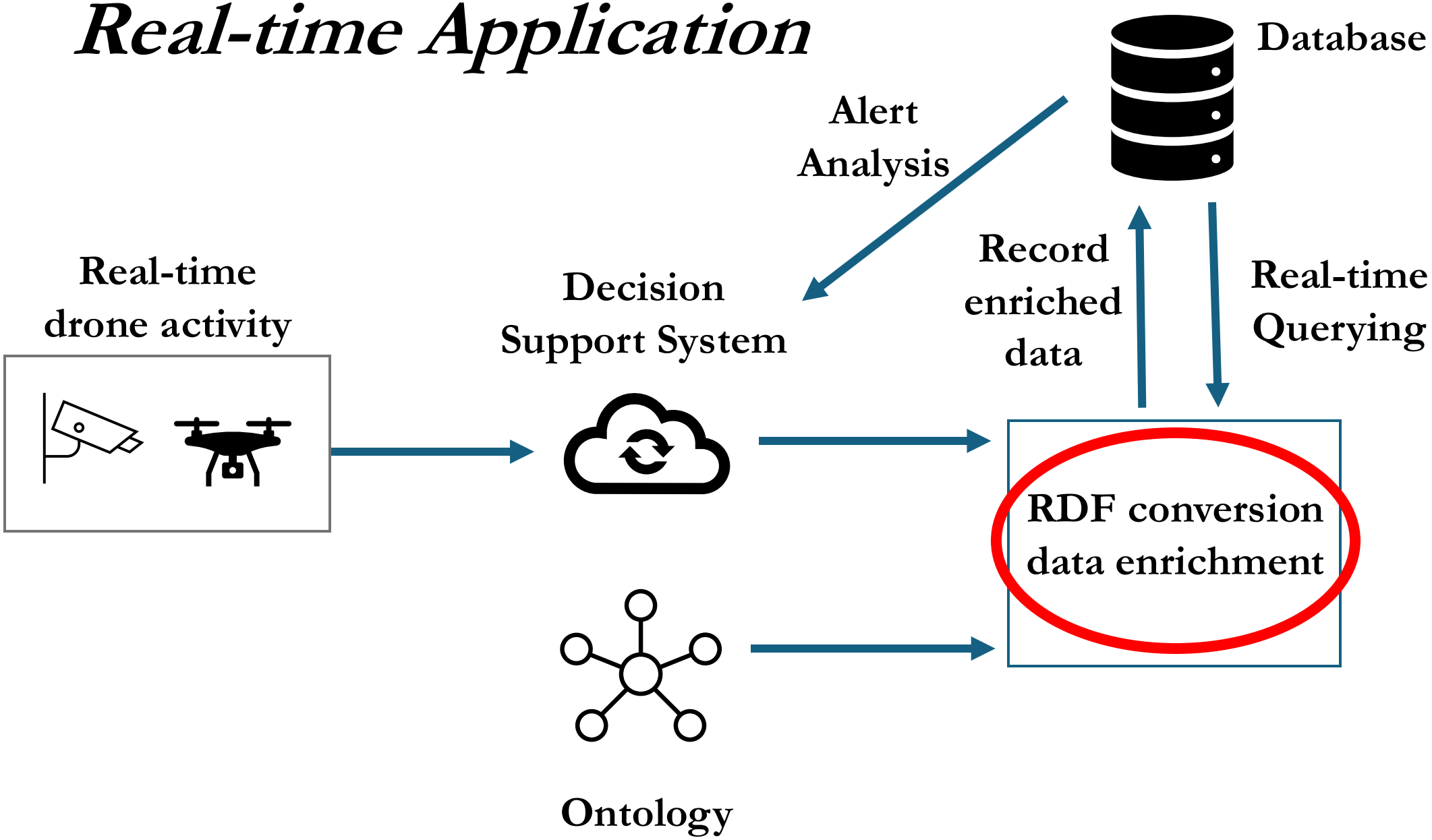
border/boundary	latitude
geographic region	altitude
drone	longitude
speed	time

*Classes not diagramed due to space constraints

Representing Drone Motion



Real-time Application



RDFLib Conversion Script

- 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

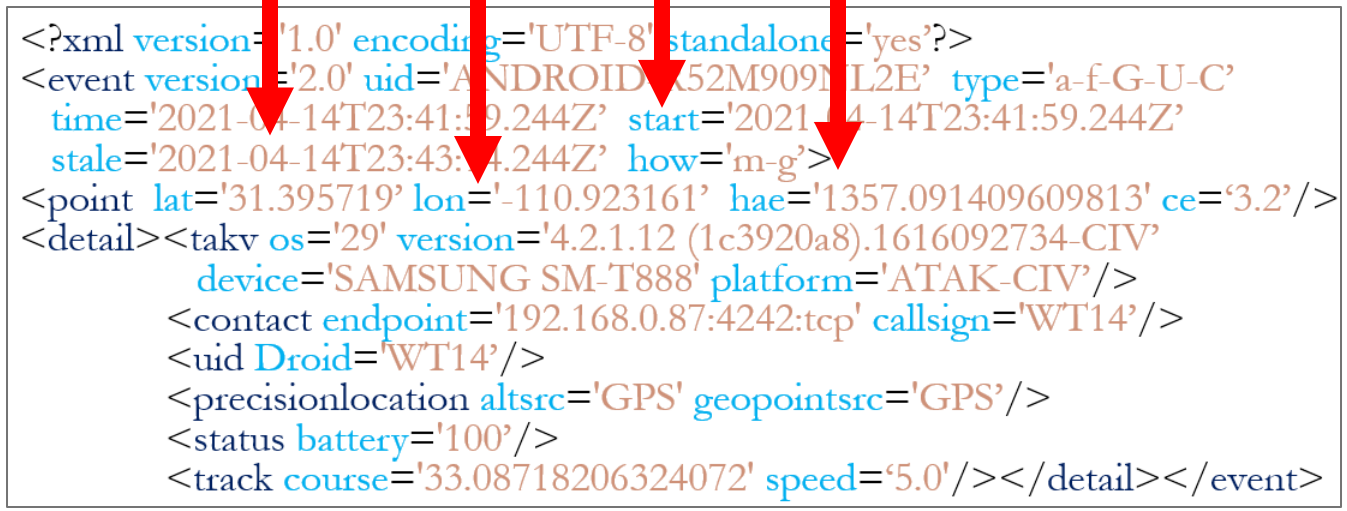
Classes, instances, and relations from existing ontologies, such as BFO, have