Systems Engineering Research Center
Presents:

ONTOLOGY BOOTCAMP
Introduction to Ontology for Systems Engineers

Instructor: Dr. Barry Smith,
SUNY Distinguished Professor of Philosophy and
Julian Park Chair,
University of Buffalo

Agenda

Time	Topic
8:00 AM	Registration & Breakfast
8:30 AM	**Introduction and Background: Semantic Technology for Systems Engineering** **Ontology Timeline** 1: 1970s–Strong AI, Robotics, PSL 2: 1990s– The Semantic Web, Linked Open Data 3: 2000s– Lessons from the Human Genome Project
9:15 AM	**Ontology Suites** Open Biomedical Ontologies (OBO) Foundry SWEET, and other domain ontology suites Joint Doctrine Ontology Common Core Ontologies (CCO) **Principles for Ontology Building** **Toy Example. Military Vehicle Ontology**
10:15 AM	Coffee
10:30 AM	**Future-Proofing Ontologies: The Case of the Gene Ontology** Building ontologies with Basic Formal Ontology Industrial Ontologies Foundry (IOF) A BFO-based ontology for materials science **Relations in BFO** **Realizables in BFO** Roles Dispositions
12:30 PM	Lunch
1:15 PM	**Example Ontology from the SE Domain** Functions Capabilities **BFO-based Ontology for Information Entities** **AFRL Digital Thread/Digital Twin** **Product Life Cycle (PLC) Ontology** **Commodities, Services and Infrastructure**
3:00 PM	Break
3:15 PM	**Interactive session: Defining 'system'**
4:30 PM	Adjourn

Who am I?

Semantic Technologies Foundation Initiative for Systems Engineering.

Chi Lin, Engineering Development Office Manager
Jet Propulsion Laboratory
Dinesh Verma, Professor, Stevens Institute of Technology
Executive Director, SERC
David Long
INCOSE Past President, Vitech President

SYSTEMS ENGINEERING RESEARCH CENTER

Jet Propulsion Laboratory
California Institute of Technology

Charter

The Semantic Technologies Foundation for Systems Engineering is to promote and champion the development and utilization of ontologies and semantic technologies to support system engineering practice, education, and research.

Specifically, The Foundation Will

- Work to build consensus around principled, rigorous use of systems engineering language
  - Not just capturing current usage, but proposing normalized usage that entails semantic rigor
- Capture and formalize this consensus in formal ontologies using well-established languages and techniques from Knowledge Representation
- Collect and promulgate methodological guidance for development of related ontologies from industry and academia
- …

Initial Core team members of ST4SE

Steve Jenkins	Jet Propulsion Lab
David Long	INCOSE Past President and Vitech President
Mark Blackburn	SERC Council Member
Todd Schneider	Engineering Semantics
Chris Paredis	Georgia Institute of Technology
Hans Peter de Koning	European Space Agency
Bill Schindel	INCOSE MBSE Patterns Working Group
Henson Graves	Lockheed Martin Retiree
Barry Smith (Consultant)	Director, National Center for Ontological Research

Foundational Concepts for Building System Models [2013 = Pre ST4SE]

SEWG MBSE Training Module 3

https://nen.nasa.gov/web/se/mbse/documents

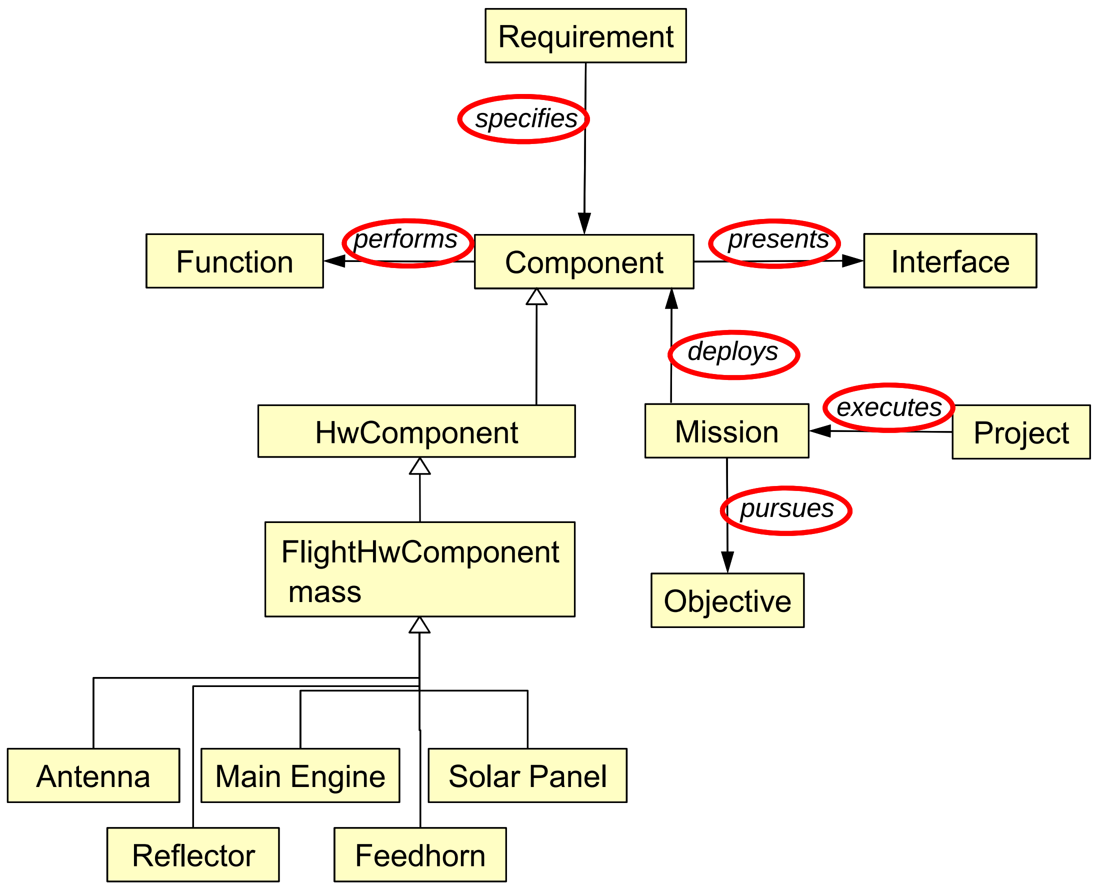
Todd Bayer, Daniel Dvorak, Sanford Friedenthal,
Steven Jenkins, Chi Lin, Sanda Mandutianu

Jet Propulsion Laboratory, California Institute of Technology

Introduction to Ontology

- **Ontology** =def. a representation of the types of entities in a given domain and of the relations between them.
- What is an ontology for? To promote interoperability across heterogeneous data systems
- How does it do this? By exploiting relative stability of natural language

[Example Ontology from SE Domain]



Ontology Timeline

1970– “Strong AI”: First-order logic formalizations of common-sense knowledge, PSL

1990– The Semantic Web, OWL, Linked Open Data

2005– The Age of Ontology Suites

Ontology Timeline 1: “Strong AI”: First-order logic formalizations of common-sense knowledge

Stanford

- 1970: Robotics, Naïve Physics, First Order Logic
- 1980: KIF: Knowledge Interchange Format (Tom Gruber … SIRI …)
- 1984: Cyc (Doug Lenat)
- 1985: Naïve Physics Manifesto; Ontology of Liquids (Patrick Hayes)

- ~1995: First engineering ontologies
- 2003: Process Specification Language (PSL) Ontology (Michael Gruninger, then at NIST, now Toronto)

1995-2005 multiple ontologies of engineering created at NIST and elsewhere

A requirement ontology for engineering design
J Lin, MS Fox, T Bilgic - *Concurrent Engineering*, 1996

Ontology as a requirements engineering product
KK Breitman, JCS do Prado Leite - *Requirements Engineering* …, 2003

Ontology-based active requirements engineering framework
SW Lee, RA Gandhi - … *Engineering Conference*, 2005

…

Process Specification Language (PSL) ~2003

Top level of PSL Ontology built around:

- **Activity** =def. a class or type of action, such as *install part*, which is the class of actions in which parts are installed
- **Activity-occurrence** =def. an event or action that takes place at a specific place and time, such as a specific instance of *install part* occurring at a specific timestamp
- **Timepoint** =def. a point in time
- **Object** =def. anything that is not a timepoint or an activity.

ISO 18629 from TC 184/SC 4 standards for industrial data

ISO 15926:
Industrial automation systems and integration—Integration of life-cycle data for process plants including oil and gas production facilities

Typical reasons for ontology failure, circa 2005

- No common methodology
- Short half life
- Approaches often tied to data modelling languages (UML, EXPRESS, …)
- Poor documentation (few definitions …)
- No standard language for use in ontology building

Consequence: very few real-world examples of successful use of ontologies in engineering

Ontology Timeline 2: The Semantic Web

1994: Tim Berners-Lee introduced “Semantic Web” at 1st WWW Conference

1994: Resource Description Framework (RDF)

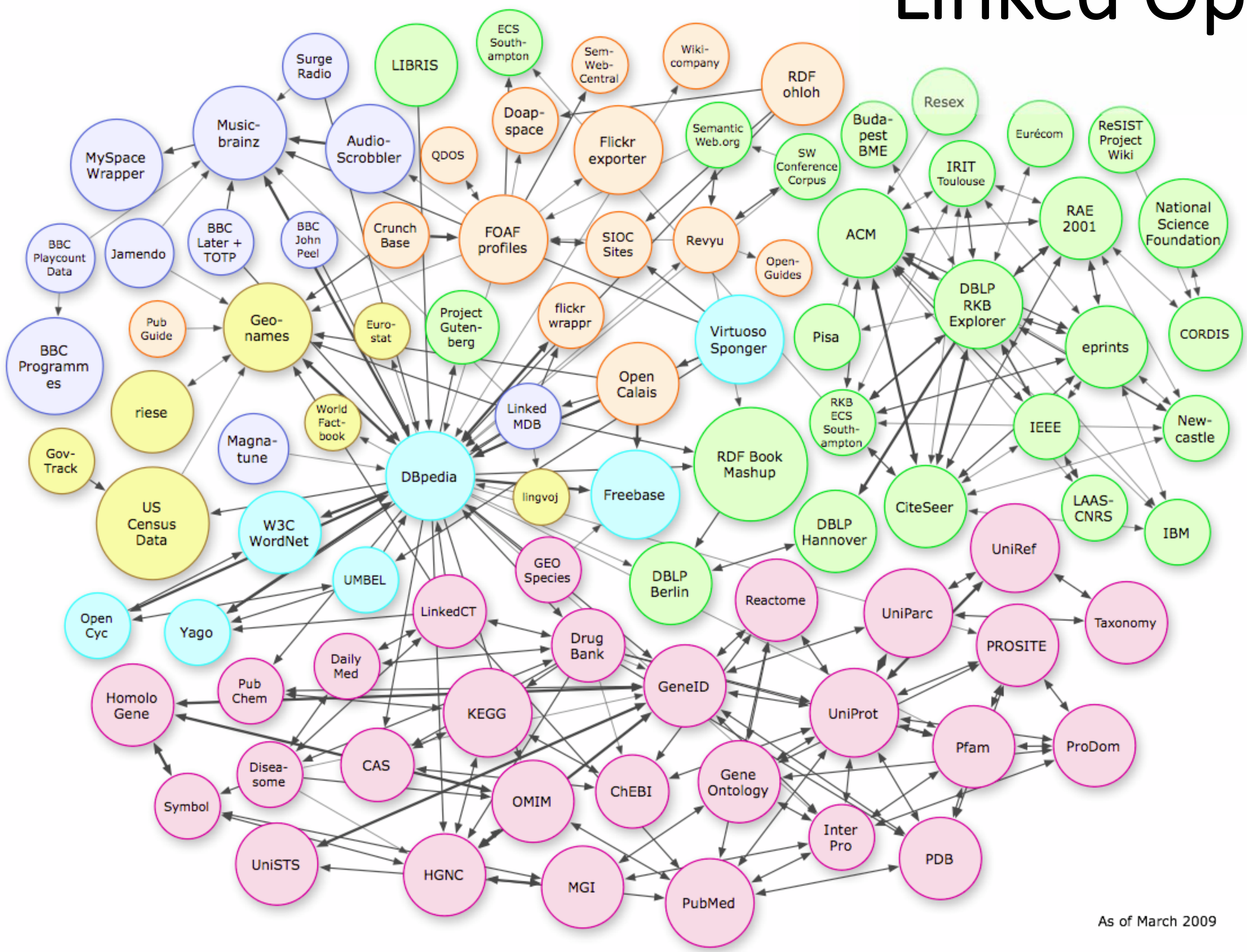
1999: Protégé

2004: Web Ontology Language (OWL) 1.0

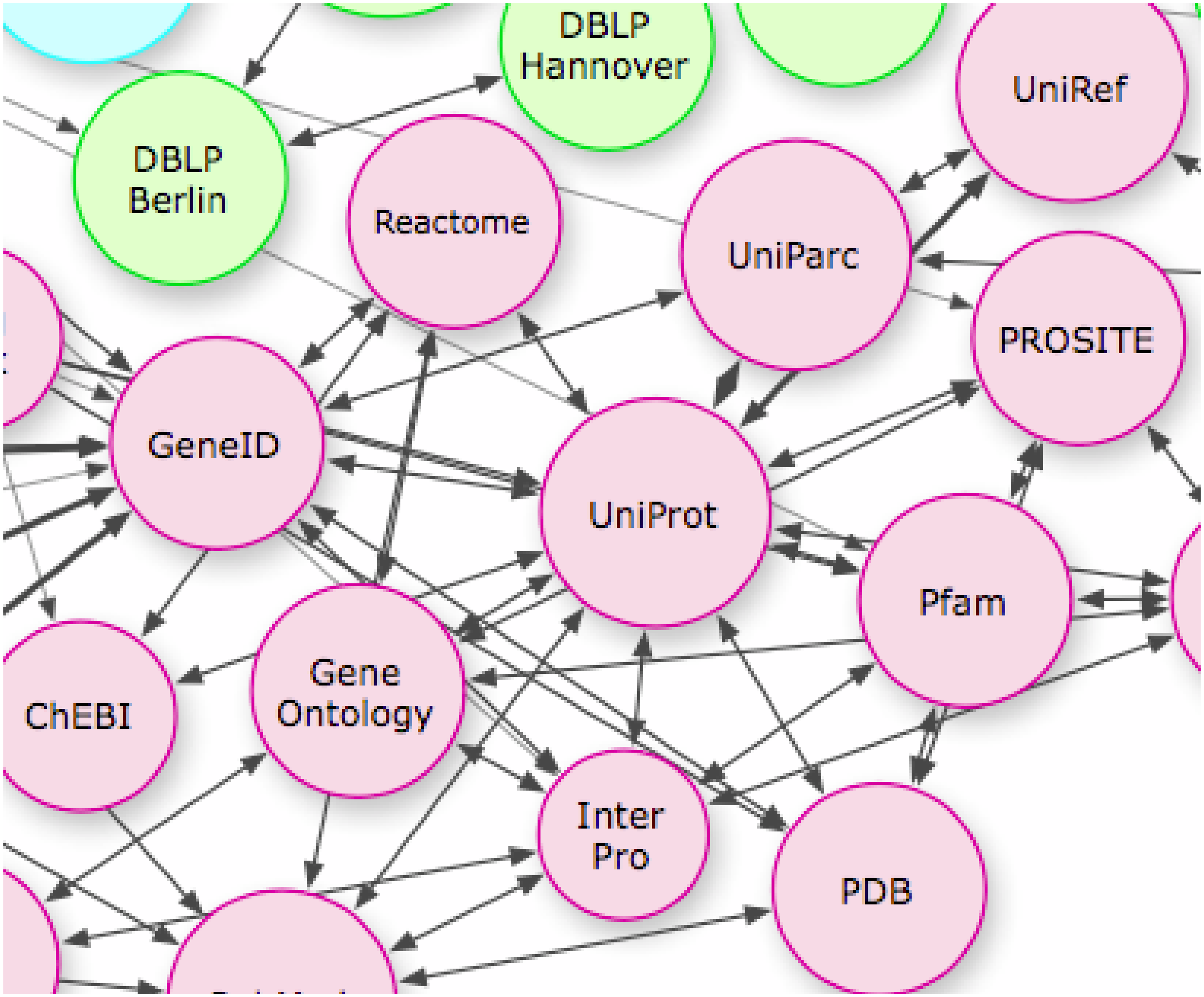
Consequence: ontology proliferation

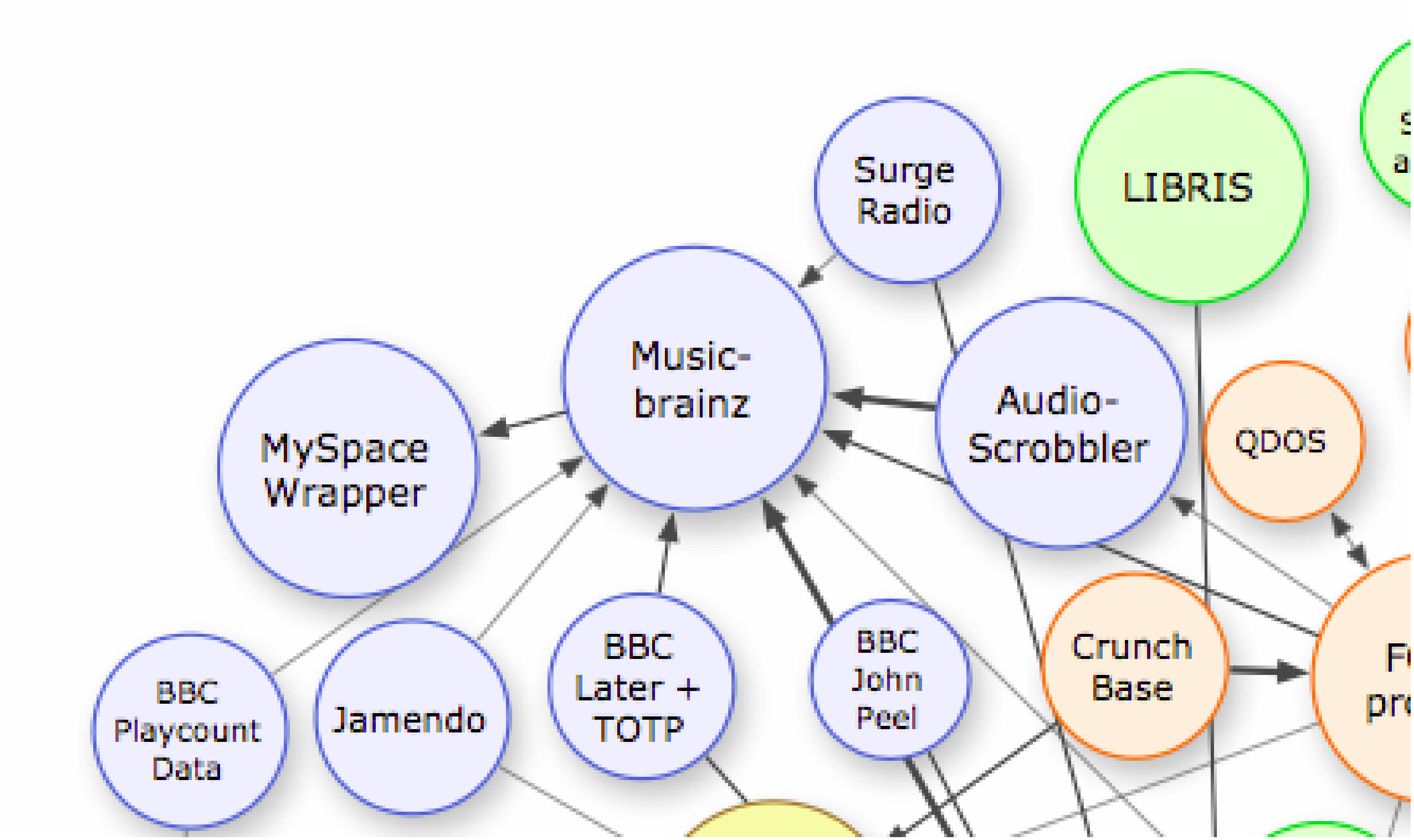
2007: Linked Open Data

Linked Open Data 2009



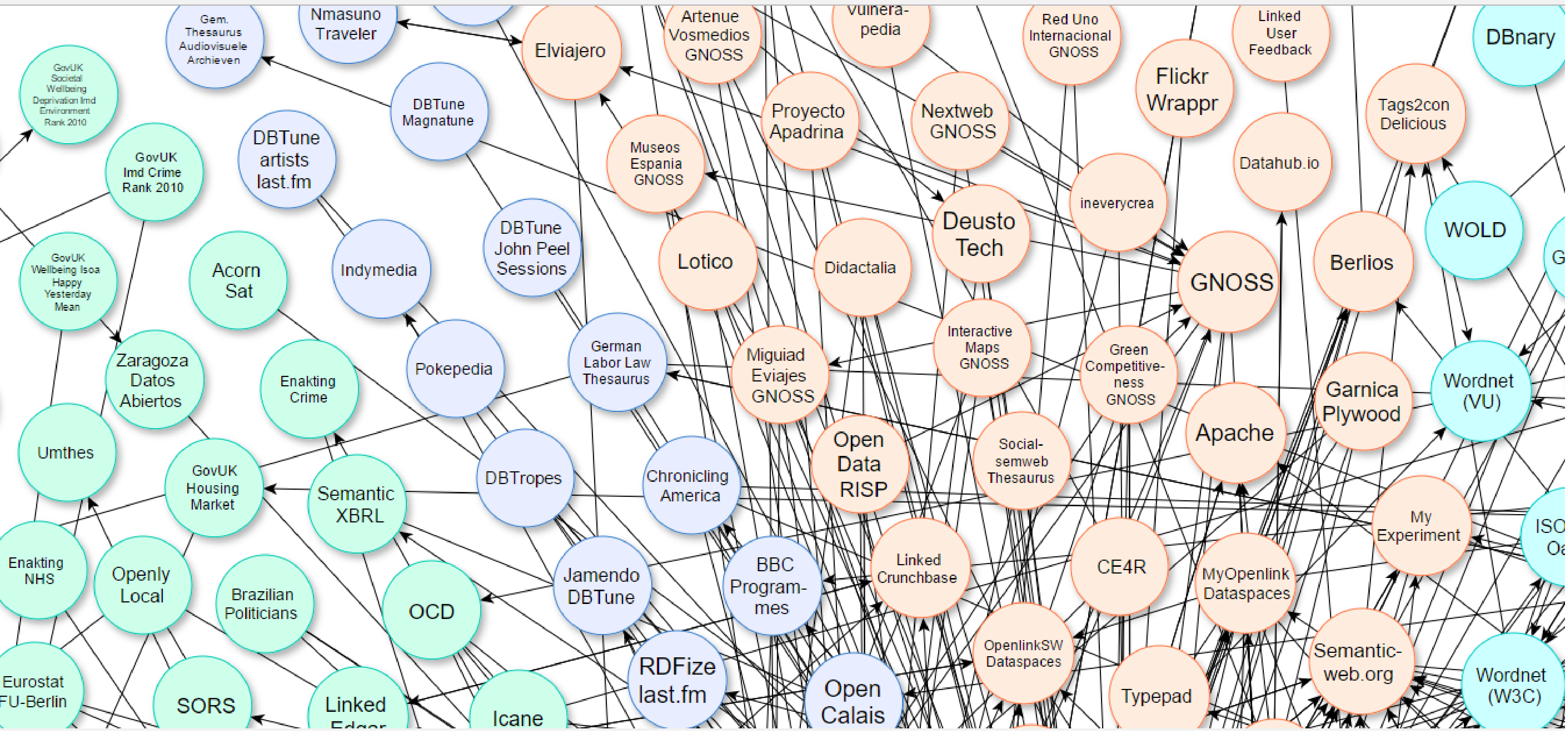
As of March 2009


DBLP Hannover
UniRef
DBLP Berlin
Reactome
UniParc
PROSITE
GeneID
UniProt
Pfam
Gene Ontology
ChEBI
Inter Pro
PDB

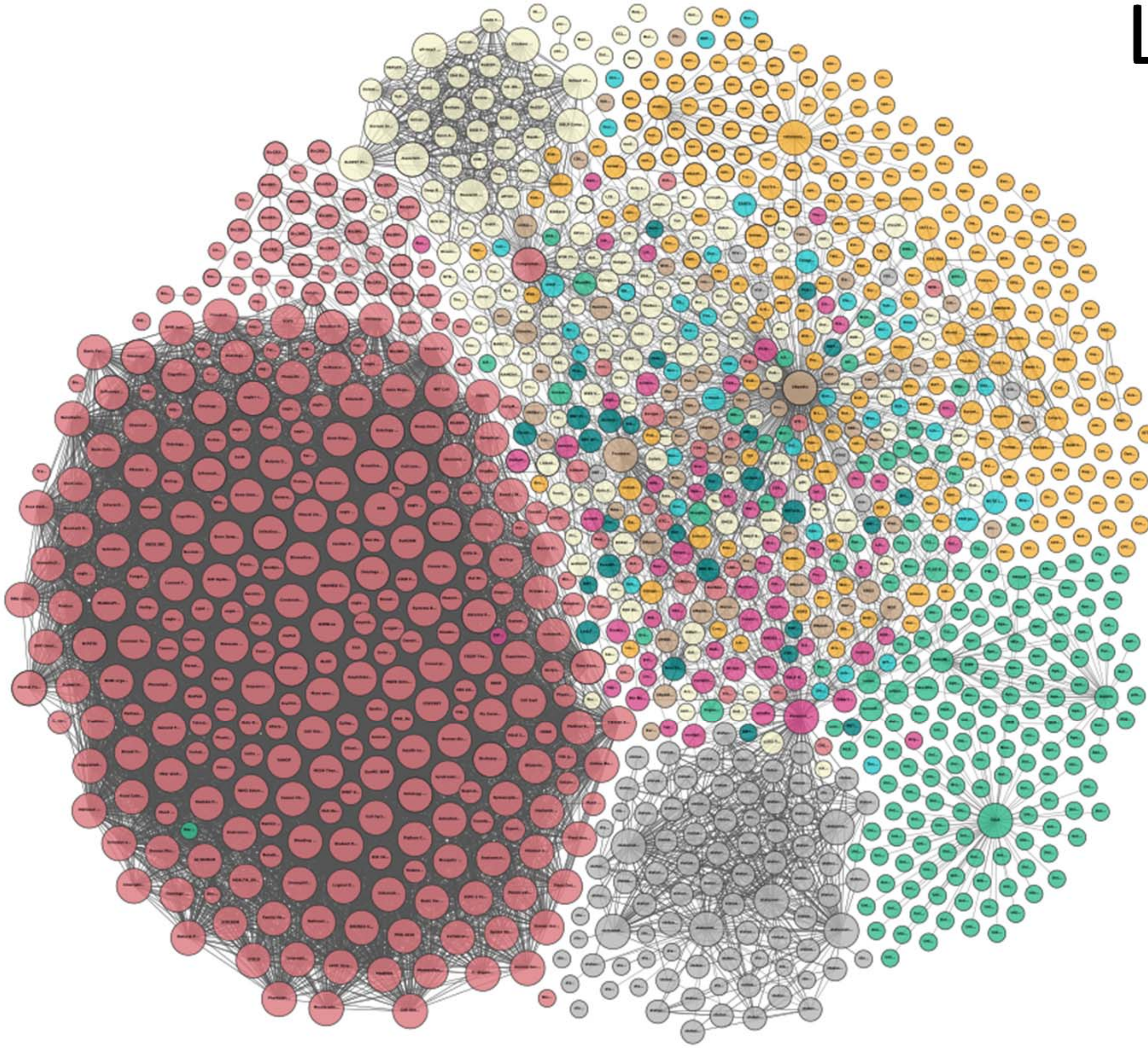


Surge Radio
LIBRIS
Music-brainz
MySpace Wrapper
Audio-Scrobbler
QDOS
BBC Playcount Data
Jamendo
BBC Later + TOTP
BBC John Peel
Crunch Base

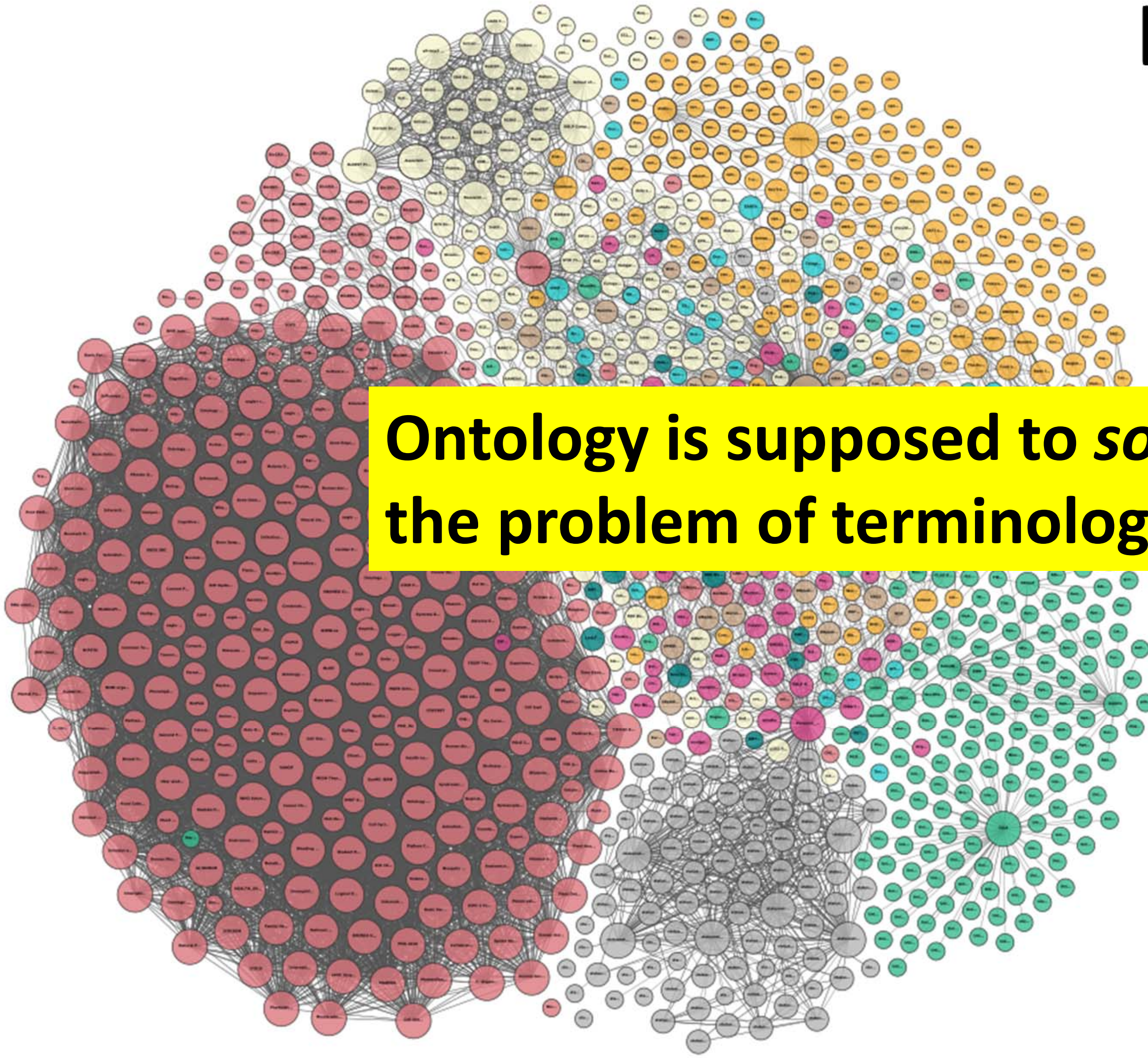
Ontologies are worse than useless when built separately, each in its own way



Linked Open Data 2017



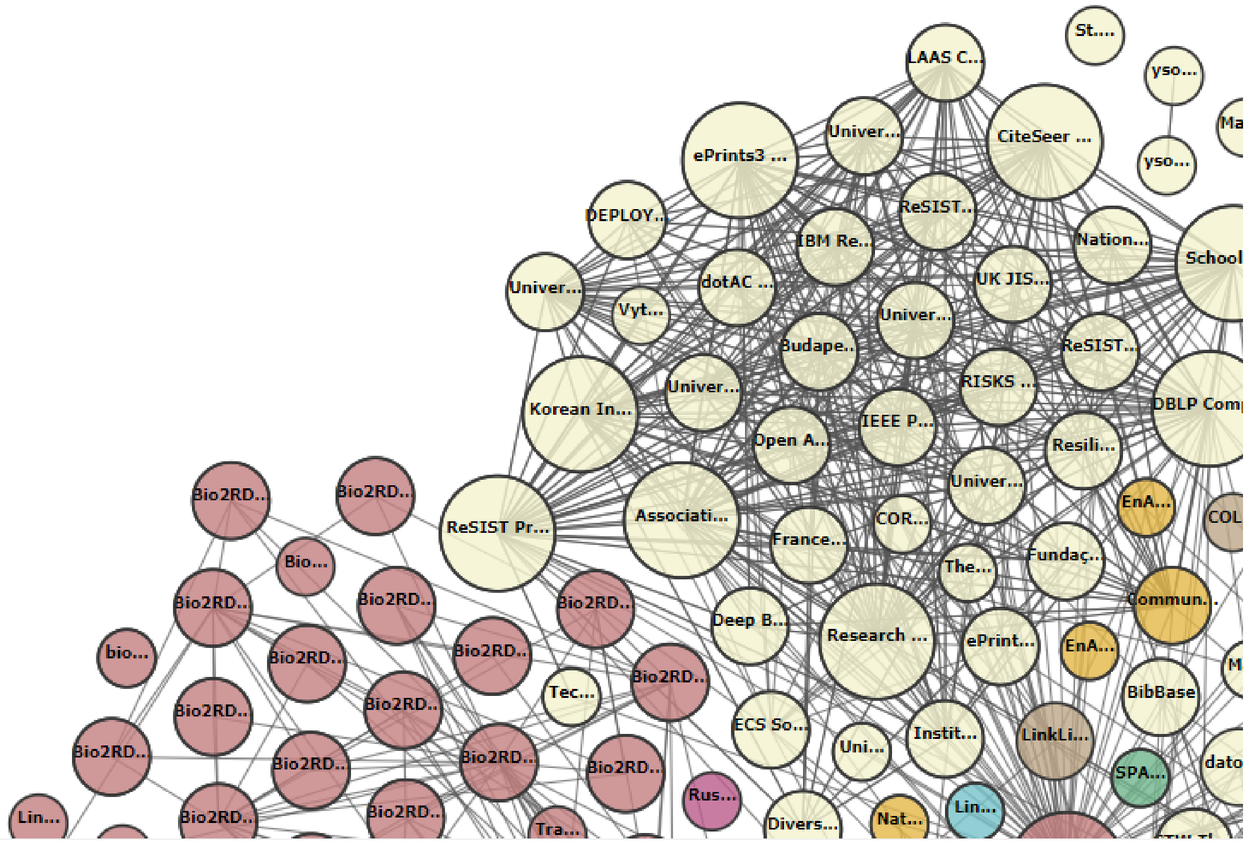
Linked Open Data 2017



Ontology is supposed to *solve* the problem of terminology bloat

Legend

Cross Domain
Geography
Government
Life Sciences
Linguistics
Media
Publications
Social Networking
User Generated
Incoming Links
Outgoing Links



Ontology Timeline 3: Lessons from biology

1990: Human Genome Project

1999: The Gene Ontology (GO)

2002: Open Biomedical Ontologies (OBO)

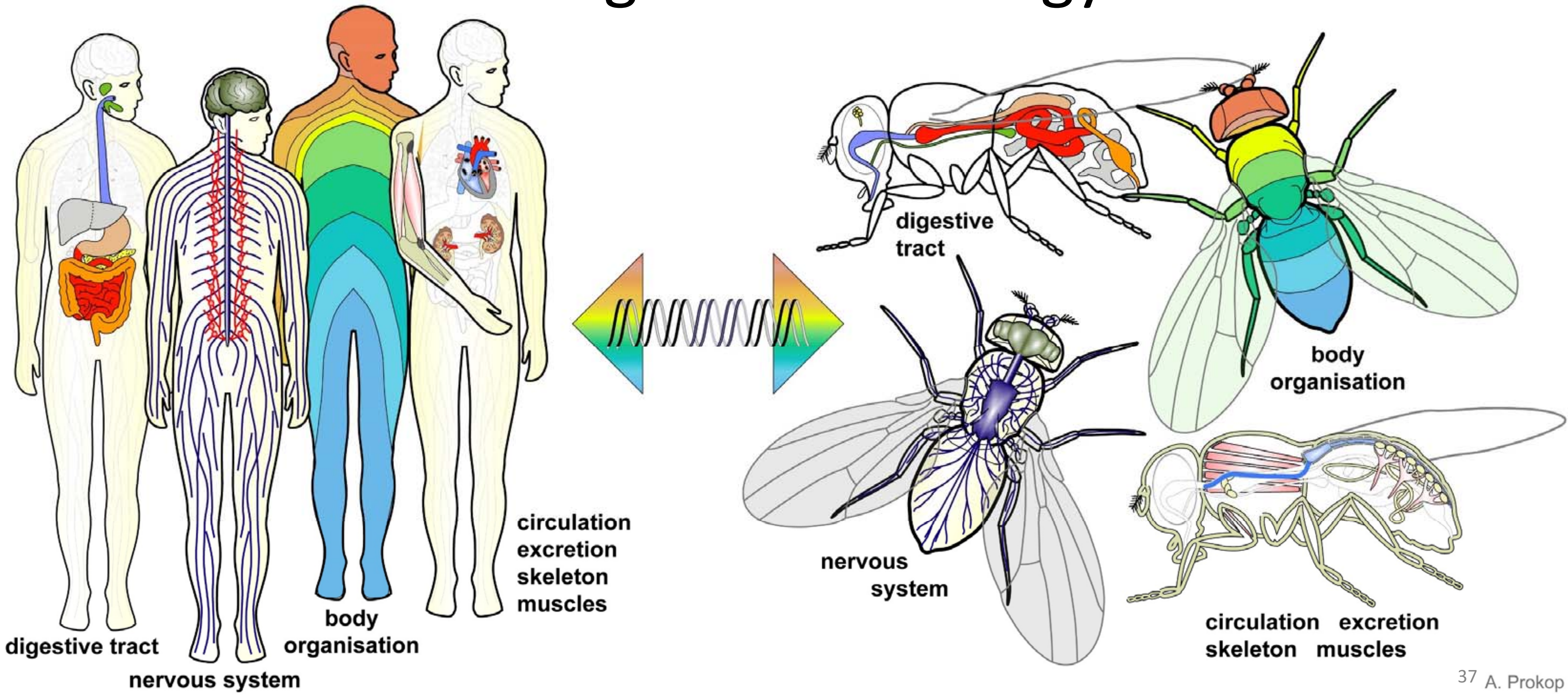
2002: Basic Formal Ontology (BFO)

2005: Age of ontology suites

The importance of the Gene Ontology (GO)

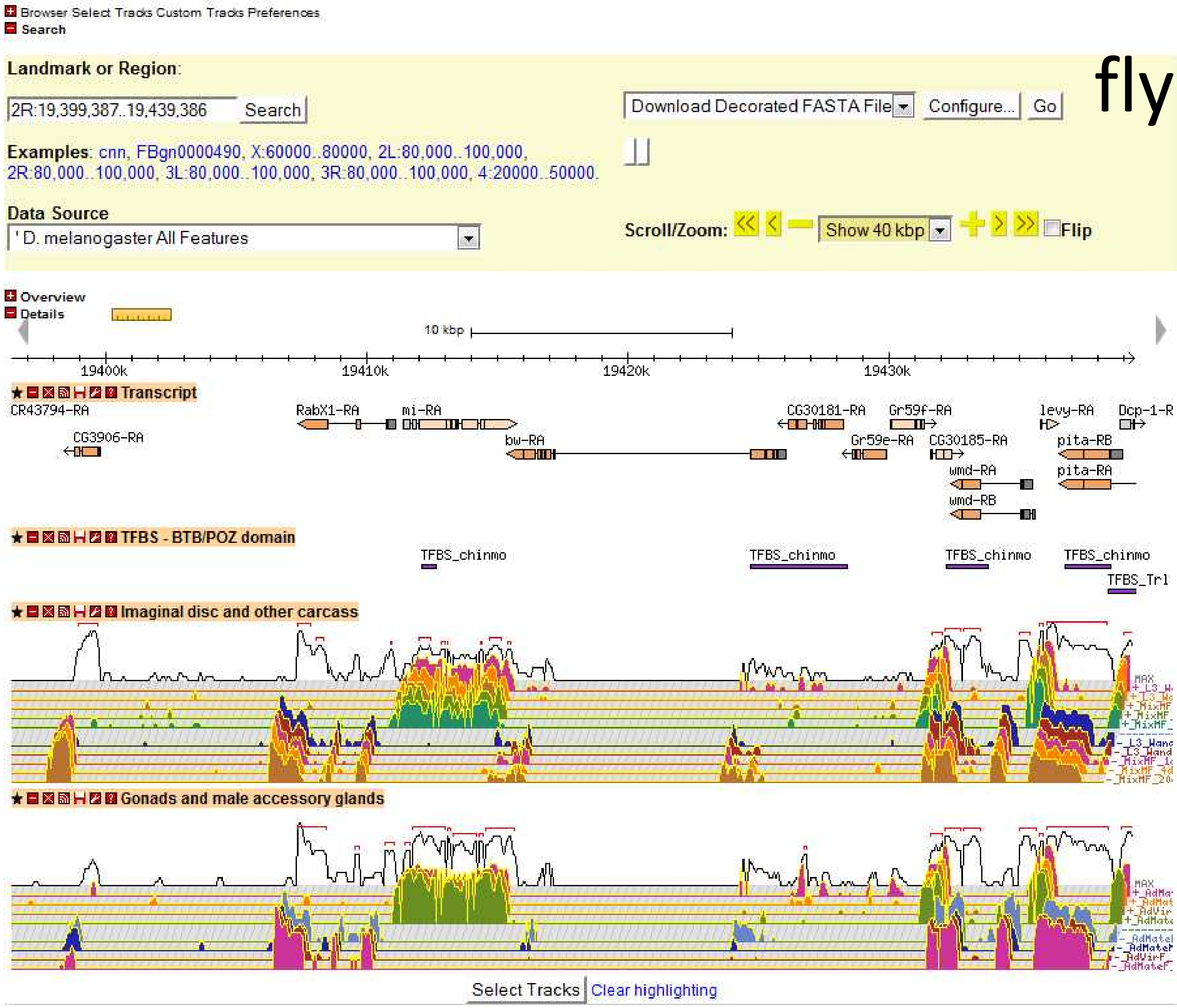
model organisms

each community has developed its own biological terminology



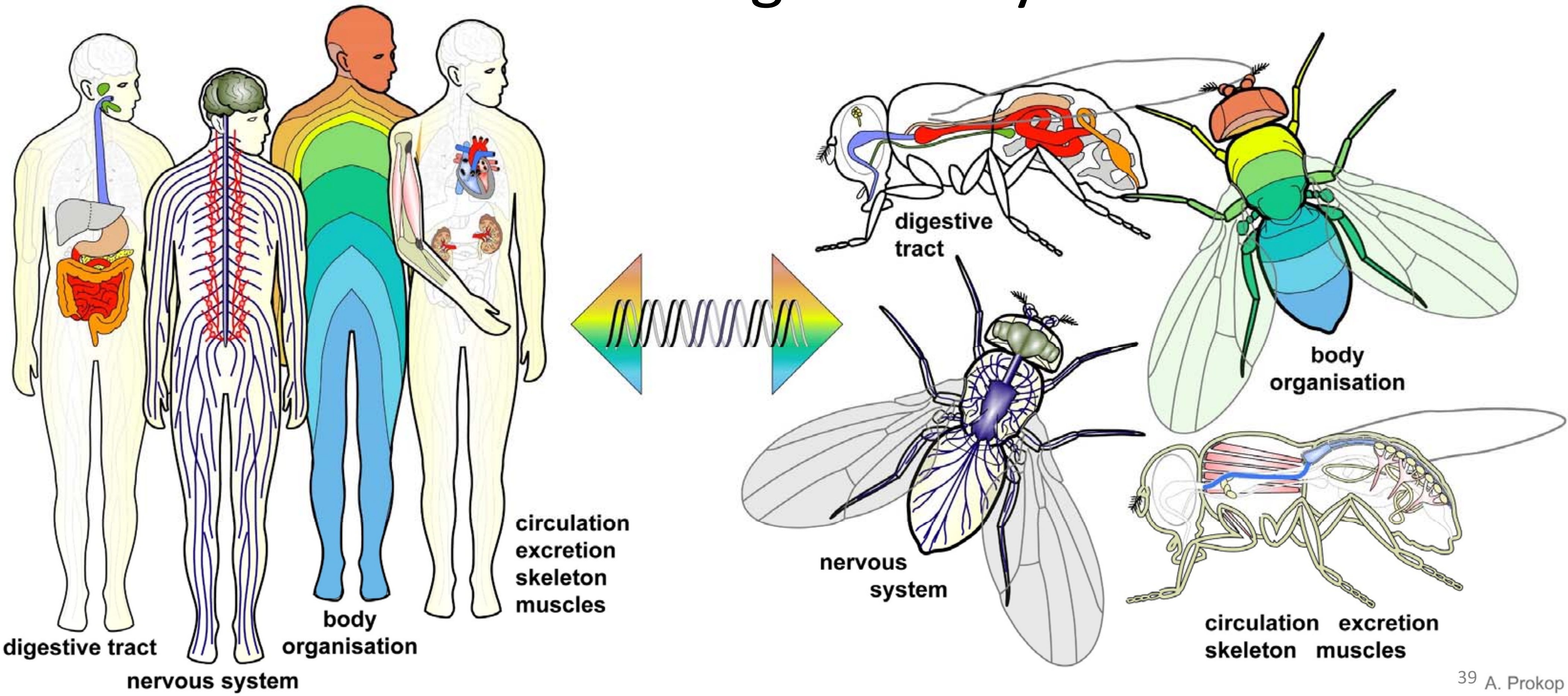
37 A. Prokop

flybase.org



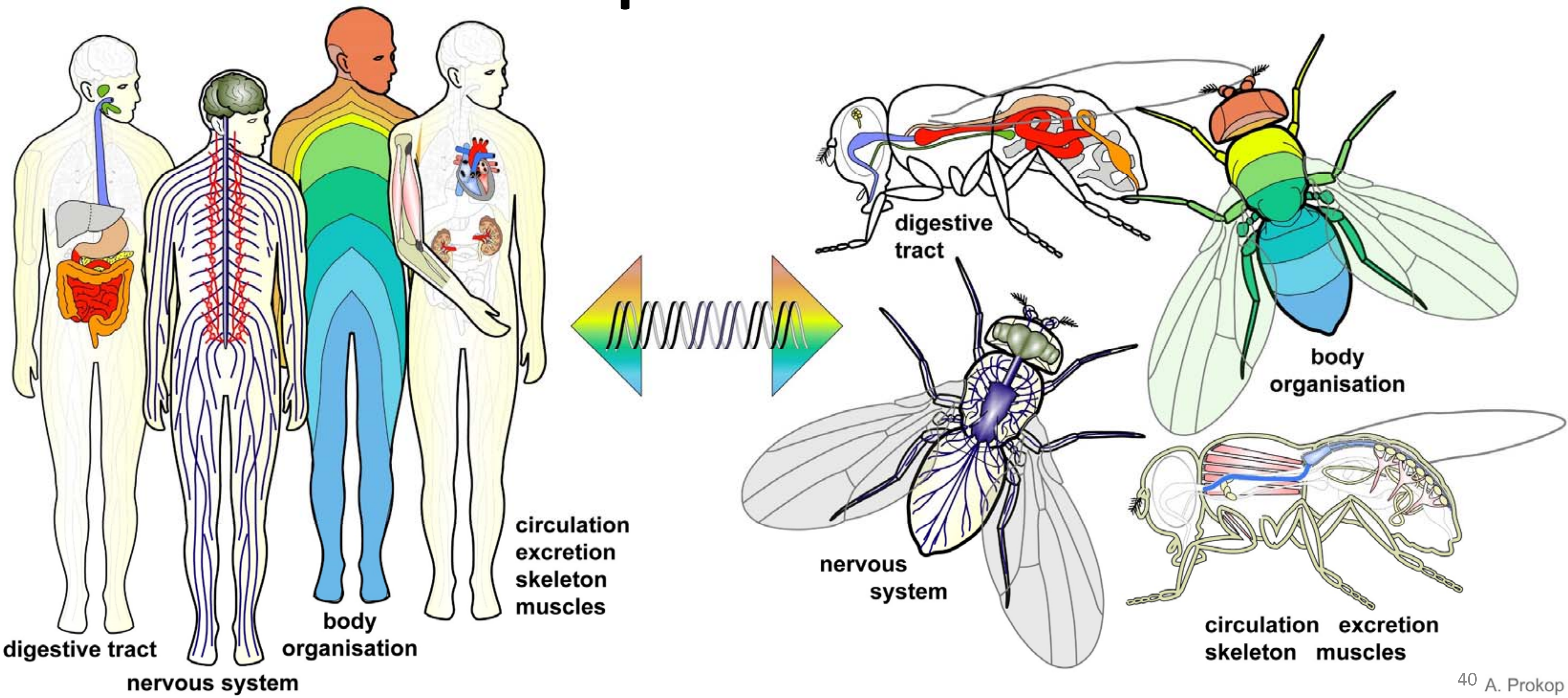
Browser Select Tracks Custom Tracks Preferences
Search
Landmark or Region:
2R:19,399,387..19,439,386
Search
Download Decorated FASTA File
Configure...
Go
Examples: cnn, FBgn0000490, X:60000..80000, 2L:80,000..100,000, 2R:80,000..100,000, 3L:80,000..100,000, 3R:80,000..100,000, 4:20000..50000.
Data Source
D. melanogaster All Features
Scroll/Zoom:
Show 40 kbp
Flip
Overview
Details
10 kbp
19400k
19410k
19420k
19430k
Transcript
CR43794-RA
CG3906-RA
RabX1-RA
mi-RA
bw-RA
CG30181-RA
Gr59f-RA
Gr59e-RA
CG30185-RA
levy-RA
Dcp-1-R
pita-RB
pita-RA
wmd-RA
wmd-RB
TFBS - BTB/POZ domain
TFBS_chinmo
TFBS_chinmo
TFBS_chinmo
TFBS_chinmo
TFBS_Trl
Imaginal disc and other carcass
MAX
Gonads and male accessory glands
MAX
Select Tracks
Clear highlighting

future proof an ontology = rise up to a higher level of generality



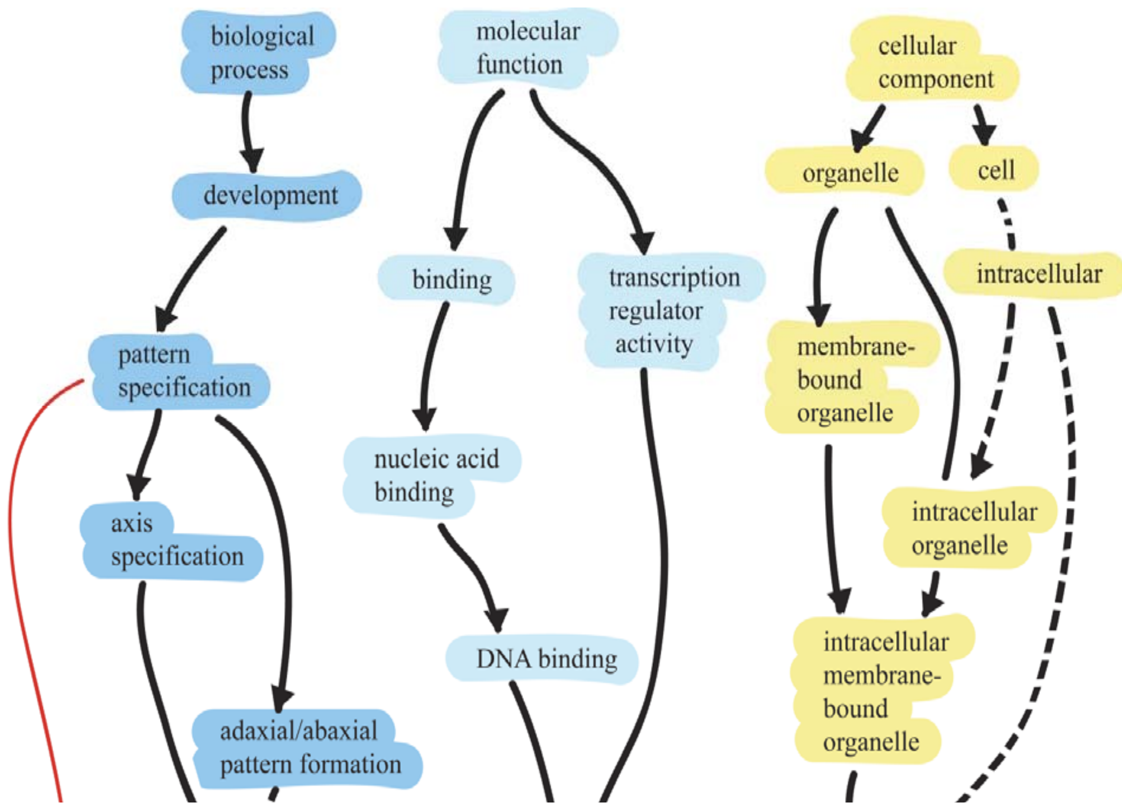
 A. Prokop

GO is an ontology for tagging genome data that is **species neutral**



GO consists of three sub-ontologies

Biological Process | **Molecular Function** | **Cellular Component**



nature biotechnology

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- *Nature Biotechnology*

Perspective

Nature Biotechnology **25**, 1251 - 1255 (2007)
Published online: 7 November 2007 | doi:10.1038/nbt1346