IRIs that can be reused during ontology development. The creation of new terms, however, requires creating new unique IRIs for each. For example, a new drone identified by a sensor will be represented by a new unique IRI, a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

```
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

```
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

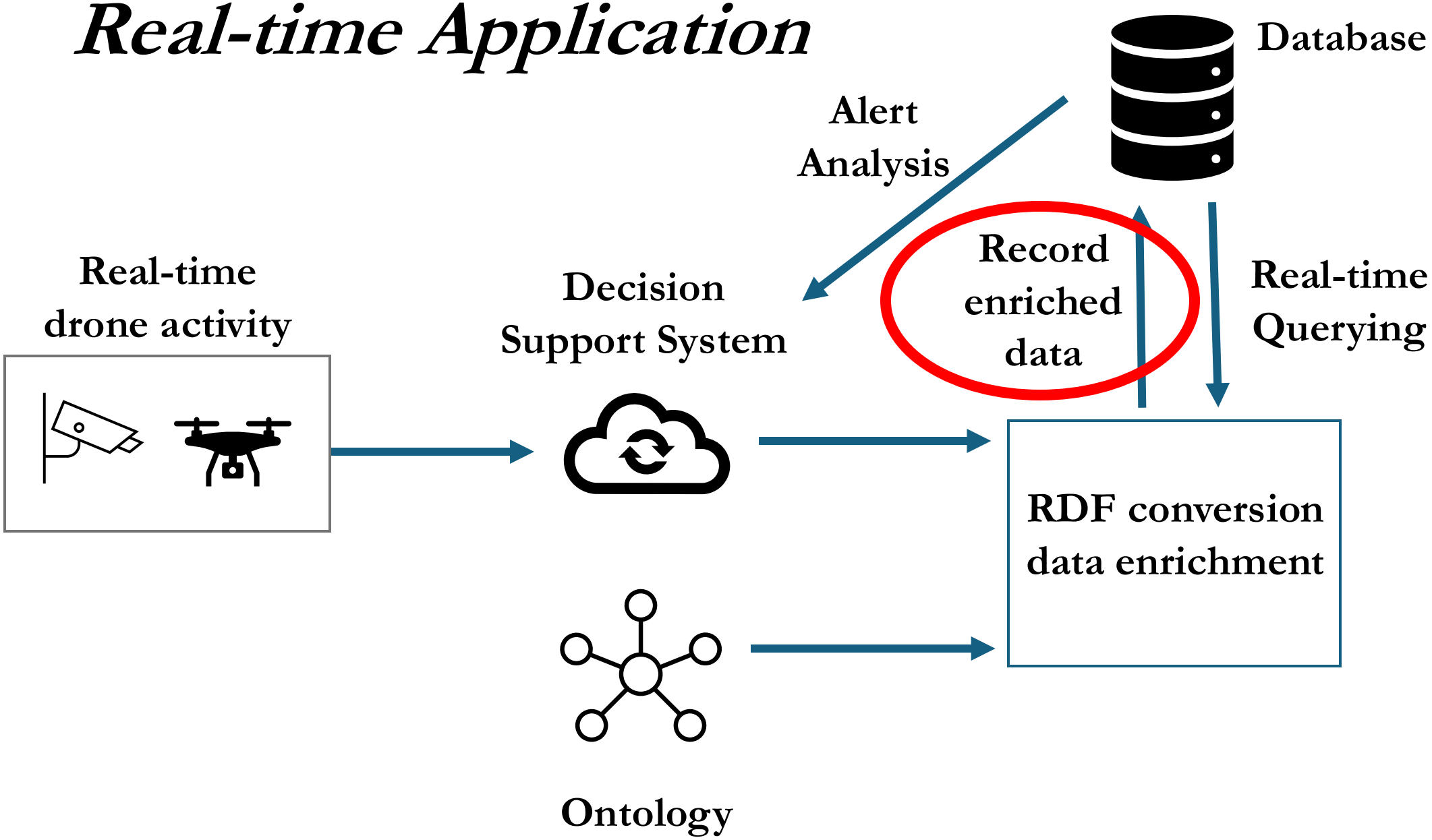
Functions from rdflib are then used to add the automatically generated IRIs to an ontology file, ensuring the IRIs bear relationships reflected in our diagrams.

```
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



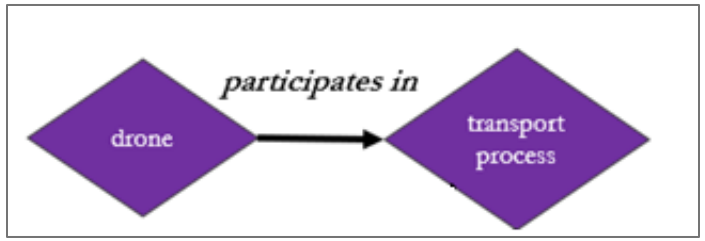
The conversion script outputs valid RDF, and has enriched the sensor data with ontological relationships relevant to addressing the competency question.

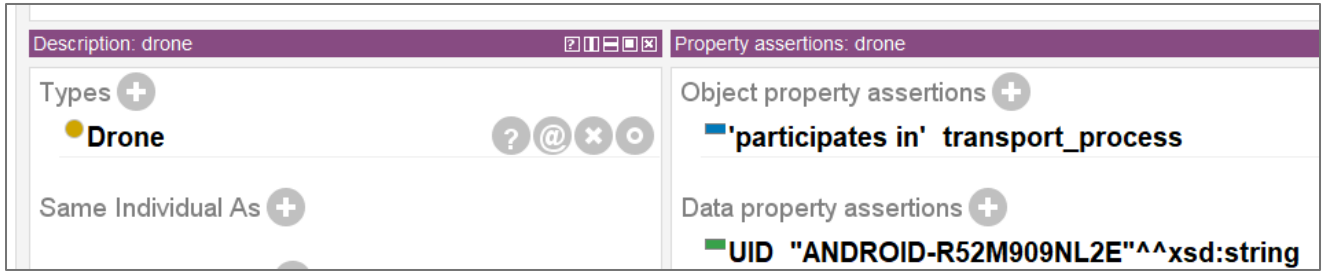
The RDF conversion script output can be viewed in standard ontology editors, such as Protégé.

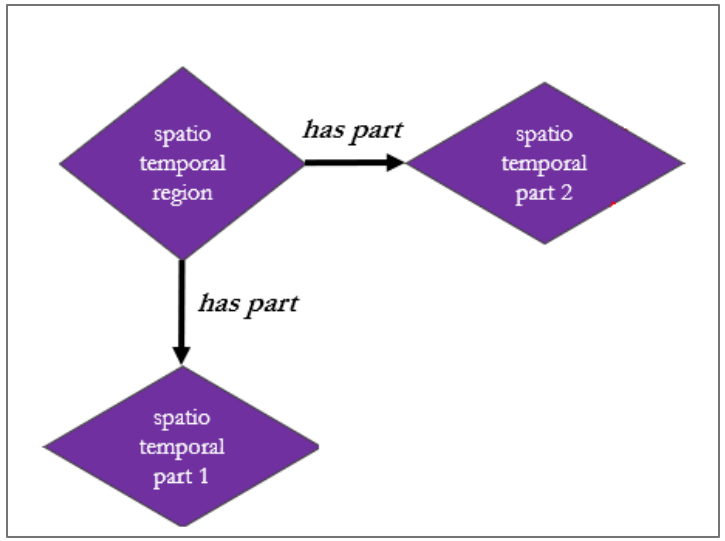
```
<NamedIndividual rdf:about="http://example.com/DEMO_0001421">
    <rdf:type rdf:resource="https://example.com/DEMO/GeographicRegion"/>
    <cco:has_latitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">110.123</cco:has_latitude_value>