The OBO Foundry: coordinated evolution of ontologies to support biomedical data integration

Barry Smith[1], Michael Ashburner[2], Cornelius Rosse[3], Jonathan Bard[4], William Bug[5], Werner Ceusters[6], Louis J Goldberg[7], Karen Eilbeck[8], Amelia Ireland[9], Christopher J Mungall[10], The OBI Consortium[11], Neocles Leontis[12], Philippe Rocca-Serra[9], Alan Ruttenberg[13], Susanna-Assunta Sansone[9], Richard H

Typical reasons for ontology failure, circa 2015

- Too many ontologies being built (people think it is easy to do)
- Too much redundancy between ontologies
- Too much inconsistency between ontologies
- Still no common methodology

But

- now we have a (mostly) accepted common language
- and we are beginning to see examples of widely acknowledged **principles of best practice**

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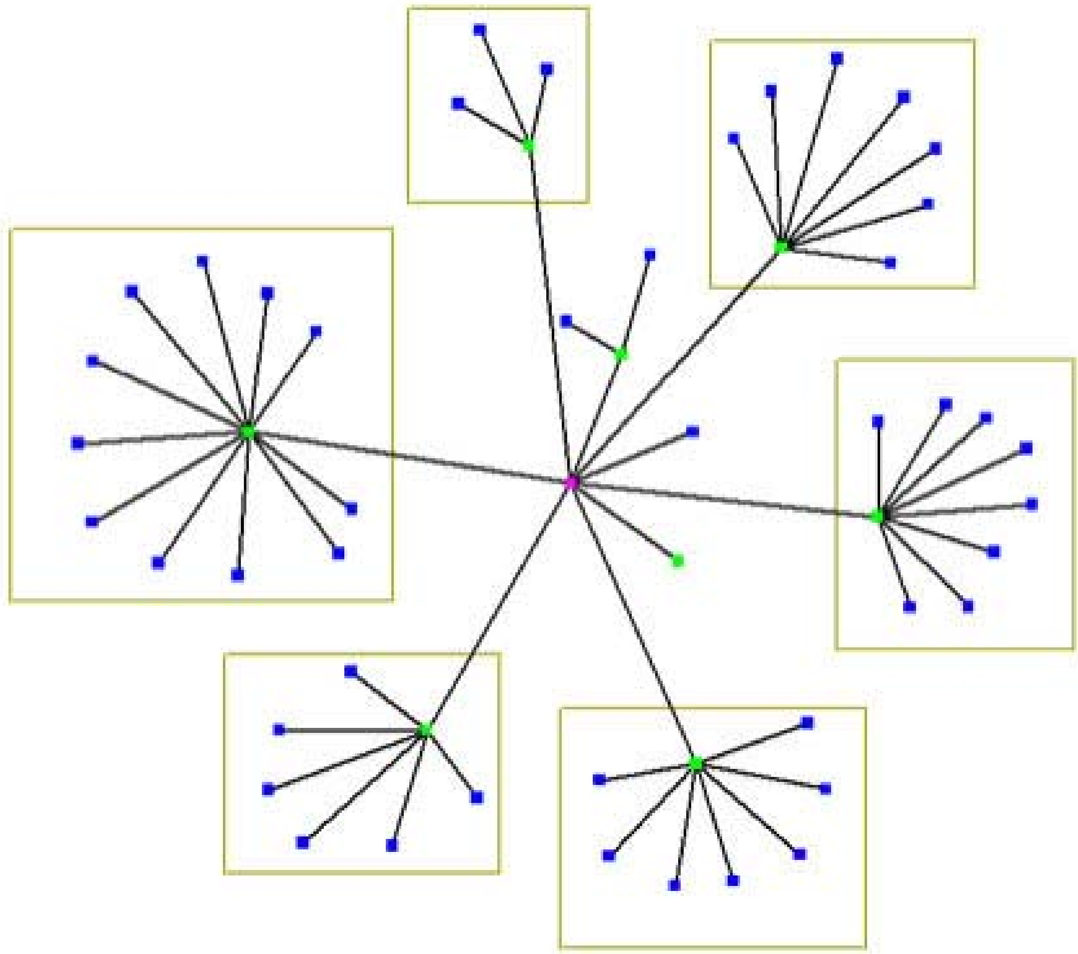
Ontology Suites

Best practice principles for ontology building

The core of these principles

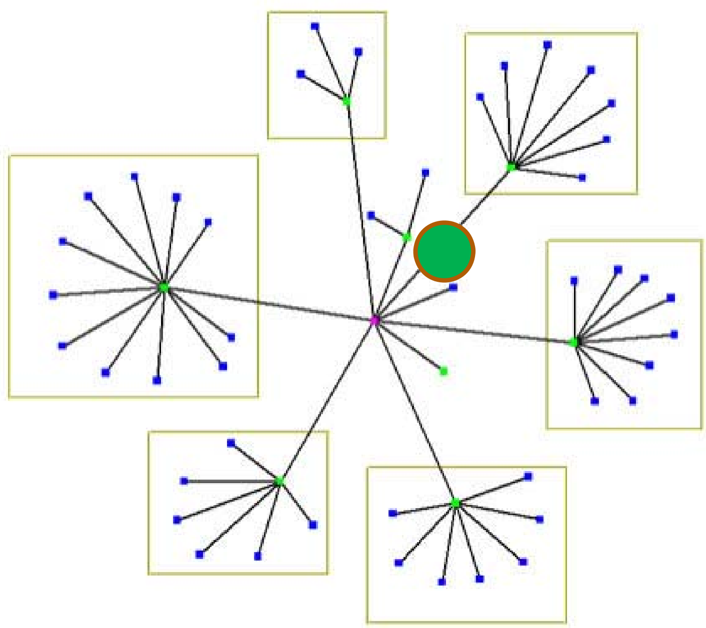
- Start out from **domain-neutral top level** ontology
- Follow a hub-and-spokes approach: Create **suites** of consistently developed ontology modules, with suite-wide oversight to ensure non-redundancy between modules
- Rigorously enforce **reuse** of more general ontology content in more specific ontology resources (from reference ontologies to application ontologies)

Hub and spokes approach



ontologies are networked together and developed in coordination with each other

terms in **spokes** ontologies are defined logically using terms from ontologies nearer the **hub**



Examples of ontology suites

suite	domain	date	IRI	hub
Toronto Virtual Enterprise (TOVE)	enterprise modeling	1998	https://www.aaai.org/ojs/index.php/aimagazine/article/view/1399	Yes
Gramene: Trait and Gene Ontologies for Rice	plant science	2002	http://onlinelibrary.wiley.com/doi/10.1002/cfg.156/full	Yes
Open Biomedical Ontologies (OBO) Library	life sciences	2003	http://onlinelibrary.wiley.com/doi/10.1002/bies.10260/full	Yes (GO)
Semantic Web for Earth and Environmental Terminology (SWEET)	earth and environmental sciences	2003	https://esto.ndc.nasa.gov/conferences/estc2003/papers/A7P2(Raskin).pdf	No
Legal Informatics Ontologies (LRI-Core)	legal informatics	2004	https://link.springer.com/article/10.1007/s10506-006-0002-1	Yes
Open Biomedical Ontologies (OBO) Foundry	life sciences	2005	https://www.nature.com/nbt/journal/v25/n11/full/nbt1346.html	Yes (BFO)
Marine Metadata Interoperability Project	oceanography	2009	http://ieeexplore.ieee.org/document/5422206/	No

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Open Biomedical Ontologies (OBO) Library	life sciences	2003	http://onlinelibrary.wiley.com/doi/10.1002/bies.10260/full	Yes (GO)
Semantic Web for Earth and Environmental Terminology (SWEET)	earth and environmental sciences	2003	https://esto.ndc.nasa.gov/conferences/estc2003/papers/A7P2(Raskin).pdf	**NO**
Legal Informatics Ontologies (LRI-Core)	legal informatics	2004	https://link.springer.com/article/10.1007/s10506-006-0002-1	Yes
Open Biomedical Ontologies (OBO) Foundry	life sciences	2005	https://www.nature.com/nbt/journal/v25/n11/full/nbt1346.html	Yes (BFO)
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Legal Informatics Ontologies (LRI-Core)	legal informatics	2004	https://link.springer.com/article/10.1007/s10506-006-0002-1	Yes
Open Biomedical Ontologies (OBO) Foundry	life sciences	2005	https://www.nature.com/nbt/journal/v25/n11/full/nbt1346.html	Yes (BFO)
Marine Metadata Interoperability Project	oceanography	2009	http://ieeexplore.ieee.org/document/5422206/	No

further examples of suite formation

suite	users	date	hub
Common Core Ontologies (CCO)	US Army / I2WD and ARL, IARPA, JIDO, ONR, AFRL …	2010	BFO
Common Intelligence Community Ontology	DNI, CIA, DIA, …	~2014	BFO
USGS National Map	United States Geological Survey	~2014	BFO
Joint Doctrine Ontologies	US Air Force Research Labs (part of CCO)	2015	BFO
Transportation Research Informatics Platform (TRIP) Ontologies	Federal Highway Administration (FHWA)	2015	BFO
UNEP Ontology Framework	United Nations Environment Programme	2016	BFO
Industrial Ontologies Foundry (IOF)	Ontologies to support digital manufacturing (NIST)	2016	BFO

suites built following OBO Foundry principles

suite	users	date	hub
Common Core Ontologies (CCO)	US Army / I2WD and ARL, IARPA, JIDO, ONR, AFRL …	2010	BFO
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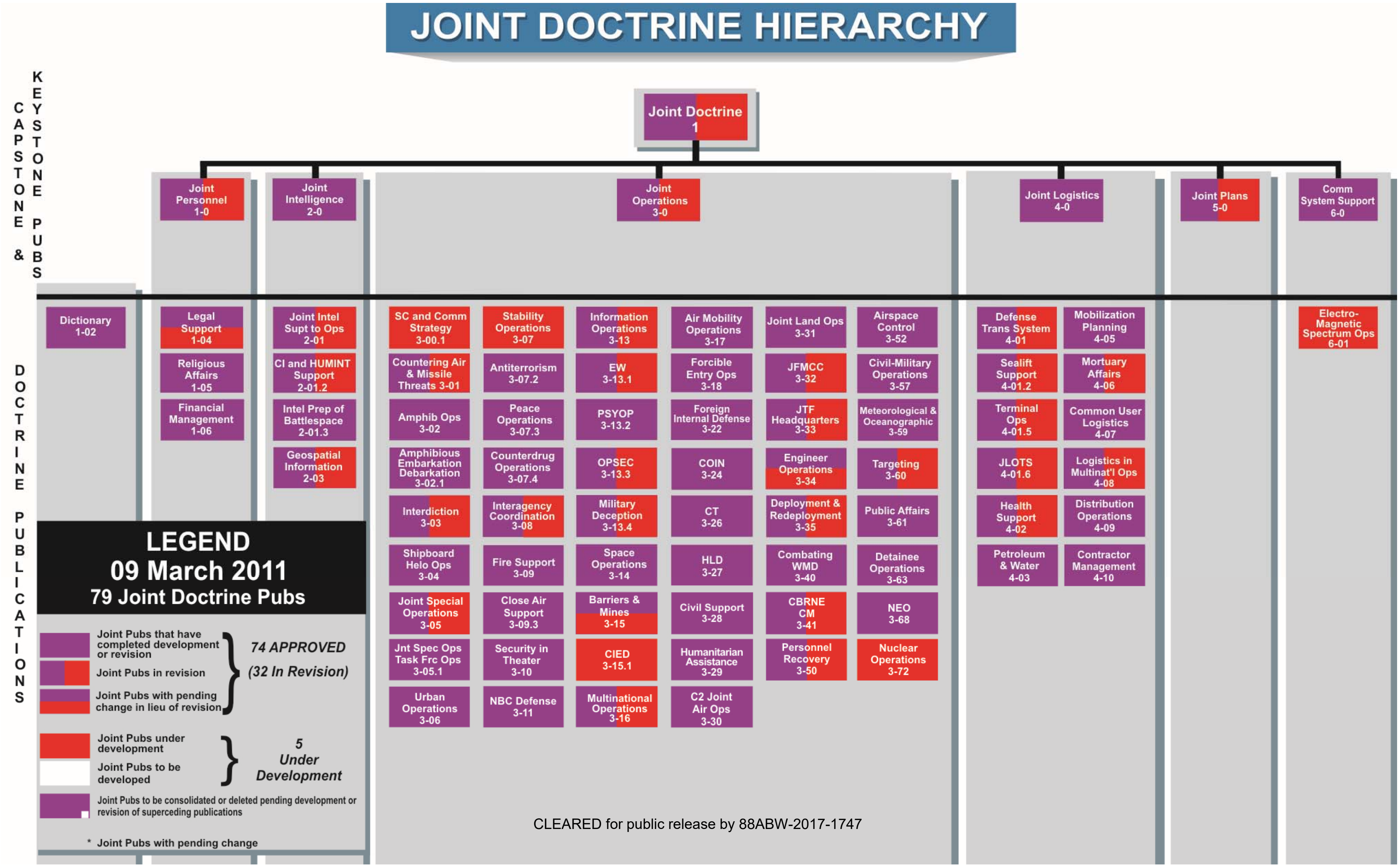
Industrial Ontologies Foundry (IOF)	Ontologies to support digital manufacturing (NIST)	2016	BFO



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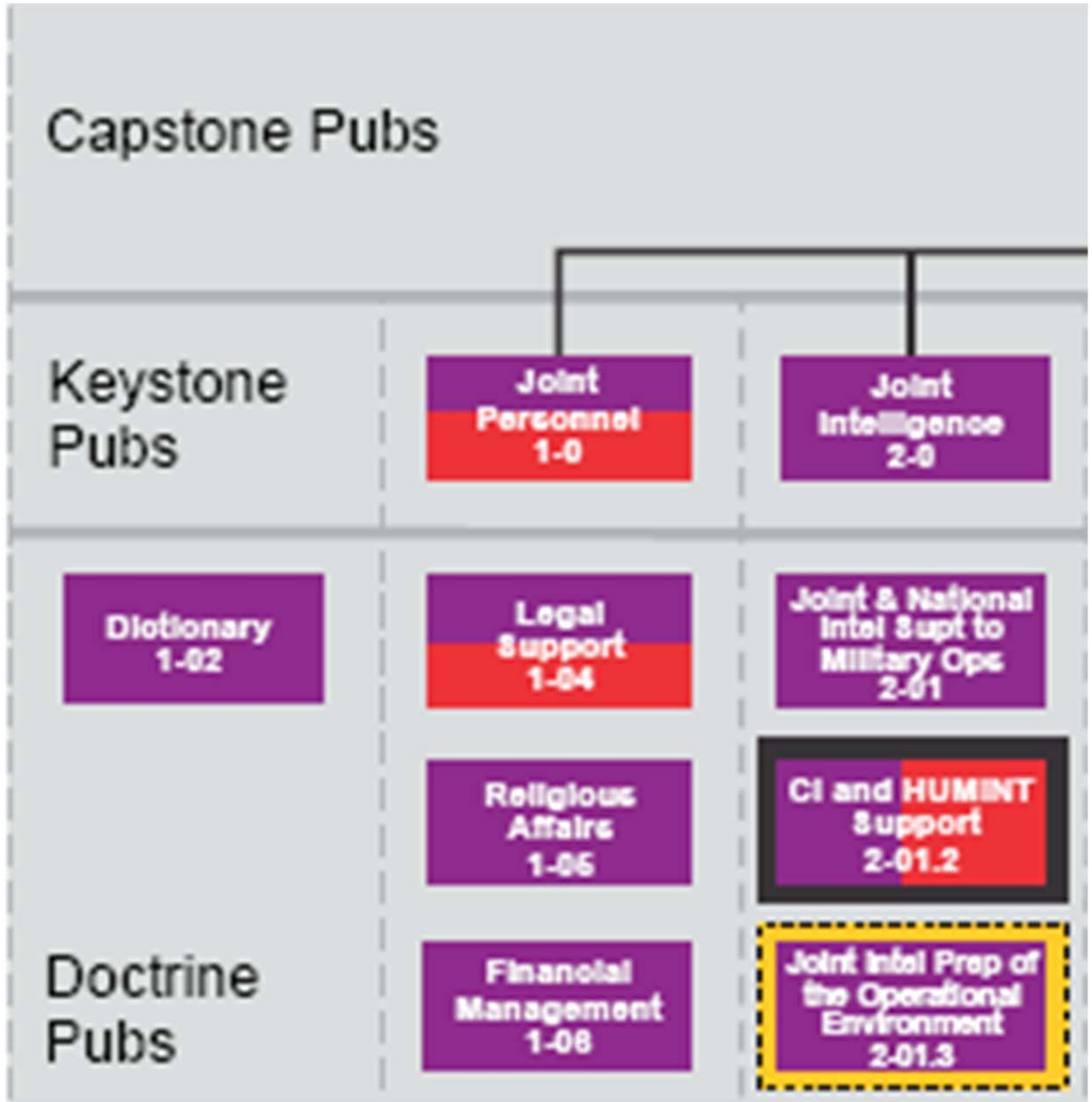
JP 1-02



Capstone Pubs
Keystone Pubs
Joint Personnel 1-0
Joint Intelligence 2-0
Dictionary 1-02
Legal Support 1-04
Joint & National Intel Supt to Military Ops 2-01
Religious Affairs 1-05
CI and HUMINT Support 2-01.2
Doctrine Pubs
Financial Management 1-06
Joint Intel Prep of the Operational Environment 2-01.3

Joint Publication 1-02

Department of Defense Dictionary of Military and Associated Terms

8 November 2010

(As Amended Through 15 December 2013)

Goals of the Joint Doctrine Ontology (JDO) initiative

1. Create JDO, a computational counterpart of the DoD Dictionary of Military and Associated Terms (JP 1-02)

2. Test JDO in Air Force Research Lab (AFRL) and related initiatives to support joint operations

3. Use JDO to promote reuse of Joint Doctrine terminology in IT resources across DoD as part of a strategy to advance interoperability

JDO as computational shadow of JP 1-02

national center for ontological research
ncor

Built for humans

intratheater airlift — Airlift conducted within a the
combatant commander or attached to a subor
intertheater airlift. (JP 3-17)

intratheater patient movement — Moving pati
command or in the continental United States.
intertheater patient movement. (JP 4-02)

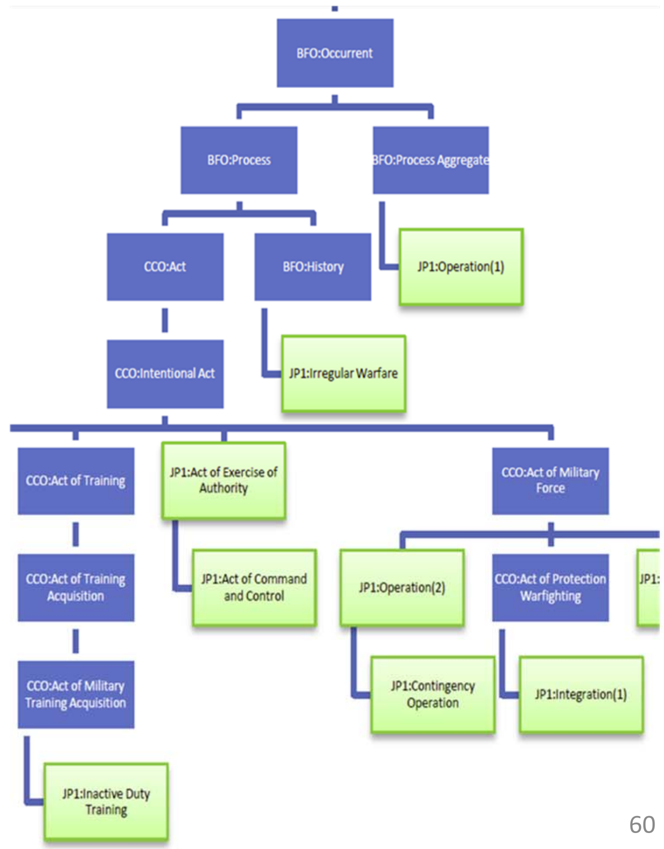
inventory control — That phase of military logis
requirements determinations, procurement, c
materiel. Also called **inventory manag**
management; supply management. (JP 4-09

inventory control point — An organizational unit o
supply system that is assigned the primary r
management of a group of items either for a
Department as a whole. Also called **ICP.** (JP 4

ionizing radiation — Particulate (alpha, beta, and n
gamma) radiation of sufficient energy to displa
(JP 3-11)

irregular warfare — A violent struggle among stat
influence over the relevant population(s). Also

Built for computers



What is Joint Doctine for?

- To achieve joint action
- Initially joint action = action involving live forces from more than one Service
- Increasingly joint action = action involving not only life forces but also automatic systems

Joint action requires interoperability of people and information systems

Interoperability = def. The ability of systems, units, or forces to provide data, information, materiel, and services to, and accept the same from, other systems, units, or forces, and to use the data, information, materiel, and services exchanged to enable them to operate effectively together.

DoD Instruction 8330.01

How is interoperability to be achieved?

DoD Instruction (DoDI) 8330.01:

By adherence to standards listed in the DoD IT Standards Registry (DISR).

How can we make the definitions of JP 1-02 serve as a benchmark of interoperability for military (IT) systems?

DoD requires that joint doctrine addresses the need for IT interoperability.

DoD does not require – and has no effective strategy to ensure – that the IT procedures themselves address the need for conformity with joint doctrine.

But such conformity is indispensable for unified action involving human warfighters and IT systems

> and it would also bring benefits to military IT systems, including the Joint Doctrine Development System itself

The role of general categories

- JP 1-02 defines the
- standard US military and associated terminology to encompass the joint activity of the Armed Forces of the United States. These military and associated terms, together with their definitions**, constitute approved Department of Defense (DOD) terminology for general use by all DOD components.**

- (JP 1-02, Preface signed by Vice Admiral William E. Gortney, Director of the Joint Staff)

Importance of categories (Peter Morosoff)

- The purpose of military doctrine is to facilitate commanders and other warfighters in understanding the realities of war and their specific situations and then in accomplishing their missions.
- It achieves these ends largely through the identification and explanation of important general categories rather than of specific instances (such as a particular aircraft or IT system).
- Doctrine is in this sense re-usable; it is applicable to many different instances and to many different subkinds of the same general categories.
- This approach is effective because the basic realities of war are not changed by the fielding of new commanders, equipment, specialties, or tactics.

Joint Doctrine Ontology will use the language of joint doctrine

- JDO is in effect a shadow of JP 1-02, incrementally adding definitional enhancements and further elements of logical regimentation, but in such a way that the ontology and the dictionary which underlies it remain synchronized with each other through each successive revision of joint doctrine.

Joint Doctrine is authoritative

1. if conflicts arise between it and Service doctrine, then the former – absent more current and specific guidance from the Chairman of the Joint Chiefs of Staff – will take precedence.
2. that it is to be followed except when, in the judgment of the commander, exceptional circumstances dictate otherwise.

Joint Doctrine is **logically** authoritative

3. Terms used in Army doctrine to refer to Army-specific categories defined should be defined as subcategories of the corresponding Joint Doctrine category

Doctrine is authoritative during real warfighting

- Doctrine provides what we can think of as a common mental model – a shared frame of reference – which remains active through every phase of every military engagement.
- Doctrine provides the principles which determine how to understand the authorized command relationships and the authority that military commanders can use.
- It establishes common ways of accomplishing military tasks and facilitates readiness by promoting coordination in all aspects of training and planning.

Examples of gaps in JP 1-02

action	nation
agent	national organization
authority	order
commander	organization
geographical area	territory
geopolitical entity	training

Step 1 for creating JDO as JP 1-02 shadow

Fill gaps with logically well-formed definitions tying JP 1-02 to Common Core Ontologies

Step 2 for creating JP 1-02 shadow

Remove logical errors in existing definitions (for example in definitions which confuse the entity you are defining with the term used to represent that entity):

operational area — An overarching term encompassing more descriptive terms (such as area of responsibility and joint operations area) for geographic areas in which military operations are conducted.

Step 3 for creating JP 1-02 shadow

Ensure that each term has exactly one definition

Disambiguate those terms in JP 1-02 which have multiple definitions

- **command** — 1. The authority that a commander in the armed forces lawfully exercises over subordinates by virtue of rank or assignment. 2. An order given by a commander; that is, the will of the commander expressed for the purpose of bringing about a particular action. 3. A unit or units, an organization, or an area under the command of one individual.

by replacing one term with multiple terms making the distinctions explicit

1. **command authority**
2. **commander’s order** (expressing the will of the commander)
3. **command unit**

Uses of JDO

- Better definitions
- Better Command and Control (C2)
- Netcentricity – discovery of data
- Outcomes research
- Facilitating DoD IT interoperability
- Facilitating unified action among IT developers.
  - today, even the best-intentioned IT developers must make assumptions on whether a warfighting term in a specification that is not listed in joint doctrine is valid as it is or has been superseded by more a current term

Approved for Public Release; Distribution Unlimited: 88ABW-2015-2881, 08 Jun 2015

Joint Doctrine Ontology: A Benchmark for Military Information Systems Interoperability

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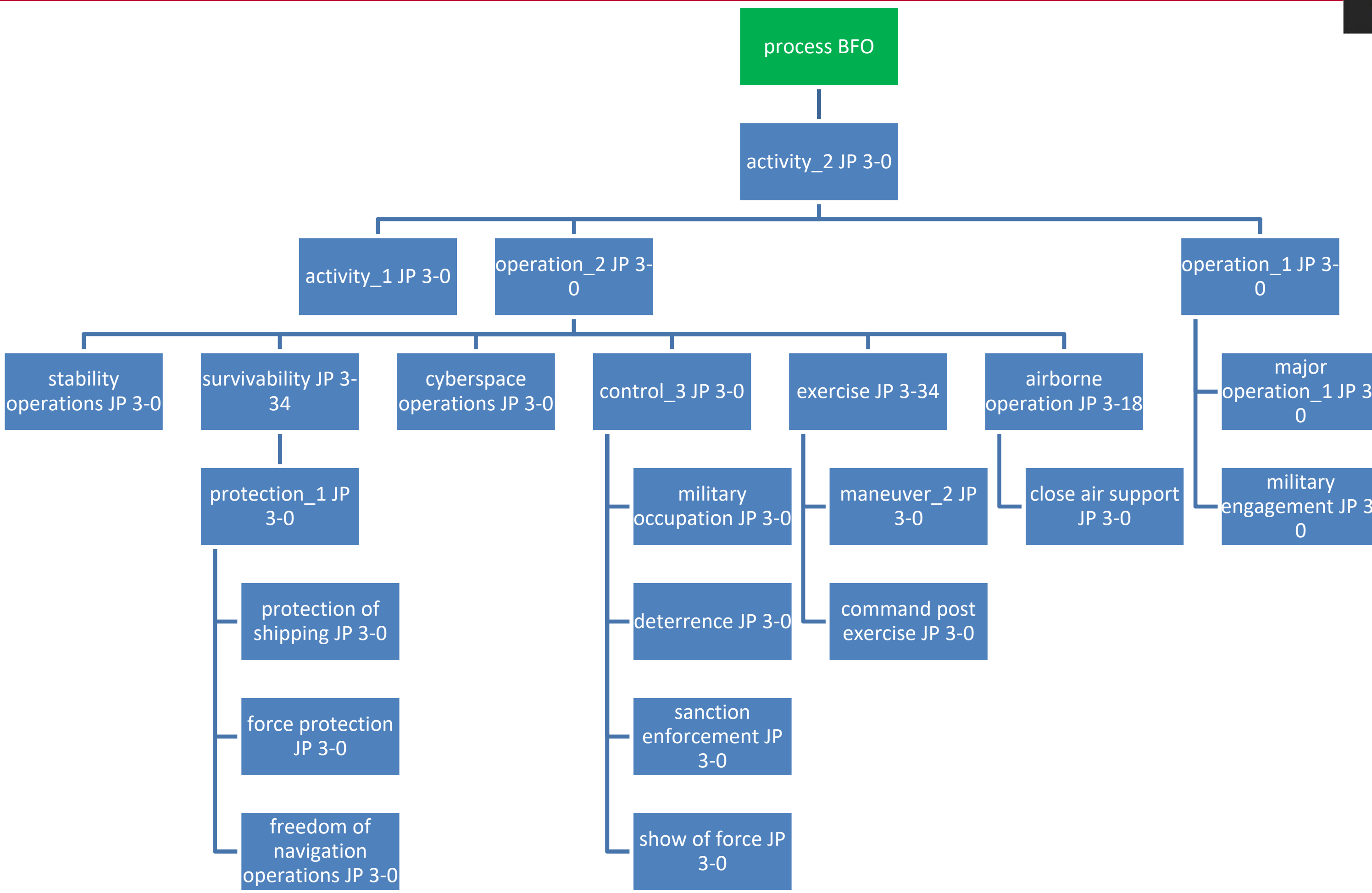
***Abstract*—When the U.S. conducts warfare, elements of a force are drawn from different Services and work together as a single team to accomplish an assigned mission on the basis of joint doctrine. To achieve such unified action, it is necessary that specific Service doctrines be both consistent with and subservient to joint doctrine. But there are two further requirements that flow from the ways in which unified action**

critical, if we are to prevent higher-level flaws cascading to domain-level doctrinal errors, that the terms of joint doctrine be defined correctly.

It is commonly supposed that doctrine provides not hard and fast rules but rather merely a loose and always revisable guide to action that is typically abandoned on first contact

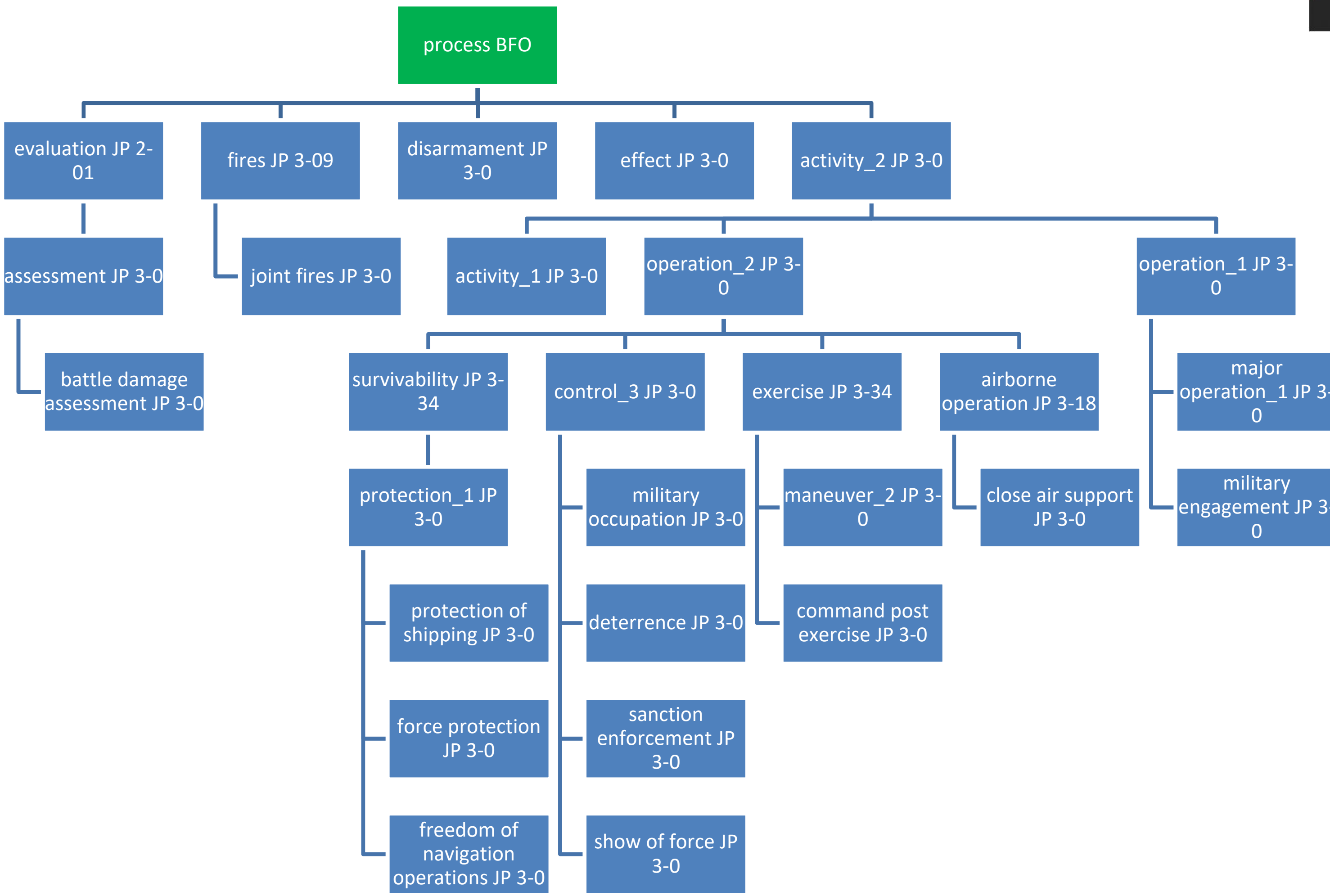
http://ncor.buffalo.edu/2015/STIDS-JDO.pdf

JP 3-0 Joint Operation Terms (pt 1)

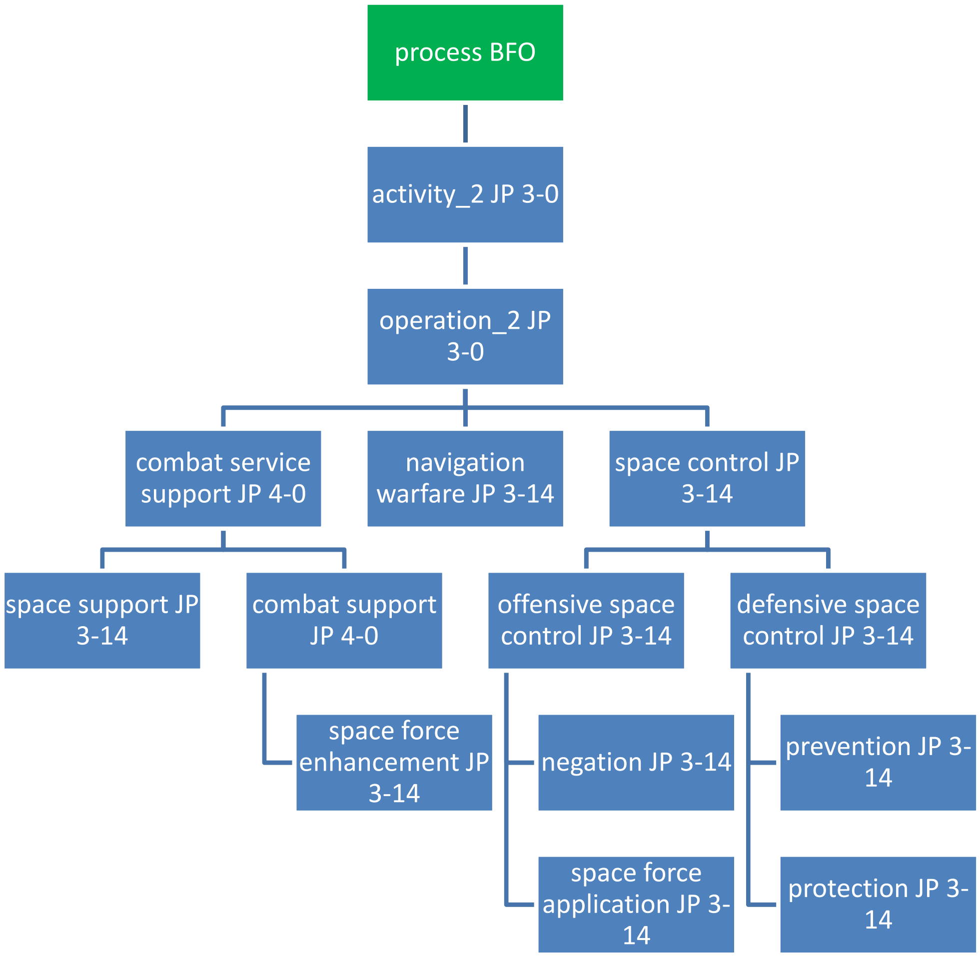


JP 3-0 Joint Operation Terms (pt 2)

national center for ontological research ncor



JP 3-14 Space Operation Terms



suites built following OBO Foundry principles

suite	users	date	hub
Common Core Ontologies (CCO)	US Army / I2WD and ARL, IARPA, JIDO, ONR, AFRL …	2010	BFO
Common Intelligence Community Ontology	DNI, CIA, DIA, …	~2014	BFO
USGS National Map	United States Geological Survey	~2014	BFO
Joint Doctrine Ontologies	US Air Force Research Labs (part of CCO)	2015	BFO
Transportation Research Informatics Platform (TRIP) Ontologies	Federal Highway Administration (FHWA)	2015	BFO
UNEP Ontology Framework	United Nations Environment Programme	2016	BFO
Industrial Ontologies Foundry (IOF)	Ontologies to support digital manufacturing (NIST)	2016	BFO

Benefits of modularity

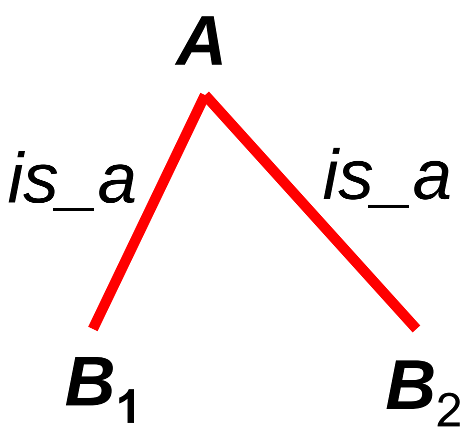
- division of labor
- division of authority
- SME ownership
- owner motivation
- user motivation
- user discoverability
- support for incrementality
- reduces need for ‘mappings’

Examples of best practice principles

1. Distinguish *reference* ontologies from *application* ontologies
2. Reference ontologies built around one or more single-inheritance backbone taxonomies

   Single inheritance = every non-root node has exactly one parent
3. Create a suite of reference ontology modules which on any given level of generality do not overlap
4. Reference ontologies are asserted, application ontologies inferred

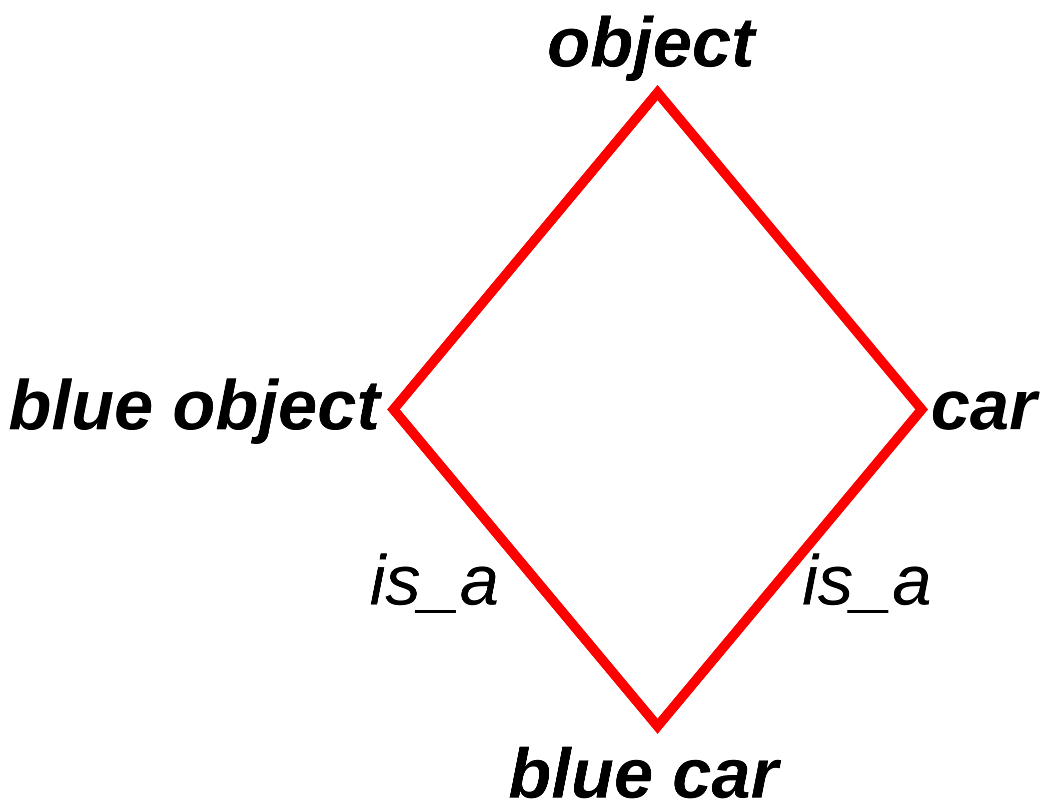
5. In a reference ontology: definitions of terms should be of the genus-species form



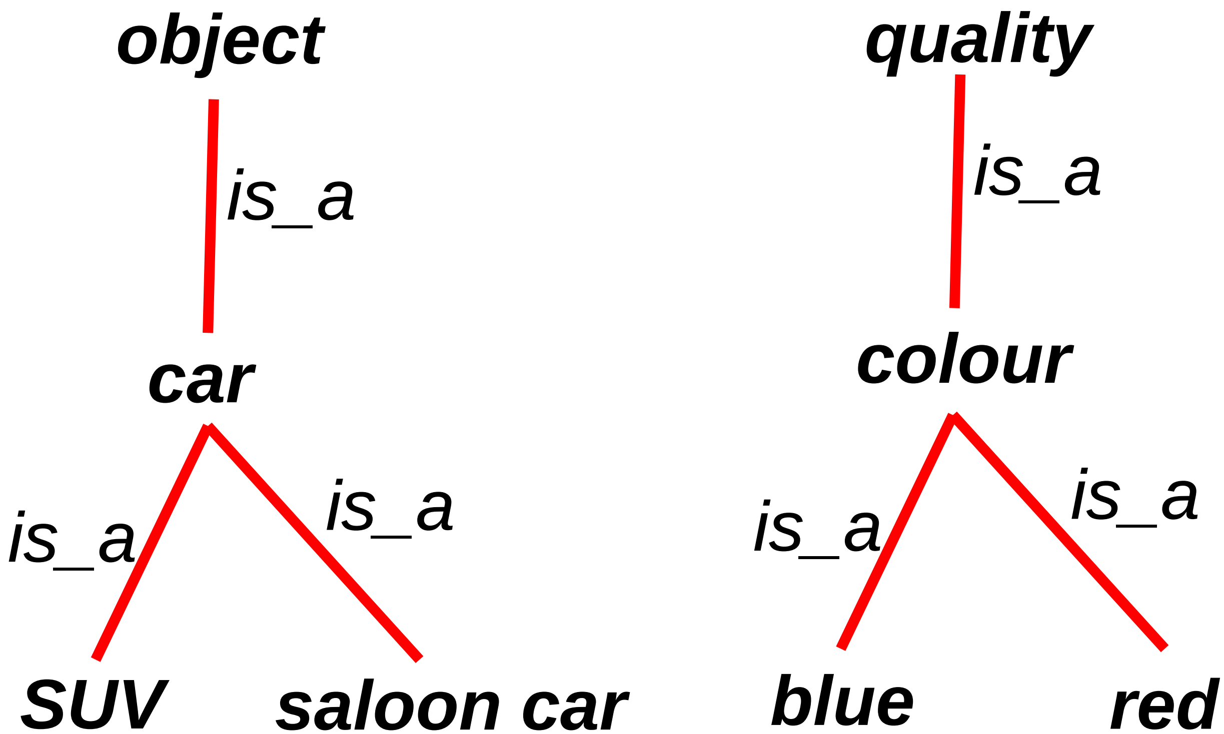
B =def. ***A*** which ***C***s

A = genus
$\boldsymbol{B}_1$ … = species
C = specific difference

Application ontology (fragment)



6. Factor ontology content into normalized reference ontology modules wherever possible



Toy example of reference ontology and application ontology for artillery vehicles

Reference Ontology Definitions

vehicle =def: an object used for transporting people or goods

tractor =def: a vehicle that is used for towing

crane =def: a vehicle that is used for lifting and moving heavy objects

vehicle platform=def: means of providing mobility to a vehicle

wheeled platform=def: a vehicle platform that provides mobility through the use of wheels

tracked platform=def: a vehicle platform that provides mobility through the use of continuous tracks

Application Ontology Definitions

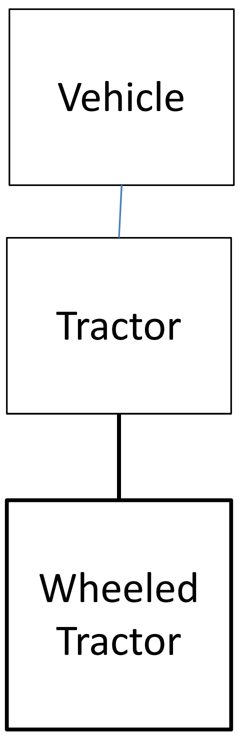
artillery vehicle = def. vehicle designed for the transport of one or more artillery weapons

Delta Battery artillery vehicle=def. an artillery vehicle that is at the disposal of Delta Battery

Delta Battery artillery tractor=def. an artillery tractor that is at the disposal of Delta Battery

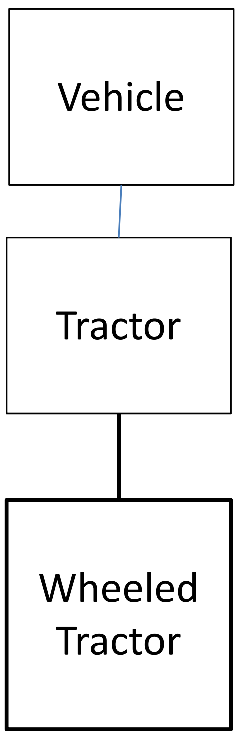
Normalized reference ontologies

Types of Vehicle

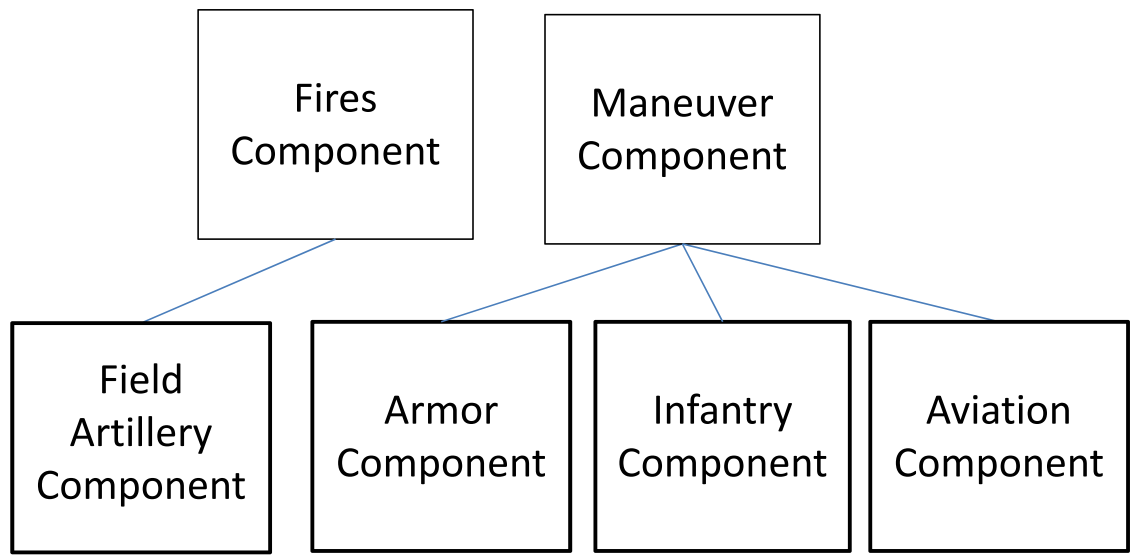


Normalized reference ontologies

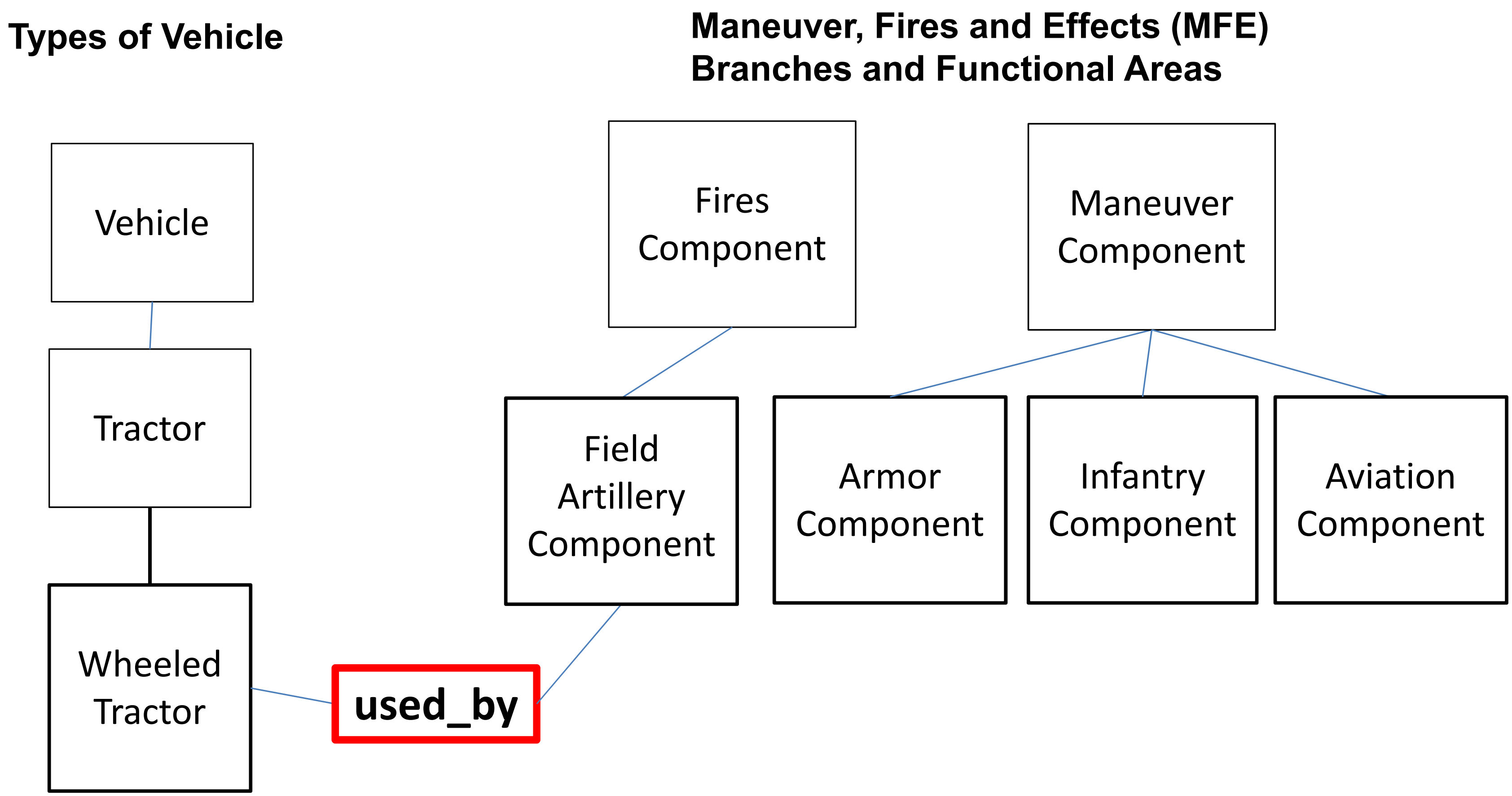
Types of Vehicle



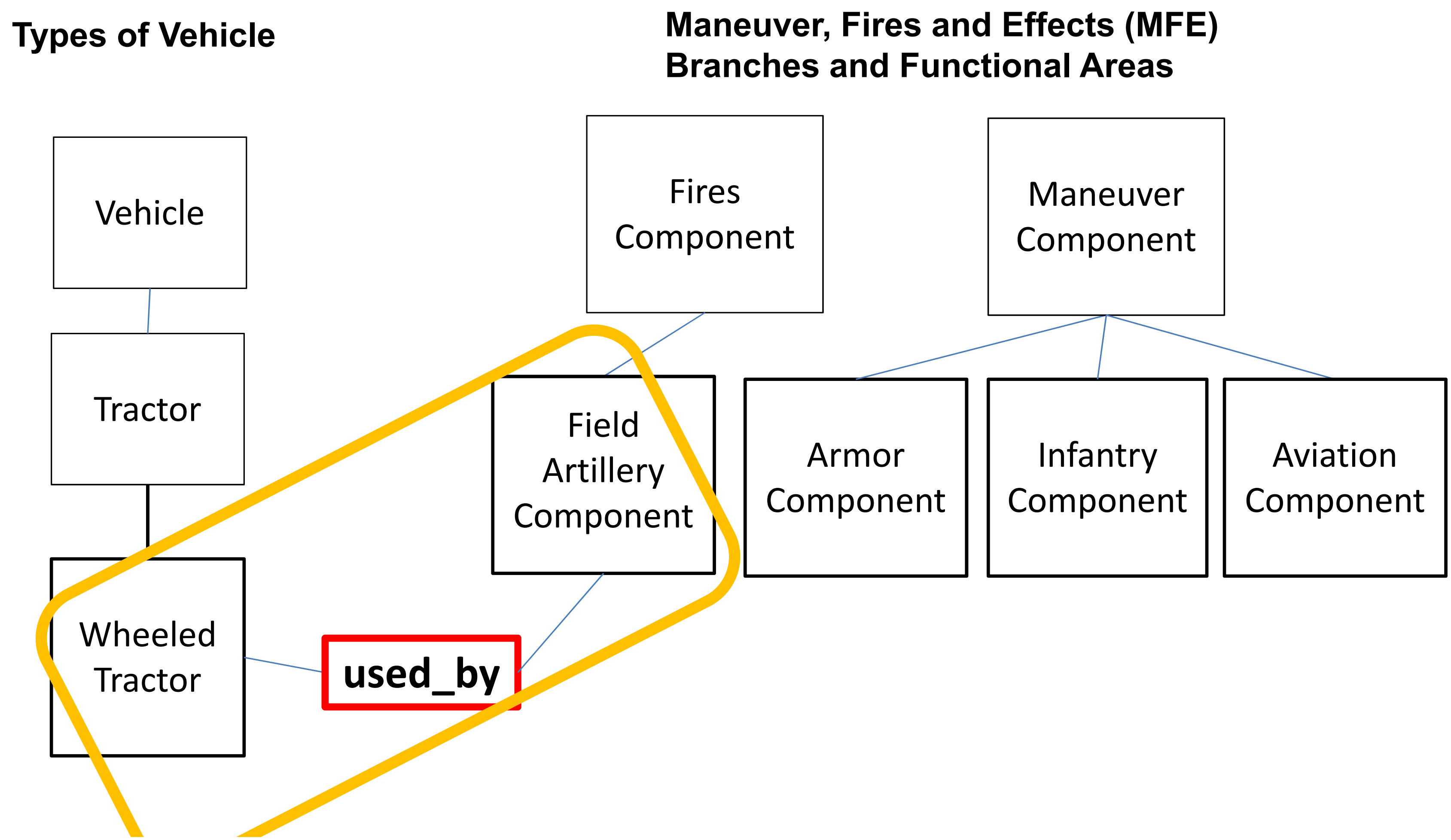
Maneuver, Fires and Effects (MFE) Branches and Functional Areas



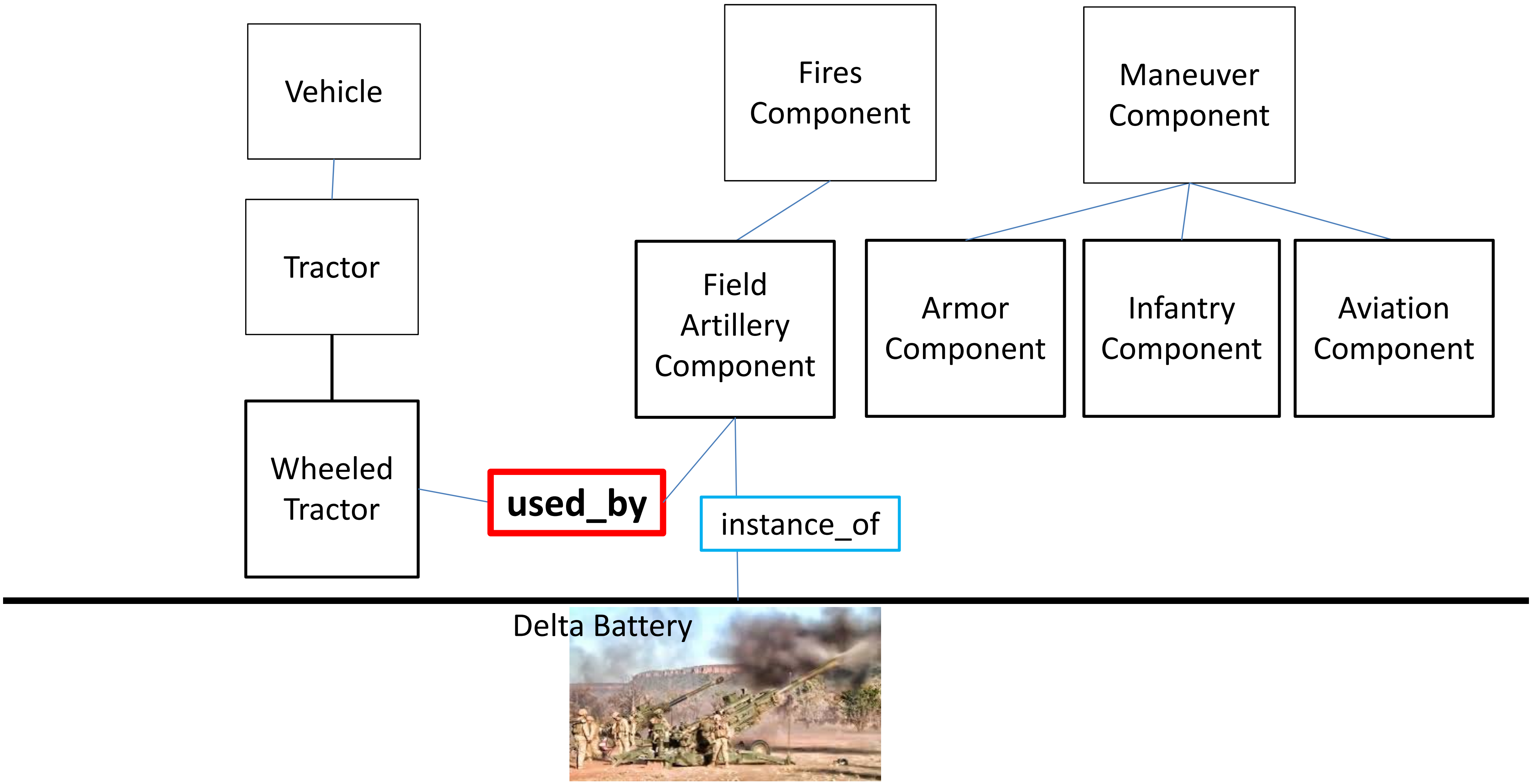
add relations as needed



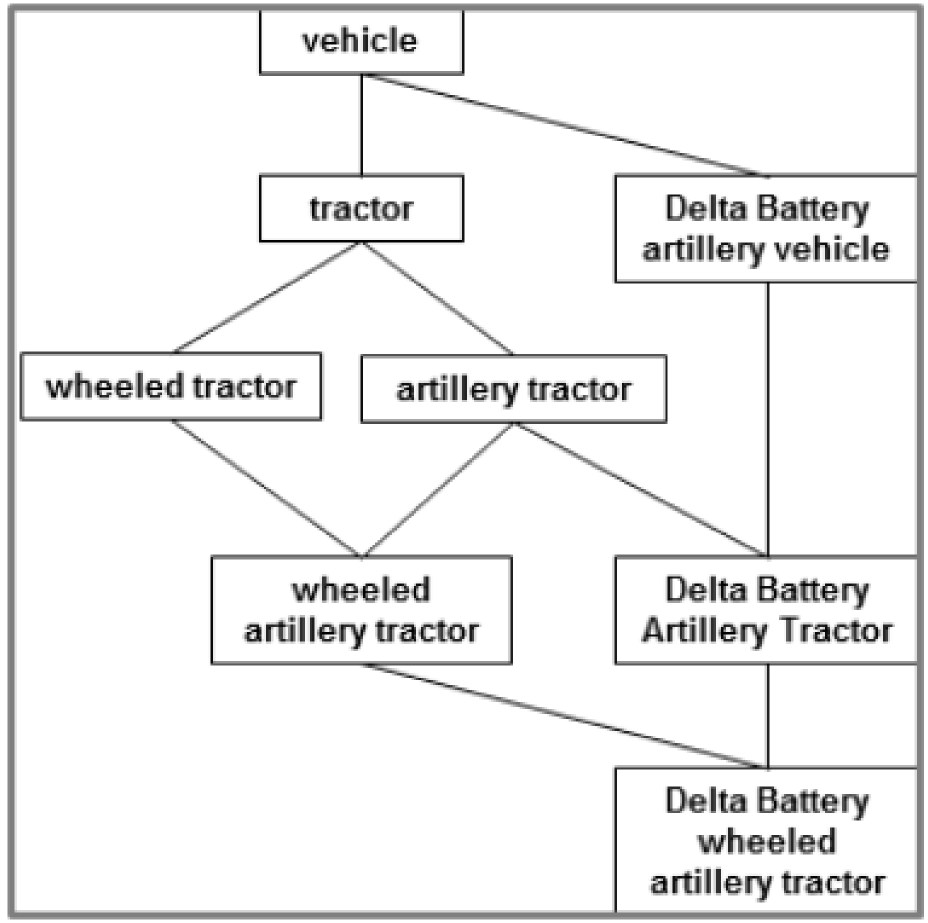
create defined class: wheeled artillery tractor



add instances of classes as needed



use reasoner to *infer* application ontology of Delta Battery artillery vehicles



use of reference ontologies as starting point promotes interoperability across different branches and easy extendability

"Horizontal Integration of Warfighter Intelligence Data"

http://ontology.buffalo.edu/smith/articles/Horizontal-integration.pdf

Time	Topic
10:30 AM	**Future-Proofing Ontologies: The Case of the Gene Ontology** Building ontologies with Basic Formal Ontology Industrial Ontologies Foundry (IOF) A BFO-based ontology for materials science **Relations in BFO** **Realizables in BFO** Roles Dispositions
12:30 PM	Lunch
1:15 PM	**Example Ontology from the SE Domain** Functions Capabilities **BFO-based Ontology for Information Entities** **AFRL Digital Thread/Digital Twin** **Product Life Cycle (PLC) Ontology** **Commodities, Services and Infrastructure**
3:00 PM	Break
3:15 PM	**Interactive session: Defining 'system'**
4:30 PM	Adjourn

Future proofing

The case of the Gene Ontology

RELATION TO TIME / GRANULARITY	CONTINUANT				OCCURRENT
	INDEPENDENT		DEPENDENT		
ORGAN AND ORGANISM	Organism (NCBI Taxonomy)	Anatomical Entity (FMA, CARO)	Organ Function (FMP, CPRO)	Phenotypic Quality (PaTO)	**Biological Process** (GO)
CELL AND CELLULAR COMPONENT	Cell (CL)	**Cellular Component** (FMA, GO)	Cellular Function (GO)		
MOLECULE	Molecule (ChEBI, SO, RnaO, PrO)		**Molecular Function** (GO)		Molecular Process (GO)

The Open Biomedical Ontologies (OBO) Foundry

<table>
<tr><td rowspan="2">RELATION TO TIME
GRANULARITY</td><td colspan="4">CONTINUANT</td><td>OCCURRENT</td></tr>
<tr><td colspan="2">INDEPENDENT</td><td colspan="2">DEPENDENT</td><td></td></tr>
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<tr><td>MOLECULE</td><td colspan="2">Molecule (ChEBI, SO, RnaO, PrO)</td><td colspan="2">Molecular Function (GO)</td><td>Molecular Process (GO)</td></tr>
</table>

Yellow = Gene Ontology (1998–)

RELATION TO TIME / GRANULARITY	CONTINUANT				OCCURRENT
	INDEPENDENT		DEPENDENT		
ORGAN AND ORGANISM	Organism (NCBI Taxonomy)	Anatomical Entity (FMA, CARO)	Organ Function (FMP, CPRO)	Phenotypic Quality (PaTO)	**Biological Process** (GO)
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~2005 suite begins to expand

<table>
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GRANULARITY</td><td colspan="6">CONTINUANT</td><td>OCCURRENT</td></tr>
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<tr><td>CELL AND CELLULAR COMPONENT</td><td>Cell (CL)</td><td>Cellular Component (FMA, GO)</td><td>Cellular Function (GO)</td></tr>
<tr><td>MOLECULE</td><td colspan="2">Molecule (ChEBI, SO, RnaO, PrO)</td><td colspan="2">Molecular Function (GO)</td><td>Molecular Process (GO)</td></tr>
</table>

Environment Ontology (EnvO)

<table>
<tr><td>RELATION TO TIME</td><td colspan="5">CONTINUANT</td><td colspan="2" rowspan="2">OCCURRENT</td></tr>
<tr><td>GRANULARITY</td><td colspan="3">INDEPENDENT CONTINUANT</td><td colspan="2">DEPENDENT CONTINUANT</td></tr>
<tr><td>ORGAN AND ORGANISM</td><td>Organism NCBI Taxonomy</td><td>Anatomical Entity (FMA, CARO)</td><td rowspan="3">Environment Ontology (ENVO)</td><td>Organ Function (FMP, CPRO)</td><td rowspan="2">Phenotypic Quality (PATO)</td><td rowspan="2">Biological Process (GO)</td><td rowspan="3">Ontology for Biomedical Investigations (OBI)</td></tr>
<tr><td>CELL AND CELLULAR COMPONENT</td><td>Cell (CL)</td><td>Cellular Component (FMA, GO)</td><td>Cellular Function (GO)</td></tr>
<tr><td>MOLECULE</td><td colspan="2">Molecule (ChEBI, SO, RnaO, PrO)</td><td colspan="2">Molecular Function (GO)</td><td>Molecular Process (GO)</td></tr>
</table>

Recognizing a new family of protocol-driven processes (investigation, assay, clinical trial …)

<table>
<tr><td>RELATION TO TIME</td><td colspan="7">CONTINUANT</td><td colspan="2" rowspan="2">OCCURRENT</td></tr>
<tr><td>GRANULARITY</td><td colspan="3">INDEPENDENT CONTINUANT</td><td colspan="2">DEPENDENT CONTINUANT</td><td>INFORMATION ARTIFACT</td></tr>
<tr><td>ORGAN AND ORGANISM</td><td>Organism NCBI Taxonomy</td><td>Anatomical Entity (FMA, CARO)</td><td rowspan="3">Environment Ontology (ENVO)</td><td>Organ Function (FMP, CPRO)</td><td rowspan="2">Phenotypic Quality (PATO)</td><td rowspan="2">Information Artifact Ontology
Software, Algorithms, …
Sequence Data, EHR Data …</td><td rowspan="2">Biological Process (GO)</td><td rowspan="2">OBI</td></tr>
<tr><td>CELL AND CELLULAR COMPONENT</td><td>Cell (CL)</td><td>Cellular Component (FMA, GO)</td><td>Cellular Function (GO)</td></tr>
<tr><td>MOLECULE</td><td colspan="2">Molecule (ChEBI, SO, RnaO, PrO)</td><td colspan="2">Molecular Function (GO)</td><td>Images, Image Data, Flow Cytometry Data, …</td><td>Molecular Process (GO)</td><td>OBI: Imaging</td></tr>
</table>

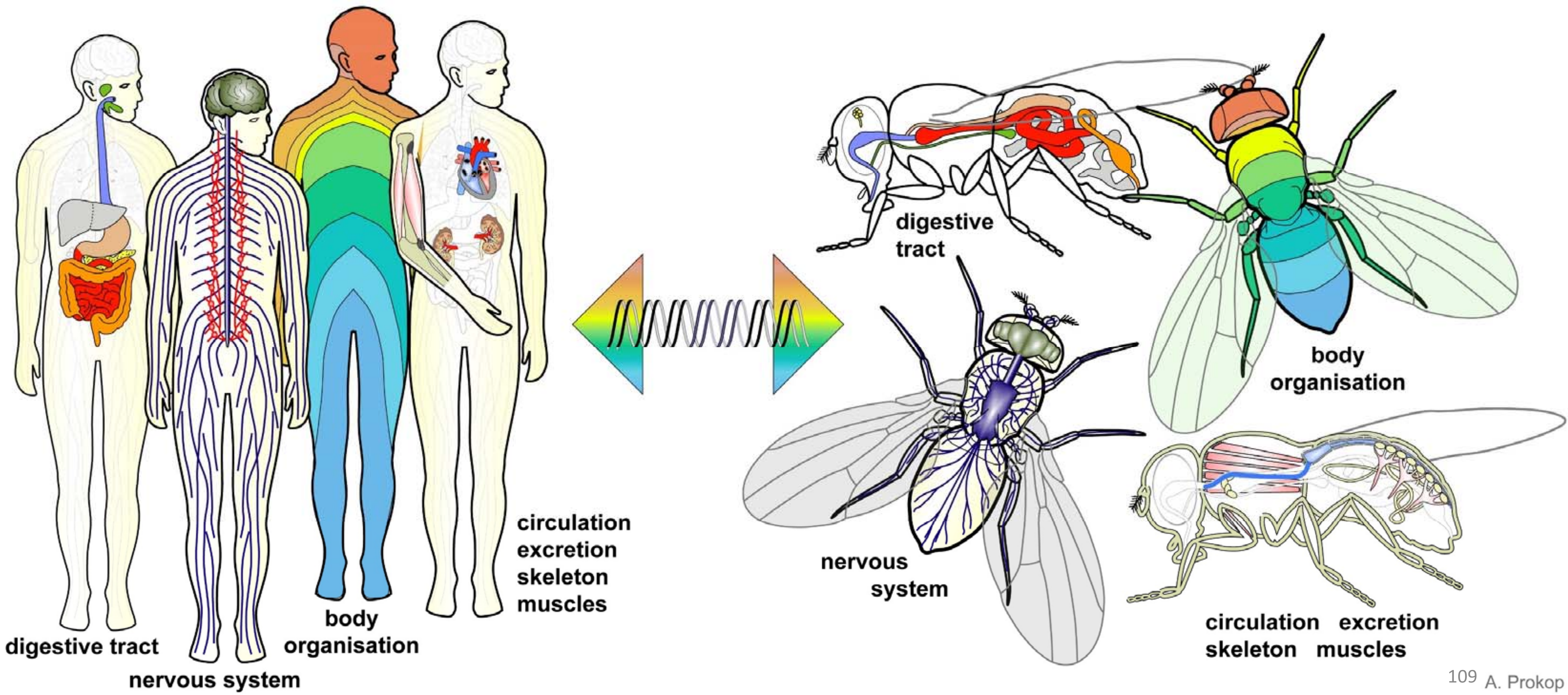
recognizing information entities: data, publications, images, algorithms, engineering models, simulations, designs (led to BFO 2.0)

Aboutness

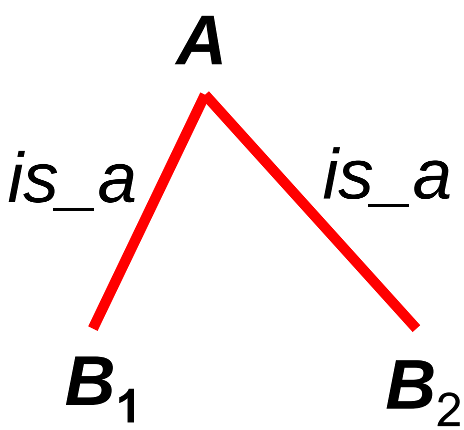
<table>
<tr><th>INDEPENDENT CONTINUANT (~THING))</th><th>DEPENDENT CONTINUANT (~ATTRIBUTE)</th><th>OCCURRENT (~PROCESS)</th><th></th><th>IAO</th><th>OBI</th></tr>
<tr><td>Patient Demo-graphics</td><td rowspan="2">Phenotype (Disease, …)</td><td rowspan="2">Disease processes</td><td rowspan="4"></td><td rowspan="4">Data about diseases, … including image data …

Algorithms, software, protocols, …</td><td rowspan="4">Instruments, Biomaterials, Functions Parameters, Assay types, Statistics …</td></tr>
<tr><td>Anatomy</td></tr>
<tr><td>Histology</td><td rowspan="2">Genotype (GO)</td><td rowspan="2">Biological processes (GO)</td></tr>
<tr><td>Chemistry</td></tr>
</table>

if {future proofing = rising up to an ever higher level of generality} then what happens when we reach the top?



Aristotelian definitions

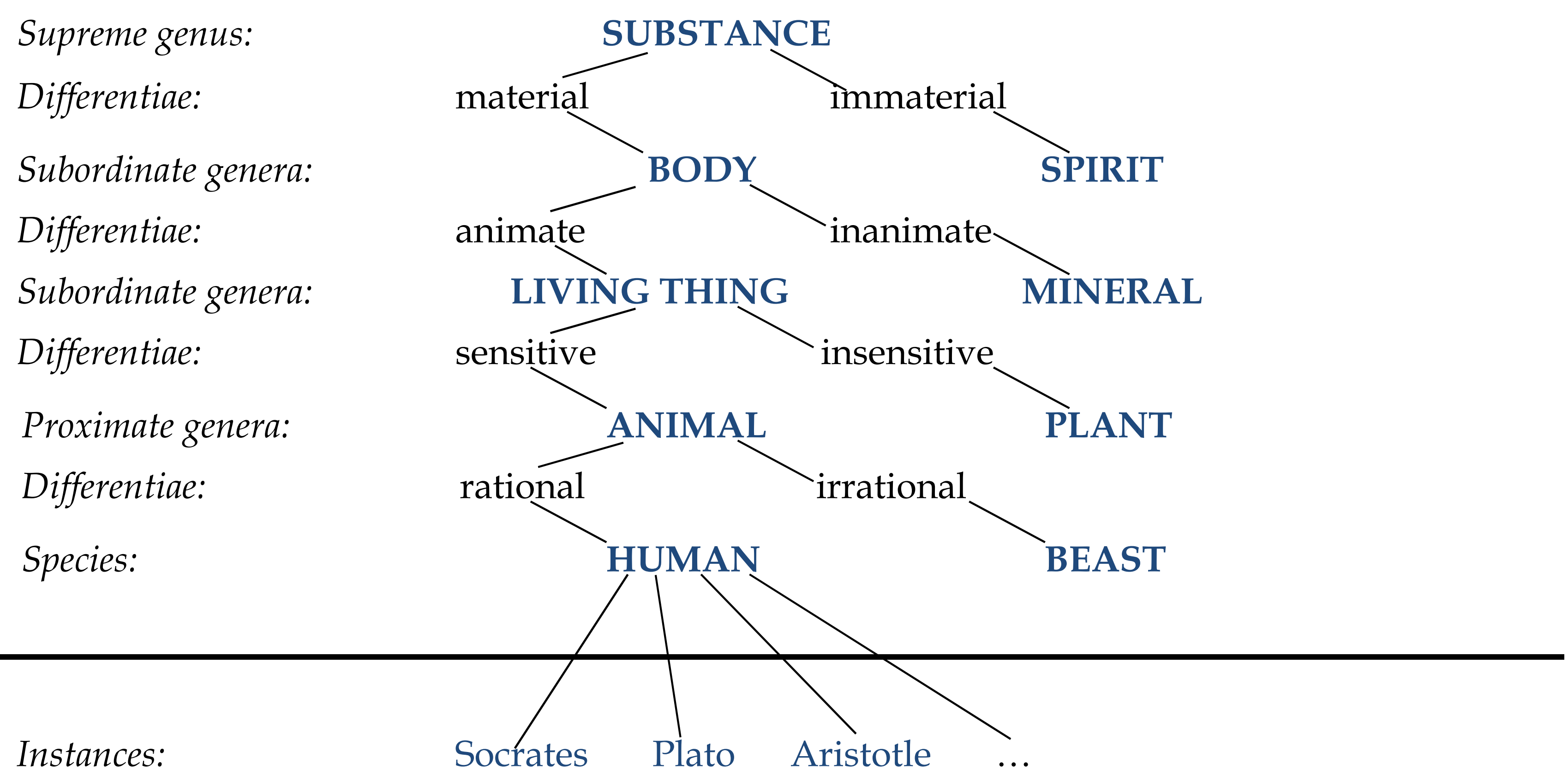


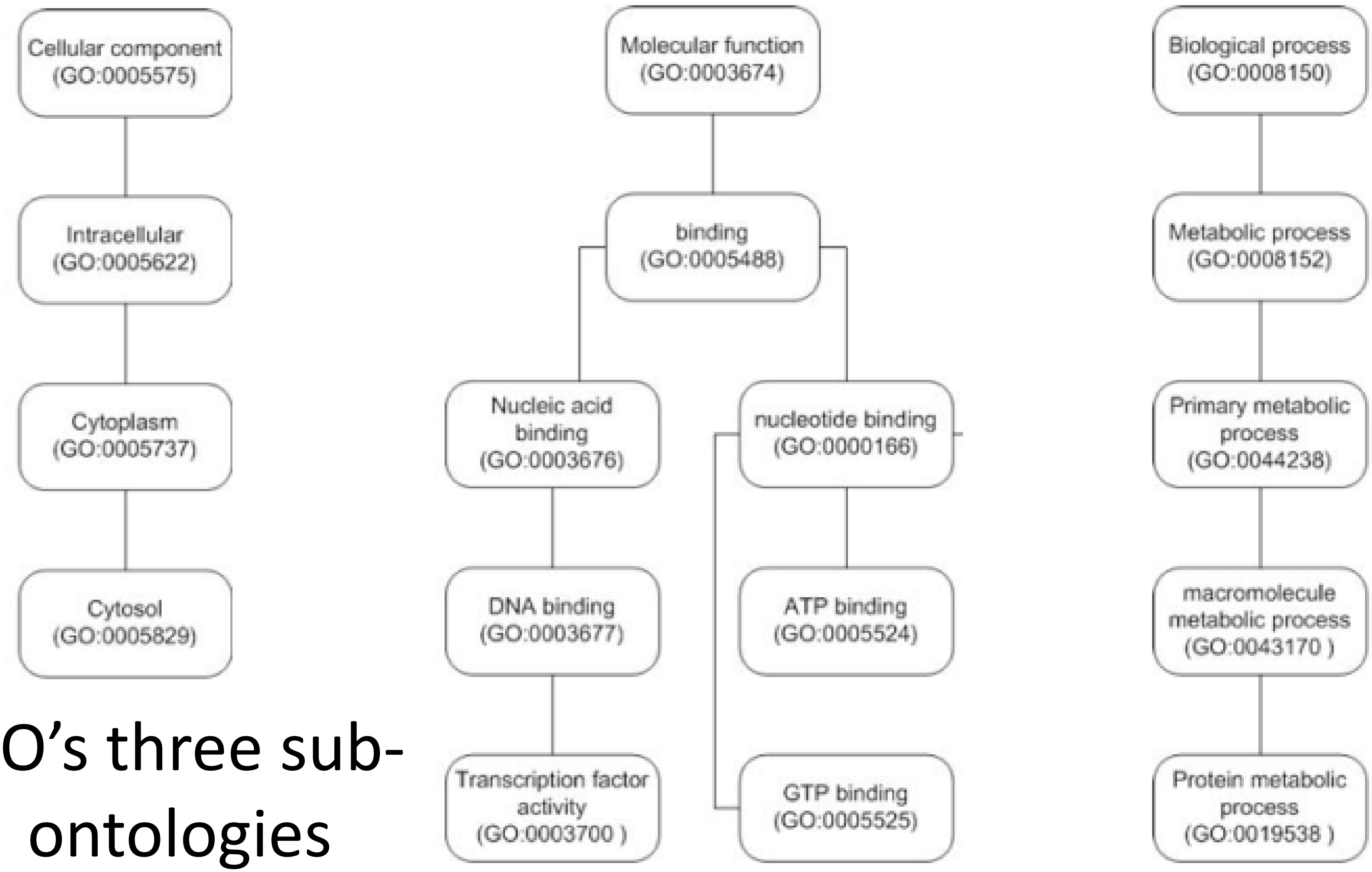
B =def. ***A*** which ***C***s

A = genus
$\boldsymbol{B_1}$ … = species
C = specific difference

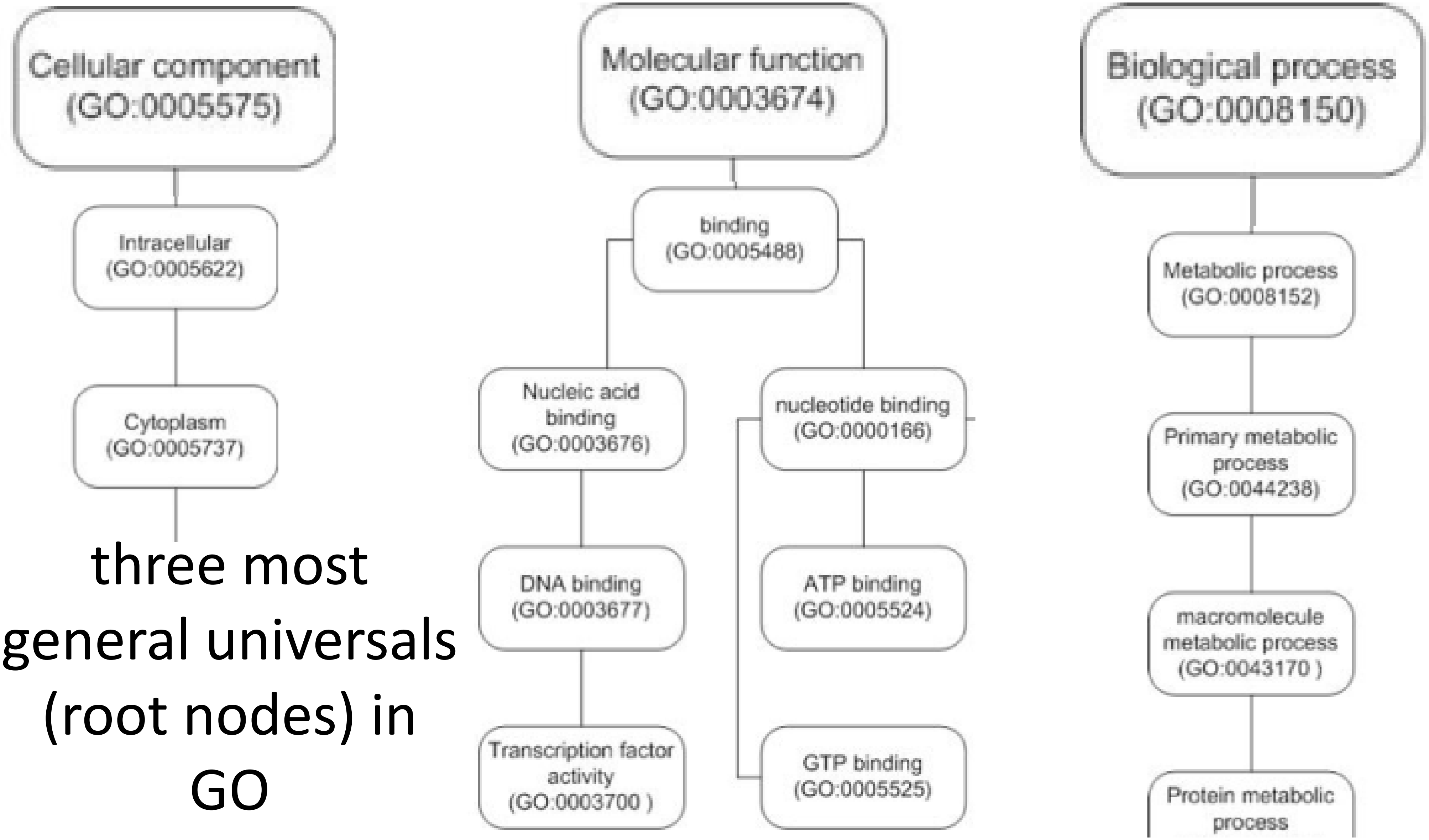
example (from Aristotle):
human being =def. animal which is rational

Porphyry's depiction of levels of more and less general universals in Aristotle



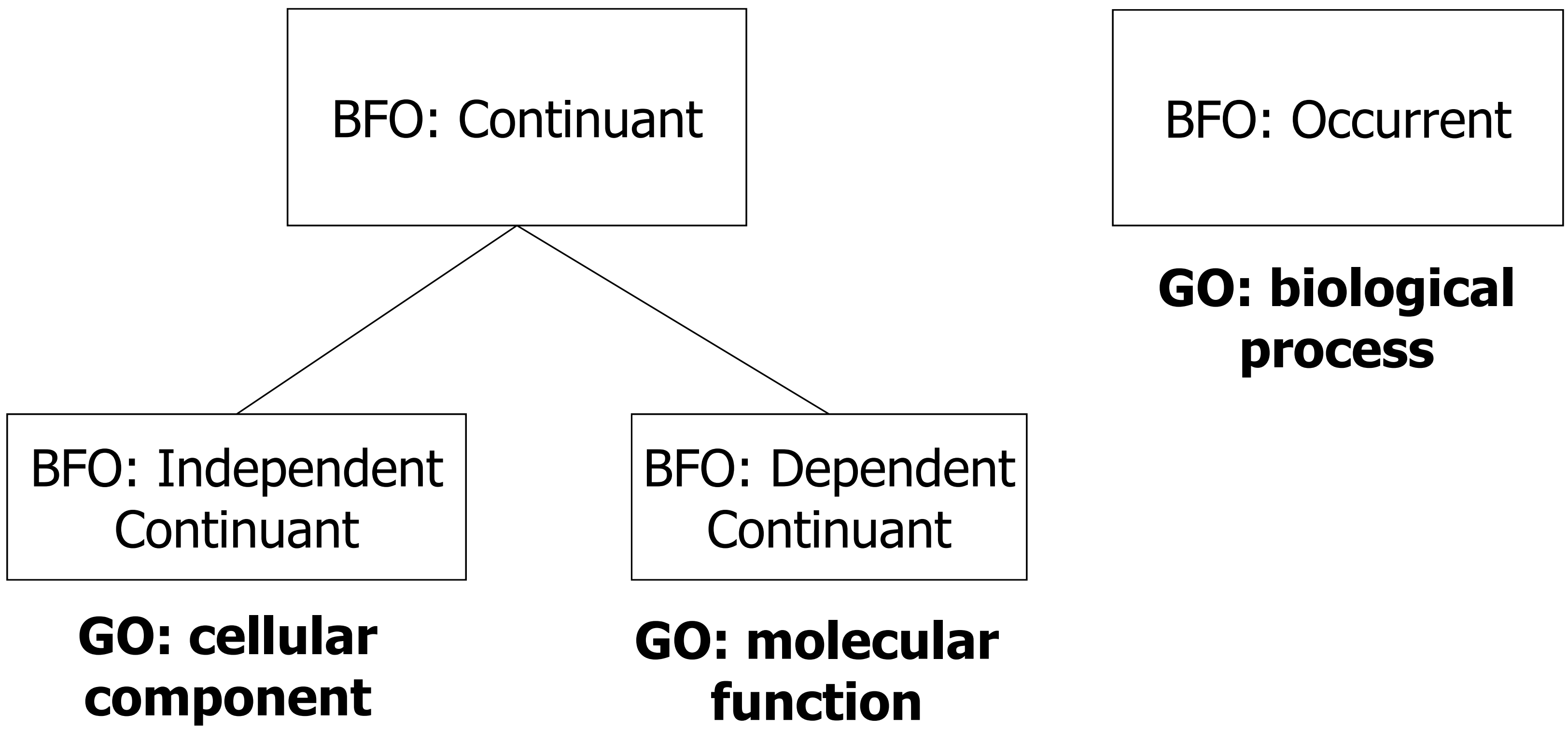


GO's three sub-ontologies

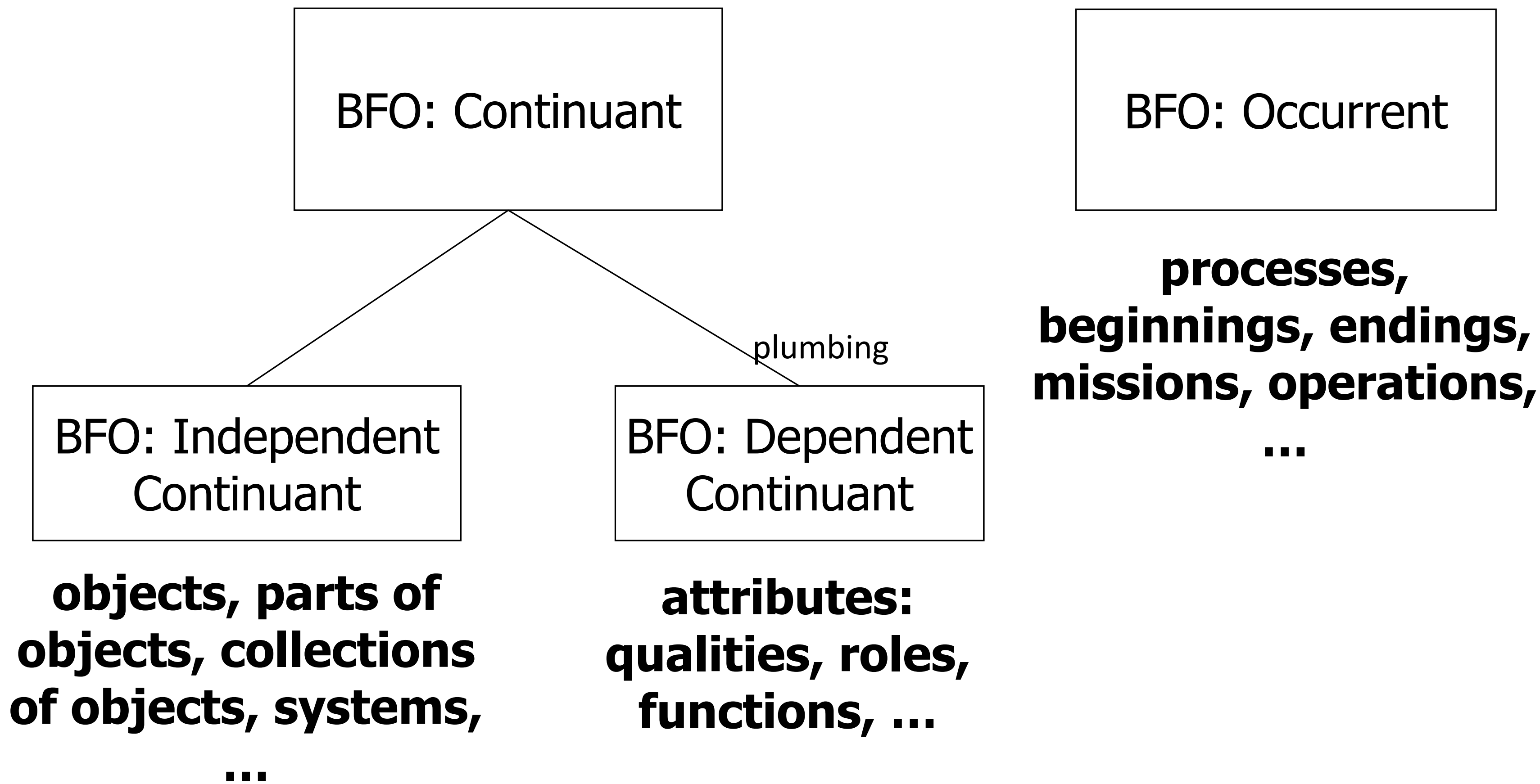


three most general universals (root nodes) in GO

three most general universals (categories)



three most general universals (categories)



independent continuants in the system realm

system designer

system

system operator

system manager

independent continuant

occurrents in the systems realm

building of system

maintenance of system

operation of system

occurrent

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rationale of OBO Foundry coverage = BFO

Building Ontologies with Basic Formal Ontology

By Robert Arp, Barry Smith and Andrew D. Spear

Overview

In the era of "big data," science is increasingly information driven, and the potential for computers to store, manage, and integrate massive amounts of data has given rise to such new disciplinary fields as biomedical informatics. Applied ontology offers a strategy for the organization of scientific information in computer-tractable form, drawing on concepts not only from computer and information science but also from linguistics, logic, and philosophy. This book provides an introduction to the field of applied ontology that is of particular relevance to biomedicine, covering theoretical components of ontologies, best practices for ontology design, and examples of biomedical ontologies in use.