    <cco:has_longitude_value rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">38.9</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  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>
```

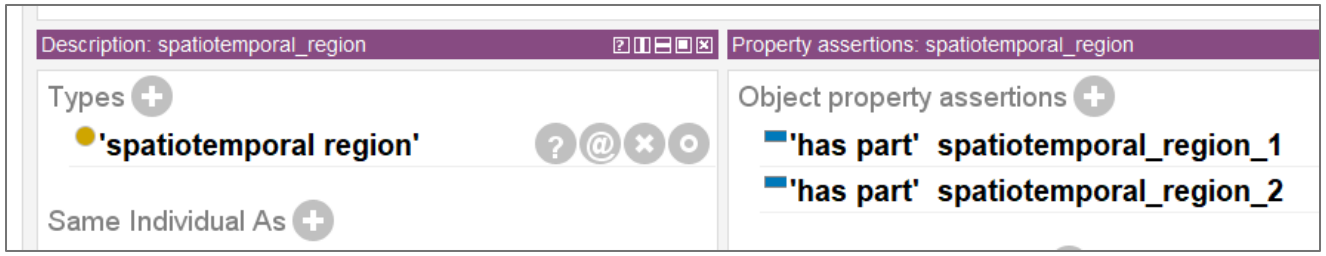
subject predicate object

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



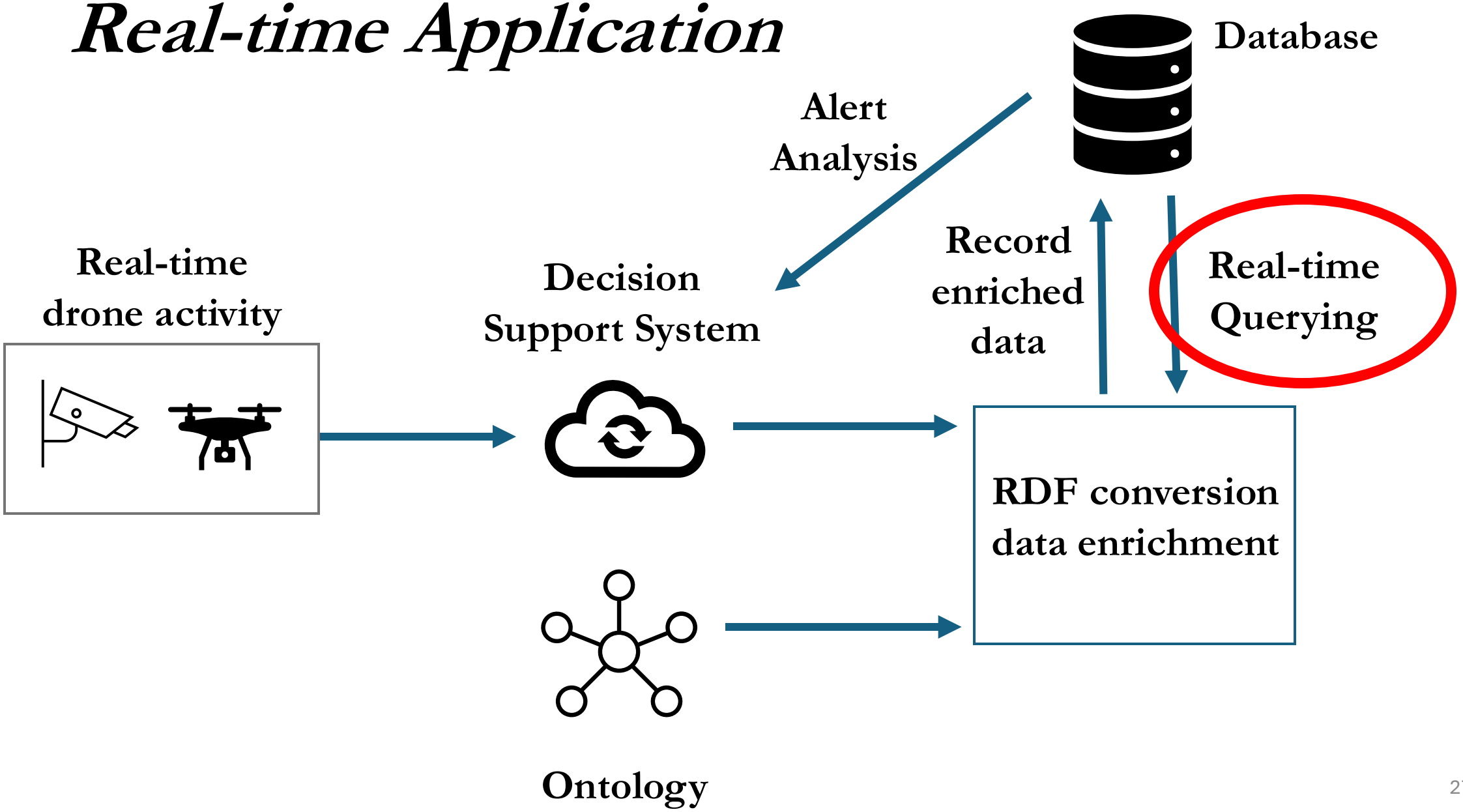






Protégé also facilitates the use of automated reasoners which can be used to uncover implicit relationships or infer unexpected consequences from the ontological relationships.