After defining an ontology as a representation of the types of entities in a given domain, the book distinguishes between different kinds of ontologies and taxonomies, and shows how applied ontology

Paperback | $30.00 | £20.95 | ISBN: 9780262527811 | 248 pp. | 7 x 9 in | 32 b&w illus.| August 2015

BFO 2.0

Very small

Evolves very slowly

Strictly formal (a domain neutral, top-level) ontology

Active user forum

Large user base

~ 250 active projects using BFO

Benefits of shared top level

all the benefits of a shared standard, including:

- improved understandability of third-party content
- improved transportability of expertise
- telephone network effect
  - data annotated using BFO-conformant ontologies becomes more valuable
  - attracts more enterprises to adopt BFO
  - creates a virtuous cycle (snowball effect)

examples of suite formation following OBO Foundry principles, including use of BFO as hub

suite	users	date	hub
Common Core Ontologies (CCO)	US Army / I2WD and ARL, IARPA, JIDO, ONR, AFRL …	2010	BFO
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USGS National Map	United States Geological Survey	~2014	BFO
Joint Doctrine Ontologies	US Air Force Research Labs (part of CCO)	2015	BFO
Transportation Research Informatics Platform (TRIP) Ontologies	Federal Highway Administration (FHWA)	2015	BFO
UNEP Ontology Framework	United Nations Environment Programme	2016	BFO
Industrial Ontologies Foundry (IOF)	Ontologies to support digital manufacturing (NIST)	2016	BFO

Reference number of working WG2 N2363

Date: 2017-05-0108-28

Reference number of document: **ISO/IEC 21838-2**

Committee identification: ISO/IEC JTC1 SC32 WG2

SC32 Secretariat: US

Information technology — Ontologies — Top-Level Ontologies (TLO) — Basic Formal Ontology (BFO)

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http://ontology.buffalo.edu/BOBFO

~ 300 ontologies re-using BFO

ACGT Master Ontology (ACGT MO)
Alzheimer Disease Ontology (ADO)
Adverse Event Ontology (AEO)
Adverse Event Reporting Ontology (AERO)
AFO Foundational Ontology
Actionable Intelligence Retrieval System (AIRS)
Bank Ontology
Beta Cell Genomics Application Ontology (BCGO)
BioAssay Ontology
Bioinformatics Web Service Ontology
Biological Collections Ontology (BCO)
Biomedical Ethics Ontology
Biomedical Grid Terminology (BiomedGT, retired)
BioTop: A Biomedical Top-Domain Ontology

http://basic-formal-ontology.org/users

Cancer Cell Ontology (OncoCL)
Cancer Chemoprevention Ontology (CanCo)
Cardiovascular Disease Ontology (CVDO)
Cell Behavior Ontology (CBO)
Cell Cycle Ontology
Cell Expression, Localization, Development and Anatomy Ontology (CELDA)

Environment Ontology (ENVO)
Epidemiology Ontology (EO)
Epilepsy and Seizure Ontology (EPSO)
Evolution Ontology (EO)
Experimental Factor Ontology (EFO)
EXperimental ACTioins Biomedical Protocol Ontology (EXACT2)
Exposé: An Ontology for Data Mining Experiments
Flybase Drosophila Anatomy Ontology (FBbt)
Fission Yeast Phenotype Ontology (FYPO)
Flower-Visiting Domain Ontology (FV),
Flower-Visiting Behavior Application Ontology (FVB)
Foundational Model of Anatomy (FMA) Ontology
Gastrointestinal Endoscopy Ontology (GIEO)
Gene Regulation Ontology (GRO)
General Information Model (GIM)
Genomic Feature and Variation Ontology (GFVO)
Gestalt: Federated Access to Cyber Observables for Detection of Targeted Attack
Health Data Ontology Trunk (HDOT)
Human Interaction Network Ontology (HINO)
Human Physiology Simulation Ontology (HuPSON)
Infectious Disease Ontology (IDO)
Information Artifact Ontology (IAO)
Informed Consent Ontology (ICO)
Interaction Network Ontology (INO)

Industrial Ontologies Foundry

suite	users	date	hub
Common Core Ontologies (CCO)	US Army / I2WD and ARL, IARPA, JIDO, ONR, AFRL …	2010	BFO
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UNEP Ontology Framework	United Nations Environment Programme	2016	BFO
Industrial Ontologies Foundry (IOF)	Ontologies to support digital manufacturing (NIST)	2016	BFO

Industrial Ontologies Foundry (IOF) initiative, to create a suite of interoperable high quality ontologies covering the domain of industrial (especially manufacturing) engineering

Industrial Ontologies Foundry – GOVERNMENT

NIST

- Nenad Ivezic
- Boonserm Kulvatunyou
- KC Morris
- Vijay Srinivasan
- Ram Sriram
- Paul Witherell
- Evan Wallace
- …

Air Force Research Lab

- Clare Paul

Potential collaborating partners

- AFRL / AFMC

  AFRL Air Vehicle Platform Ontology

- Jet Propulsion Lab (+DoD, …)

  Semantic Technologies for Systems Engineering Working Group (STSEWG)

- European Materials Modeling Council
  - **European Materials Modeling Ontology (EMMO)**

Industrial Ontologies Foundry – INDUSTRY

- Airbus
- Autodesk
- Cambridge Semantics
- CIMData
- CUBRC
- Dassault Industries
- …

Industrial Ontologies Foundry – ACADEMIA

- Clemson University (Venkat Krovi)
- École polytechnique fédérale de Lausanne (Dimitris Kiritsis)
- INP-ENIT, University of Toulouse (Hedi Karray)
- Loughborough University, UK (Bob Young)
- National Center for Ontological Research (Kemper Lewis, Neil Otte Rahul Rai, Ron Rudnicki, Barry Smith)
- Penn State (Timothy Simpson)
- Texas State (Farhad Ameri)
- UMass Amherst (Ian Grosse)
- University of Toronto (Michael Grüninger)
- …

CUBRC
Advantage through technology

Home / Data Science and Information Fusion / Ontology

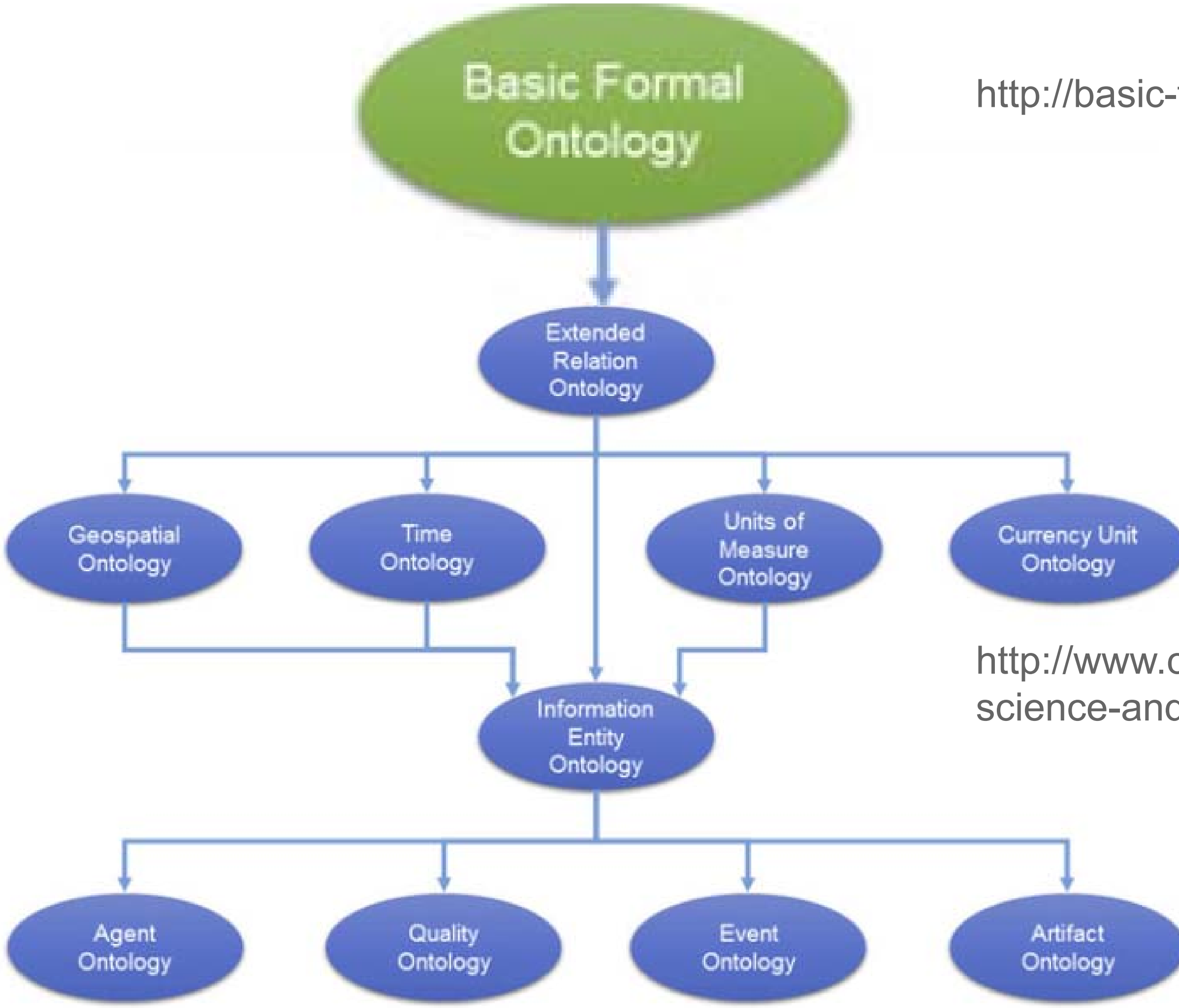
Common Core Ontologies for Data Integration

Data Science and Information Infusion

Print Email

The Common Core Ontology Method

The Data Science and Information Fusion Group's work in ontologies started in 2008. Since 2010, our participation in IARPA's Knowledge, Discovery and Dissemination program focused our work on the development of the Common Core Ontologies (CCO).

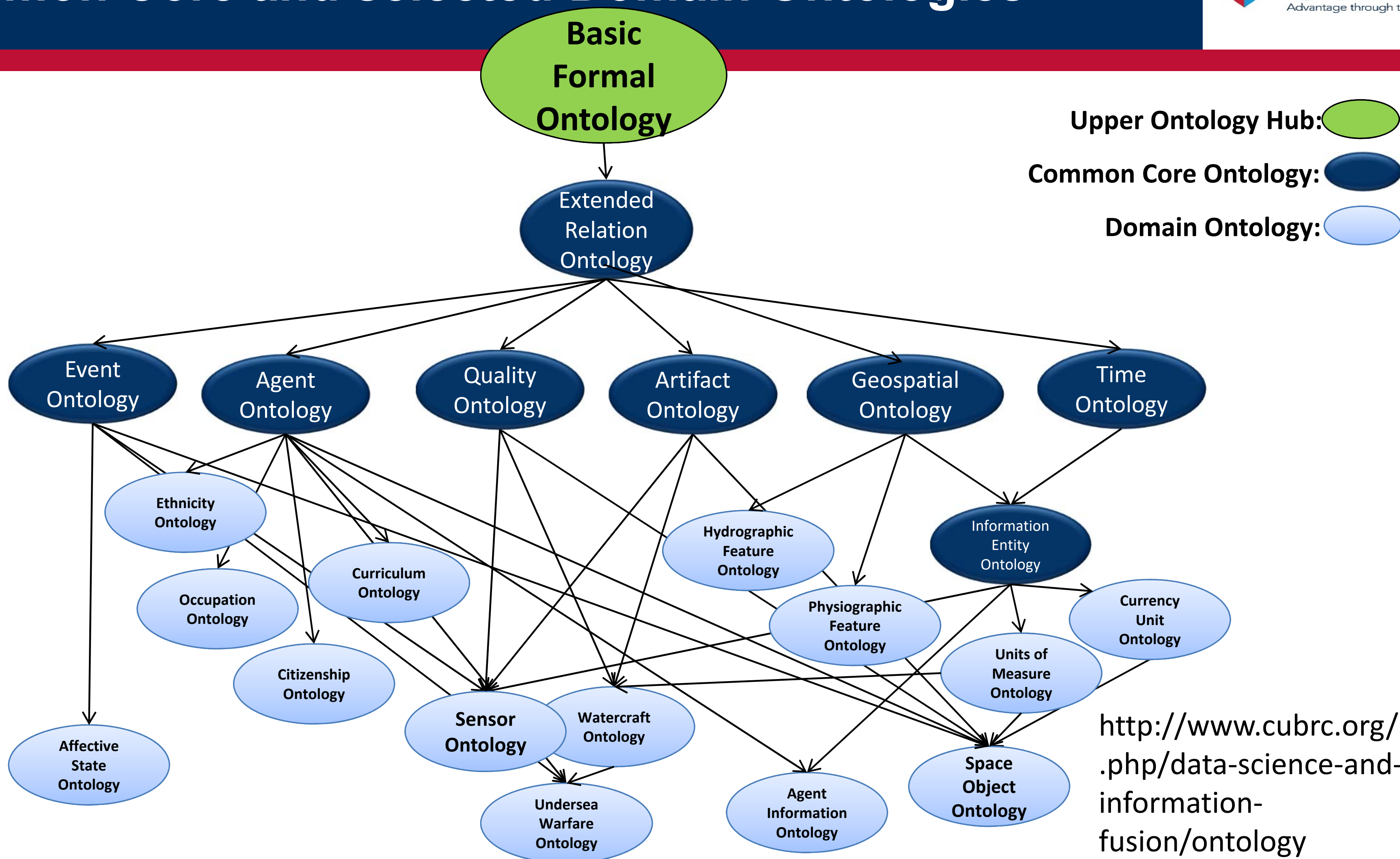


http://basic-formal-ontology.org

http://www.cubrc.org/index.php/data-science-and-information-fusion/ontology

The Common Core Ontologies

The Common Core and selected Domain Ontologies

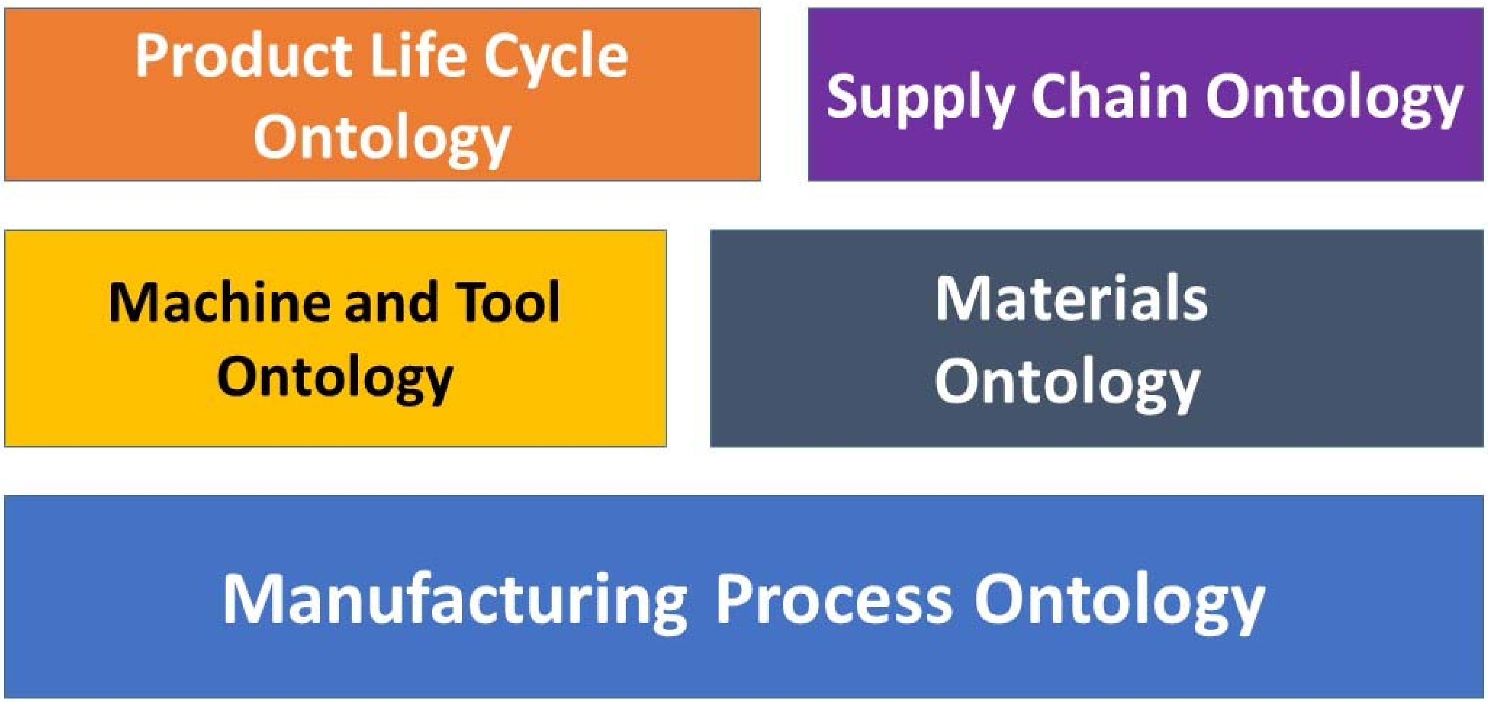


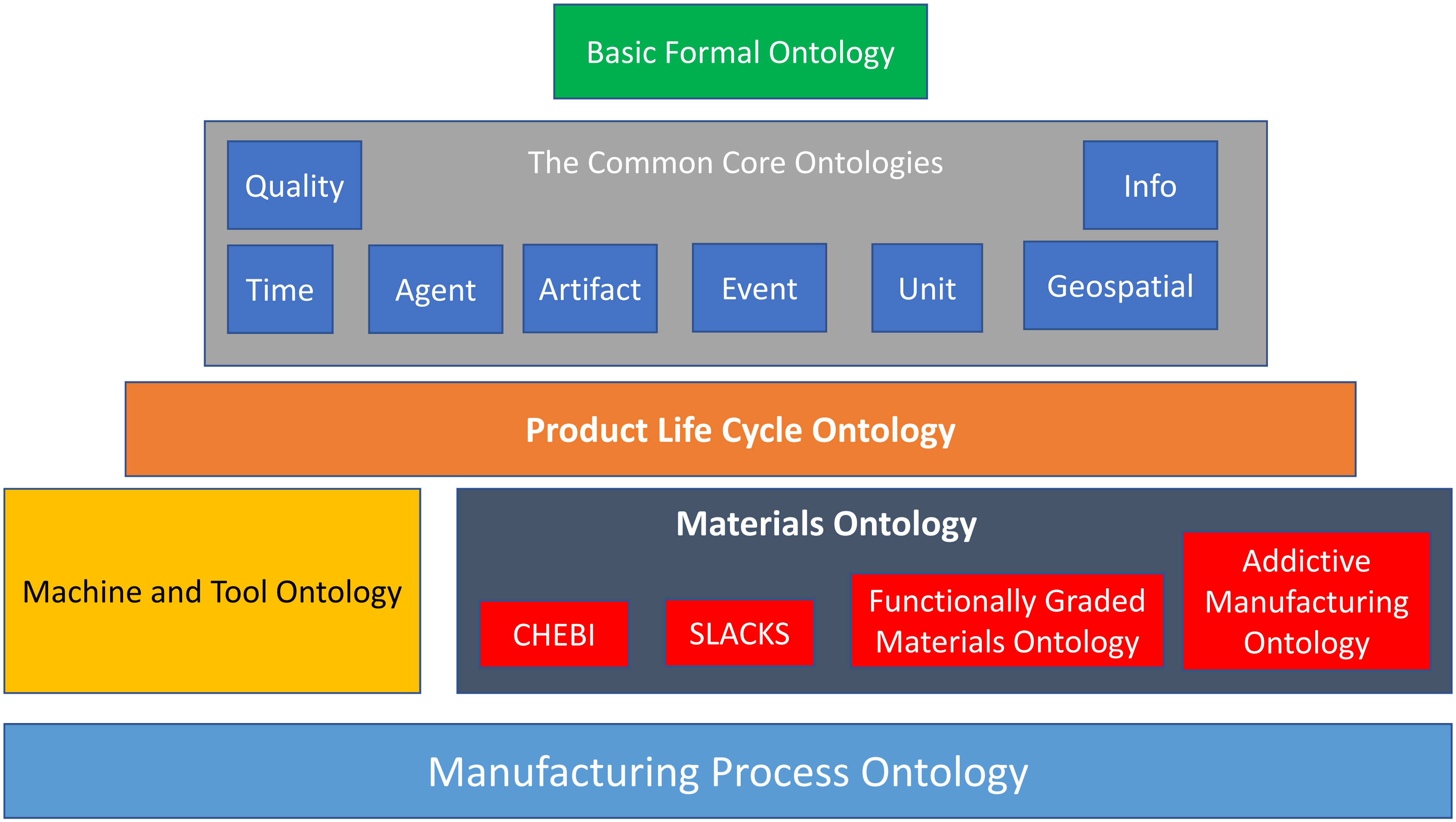
http://www.cubrc.org/index.php/data-science-and-information-fusion/ontology

CLEARED for public release by 88ABW-2017-1747


Basic Formal Ontology
The Common Core Ontologies
Quality
Info
Time
Agent
Artifact
Event
Unit
Geospatial

Proposed IOF suite of common ontologies to support interoperability of manufacturing software especially for small and medium-sized companies




Basic Formal Ontology
The Common Core Ontologies
Quality
Info
Time
Agent
Artifact
Event
Unit
Geospatial
Product Life Cycle Ontology
Machine and Tool Ontology
Materials Ontology
CHEBI
SLACKS
Functionally Graded Materials Ontology
Addictive Manufacturing Ontology
Manufacturing Process Ontology

MatOnto: A suite of ontology modules based on BFO

Existing ontologies in process of being re-engineered to be BFO-conformant:

for **Laminated Composites**: SLACKS (UMass)

for **Functionally Graded Materials**: FGMO (NCOR, Milan Polytechnic)

Existing ontologies already BFO-conformant:

for **Polymers**: CHEBI (EBI)

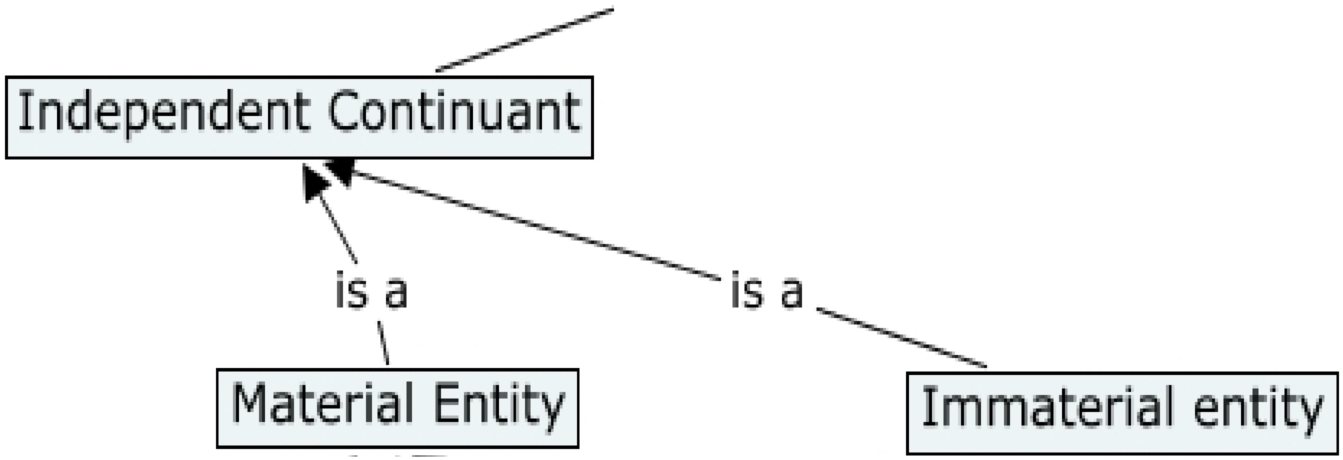
See: http://ncorwiki.buffalo.edu/index.php/MatOnto_Ontology_Meetings

EMMO

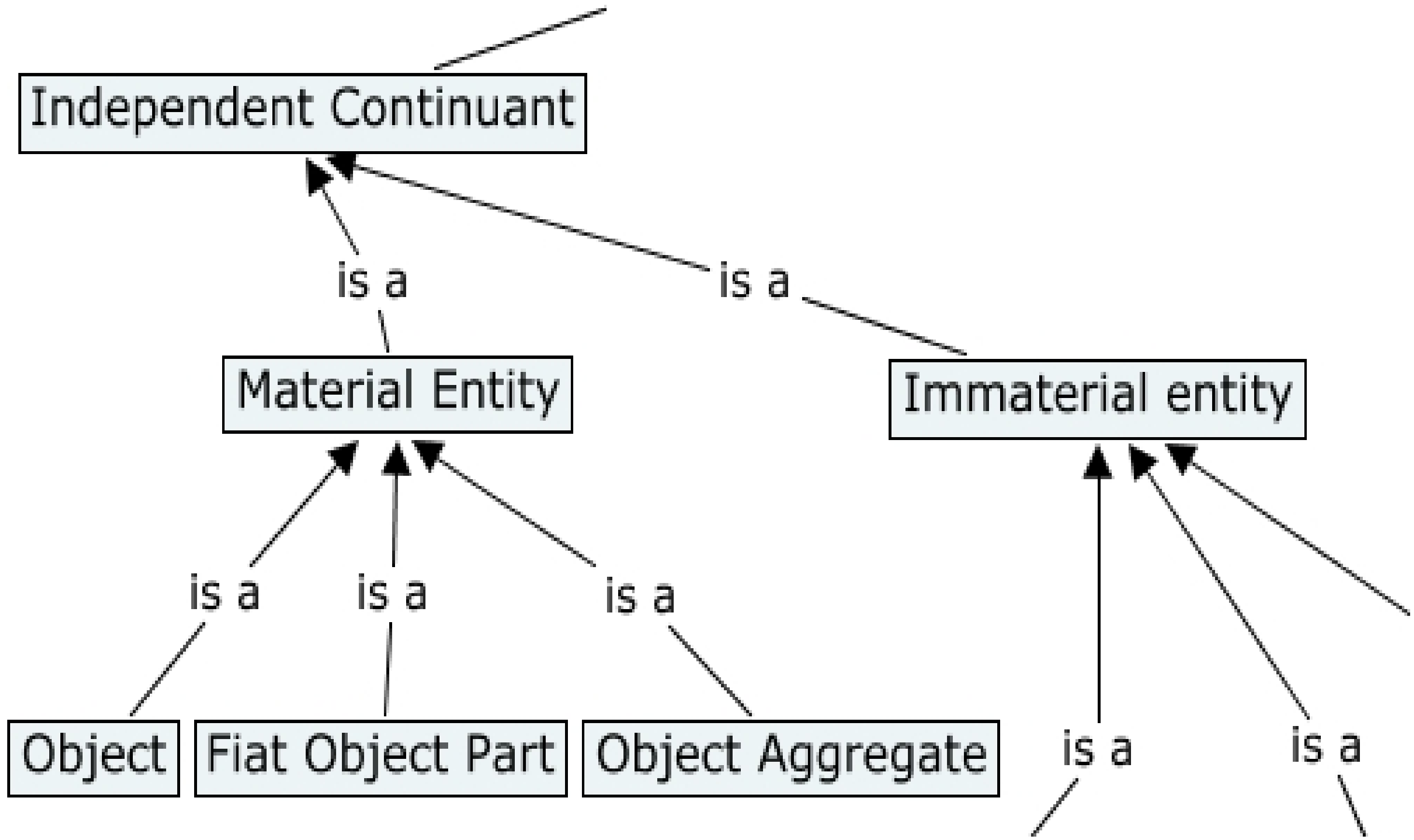
the EUROPEAN MATERIALS MODELLING ONTOLOGY

Emanuele Ghedini	*(University of Bologna)*
Adham Hashibon	*(Fraunhofer IWM)*
Jesper Friis	*(SINTEF)*
Gerhard Goldbeck	*(Goldbeck Consulting)*
Georg Schmitz	*(ACCESS)*
Anne de Baas	*(European Commission)*

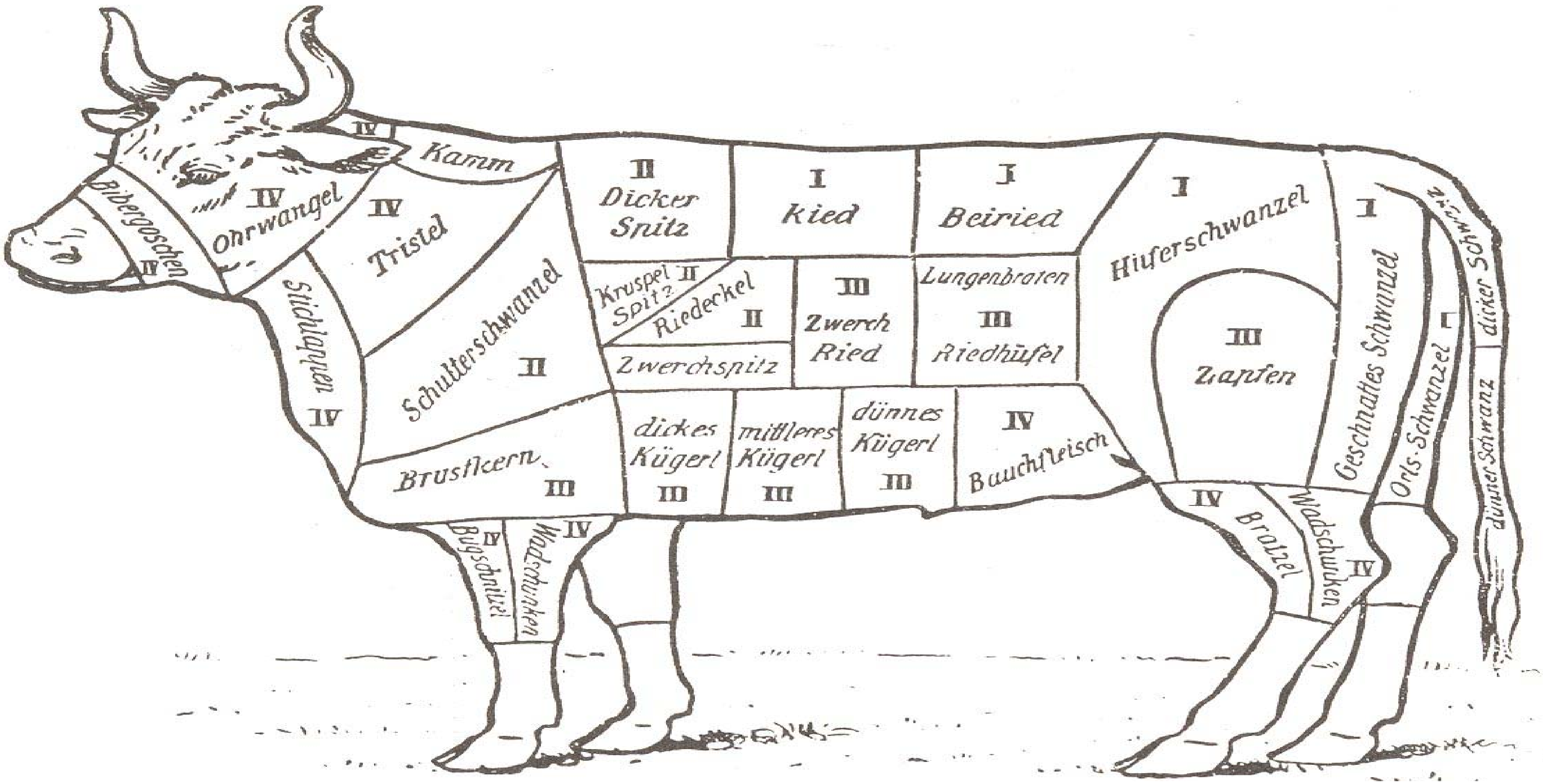
BFO:*material_entity*



BFO:*object* (& its siblings)

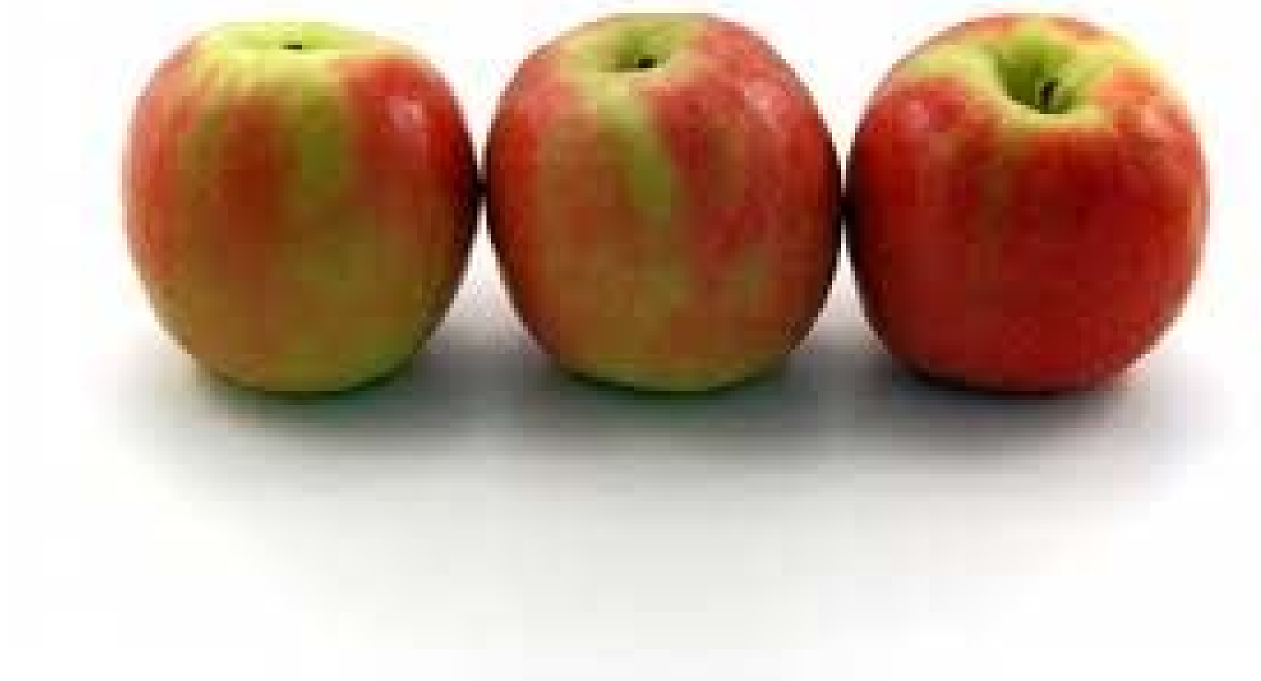


BFO: *fiat_object_part*



BFO:*object_aggregate*

not a mereological sum of objects, but something like a set:



BFO:*object_aggregate*

not a mereological sum of objects, but something like a set:

BFO:*object_aggregate*

can change its members over time

examples: collections, populations, families, tribes, species, planetary systems – anything associated with a *count,* a *registry*, an *inventory*, a *census*

inventory

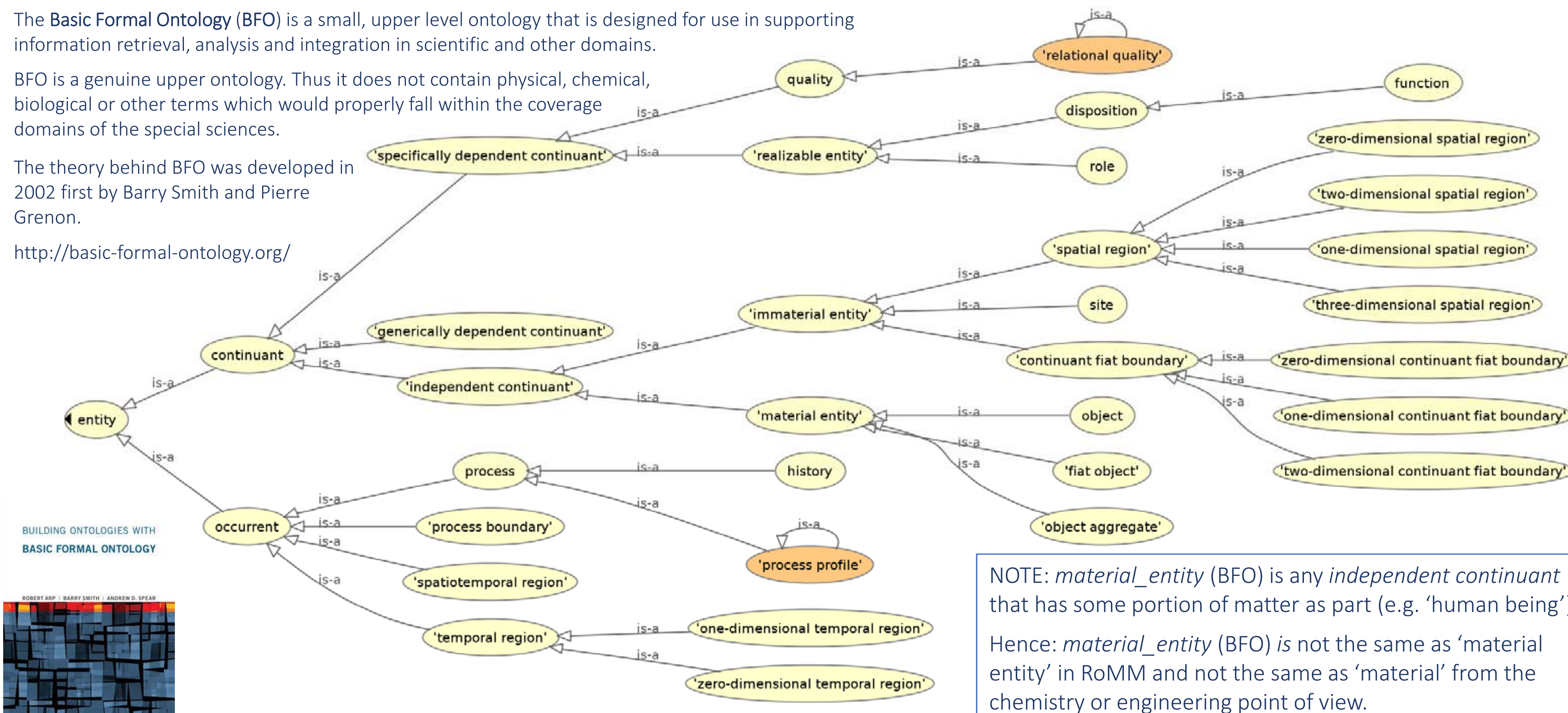
EMMO RELIES ON THE STRUCTURE OF BASIC FORMAL ONTOLOGY (BFO).

The **Basic Formal Ontology** (**BFO**) is a small, upper level ontology that is designed for use in supporting information retrieval, analysis and integration in scientific and other domains.

BFO is a genuine upper ontology. Thus it does not contain physical, chemical, biological or other terms which would properly fall within the coverage domains of the special sciences.

The theory behind BFO was developed in 2002 first by Barry Smith and Pierre Grenon.

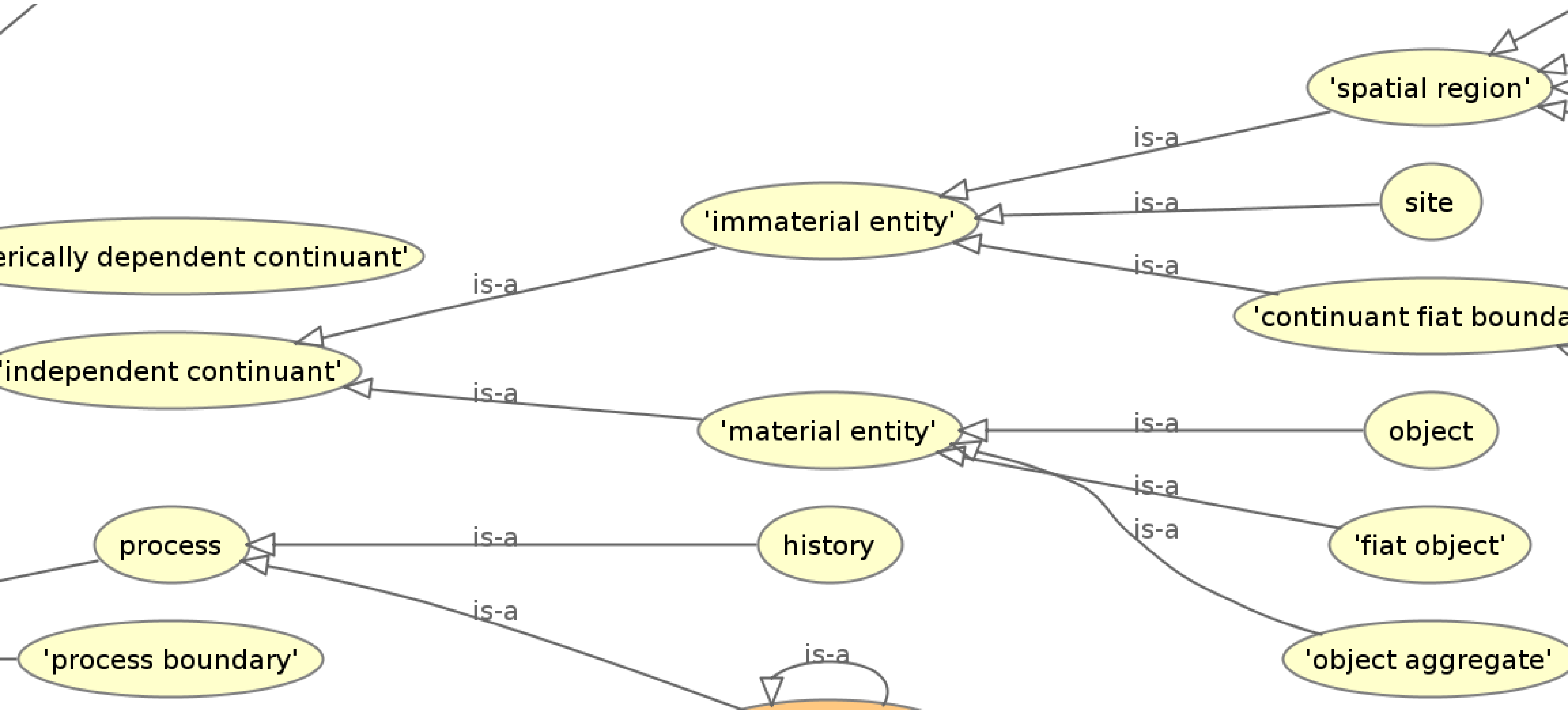
http://basic-formal-ontology.org/



NOTE: *material_entity* (BFO) is any *independent continuant* that has some portion of matter as part (e.g. 'human being')

Hence: *material_entity* (BFO) *is* not the same as 'material entity' in RoMM and not the same as 'material' from the chemistry or engineering point of view.

EMMO RELIES ON THE STRUCTURE OF BASIC FORMAL ONTOLOGY (BFO).



EMMO Material Entity Branch Requirements

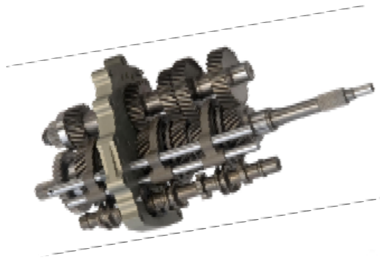
1 A robust, flexible and multi-perspective ontological framework for representing materials

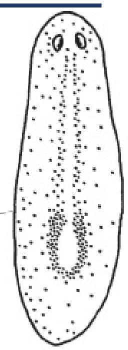
2 Since materials are perceived at different scales, the *material entities* (BFO) should be sub-categorized to cover all granularity levels, so that the same material can be represented in **EMMO** as a black box or as a collection of sub-parts.

e.g. *a molecule seen as a single rigid body*

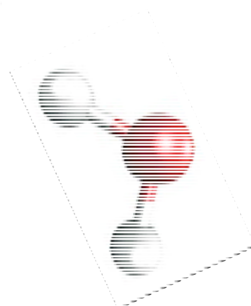
the same molecule seen as a collection of atoms

BFO OBJECT



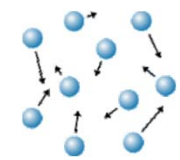


Schmidtea mediterranea



a causally unified set of *material entities*
BFO distinguishes thus far 3 varieties of causal unity

BFO OBJECT AGGREGATE



collections having as parts only *objects*

EMMO Mereology Definitions

EMMO BASIC MATERIAL ENTITIES BRANCH IS BUILT UPON A **HIERARCHY OF MEREOLOGICAL RELATIONS** SUCH AS:

antisymmetric
transitive
reflexive

BFO
is_part_of

↑

transitive
proper parthood

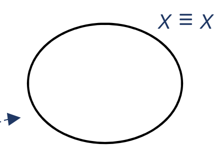
BFO
is_proper_part_of

↑

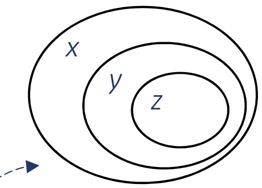
proper parthood

EMMO
is_direct_part_of

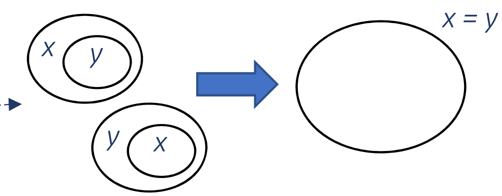
reflexive Pxx



transitive $(Pxy \wedge Pyz) \longrightarrow Pxz$

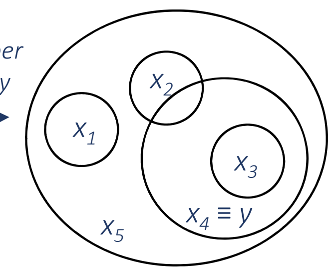


antisymmetric $(Pxy \wedge Pyx) \longrightarrow x = y$



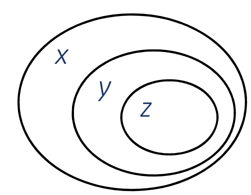
proper parthood $PPxy =_{df} Pxy \wedge \neg x = y$

only x_3 is proper parthood of y



By dropping transitivity **is_direct_part_of** identifies the entity proper parts that are at the <u>very next lower granularity level</u>

e.g.: nucleus **is_direct_part_of** atom
proton **is_direct_part_of** nucleus



y is_direct_part_of x
z is_direct_part_of y

z <u>is not</u> direct part of x

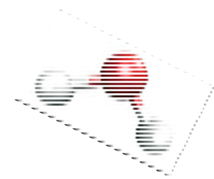
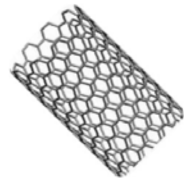
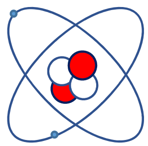
BFO 3 Types of Causal Unity

CU 1 : Causal unity via physical covering
Here the parts in the interior of the unified entity are combined together causally through a common membrane or other physical covering.

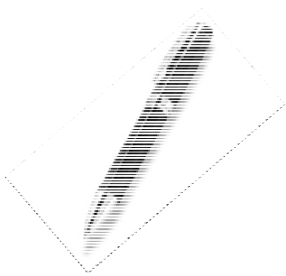



CU 2 : Causal unity via internal physical forces
Here the material parts of a material entity are combined together causally by sufficiently strong physical forces strong enough to act in such a way as to hold the object together relative to the strength of attractive or destructive forces in its ordinary environmental neighbourhood.

BFO

CU 3 : Causal unity via engineered assembly of components *Here the material parts of a material entity are combined together via mechanical assemblies joined for example through screws or other fasteners.*



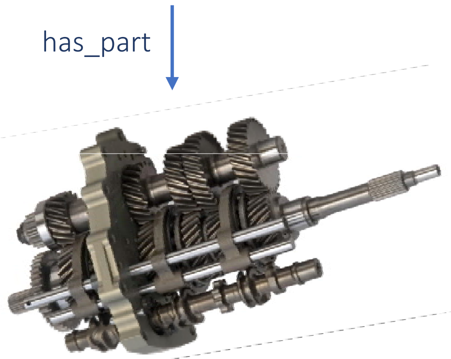
EMMO Mereology

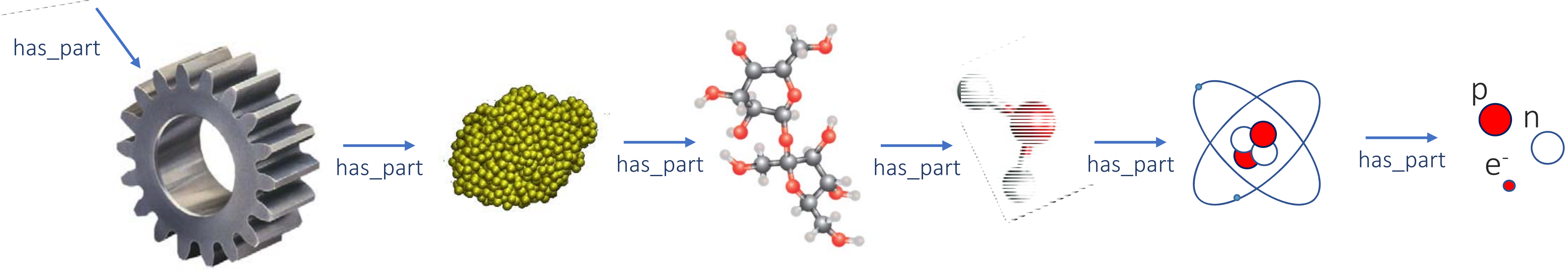
EMMO Material Entities are defined by a
<u>hierarchy of parthood relations,</u>
combining the concepts of direct parthood and object

With **EMMO** we create a representation of the <u>real world granularity</u> of *material entities* that follows physics and materials science perspectives.