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?

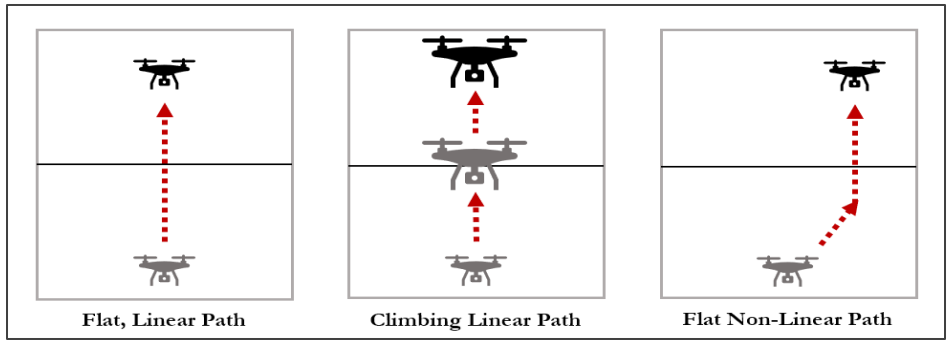
```
SELECT ?lat1 ?lon1 ?alt1 ?lat2 ?lon2 ?alt2 ?time1 ?time2
WHERE {
   ?drone rdf:type ex:DEMO_0001440 ;
          bfo:RO_0000056 ?motion_process .
   ?motion_process bfo:BFO_0000130 ?spt .
   ?spt bfo:BFO_0000051 ?spt1 ;
        bfo:BFO_0000051?spt2 .
   ?spt1 ex:DEMO_0001438 ?geo1 ;
         ex:DEMO_0001439 ?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 lon2 alt1	31.395719 -110.923161 1357.0914096
lat2 lon2 alt2	31.178655 -110.923172 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 )}
```

WE MAKE EXPLICIT THE IMPLICIT SEMANTICS IN DATASETS, IN THE INTEREST OF ADDRESSING INTEROPERABILITY CHALLENGES AND IMPROVING DATA QUALITY VIA GENERAL AND TARGETED REASONING

WHEN WE RETURN, YOU WILL PRACTICE TRANSLATING DATA INTO DESIGN PATTERNS THAT CAN IN TURN BE USED TO ANSWER COMPETENCY QUESTIONS

Outline

- **Module 1**: Motivation for Ontology Engineering
- **Module 2**: Motivation for Basic Formal Ontology
- **Module 3**: Theory of BFO
- **Module 4**: Building Ontologies with BFO
- **Module 5**: Exercises

Assignment

For each case, construct a BFO-conformant design pattern with justification

https://github.com/Applied-Ontology-Education/2025-C-FORS-BFO-Session

Design Pattern Guidance

- Include a legend or key
- Visually distinguish **classes** from **instances** from **strings**
- Distingish **direct relations** from **shortcuts**
- Read arrows as reflecting "any instance of class X arrow some instance of class Y"
- Carefully determine how specific/broad to make your design patterns

Submission Guidance

- Create a GitHub account and fork the **C-FORS** BFO Summer repo (see **here for GitHub** guidance)
- Save a diagram reflecting your design pattern to your forked repository in the "Submit" directory
- Save a written justification of your design pattern choices
- Open a Pull Request to the **C-FORS** repository

Case 1

In aircraft_data.xlsx you will find a row for the Airbus A320 Neo.

Construct a BFO-conformant design pattern reflecting the content of every column associated with that row.

Case 2

In aircraft_data.xlsx you will find a row for the Airbus A321-111, designed to have a maximum knot approach speed of 142. However, after 5 approaches, an instance has obtained an average maximum knot approach speed of 139.

Construct a BFO-conformant design pattern reflecting the preceding phenomena.