A ‘material’ in the user case can be <u>described univocally</u> by declaring *entities* under **EMMO** hierarchy.

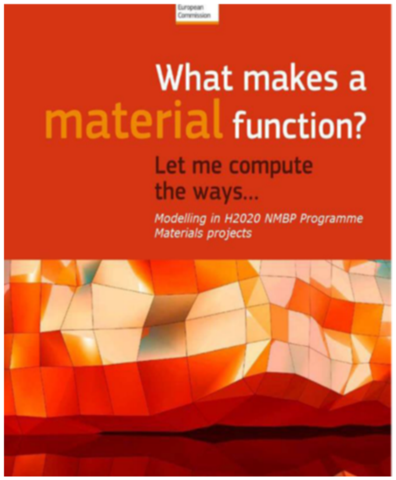
The basic idea is that <u>the ‘material’ can be represented at different levels of granularity,</u> depending on **perspective**.





RoMM Model Types

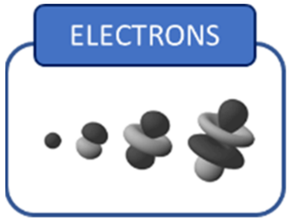
RoMM VI



Modelling in H2020 LEIT-NMBP Programme Materials and Nanotechnology projects

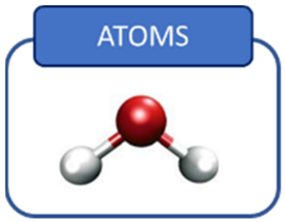
One reality with four veridical views each at a different level of granularity.

This is true for observations and for simulations.



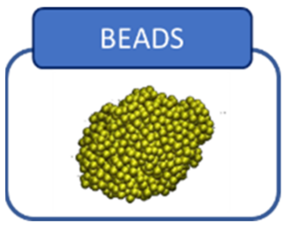
Electronic Model

Physics Based Model using a Physics Equation and Material Relation describing the behaviour of electrons quasi particles either as waves, particles or distributions.



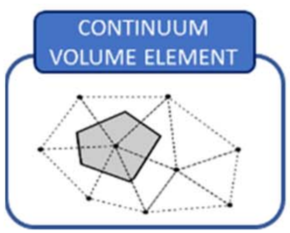
Atomistic Models

Physics Based Model using a Physics Equation and Material Relation describing the behaviour of atoms either as waves, particles or distributions.



Mesoscopic Models

Physics Based Model using a Physics Equation and Material Relation describing the behaviour of Beads either as particles or distributions.

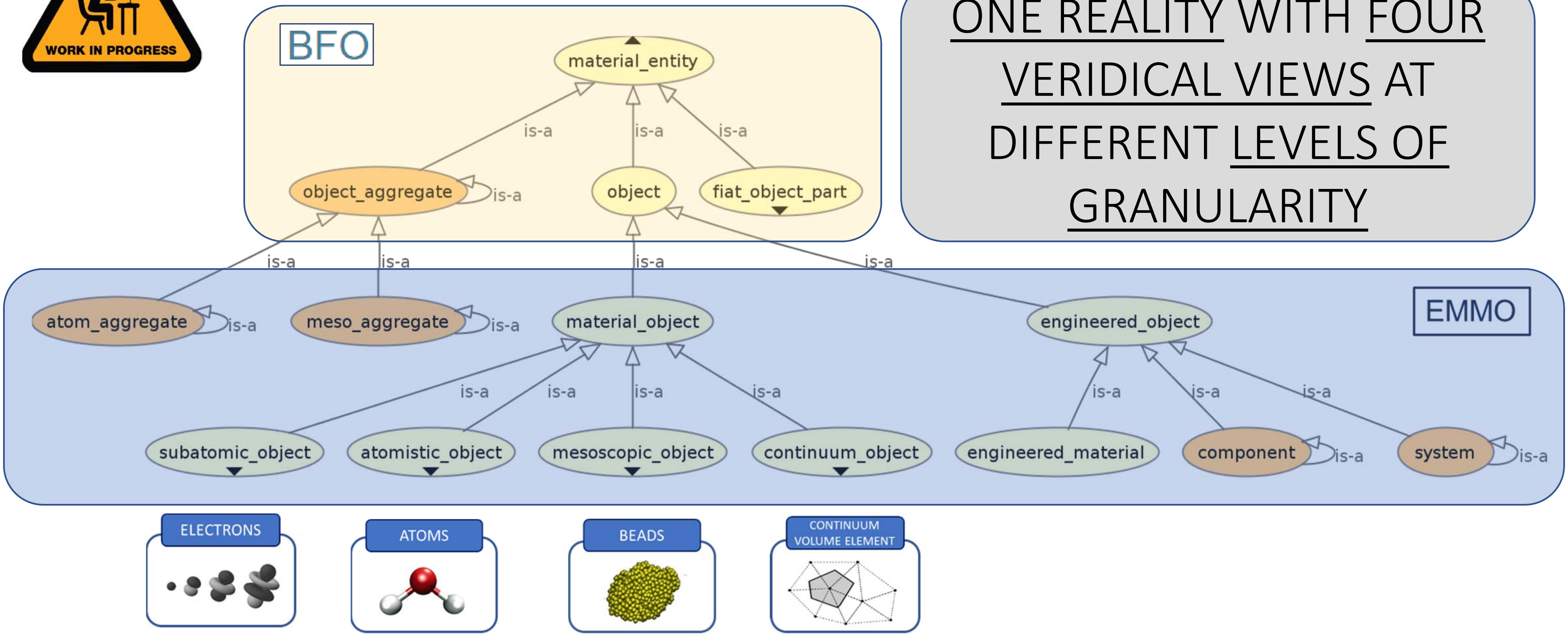


Continuum Models

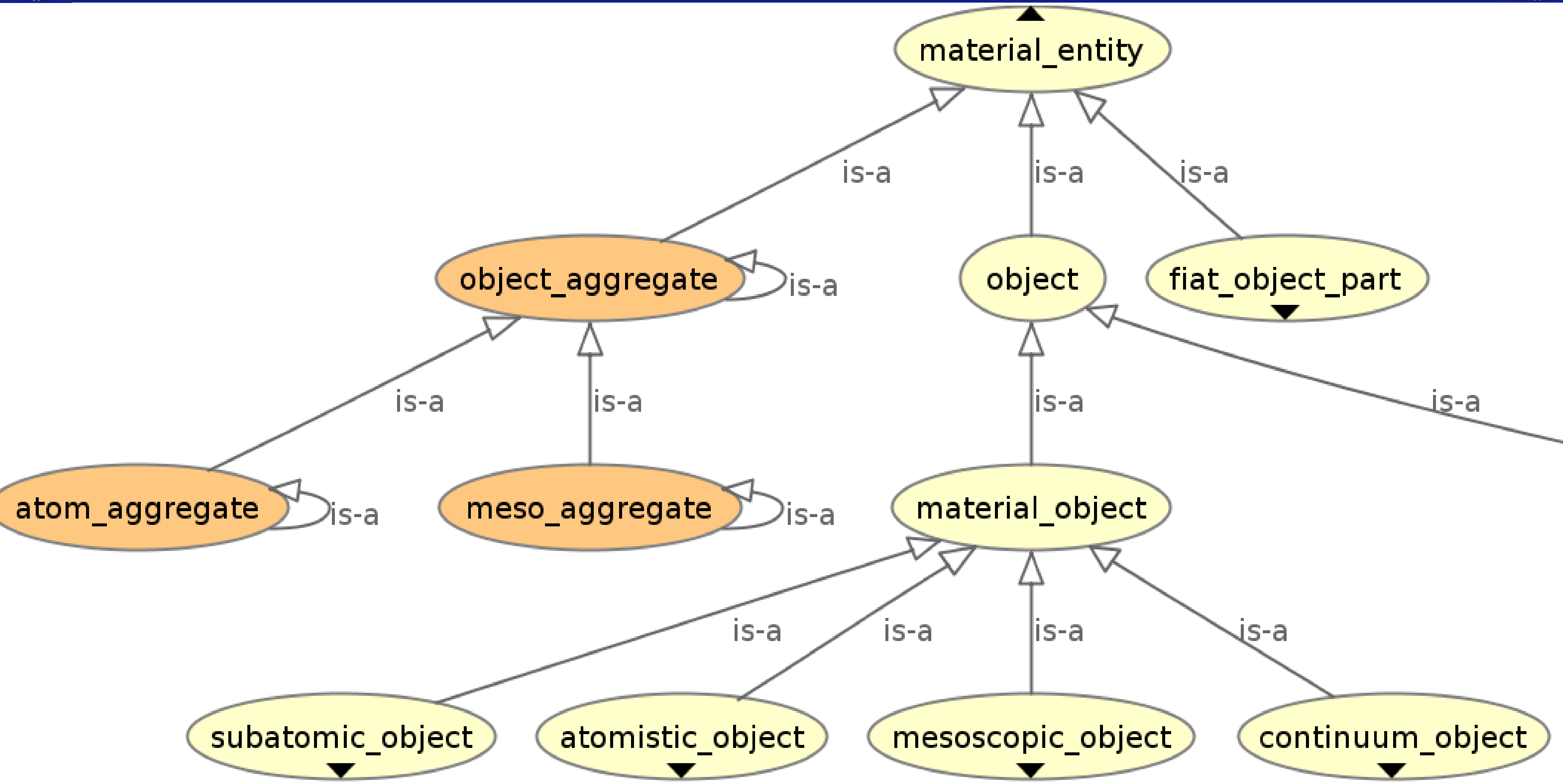
Physics Based Model using a Physics Equation and Material Relation describing the behaviour of Continuum Volume.

EMMO MATERIAL BRANCH (FIRST LEVELS)

ONE REALITY WITH FOUR VERIDICAL VIEWS AT DIFFERENT LEVELS OF GRANULARITY

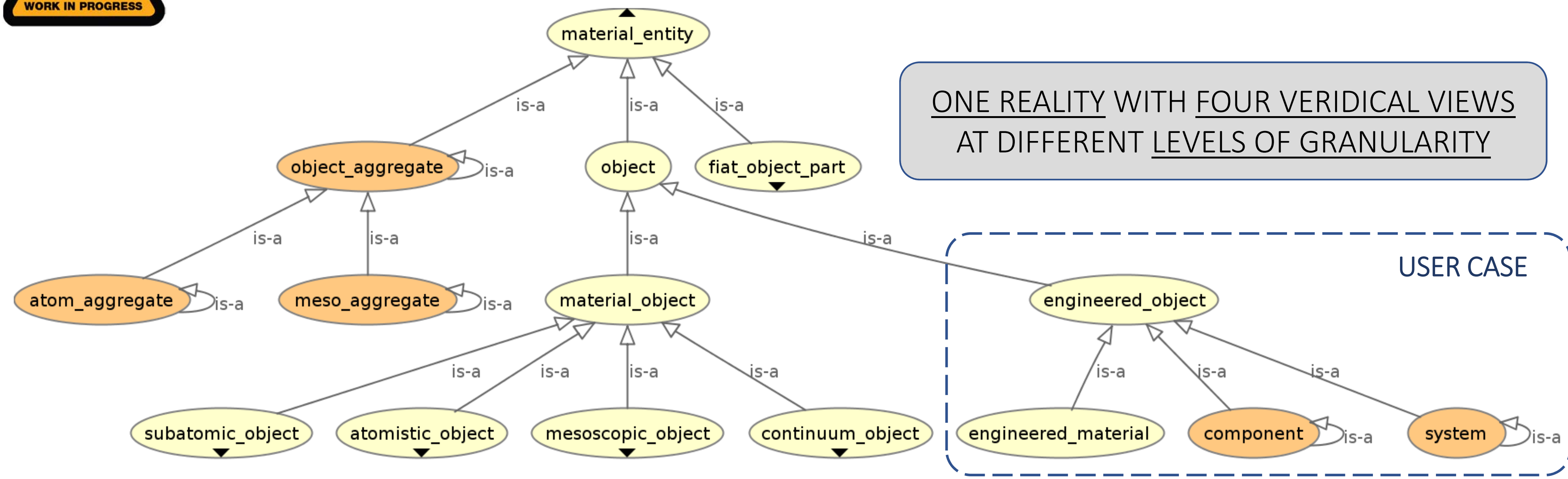


EMMO Material Branch (first levels)

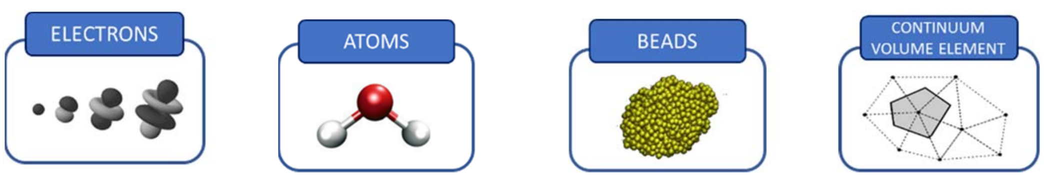


EMMO Material Branch (first levels)

THE **EMMO** MATERIAL BRANCH EXTENDS THE **BFO** MATERIAL ENTITY WITH MATERIAL OBJECTS AT 4 DIFFERENT LEVELS OF GRANULARITY.



ONE REALITY WITH FOUR VERIDICAL VIEWS AT DIFFERENT LEVELS OF GRANULARITY

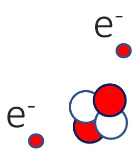


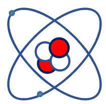
← Key to understanding systems is here (?)

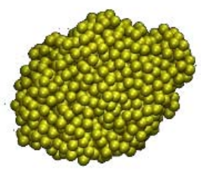
EMMO Mereology for Observations and Simulations

EMMC

EACH ‘material’ can be observed at different levels of granularity and can then be modelled using more then one model type.







electron and nucleus objects

aggregate of electrons and nuclei

aggregate of electrons and nuclei

aggregate of electrons and nuclei

ELECTRONIC OBSERVATIONS AND MODELS

atom objects

aggregate of atoms

aggregate of atoms

ATOMISTIC OBSERVATIONS AND MODELS

meso objects

aggregate of meso objects

MESOSCOPIC OBSERVATIONS AND MODELS

continuum objects

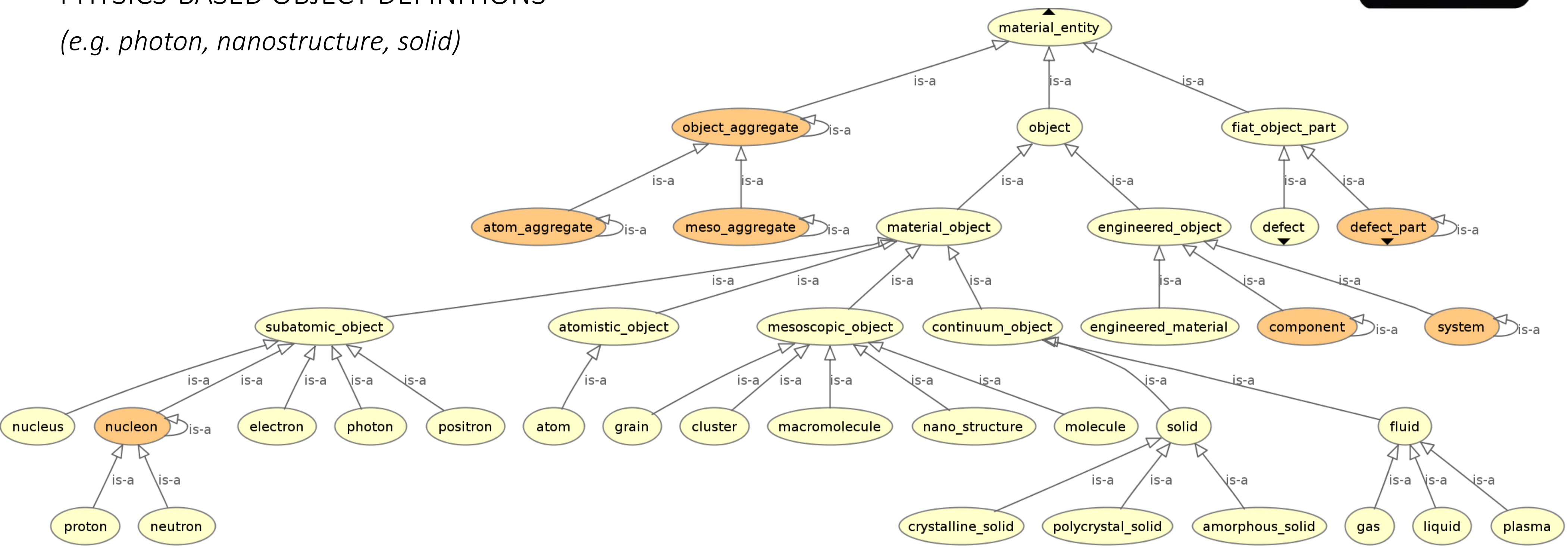
CONTINUUM OBSERVATIONS AND MODELS

ONE USER CASE:
MULTIPLE OBSERVATION GRANULARITY LEVELS
MULTIPLE MODEL GRANULARITY LEVELS

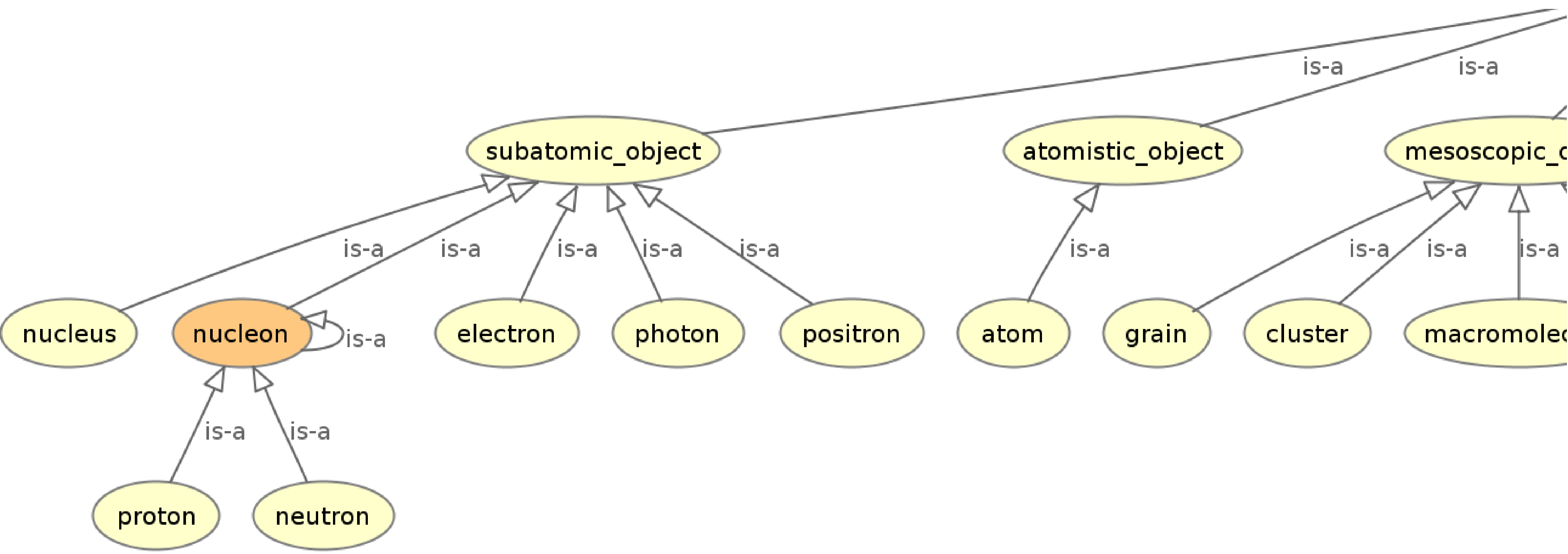
EMMO MATERIAL BRANCH (FULL LEVELS)

THE **EMMO** MATERIAL BRANCH PROVIDES AN EXTRA LEVEL OF DETAIL AS REGARDS *material objects* BY INTRODUCING PHYSICS-BASED OBJECT DEFINITIONS

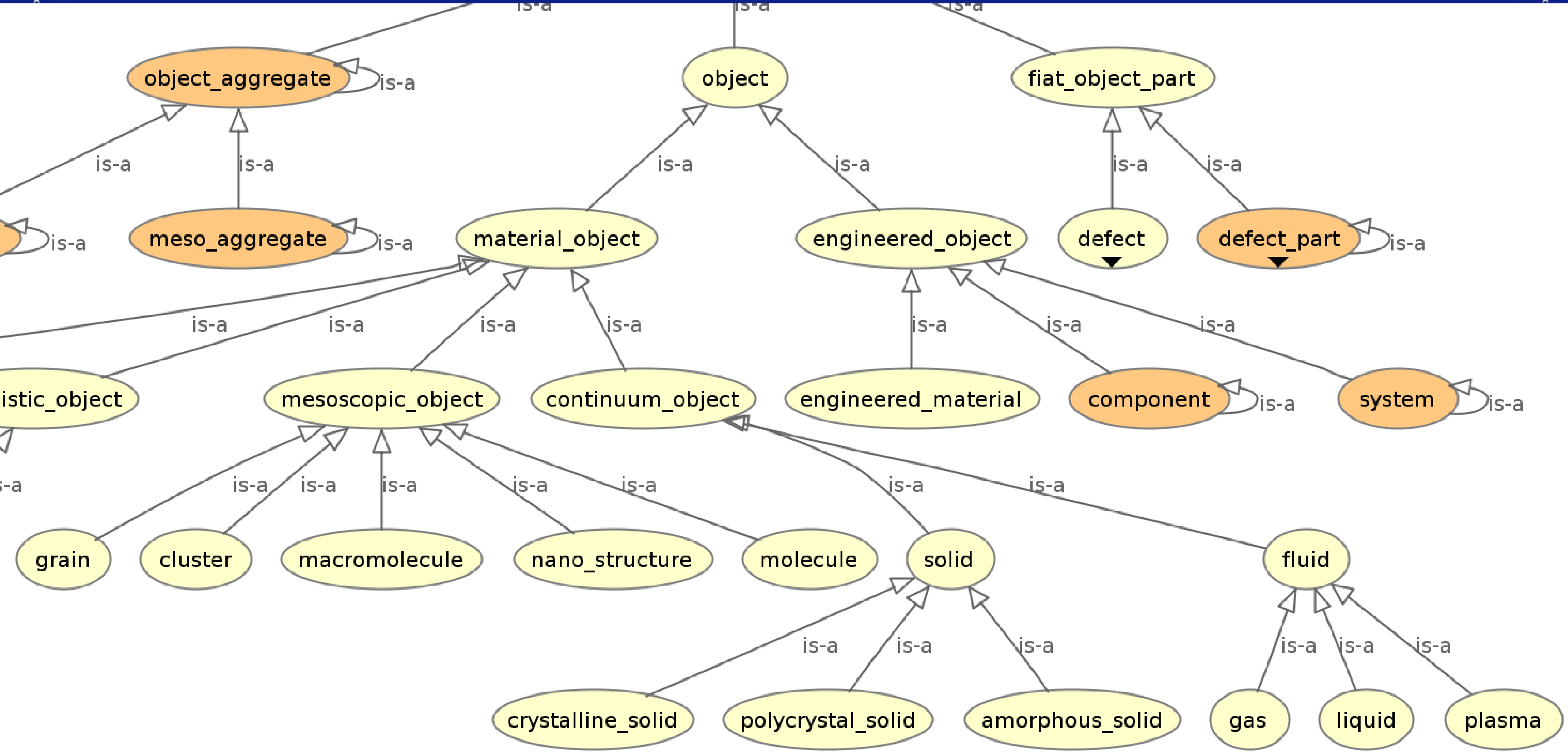
(e.g. photon, nanostructure, solid)



EMMO MATERIAL BRANCH (FULL LEVELS)



EMMO MATERIAL BRANCH (FULL LEVELS)



EMMO Example on Plasma Nanoparticle Synthesis Reactor

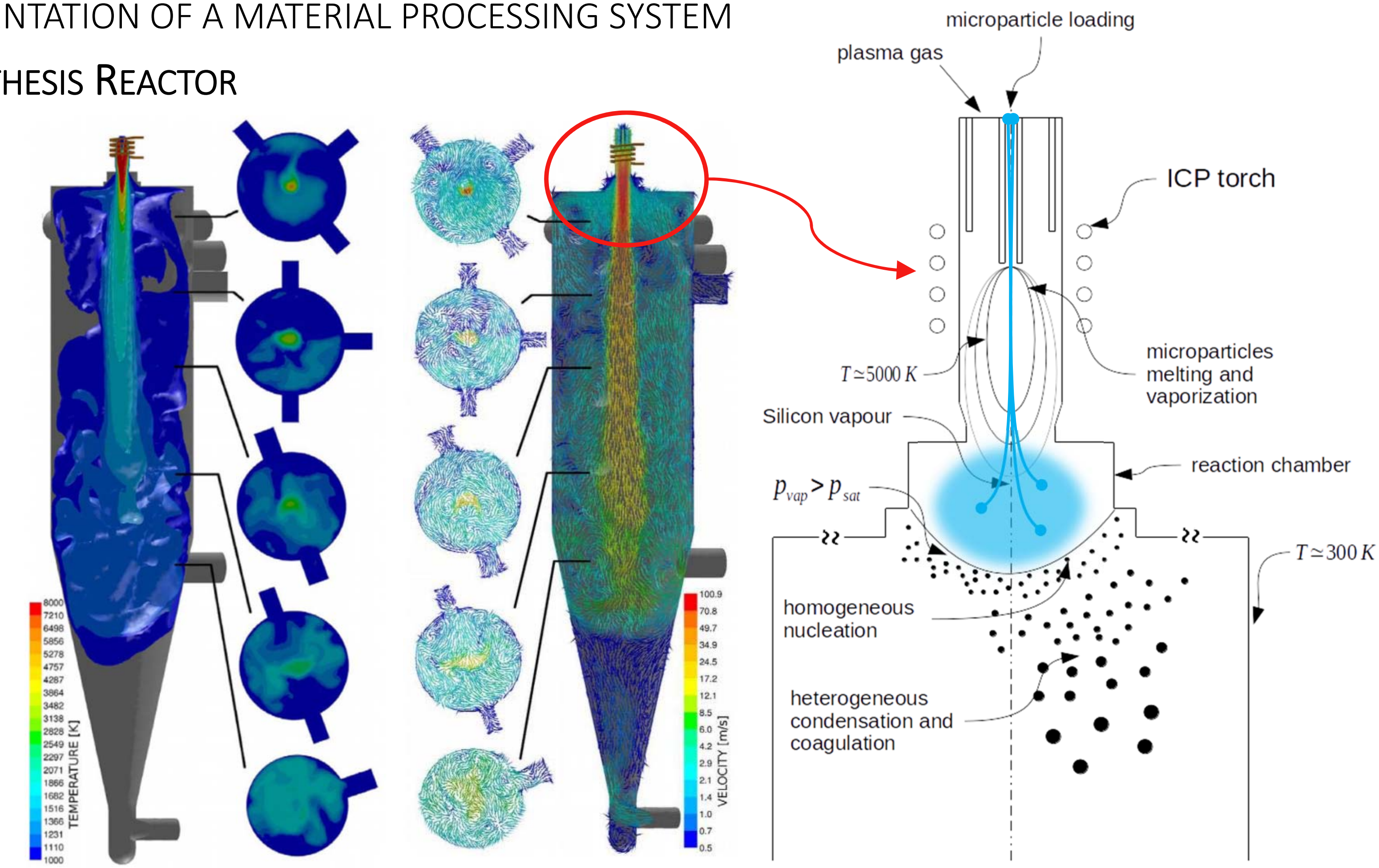
Example of EMMO representation of a material processing system

Plasma Nanoparticle Synthesis Reactor

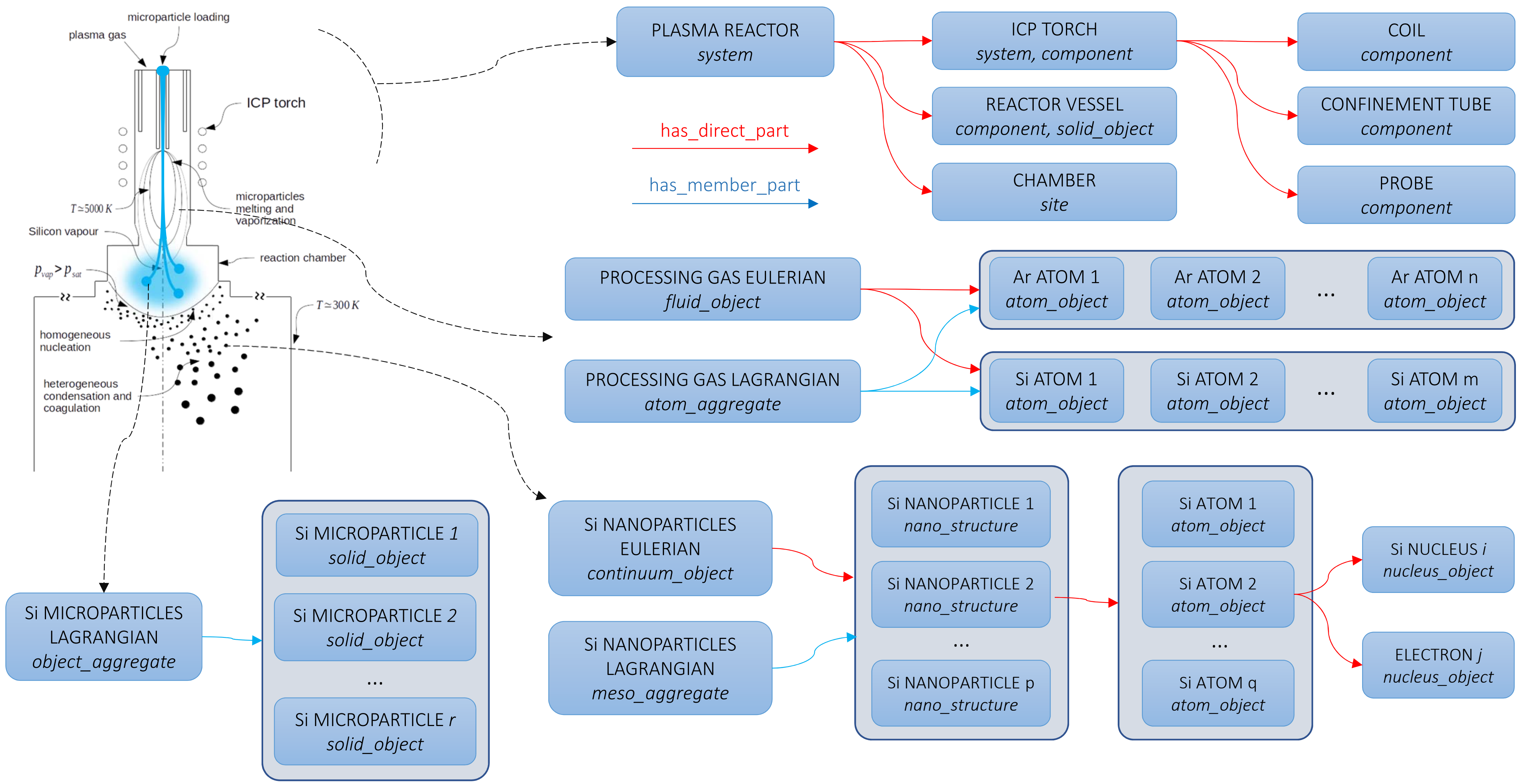
NanoDome

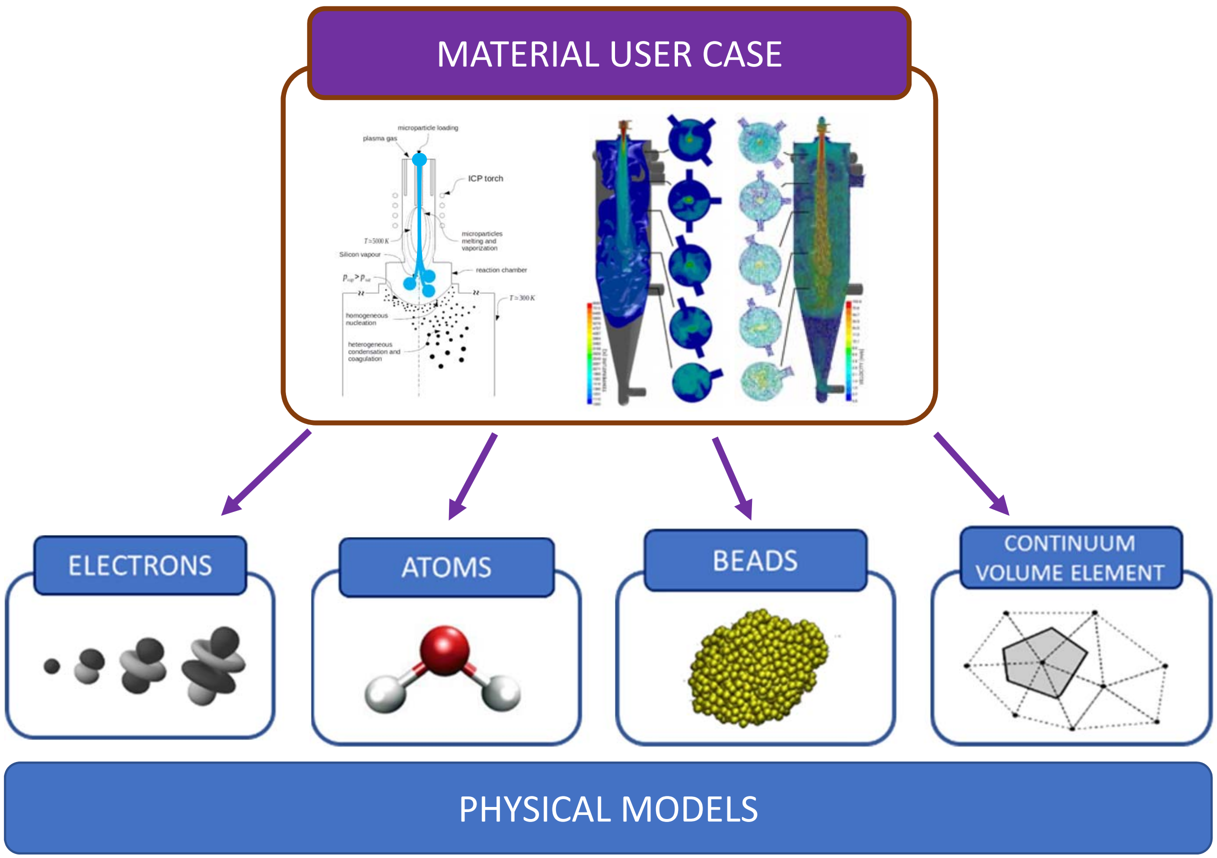
Nanomaterials via **Gas-Phase Synthesis**: A Design-Oriented Modelling and Engineering Approach

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA



EMMO Example on Plasma Nanoparticle Synthesis Reactor



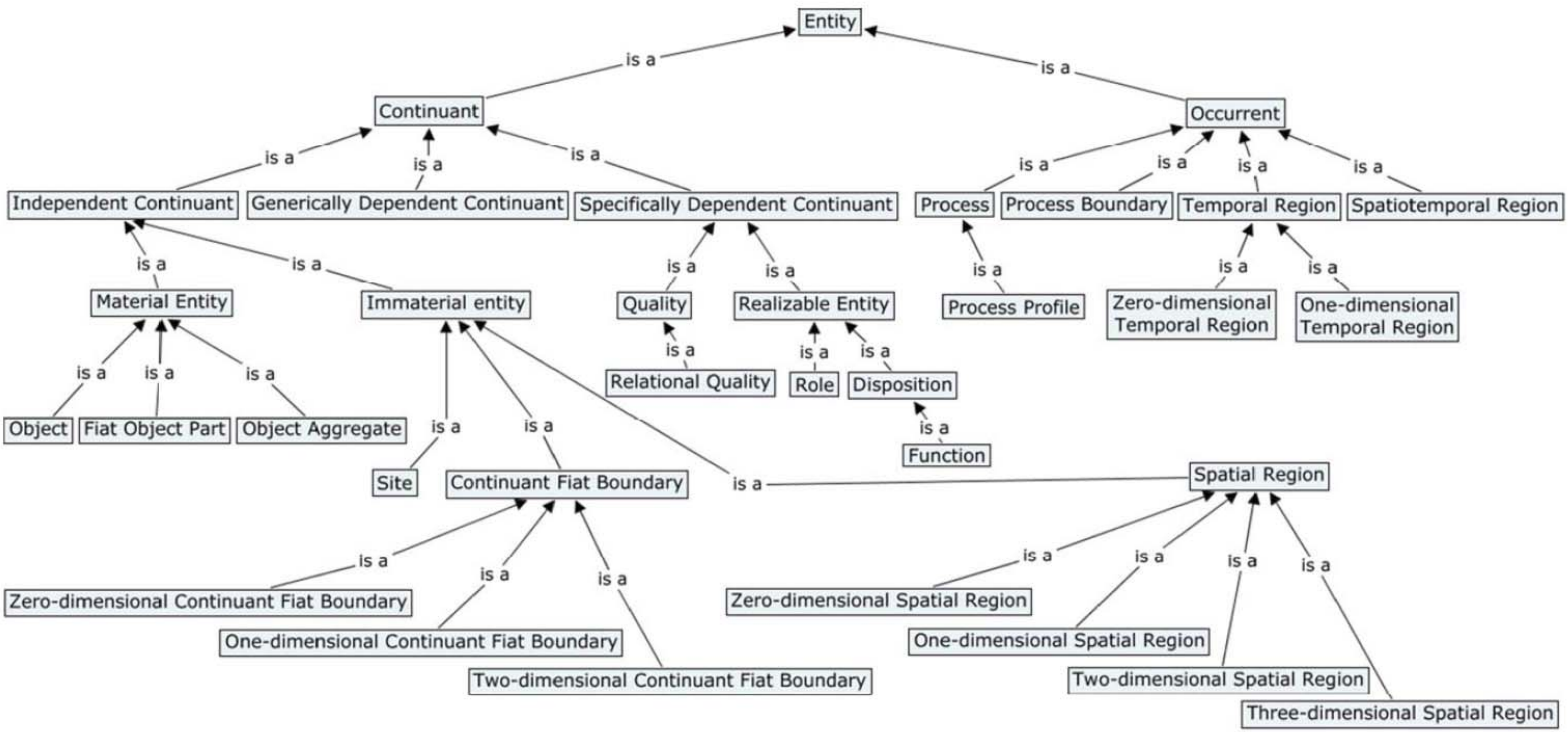


ONE USE CASE, MULTIPLE MODELS

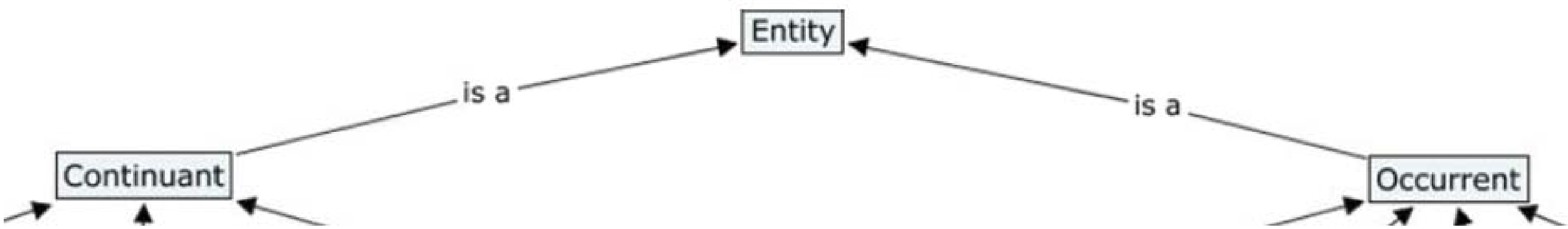
- the choice of the model to apply for a particular part of the use case is done by the modeller
- more than one approach can be used for the same component
- this approach facilitate a multi-scale approach

One ontology to rule them all.

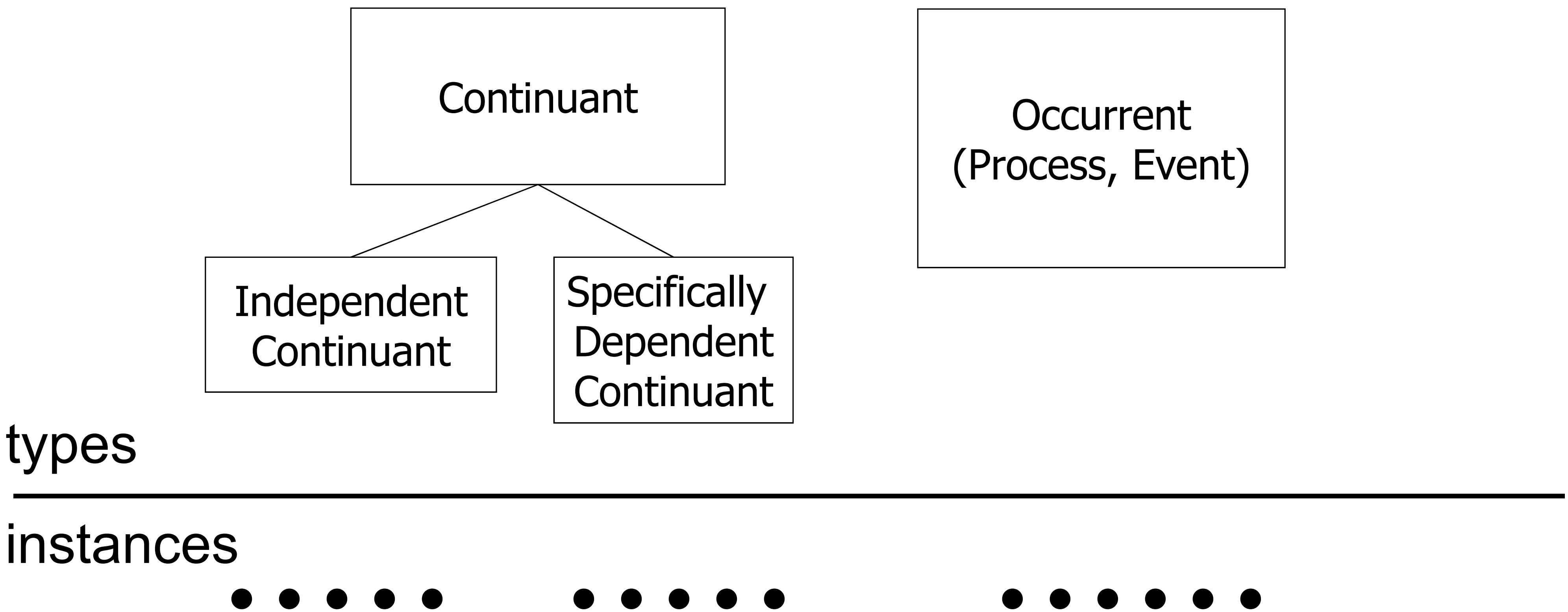
BFO 2.0

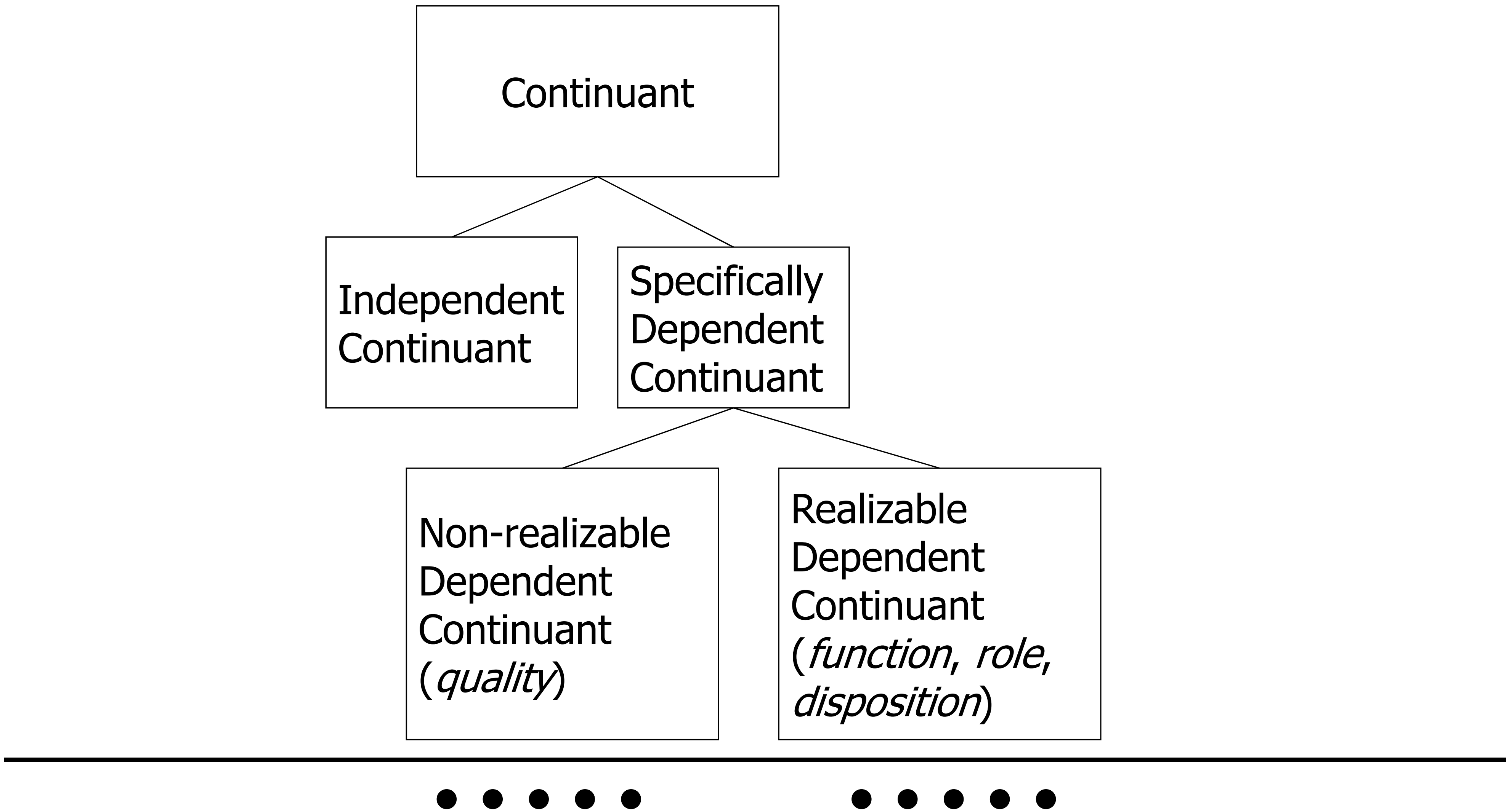

Entity
is a
Continuant
Occurrent
Independent Continuant
Generically Dependent Continuant
Specifically Dependent Continuant
Process
Process Boundary
Temporal Region
Spatiotemporal Region
Material Entity
Immaterial entity
Quality
Realizable Entity
Process Profile
Zero-dimensional Temporal Region
One-dimensional Temporal Region
Object
Fiat Object Part
Object Aggregate
Relational Quality
Role
Disposition
Function
Site
Continuant Fiat Boundary
Spatial Region
Zero-dimensional Continuant Fiat Boundary
One-dimensional Continuant Fiat Boundary
Two-dimensional Continuant Fiat Boundary
Zero-dimensional Spatial Region
One-dimensional Spatial Region
Two-dimensional Spatial Region
Three-dimensional Spatial Region

BFO backbone taxonomy

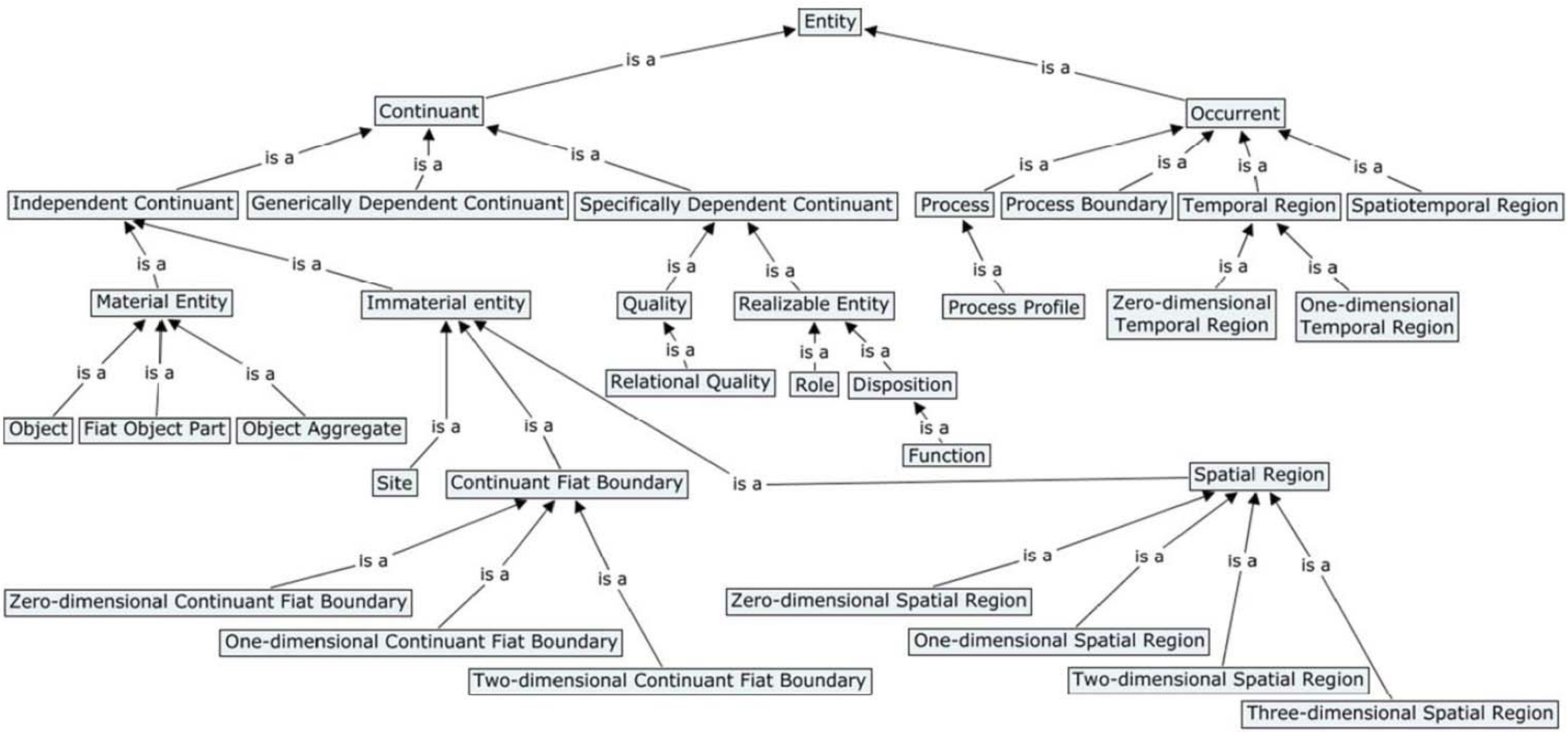


BFO: A First Look

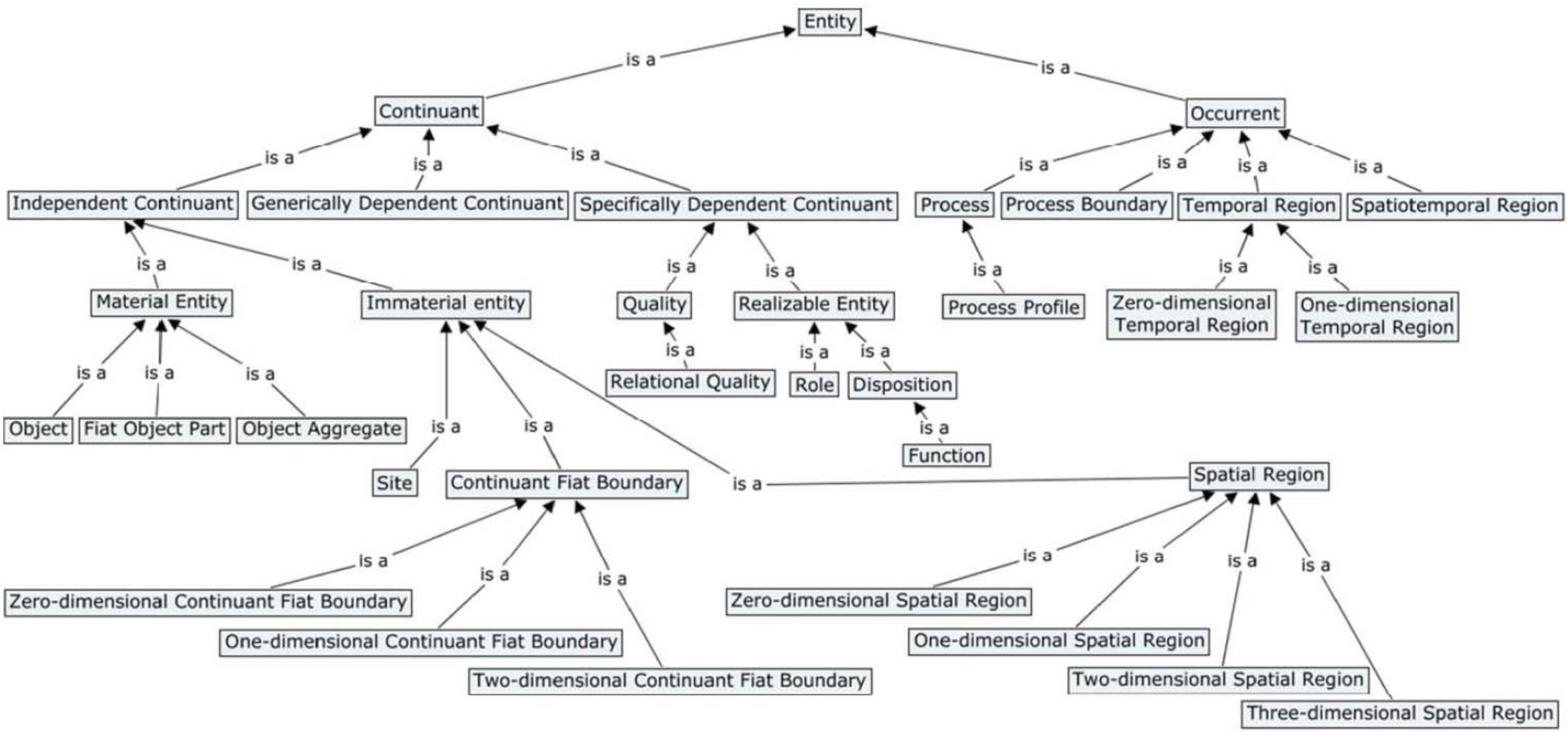



Continuant
Independent Continuant
Specifically Dependent Continuant
Non-realizable Dependent Continuant (*quality*)
Realizable Dependent Continuant (*function*, *role*, *disposition*)

BFO backbone taxonomy



all relations here are *is_a* (*type_of*)



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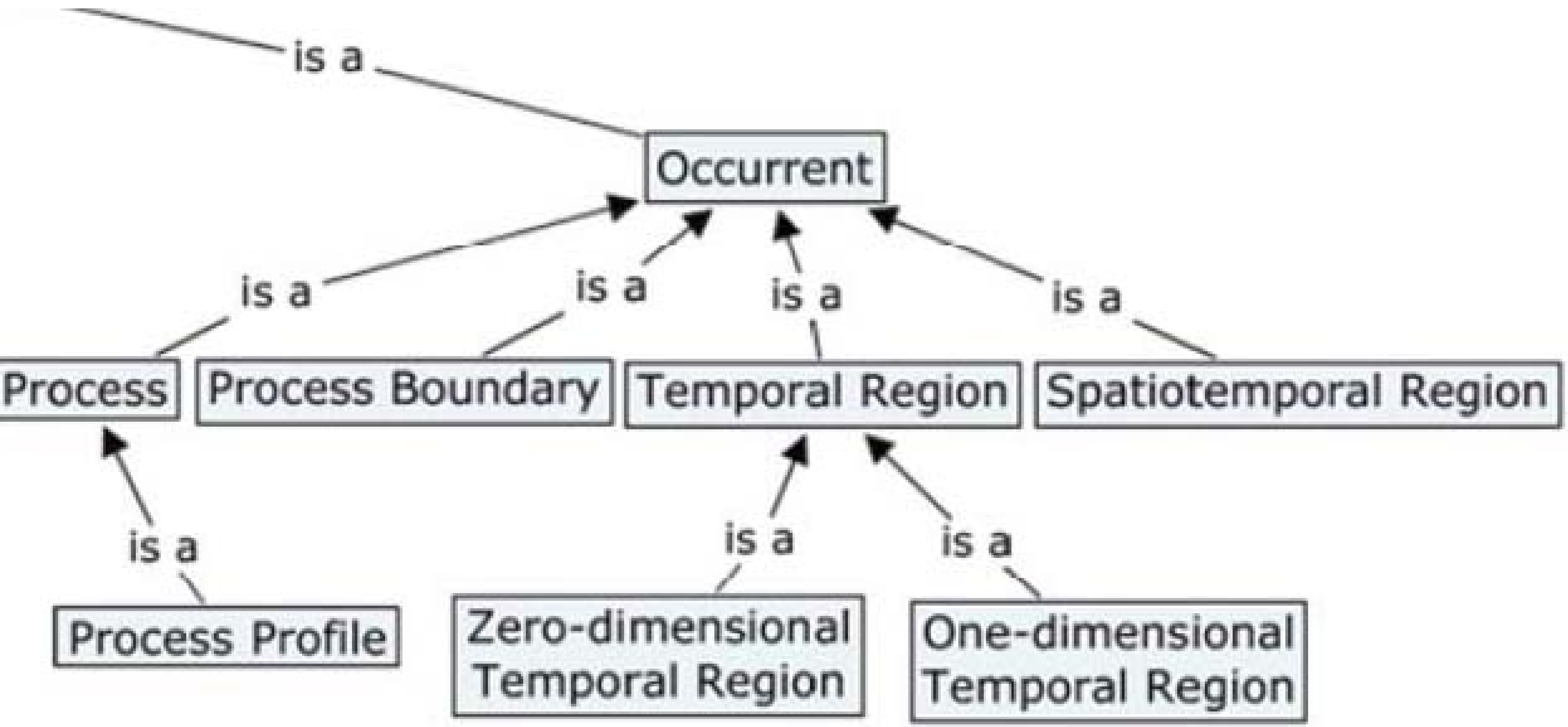
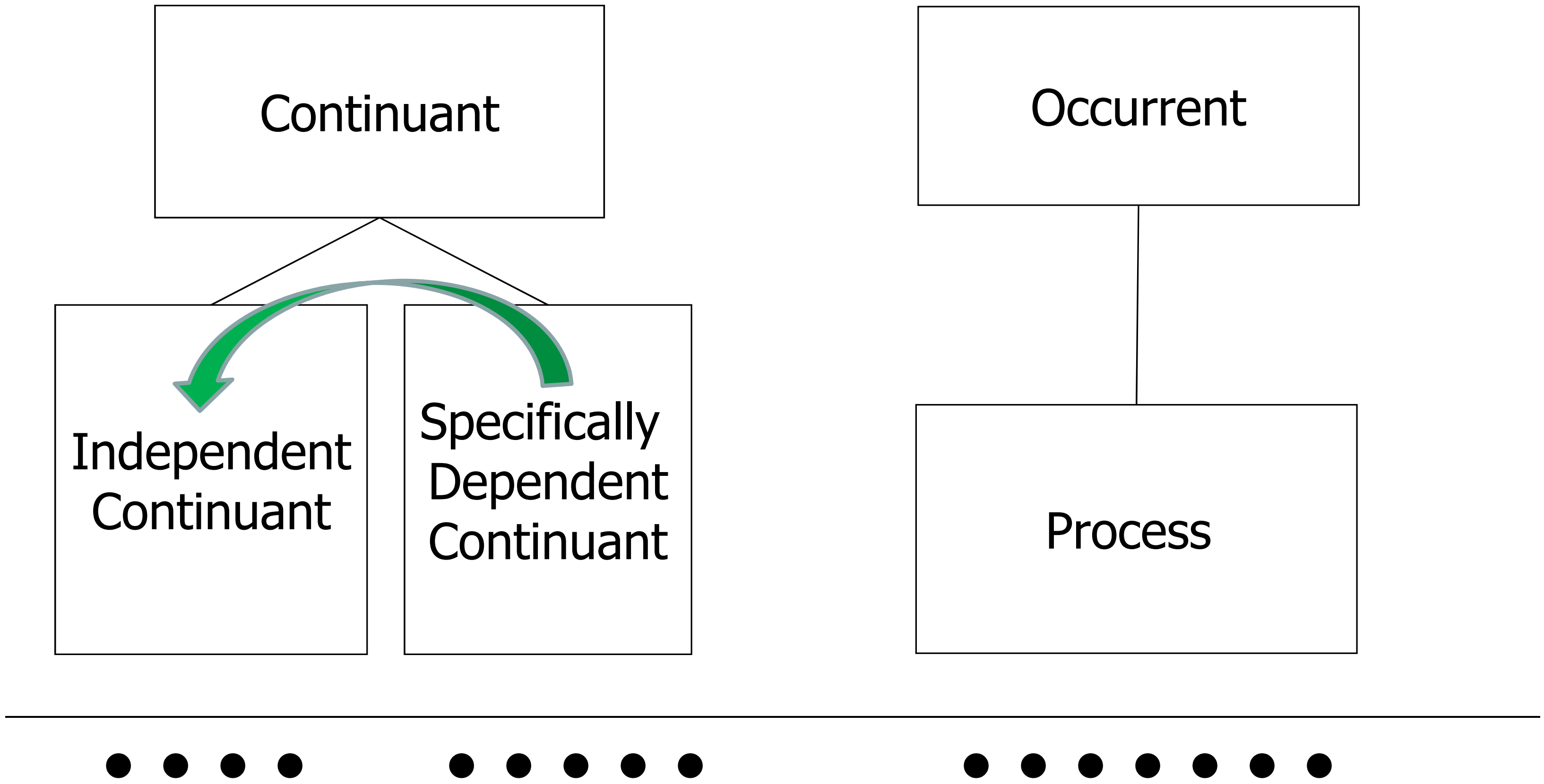


specifically_depends_on



What does ‘*specifically_depends_on*’ mean?

To say that type *A specifically_depends_on* type *B,* is to say that **every instance of *A* requires some instance of *B* in order to exist**

headache depends_on head

All instances of *headache* depend on **some** instance of *head*

This *all-some rule* applies to all relations other than *is_a*

Examples of relations

is_a

specifically_depends_on

bearer_of

part_of

has_part

located_in

realizes

has_participant

The All-Some Rule

Before we add a relational assertion

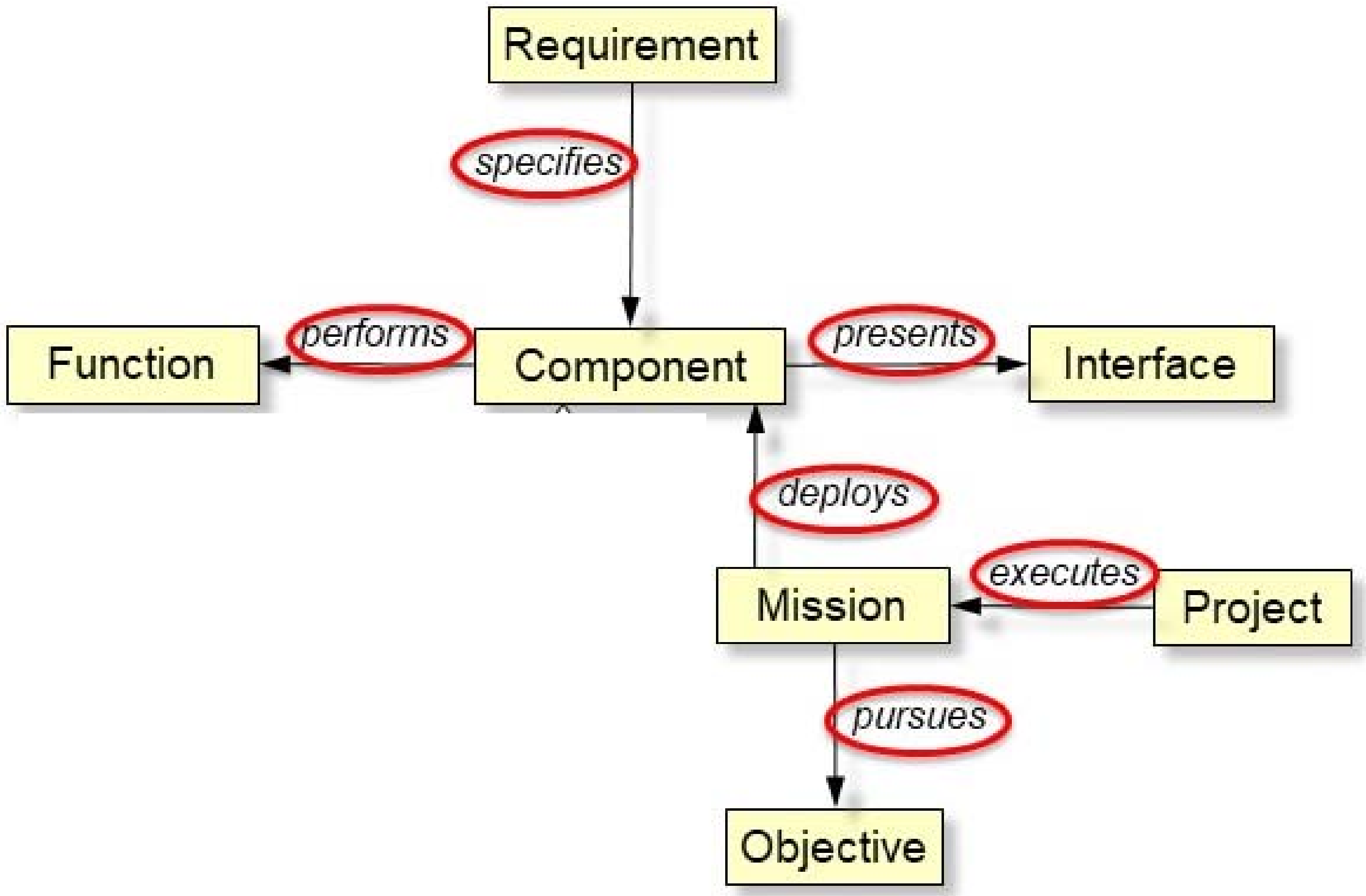
$$A\ R\ B$$

to an ontology graph, we need to check that

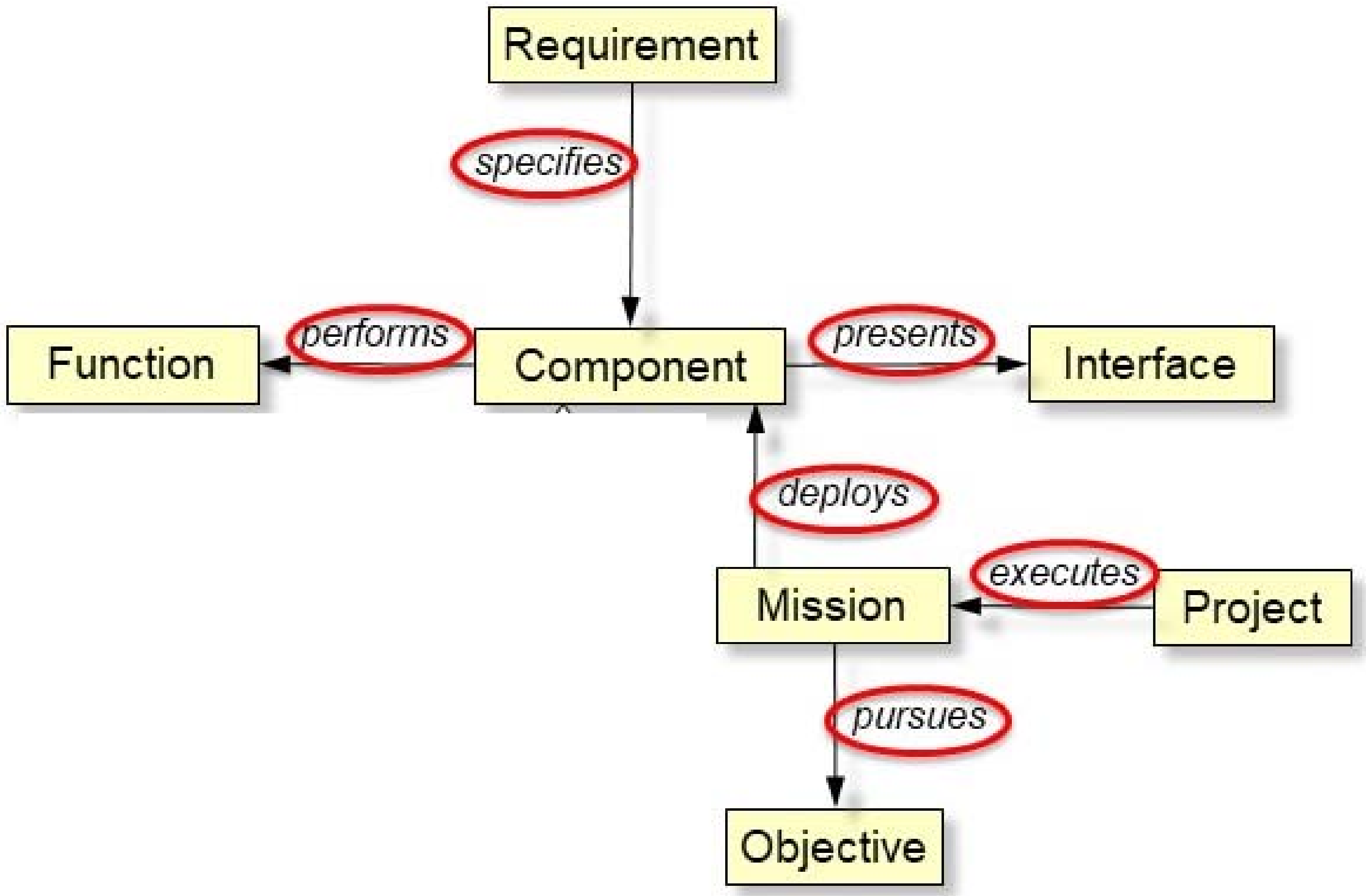
> all instances of *A* stand in the instance-level counterpart of *R* to some instance of *B*

Time	Topic
1:15 PM	**Example Ontology from the SE Domain** Functions Capabilities **BFO-based Ontology for Information Entities** **AFRL Digital Thread/Digital Twin** **Product Life Cycle (PLC) Ontology** **Commodities, Services and Infrastructure**
3:00 PM	Break
3:15 PM	**Interactive session: Defining 'system'**
4:30 PM	Adjourn

[Example Ontology from SE Domain]

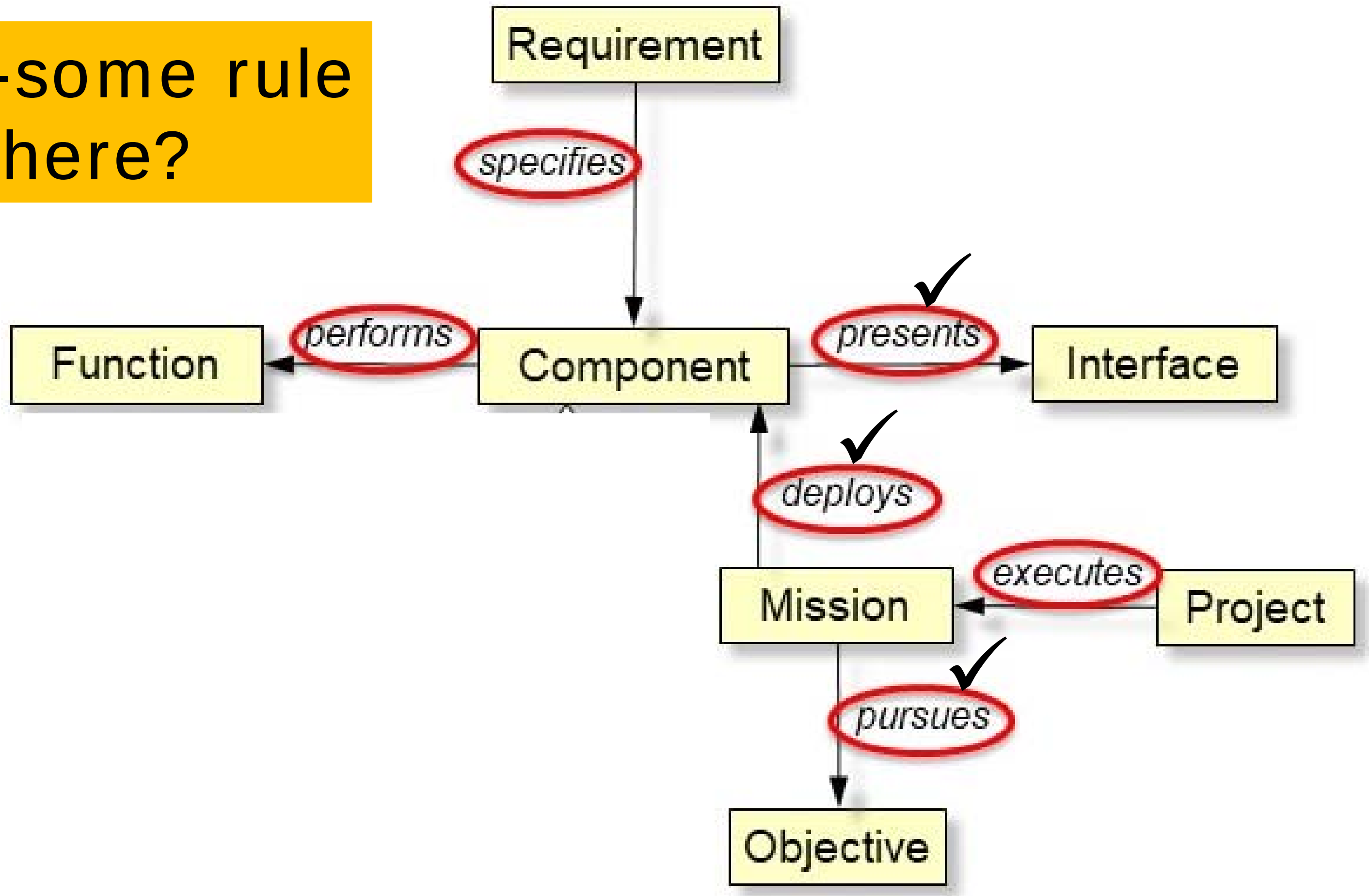


[Example Ontology from SE Domain]



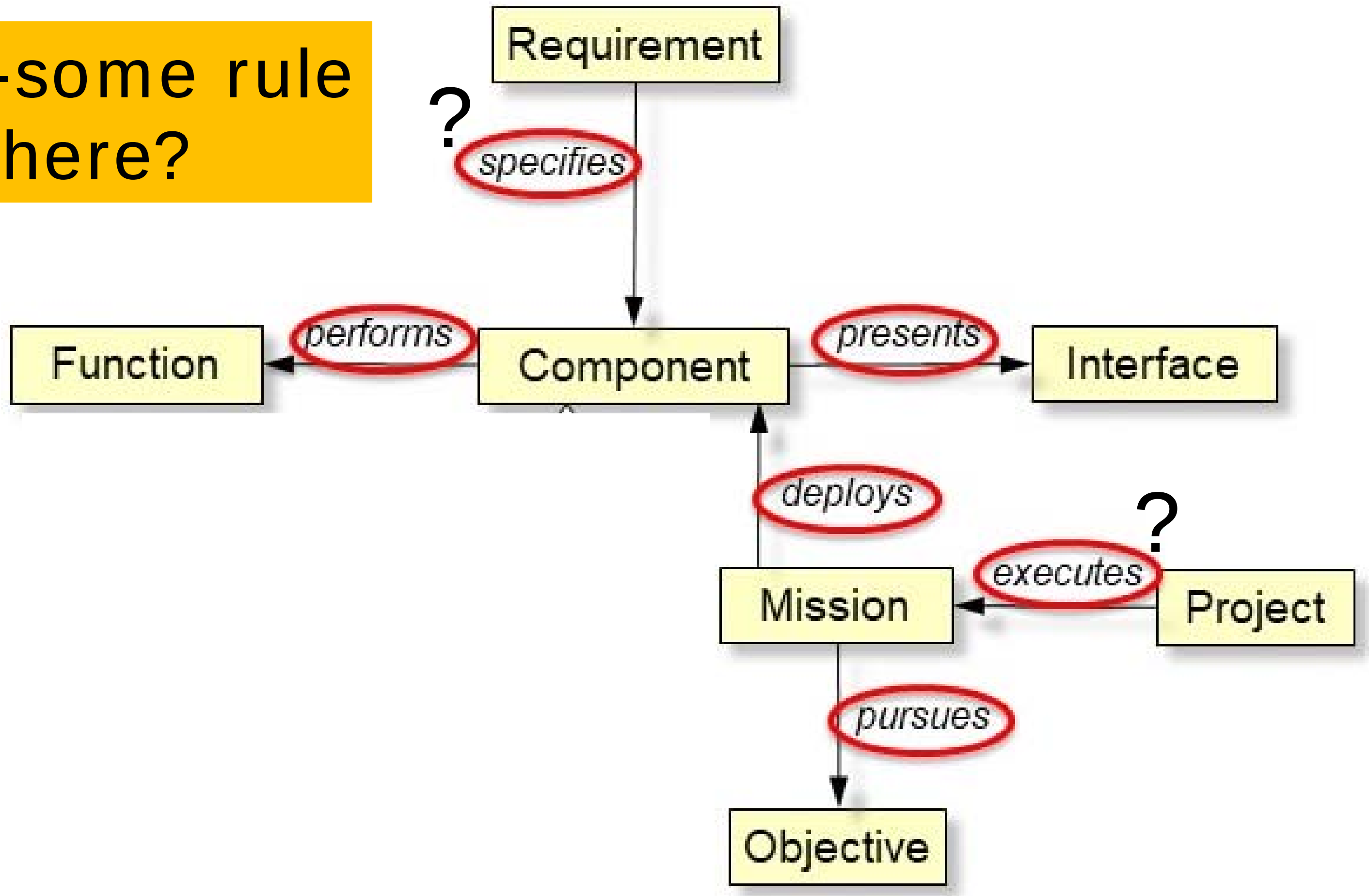
[Example Ontology from SE Domain]

is the all-some rule satisfied here?



[Example Ontology from SE Domain]

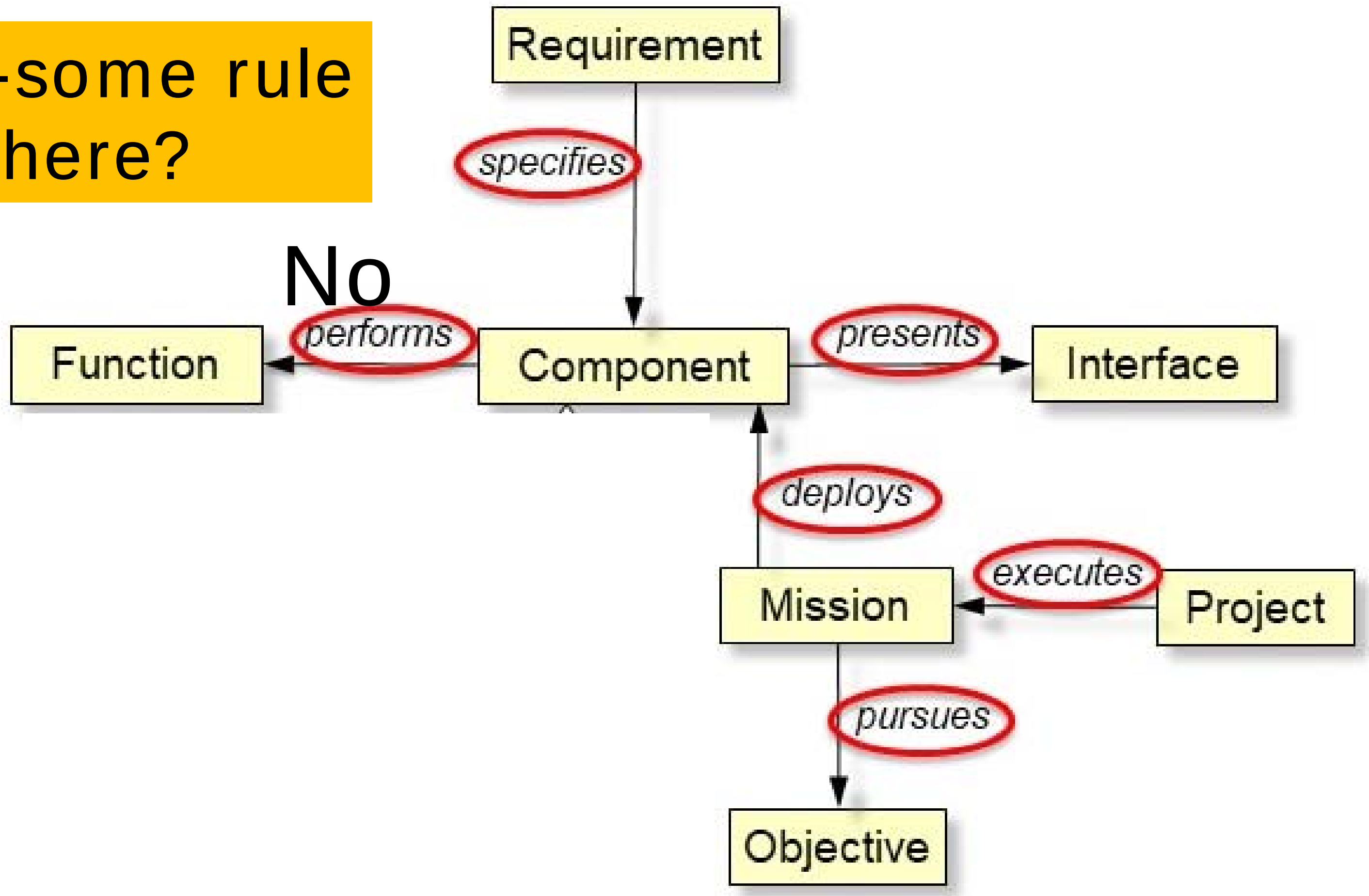
is the all-some rule satisfied here?



[Example Ontology from SE Domain]

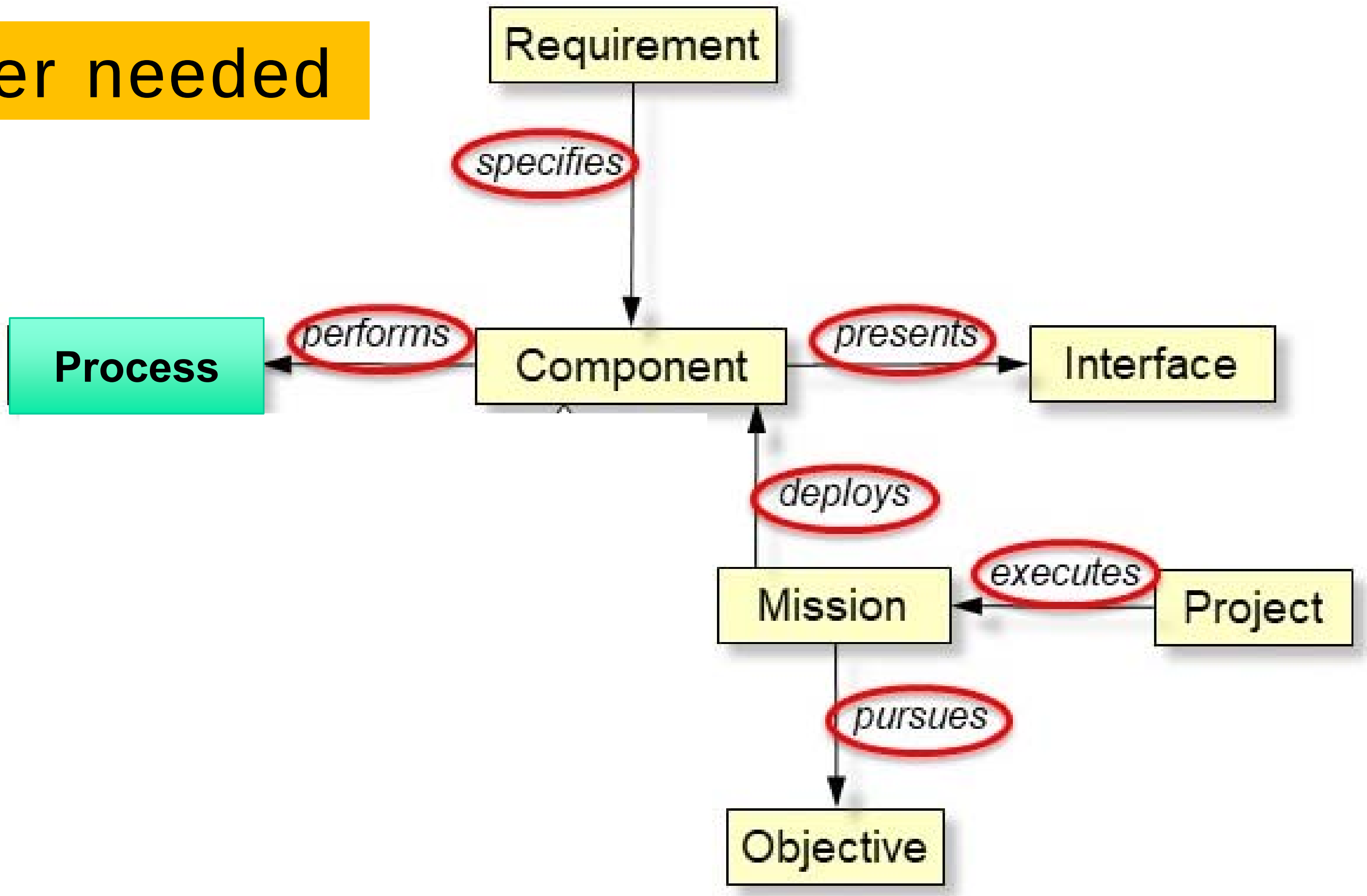
is the all-some rule satisfied here?

No



[Example Ontology from SE Domain]

extra layer needed



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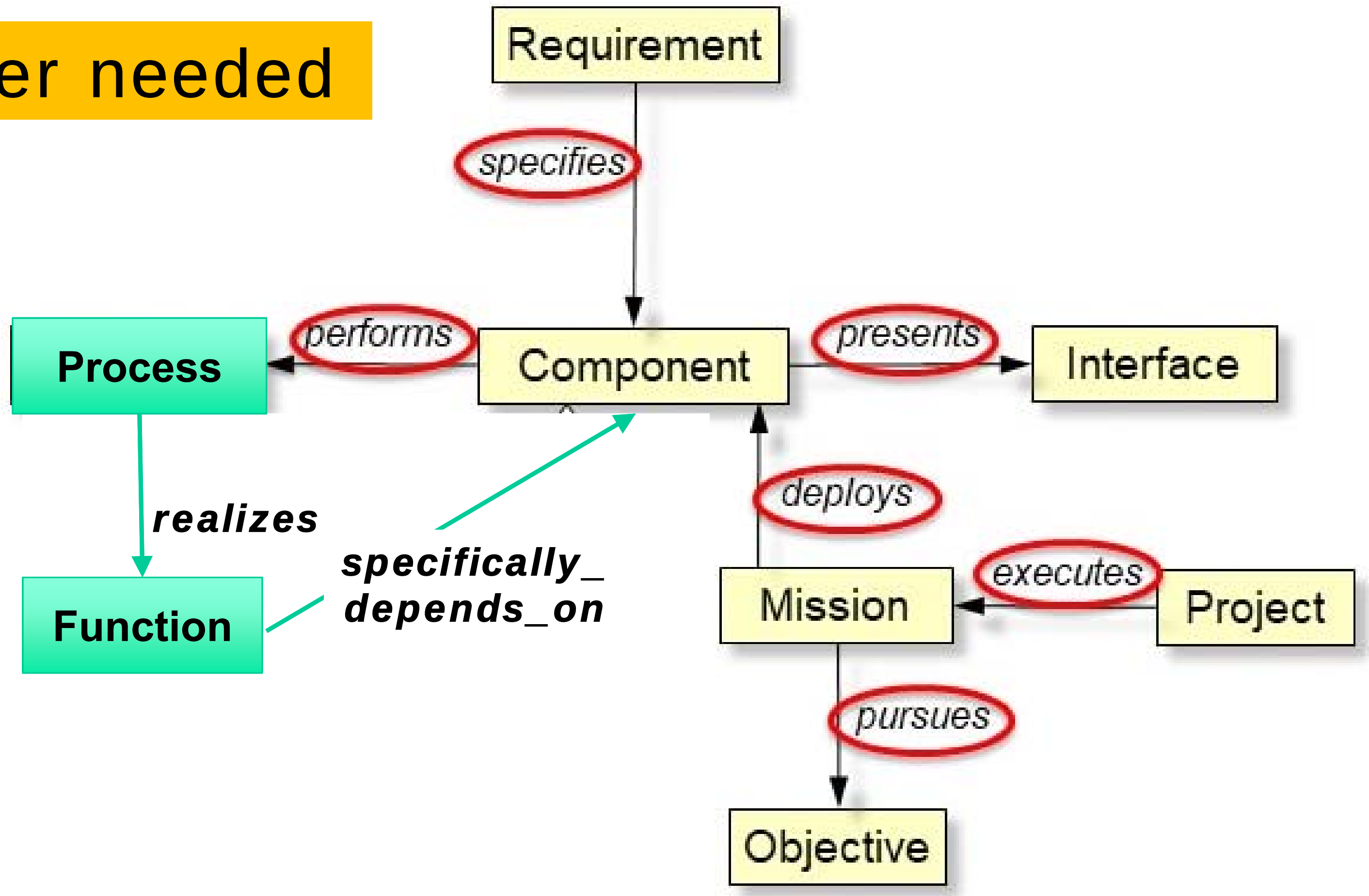
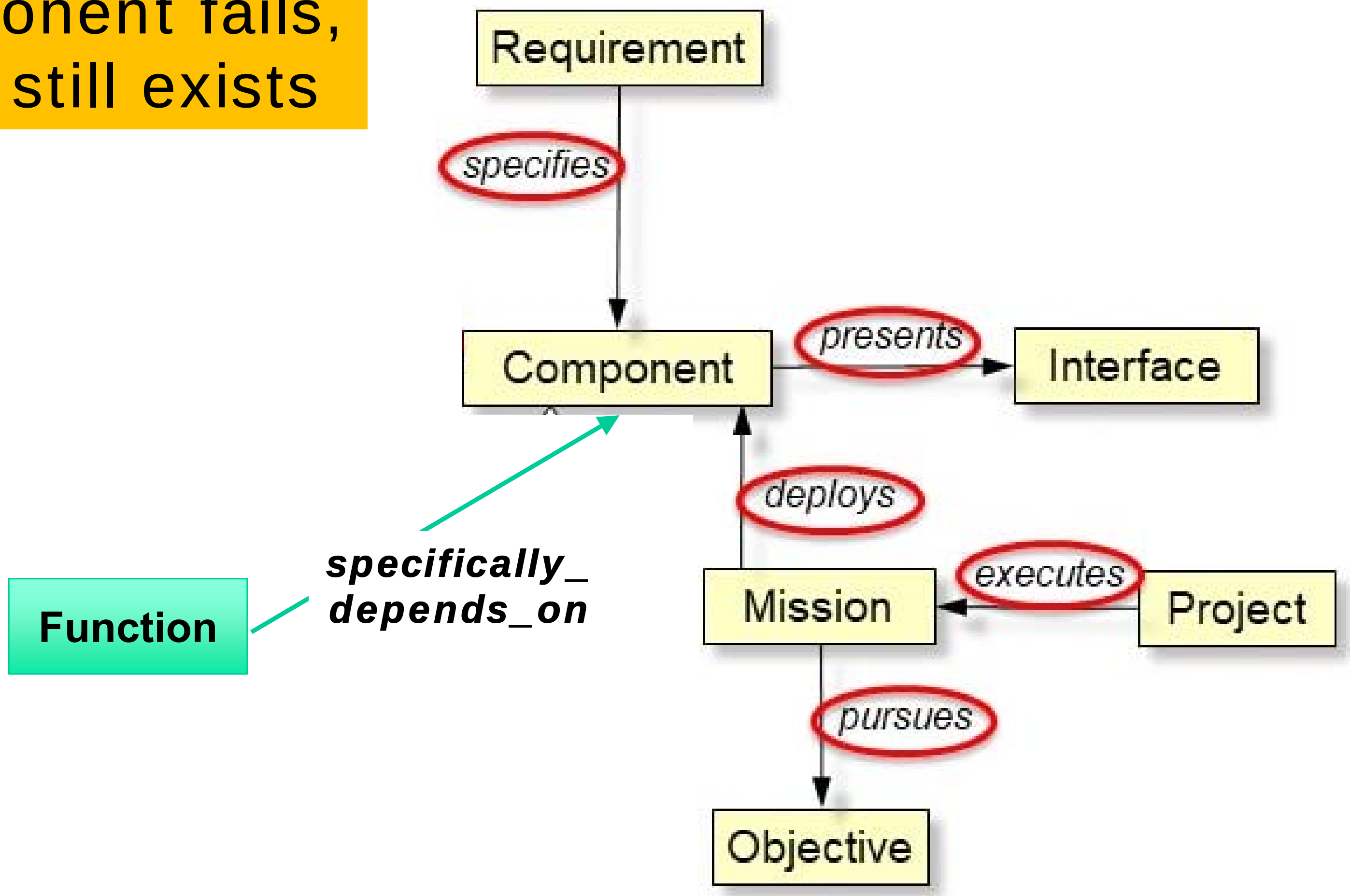
extra layer needed