Case 3

In soc_structure_definitions.xlsx you will find three "SOC_TITLE" entries that mention "Aerospace Engineer".

Construct a BFO-conformant design pattern that reflects all three entries and their respective "SOC Definitions".

Case 4

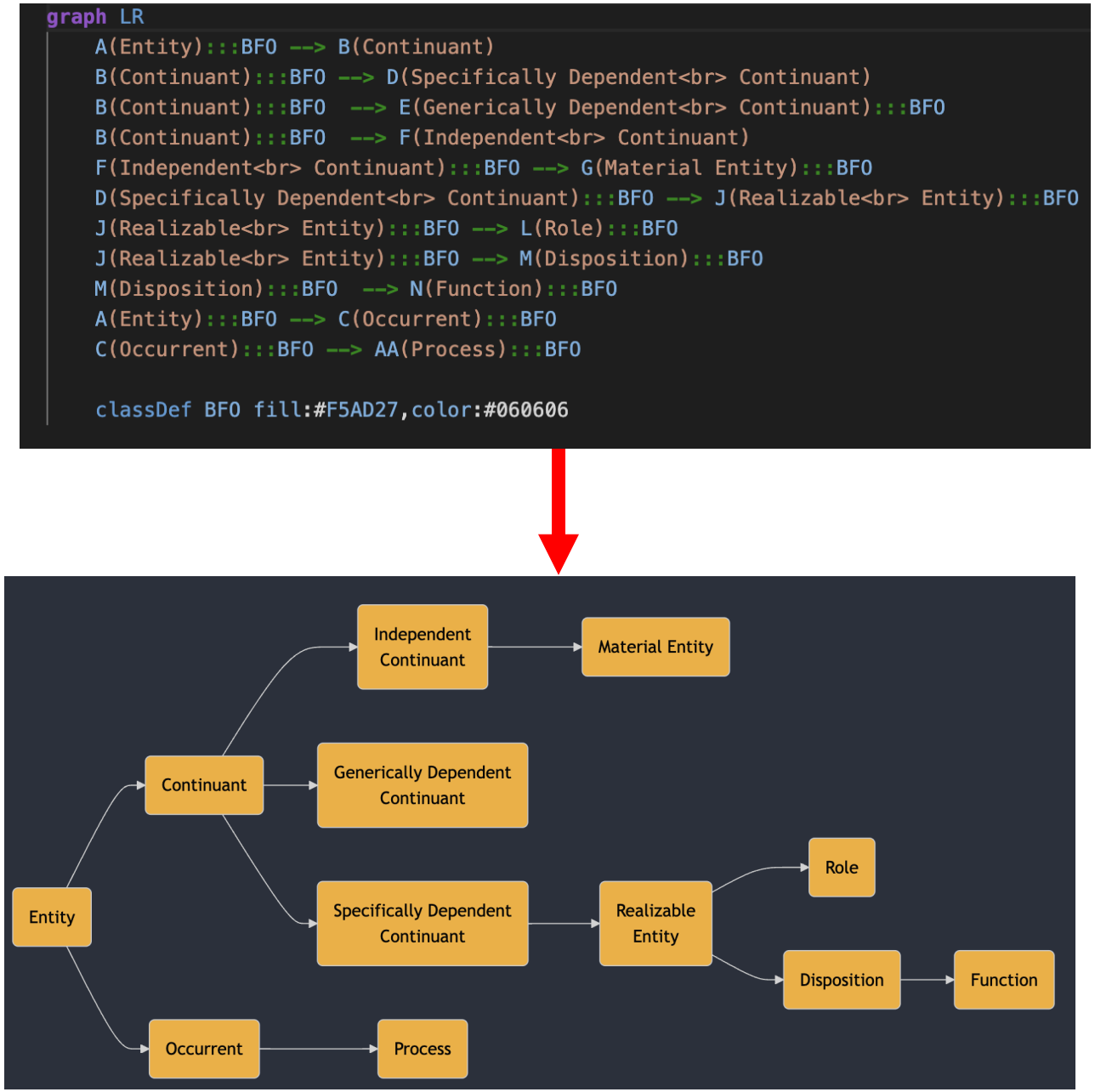
In employment_wage_May_2024.xlsx you will find three "OCC_TITLE" entries that mention "Aerospace Engineer".

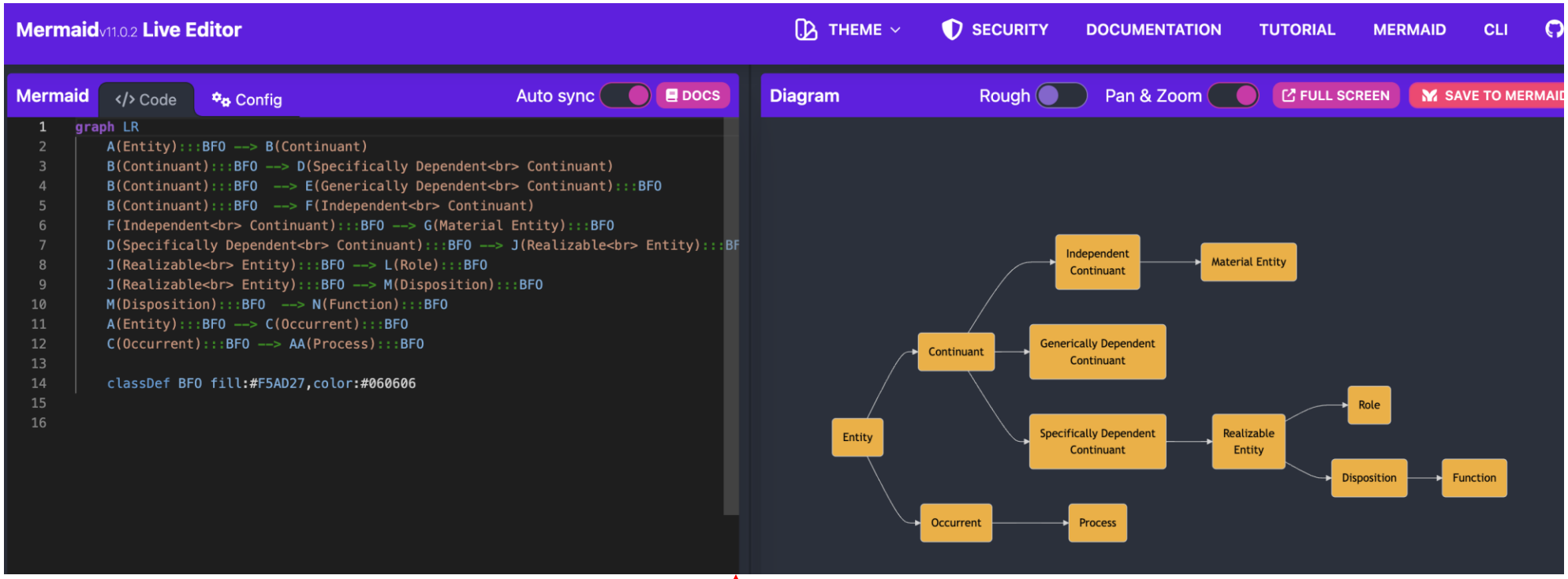
Construct a BFO-conformant design pattern that reflects all three entries and their associated column information.

Mermaid

- Mermaid is a flavor of Markdown specialized for representing diagrams

- You'll be using mermaid to represent design patterns in this course





Play around in the live editor:
https://mermaid.live/edit

- Flowchart
- Sequence Diagram
- Class Diagram
- State Diagram
- Entity Relationship Diagram
- User Journey
- Gantt
- Pie Chart
- Quadrant Chart
- Requirement Diagram

Navigate to the helpful tutorials:
https://mermaid.js.org/ecosystem/tutorials.html