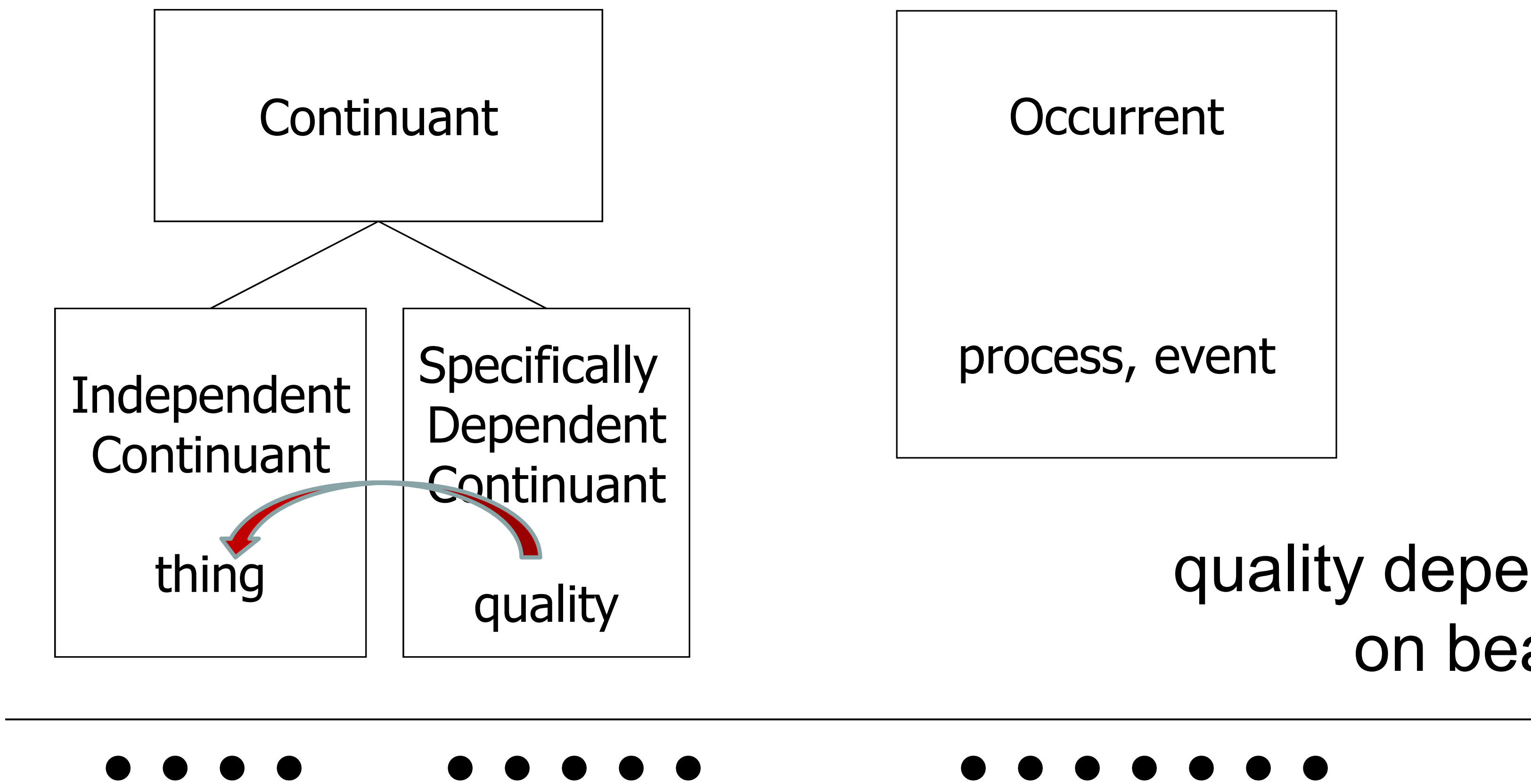


[Example Ontology from SE Domain]

when component fails, its function still exists

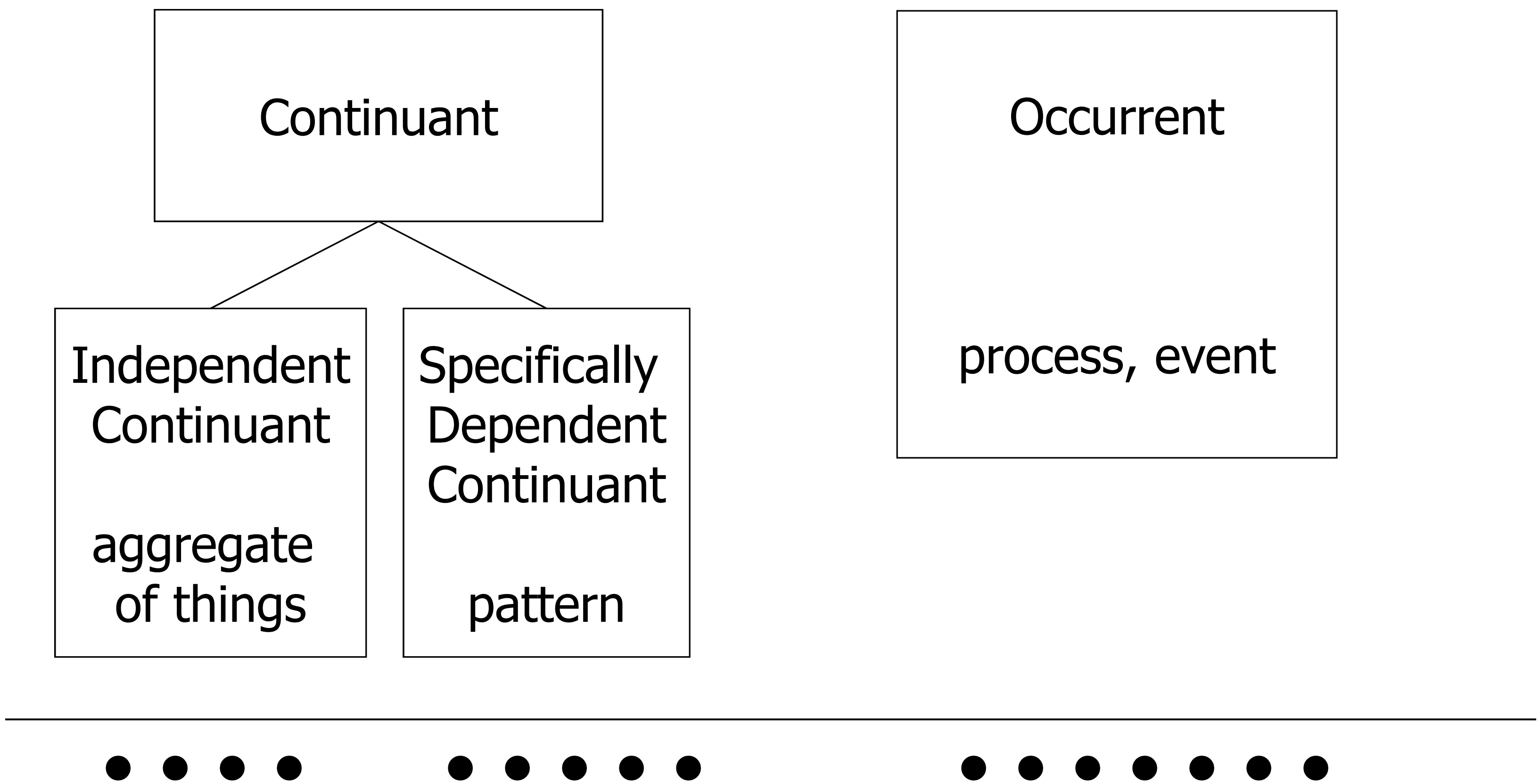


quality specifically_depends_on bearer

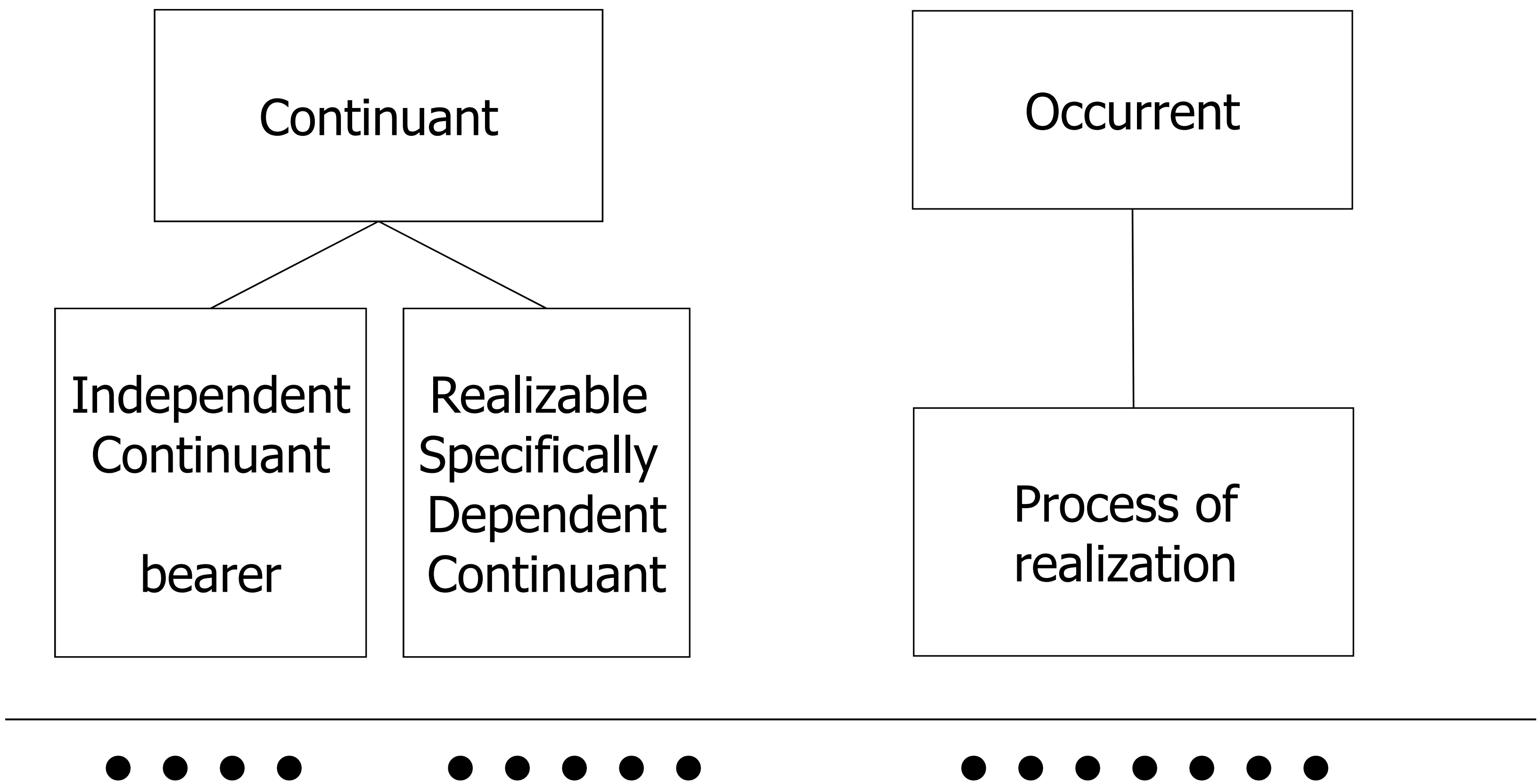


quality depends on bearer

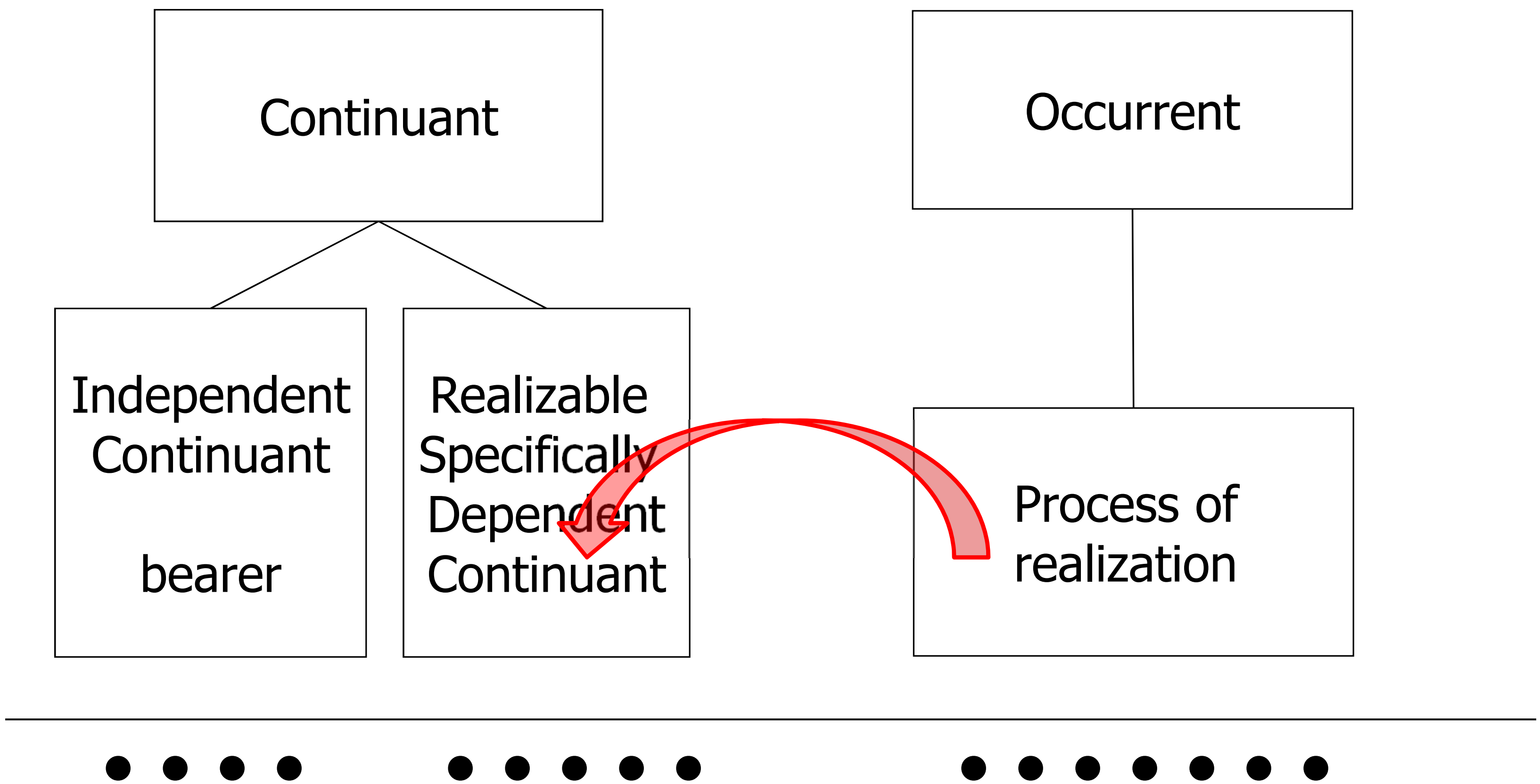
complex quality = pattern



realizables go hand in hand with *processes of realization*



realization (when it happens) *specifically_depends_on realizable*



Specifically dependent continuants

the *quality* of my hair: to be grey

realizables

your *role* as auditor of this lecture,

my *disposition*: to fidget with my nose, to say ‘erm’

my *capability*: to speak English, to type

function of my hands: to grip, to exert pressure, …

Specifically dependent continuants

the *quality* of this phone: to weigh 6.63 oz

realizables

the *role* of this room: as lecture hall

the *disposition* of this bulb: to get hot

the *capability* of this room: to have its temperature adjusted

the *function* of that heater: to heat

More examples of specifically dependent continuants

Quality: temperature, mass, color, length

Realizables:

- **Role**: nurse role, pathogen role, food role
- **Disposition**: fragility, virulence, disease risk factor
- **Capability**: to speak Greek, to swim, to make friends
- **Function**: to pump (of the heart), to unlock (of the key), to transport

Continuant	Occurrent
Function	Functioning
to pump	pumping
to ignite	igniting
to drain	draining

Some functions (of a fence, to keep people or things in or out; of a heart, to pump) are realized continuously

Some functions (of a gun, to fire) are realized occasionally

Some functions (of this sperm, to penetrate an egg) exist without ever being realized

Examples of realizables

plan
function
role
disposition
capability
tendency

continuants

Their realizations

execution
exercise
realization
application
operation
performance
functioning

occurrents

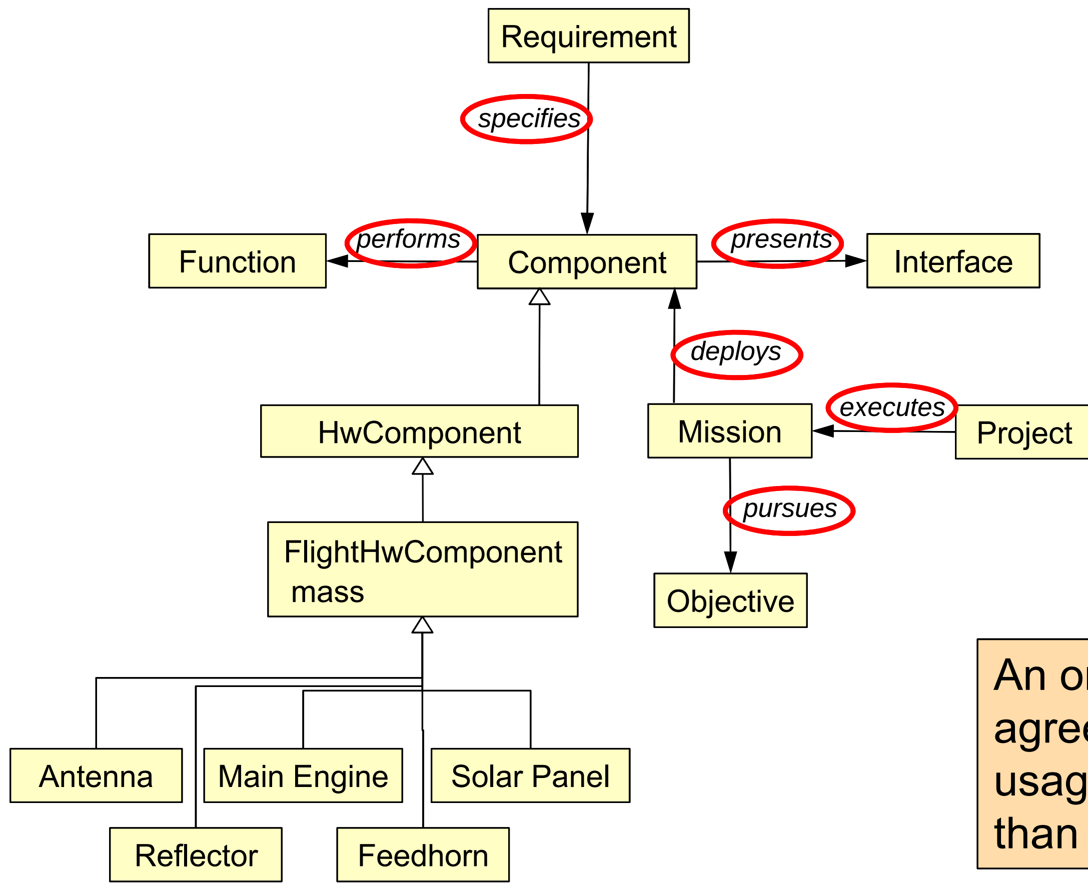
Foundational Concepts for Building System Models [2013 = Pre ST4SE]

SEWG MBSE Training Module 3
https://nen.nasa.gov/web/se/mbse/documents

Todd Bayer, Daniel Dvorak, Sanford Friedenthal,
Steven Jenkins, Chi Lin, Sanda Mandutianu

Jet Propulsion Laboratory, California Institute of Technology

[Example Ontology from SE Domain]

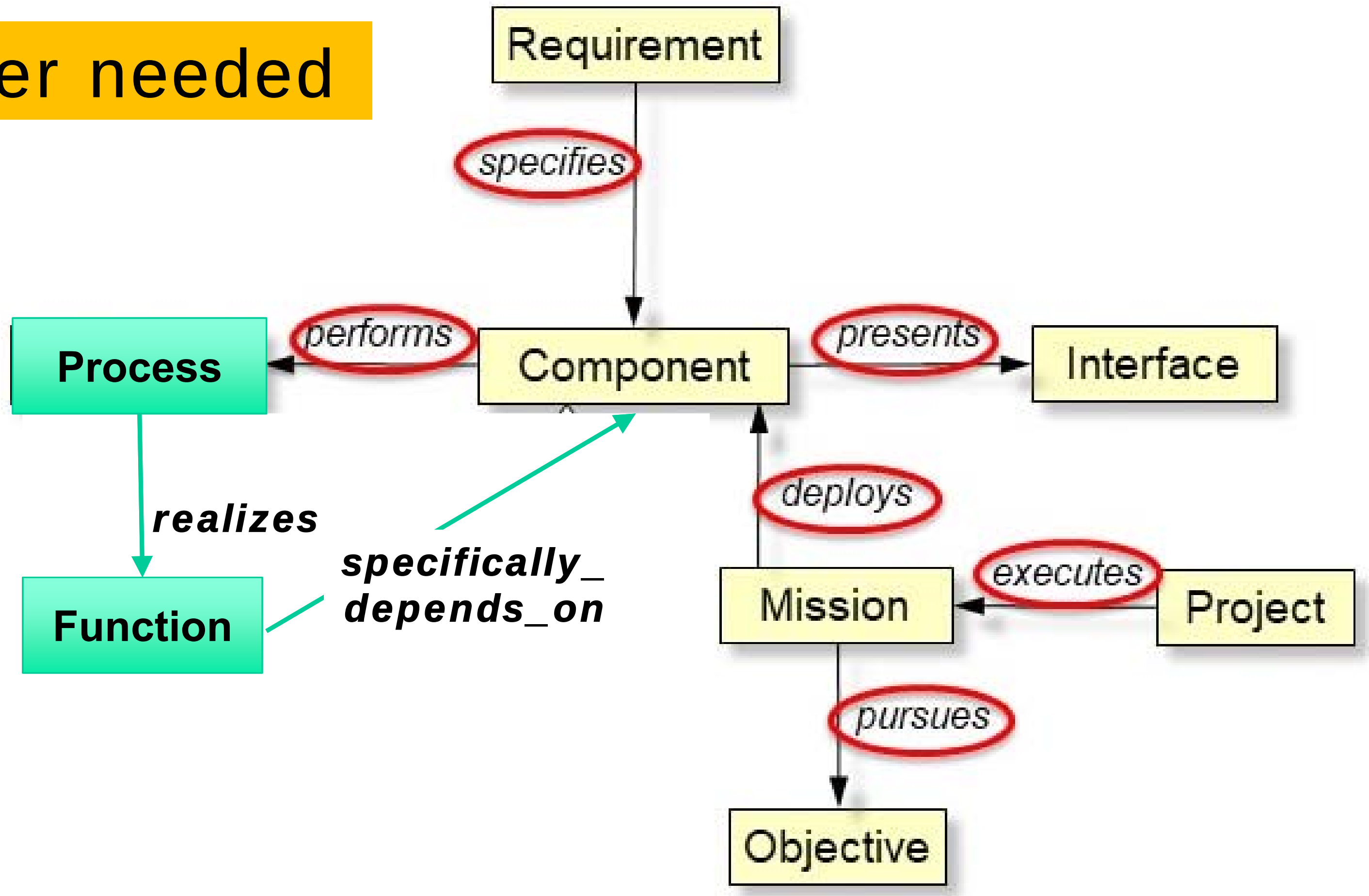


Legend
relationship
a type of

An ontology is an agreement on usage, rather than a dictionary

[Example Ontology from SE Domain]

extra layer needed



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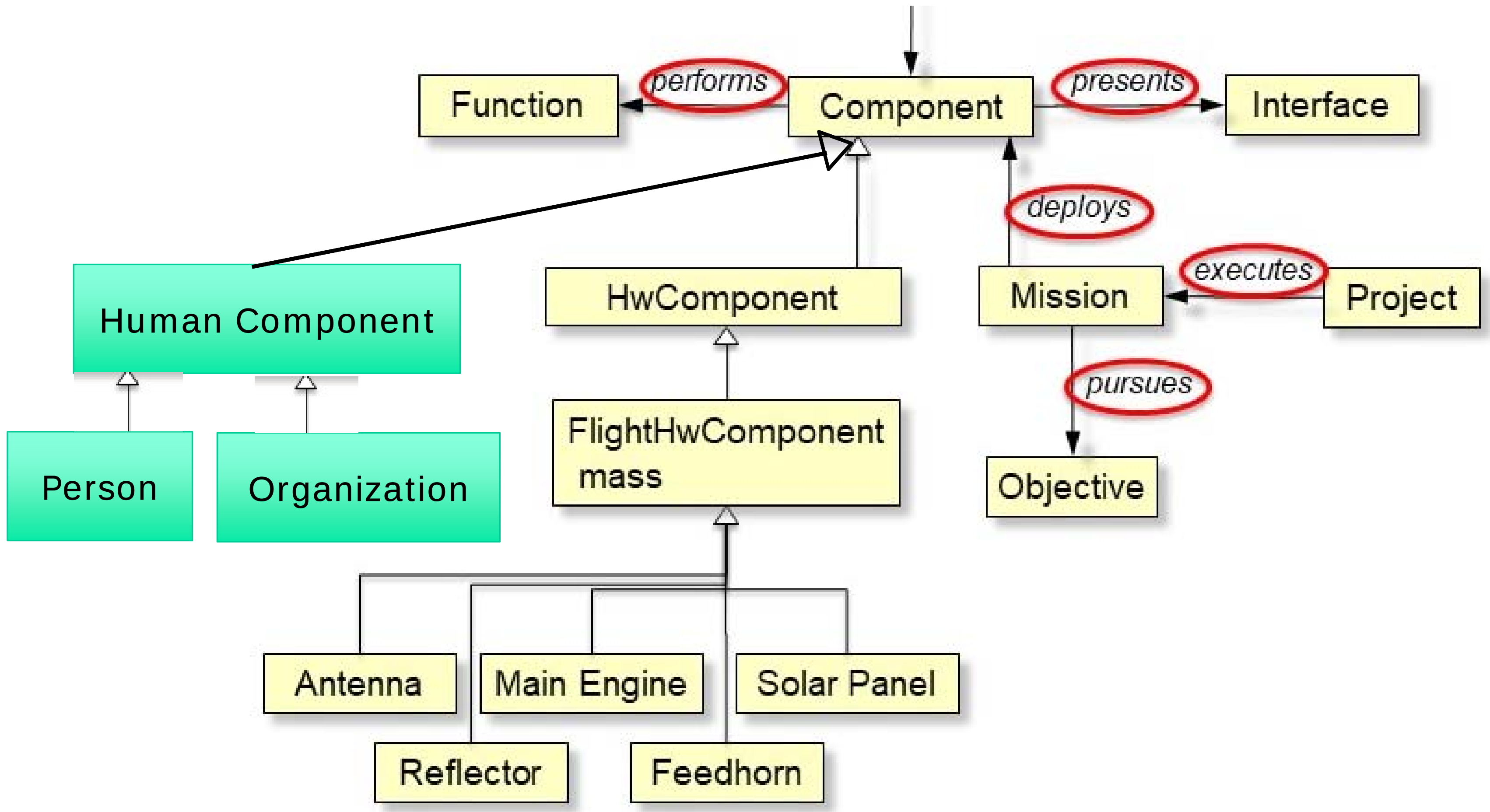

Use of ‘role’

student =def. human being who bears the student role

lawyer =def. human being who bears the lawyer role

Roles very often go hand in hand with dispositions acquired by the bearer of the role as a result of exercising the role

Role (externally-grounded realizable entity)

role =def. a realizable entity

- which exists because the bearer is in some special physical, social, or institutional set of circumstances in which the 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.

Disposition (an internally-grounded realizable entity)

disposition =def.

a realizable entity which if it ceases to exist, then its bearer is physically changed, and

whose realization occurs when this bearer is in some special physical circumstances, in virtue of the bearer's physical make-up

Capability (a beneficial disposition)

Capability = def.

a disposition whose realization

1. can be graded on a scale starting from zero
2. is such that its realization brings benefits either

   to the bearer or a group to which the bearer belongs (family, organization, …)

   or: to the owner or user of the bearer (where the bearer is an artifact)

CaMDiF

Capability Modeling for Digital Factory

IFIP International Conference on Advances in Production Management Systems

APMS 2017: Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing pp 202-212

A Thesaurus-Guided Framework for Visualization of Unstructured Manufacturing Capability Data

Authors   Authors and affiliations

Farhad Ameri, William Bernstein

Conference paper

First Online: 31 August 2017

Part of the IFIP Advances in Information and Communication Technology book series (IFIPAICT, volume 513)

Function (a disposition designed or selected for)

Function =def.

a capability 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 artifacts), in order to realize processes of a certain kind.

Artifacts have functions

An artifact's function is the reason why the artifact was built (why the bearer of the function exists)

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But artifacts also have capabilities (e.g. to operate at high temperature, to operate continuously,

Artifacts have functions and other capabilities

An artifact's function is the reason why the artifact was built (why the bearer of the function exists)

But artifacts also have capabilities (e.g. to operate at high temperature, to operate continuously, to operate safely, …)

Capability of an engineered artifact

=def. a disposition of an engineered artifact whose realizations can be graded along a scale in a way that tracks degree of benefit to the owner or user of the artifact

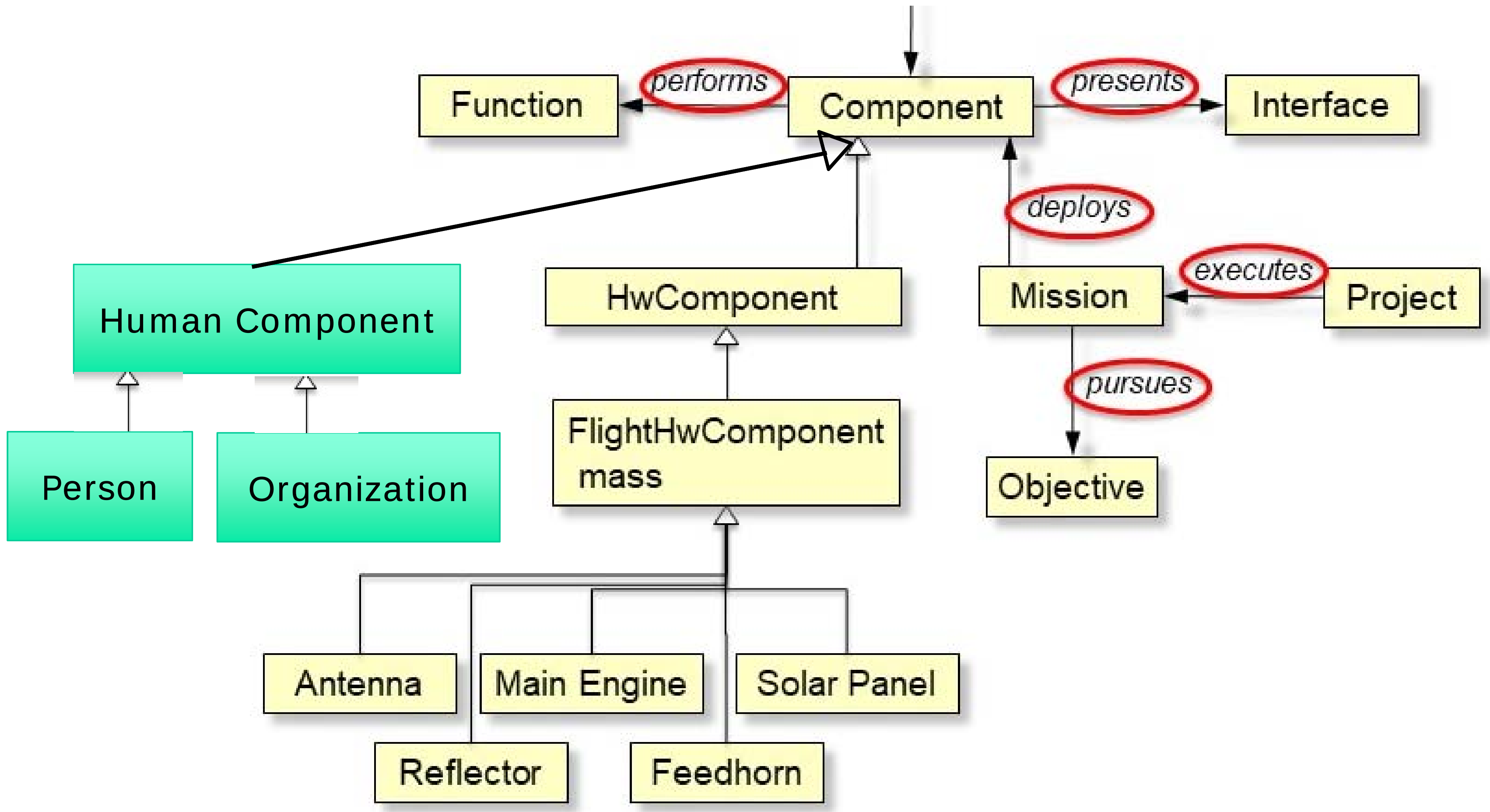
Function of an engineered artifact

=def. capability of an engineered artifact which exists because an entity was needed to function (operate, perform) in just this way

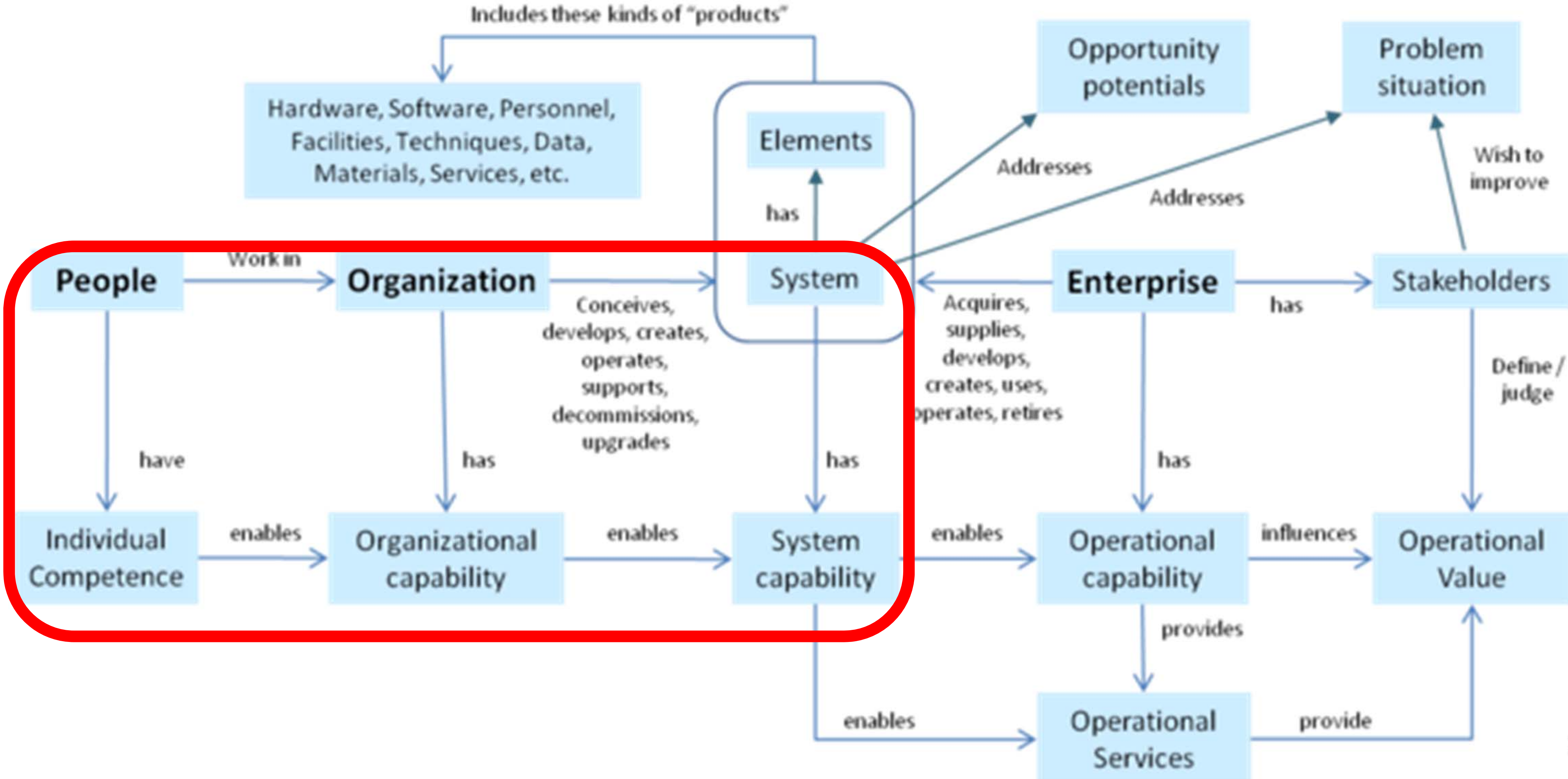
One idea for a schematic definition of ‘engineered system’

- An engineered system s is an aggregate of engineered artifacts $a_1, \ldots, a_m$
- Each of the artifacts a_i has functions $a_i{:}f_1, \ldots, a_i{:}f_n$ and capabilities $a_i{:}c_1, \ldots, a_i{:}c_p$
- s itself has function f, and s exists because something was needed to realize function f, and f is realized through the coordinated realization of $a_i{:}f_1, \ldots, a_i{:}f_n$ and $a_i{:}c_1, \ldots, a_i{:}c_p$

[Example Ontology from SE Domain]



Capabilities Engineering



BFO Ontology of Information Entities

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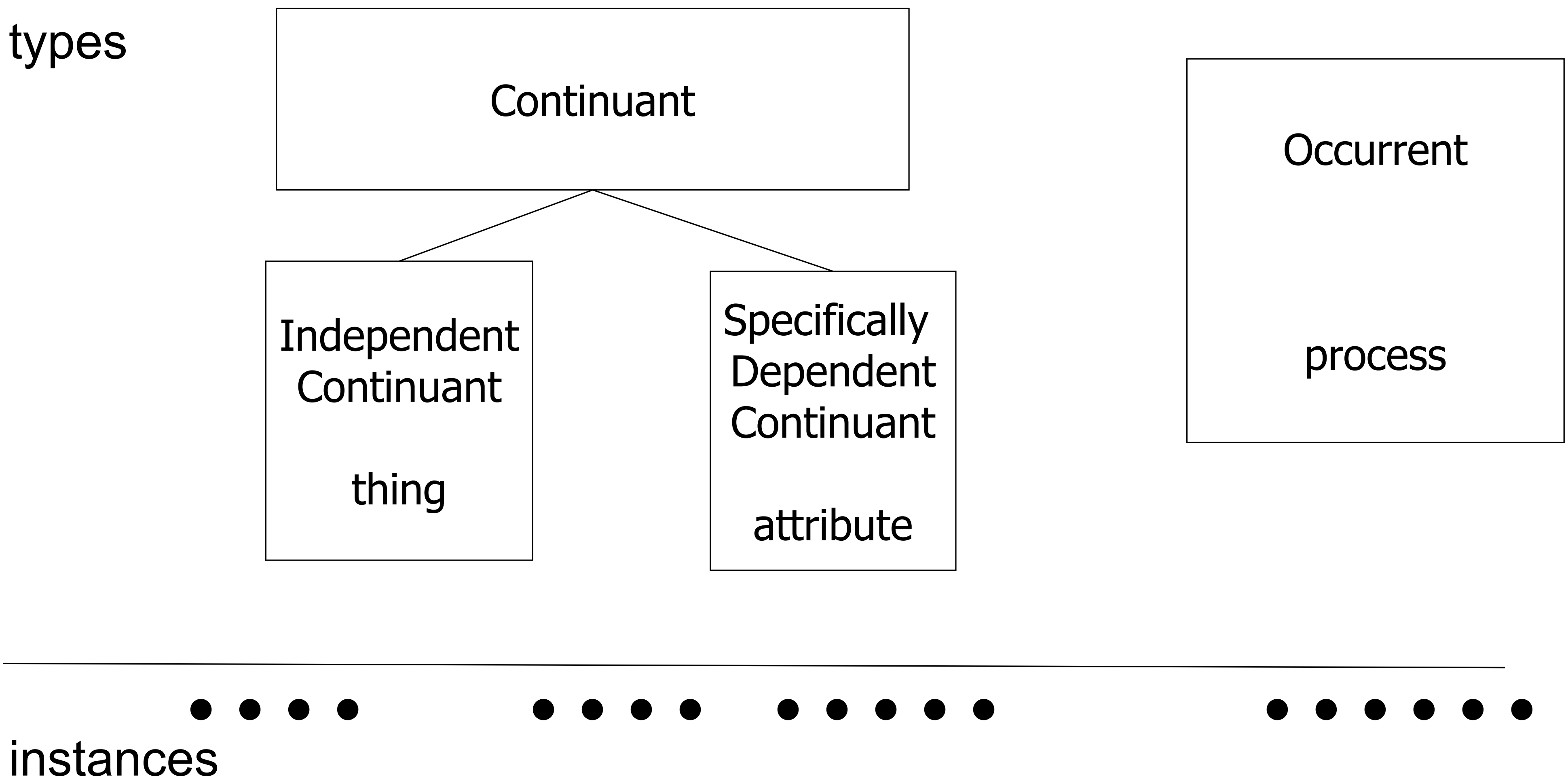
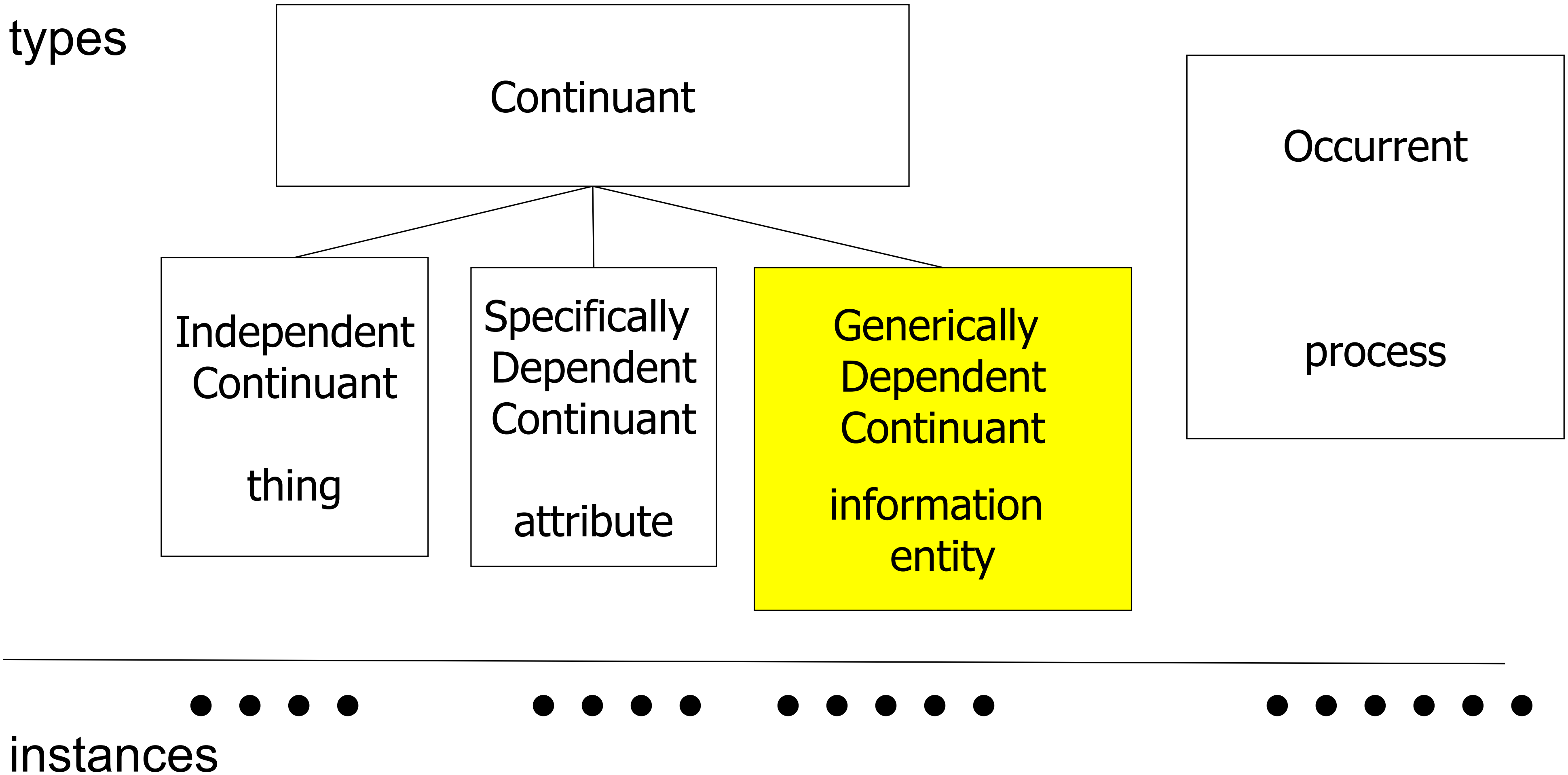
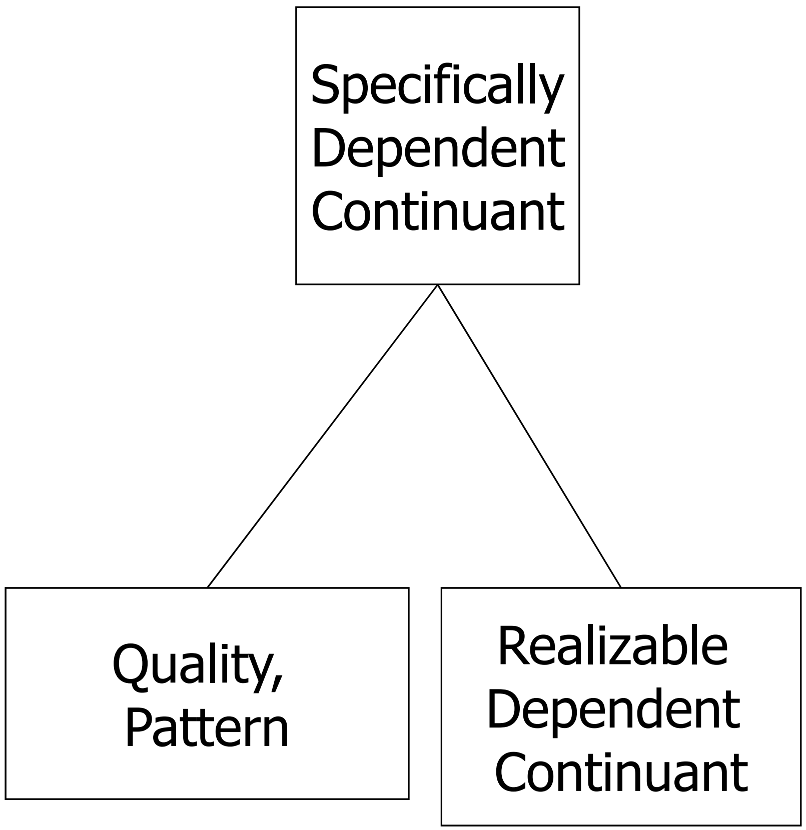


BFO Ontology of Information Entities



Specifically Dependent Continuants



if the bearer ceases to exist, then its quality, function, role ceases to exist

the color of my skin

the function of my heart to pump blood

my weight

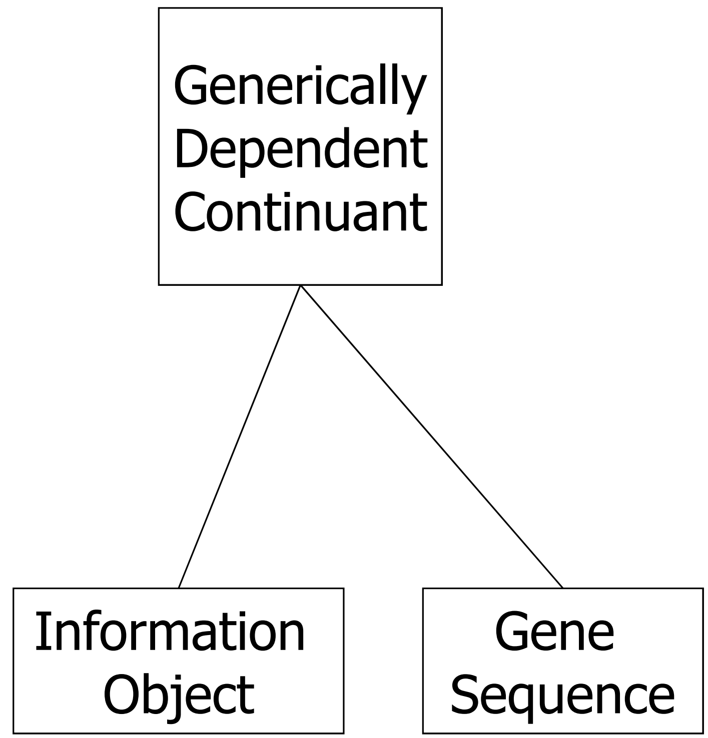
Generically Dependent Continuants

if one bearer ceases to exist, then the entity can survive, because there are other bearers

(copyability)

the pdf file on my laptop

the DNA (sequence) in this chromosome



Relation of Concretization

GDC: novel

SDC: pattern of ink marks on the pages of a copy of the novel

GDC: plan specification

SDC: concretization of this plan specification in the patterns of ink in this printed document

SDC: concretization of this plan specification in your head (allowing you to adopt it as the specification of your plan)

experimental protocol

This **experimental protocol instance_of** *plan specification*

The **protocol** is **concretized in** the mind of the **leader** of the research team in the form of a **plan** to carry out the **experiment**, which is an **instance_of** *process*

The **process** realizing this **plan** starts with the creation of a series of sub-protocols, which are **plan specifications** for each **team member**.

The **experiment** itself is the sum of the **realizations** of these **plans**, having **outputs** further **information entities**, such as **publications**, **databases** …

and similarly for the engineering design / testing process

This **engineering design instance_of** *artefact specification*

Artefact specification is_a GDC

The **design** is **concretized in** the mind of a prototype builder who converts it into a **plan to build a prototype** for use in processes of testing the design

The **process** realizing this **plan has_output** some **instance_of** *prototype artifact*.

Unlocking Digital Thread Data for More Effective & Economical Systems Health Monitoring

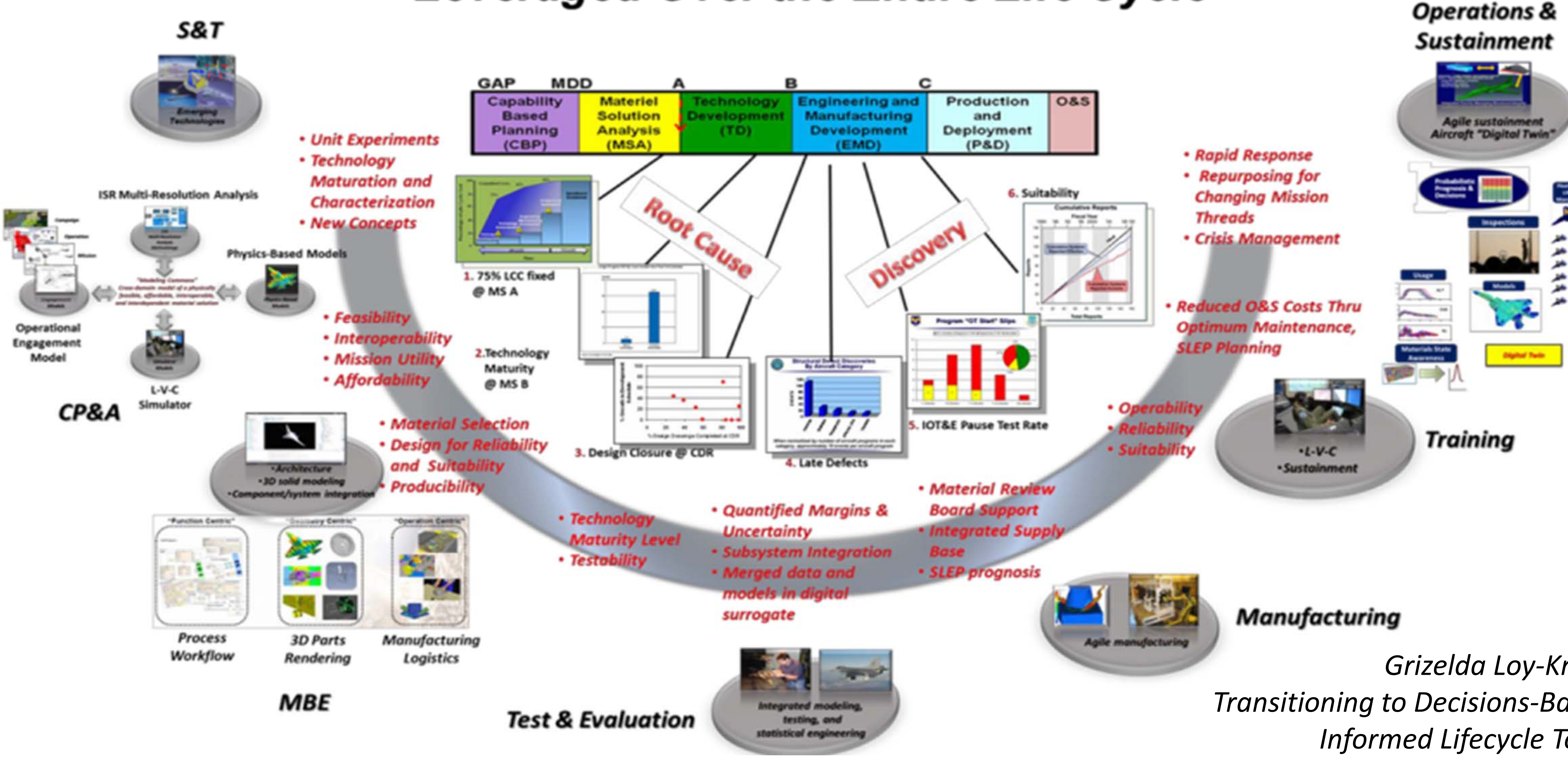
with thanks to Ron Rudnicki, CUBRC

Digital Twin (Glaesgen and Stargel, 2012)

an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin.

https://ntrs.nasa.gov/search.jsp?R=20120008178

A Continuum of Authoritative Digital Surrogate Representations Leveraged Over the Entire Life Cycle



Grizelda Loy-Kraft, Transitioning to Decisions-Based Informed Lifecycle Tools

CLEARED for public release by 88ABW-2017-1747

Ontologies vs Databases

- can be relatively stable and can be centrally managed

- databases differ massively from enterprise to enterprise and from one day to the next

OSCAR

Ontological Semantic Concept Alignment and Refinement (OSCAR) – extension of KARMA tool from USC:
http://usc-isi-i2.github.io/karma/

transforms into RDF graphs data about products, parts, functional capabilities, failure modes, tests, test equipment and locations, failures, root causes, corrective actions ...

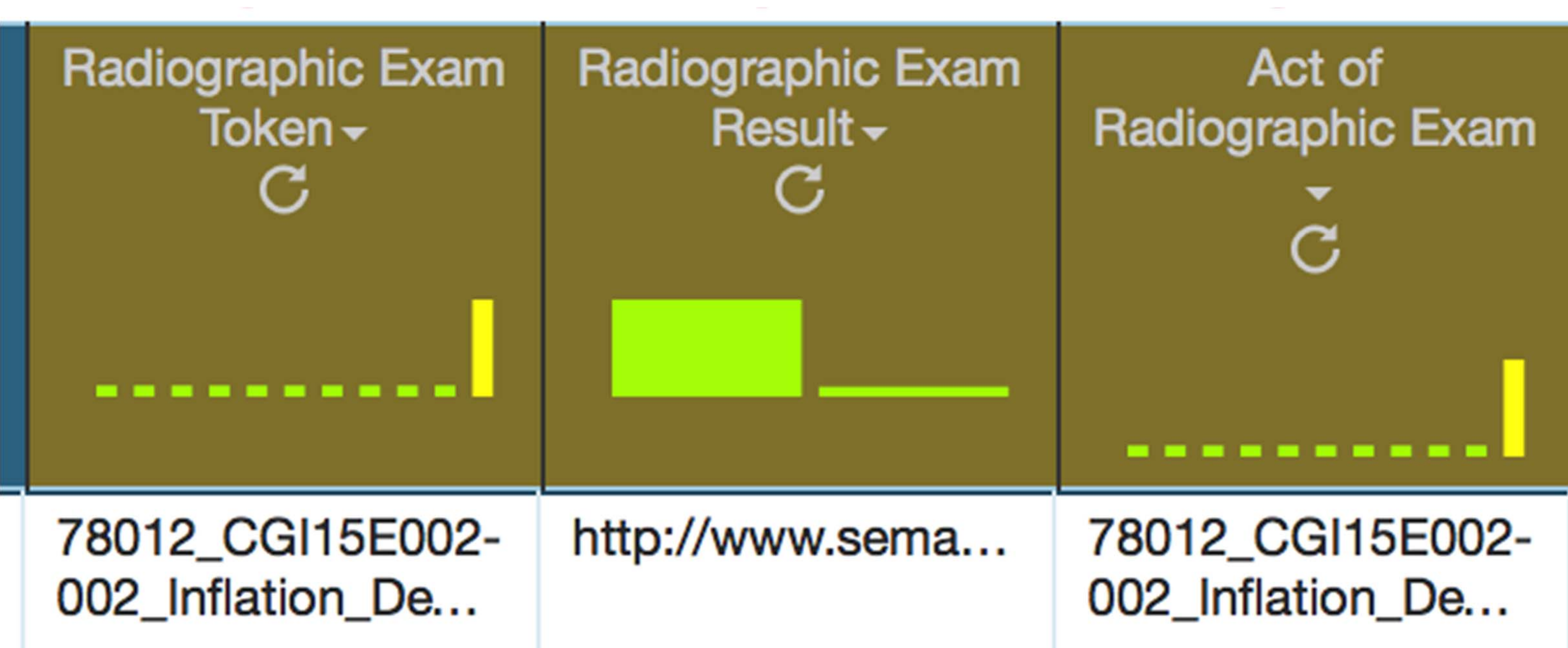
examples of questions to be answered by data in ontological representation (as RDF graphs)

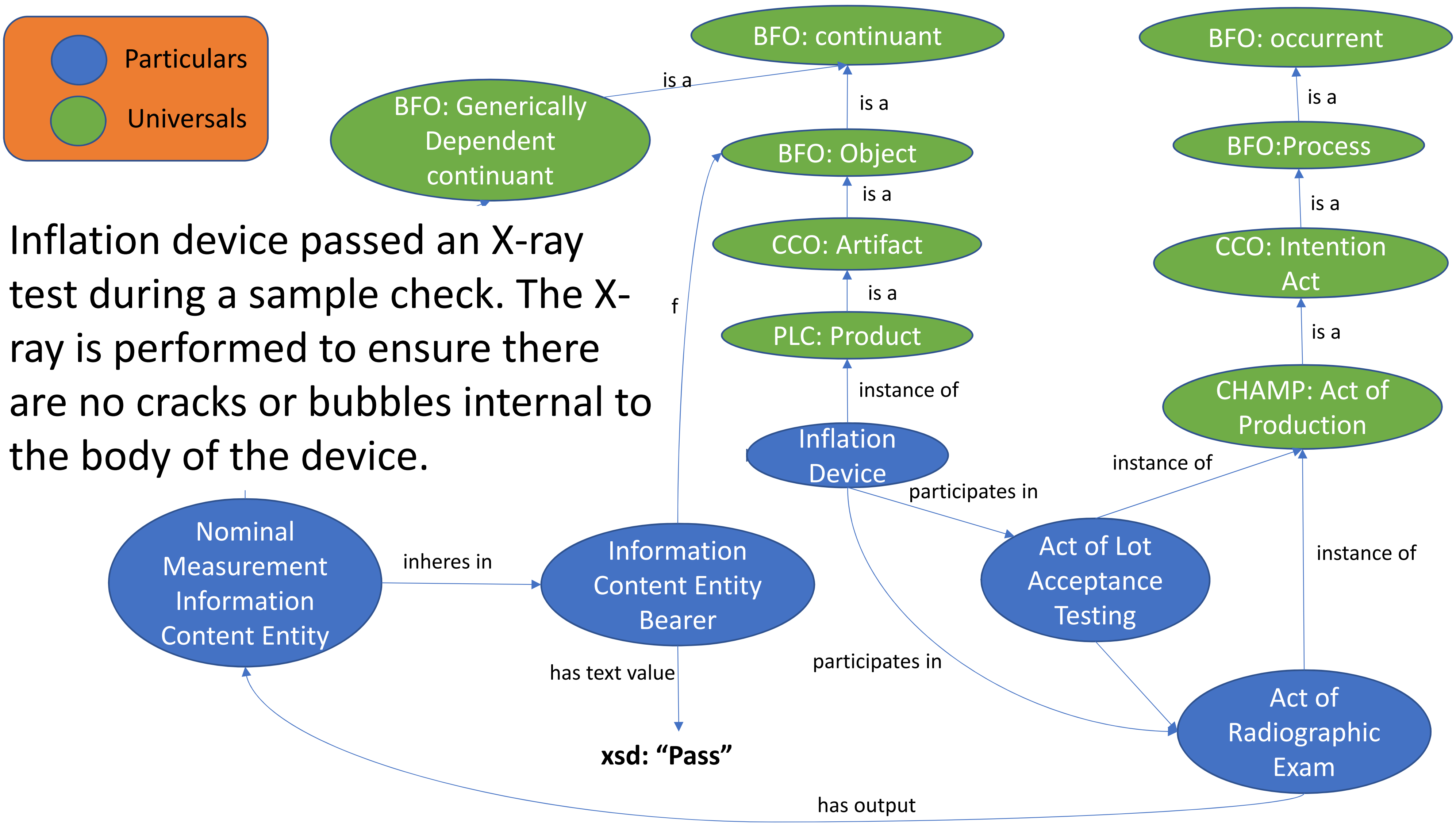
- *(Airforce) Return the 25 products having the longest durations of unscheduled maintenance during 2016*
- *(Manufacturer) How have changes in the quality of vendor-supplied parts led to product failures over time?*
- *(Manufacturer) How do the parts supplied by different suppliers affect testing outcomes of assembled products?*

Testing data

LOT ID	Inflation Device ID	FLU-12 ID	Act of Lot Acceptance Testing	Unit S/N	Radiographic Examination	Radiographic Exam Token	Radiographic Exam Result	Act of Radiographic Exam
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104699	ActOfLotAccepta… 12-78012-CGI15E002-002	104699	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104706	ActOfLotAccepta… 12-78012-CGI15E002-002	104706	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104758	ActOfLotAccepta… 12-78012-CGI15E002-002	104758	Fail	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104820	ActOfLotAccepta… 12-78012-CGI15E002-002	104820	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104968	ActOfLotAccepta… 12-78012-CGI15E002-002	104968	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104973	ActOfLotAccepta… 12-78012-CGI15E002-002	104973	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104993	ActOfLotAccepta… 12-78012-CGI15E002-002	104993	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_…	FLU-12_104998	ActOfLotAccepta… 12-78012-CGI15E002-002	104998	Pass	78012_CGI15E002-002_Inflation_De…	http://www.sema…	78012_CGI15E002-002_Inflation_De…

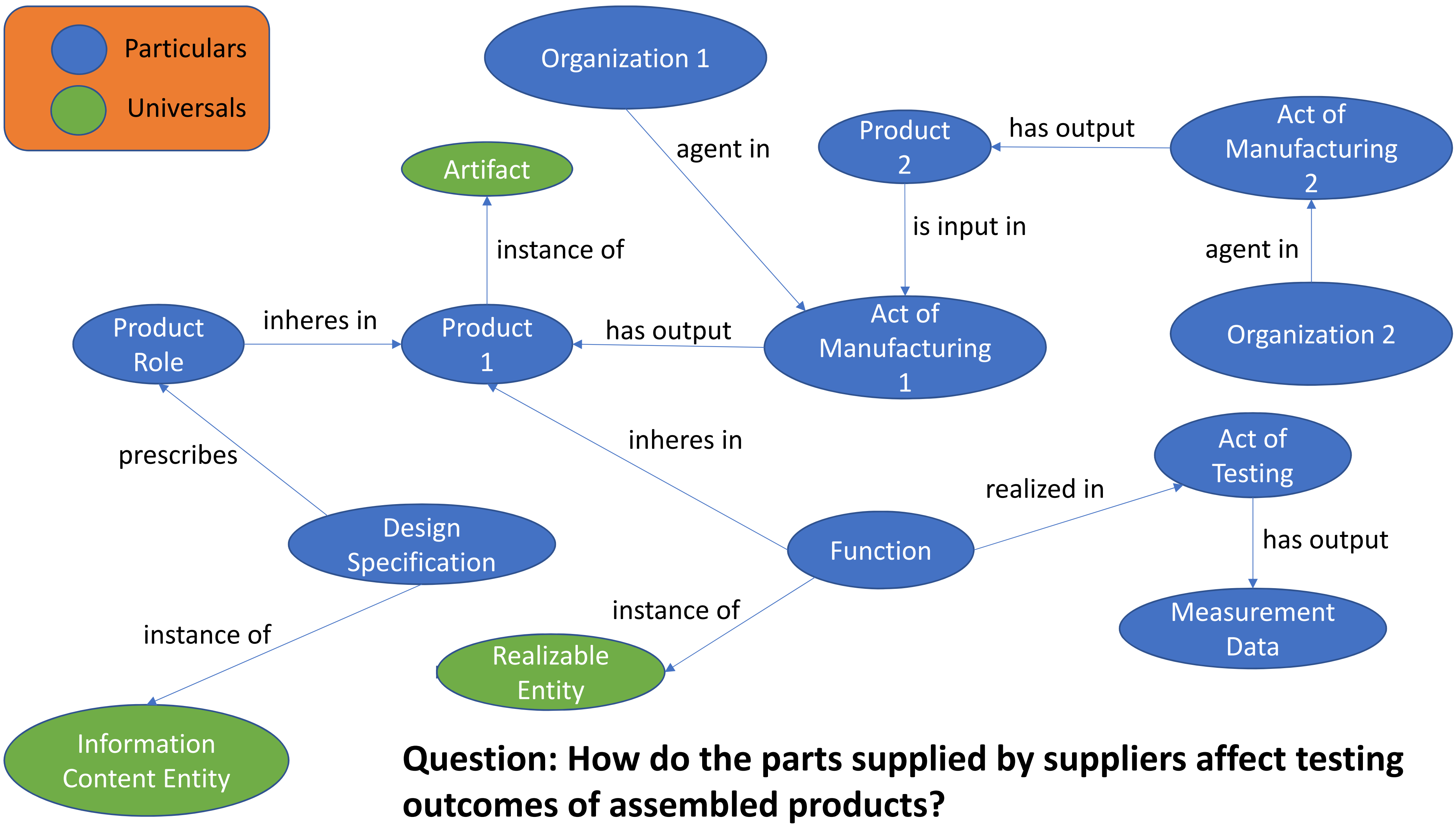
Testing data



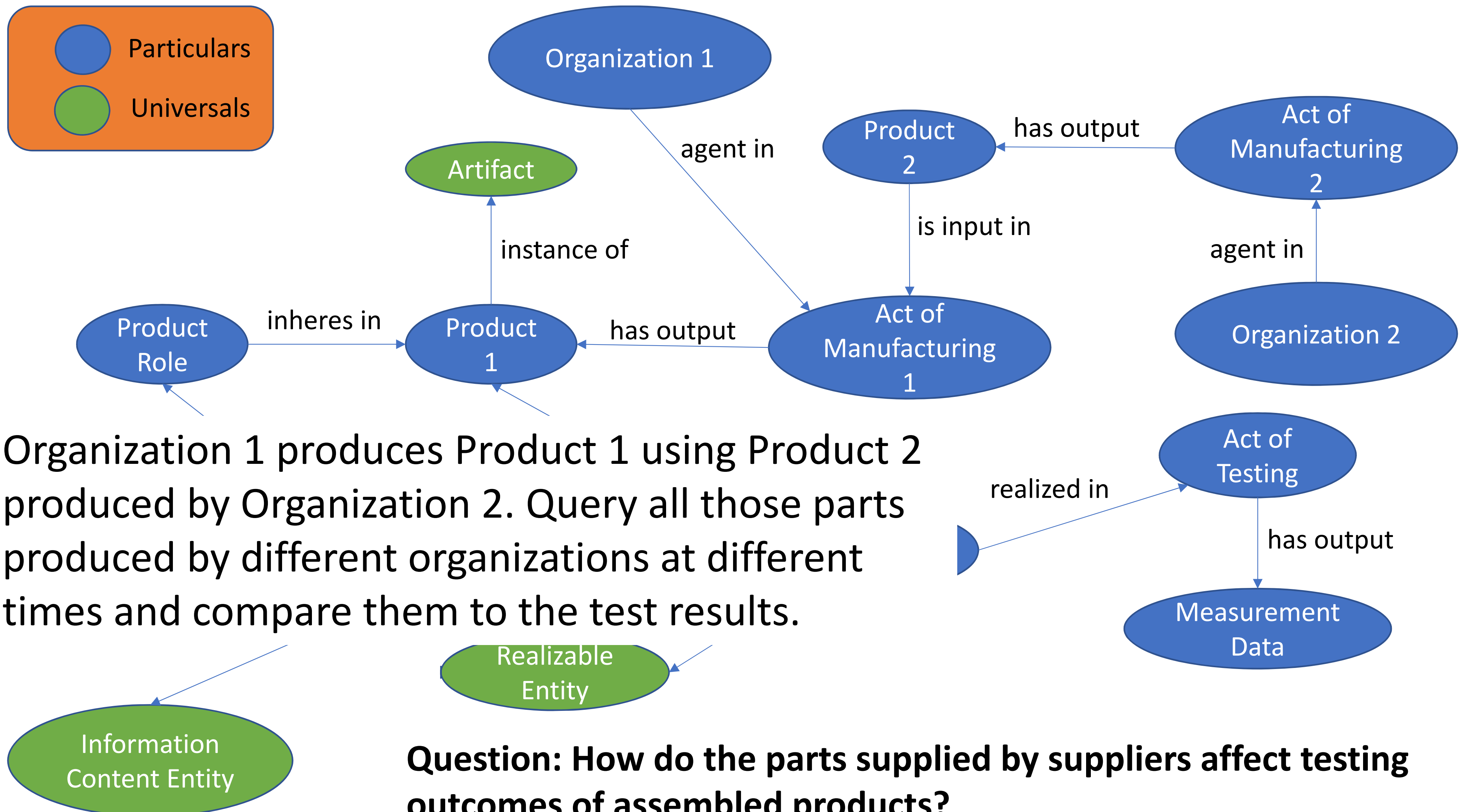

Particulars
Universals
BFO: continuant
BFO: occurrent
is a
BFO: Generically Dependent continuant
is a
BFO: Object
is a
BFO:Process
is a
CCO: Artifact
is a
CCO: Intention Act
is a
PLC: Product
is a
instance of
CHAMP: Act of Production
Inflation Device
Inflation device passed an X-ray test during a sample check. The X-ray is performed to ensure there are no cracks or bubbles internal to the body of the device.
f
instance of
participates in
Nominal Measurement Information Content Entity
inheres in
Information Content Entity Bearer
Act of Lot Acceptance Testing
instance of
has text value
participates in
Act of Radiographic Exam
xsd: “Pass”
has output

Tagging with both type and instance identifiers
Tagging the data according to source organization allows us to query all parts produced by each organization at different times and compare their test results

Organization 1 produces Product 1
using
Product 2 produced by Organization 2
using …

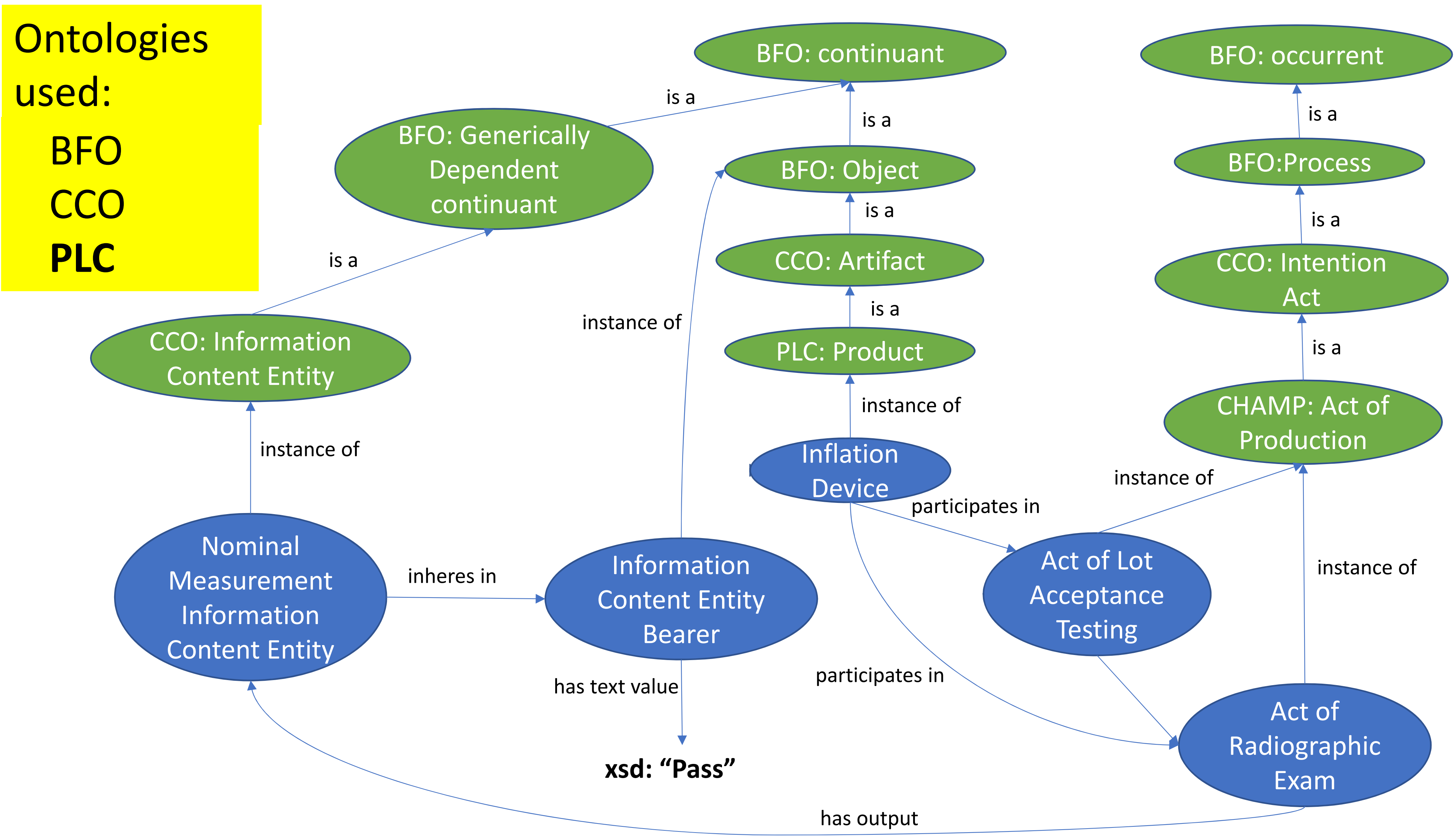


Question: How do the parts supplied by suppliers affect testing outcomes of assembled products?



Organization 1 produces Product 1 using Product 2 produced by Organization 2. Query all those parts produced by different organizations at different times and compare them to the test results.

Question: How do the parts supplied by suppliers affect testing outcomes of assembled products?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inheres in
Information Content Entity Bearer
Act of Lot Acceptance Testing
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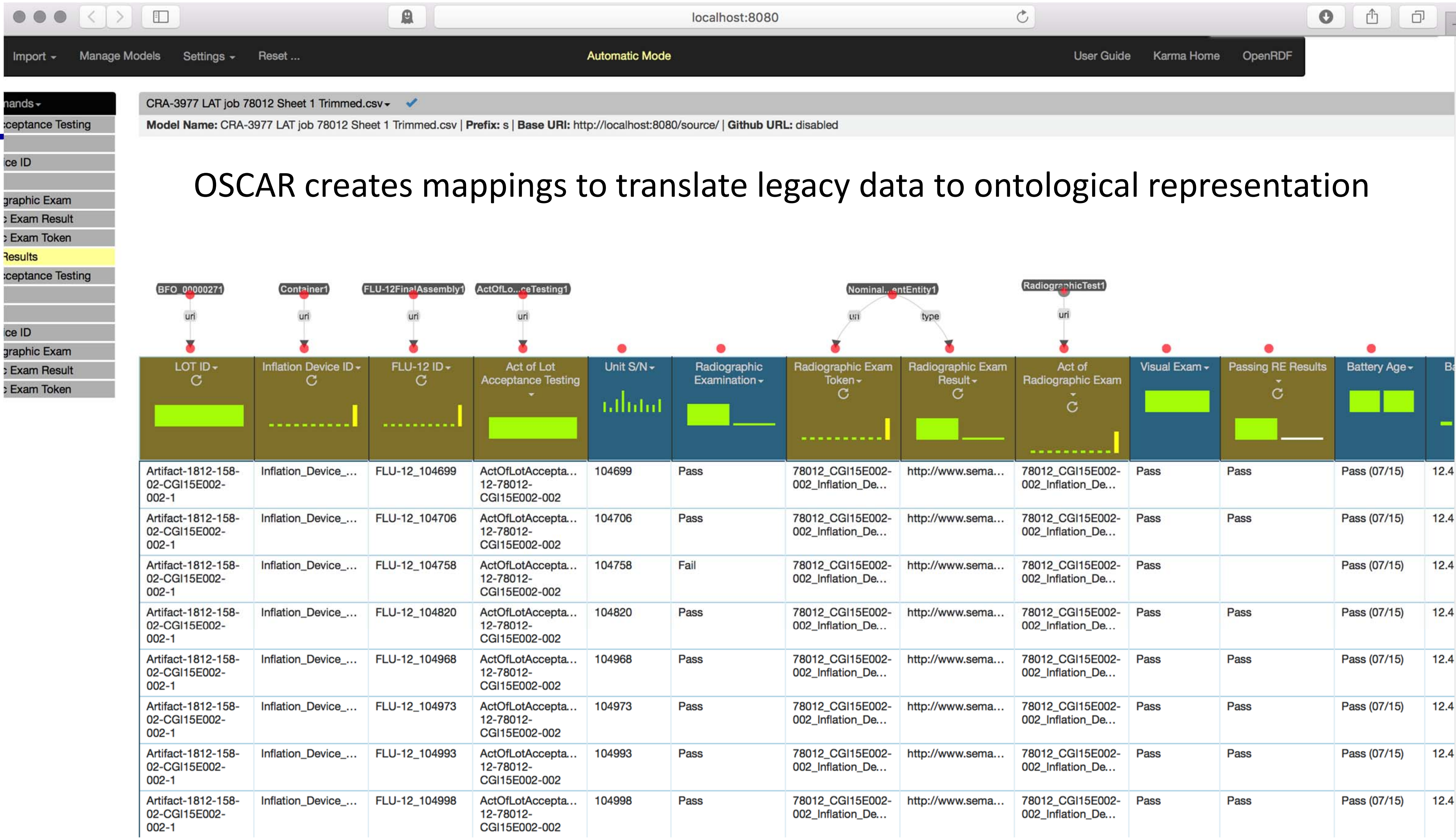
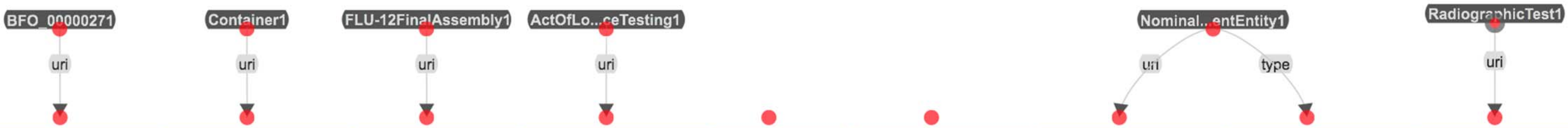
OSCAR creates mappings to translate legacy data to ontological representation





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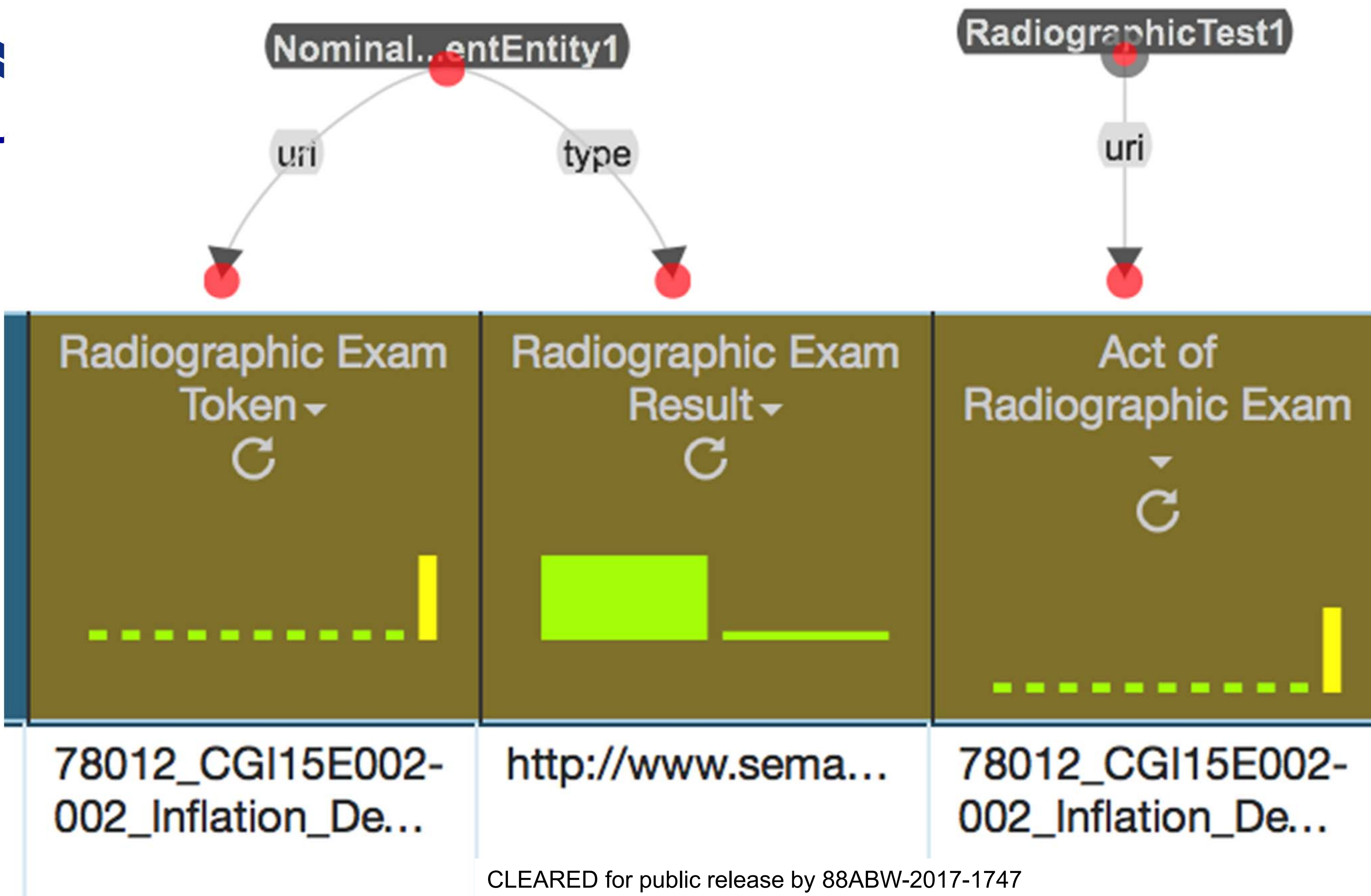
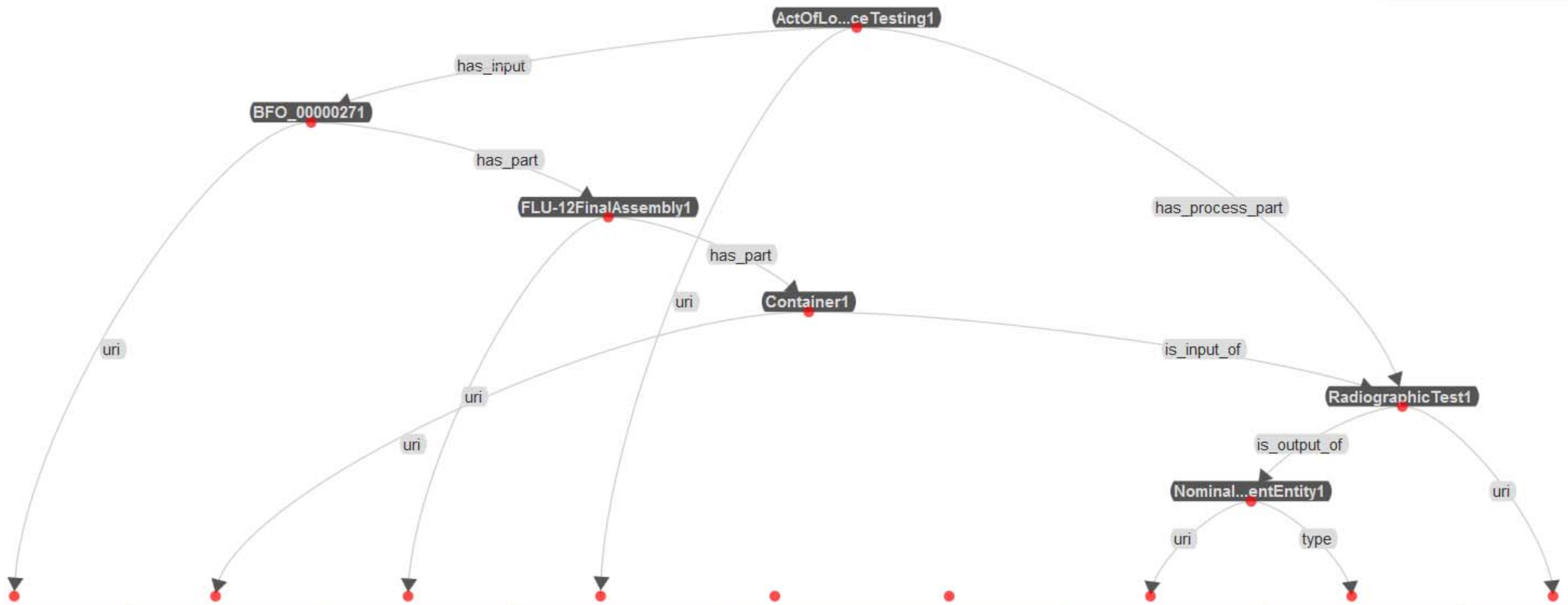
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_...	FLU-12_104758	ActOfLotAccepta... 12-78012-CGI15E002-002	104758	Fail	78012_CGI15E002-002_Inflation_De...	http://www.sema...	78012_CGI15E002-002_Inflation_De...
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_...	FLU-12_104820	ActOfLotAccepta... 12-78012-CGI15E002-002	104820	Pass	78012_CGI15E002-002_Inflation_De...	http://www.sema...	78012_CGI15E002-002_Inflation_De...
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_...	FLU-12_104968	ActOfLotAccepta... 12-78012-CGI15E002-002	104968	Pass	78012_CGI15E002-002_Inflation_De...	http://www.sema...	78012_CGI15E002-002_Inflation_De...
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_...	FLU-12_104973	ActOfLotAccepta... 12-78012-CGI15E002-002	104973	Pass	78012_CGI15E002-002_Inflation_De...	http://www.sema...	78012_CGI15E002-002_Inflation_De...
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_...	FLU-12_104993	ActOfLotAccepta... 12-78012-CGI15E002-002	104993	Pass	78012_CGI15E002-002_Inflation_De...	http://www.sema...	78012_CGI15E002-002_Inflation_De...
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_...	FLU-12_104998	ActOfLotAccepta... 12-78012-CGI15E002-002	104998	Pass	78012_CGI15E002-002_Inflation_De...	http://www.sema...	78012_CGI15E002-002_Inflation_De...

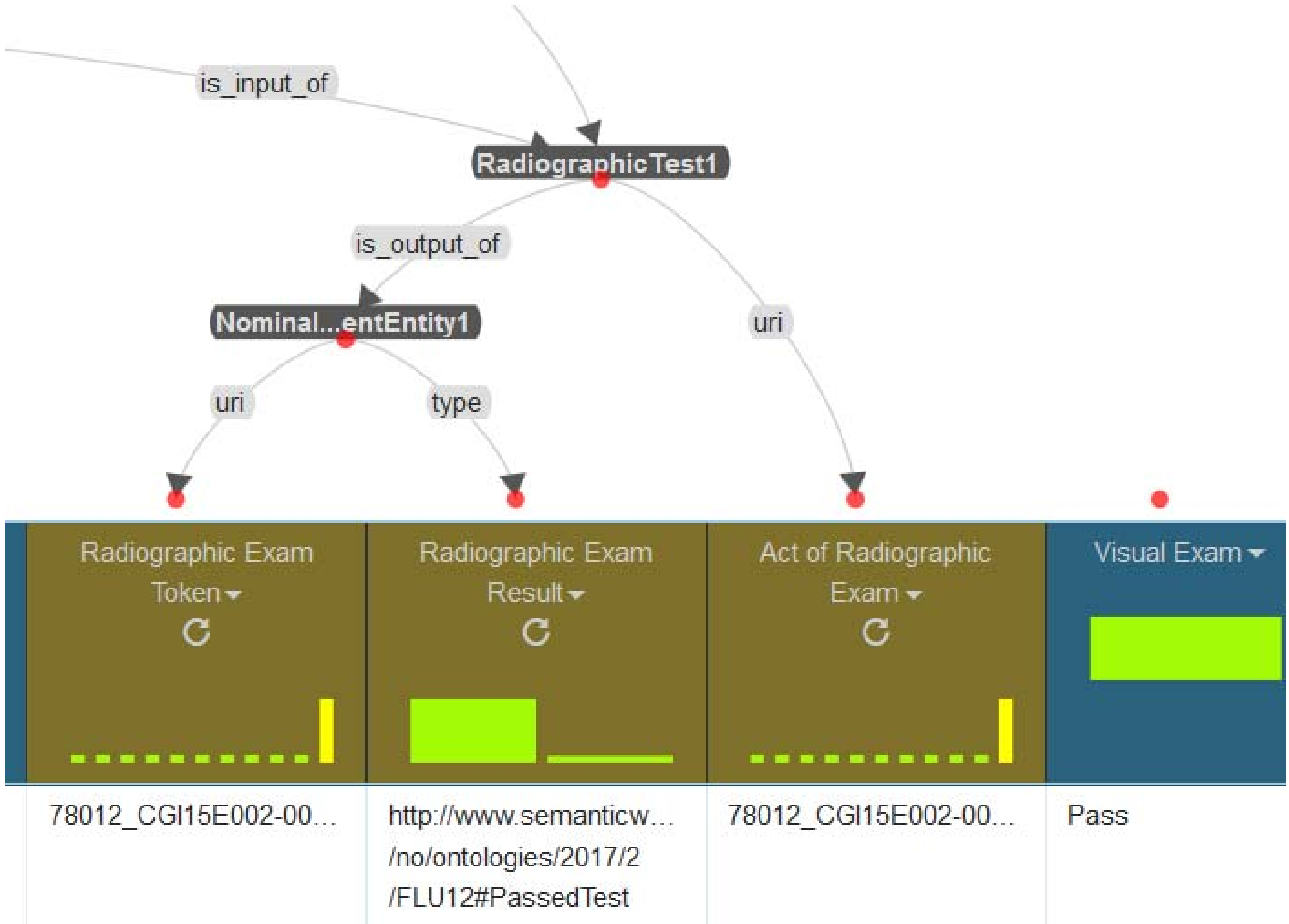


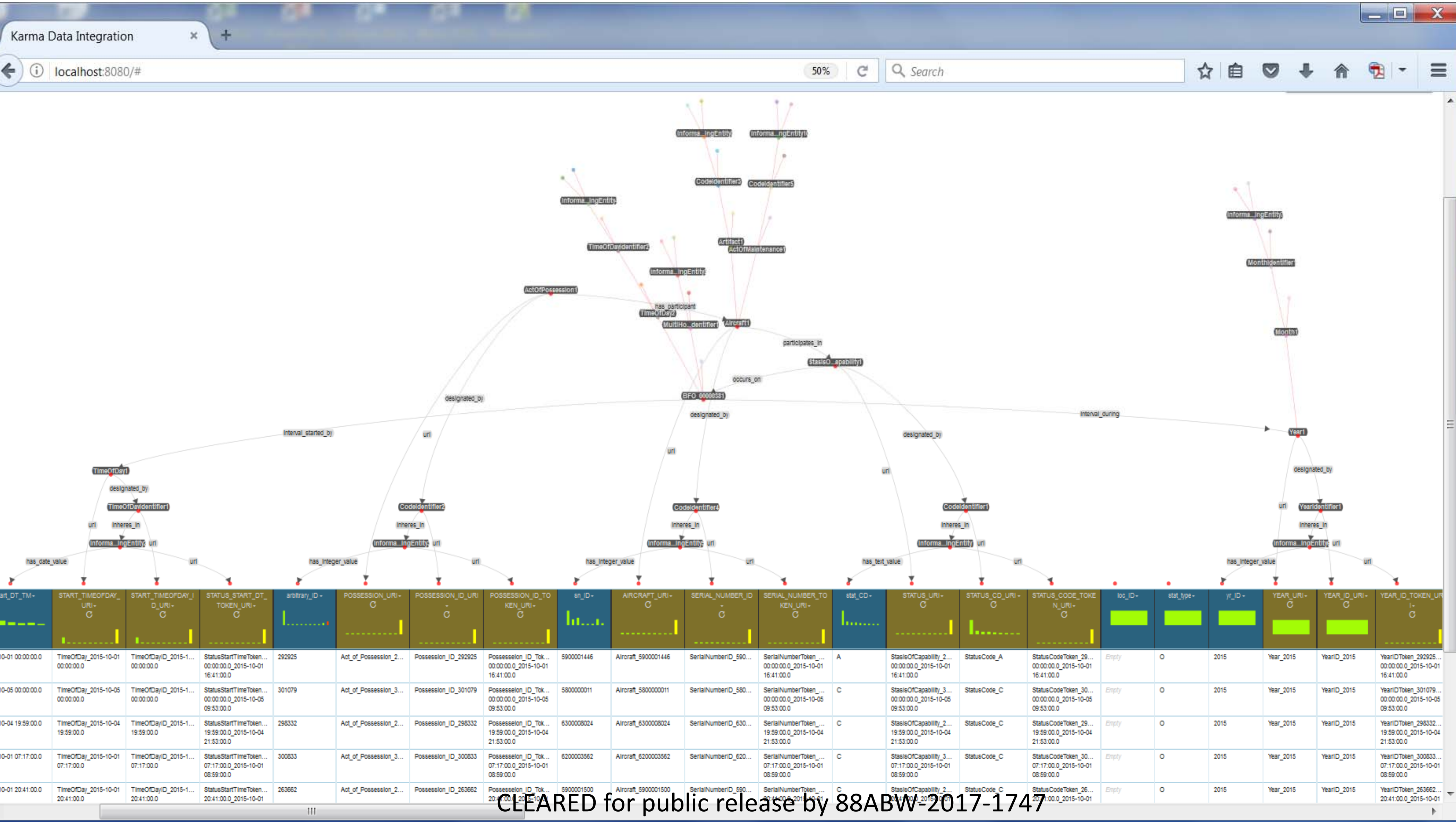
Nominal...entEntity1
uri
type
RadiographicTest1
uri
Radiographic Exam Token
Radiographic Exam Result
Act of Radiographic Exam
78012_CGI15E002-002_Inflation_De...
http://www.sema...
78012_CGI15E002-002_Inflation_De...

ontologies allow reasoning over the data



LOT ID	Inflation Device ID	FLU-12 ID	Act of Lot Acceptance Testing	Unit S/N	Radiographic Examination	Radiographic Exam Token	Radiographic Exam Result	Act of Radiographic Exam	Visual Exam
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_104699	FLU-12_104699	ActOfLotAcceptanceT... 12-78012-CGI15E002-002	104699	Pass	78012_CGI15E002-00...	http://www.semanticw... /no/ontologies/2017/2 /FLU12#PassedTest	78012_CGI15E002-00...	Pass
Artifact-1812-158-02-CGI15E002-002-1	Inflation_Device_104706	FLU-12_104706	ActOfLotAcceptanceT... 12-78012-CGI15E002-002	104706	Pass	78012_CGI15E002-00...	http://www.semanticw... /no/ontologies/2017/2 /FLU12#PassedTest	78012_CGI15E002-00...	Pass


is_input_of
RadiographicTest1
is_output_of
Nominal...entEntity1
uri
uri
type
Radiographic Exam Token
Radiographic Exam Result
Act of Radiographic Exam
Visual Exam
78012_CGI15E002-00...
http://www.semanticw...
/no/ontologies/2017/2
/FLU12#PassedTest
78012_CGI15E002-00...
Pass



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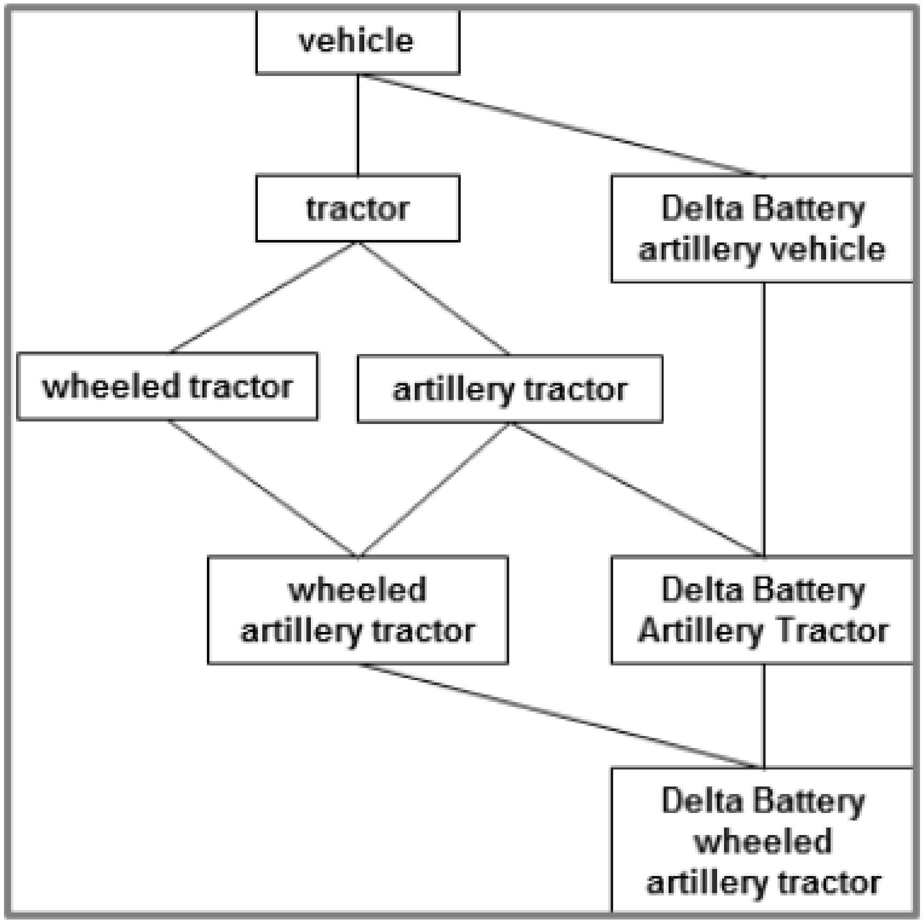
Recall:

application ontology of Delta Battery artillery vehicles



"Horizontal Integration of Warfighter Intelligence Data"

http://ontology.buffalo.edu/smith/articles/Horizontal-integration.pdf

slicing and dicing with ontological representations

once the data are tagged with ontologies we can slice and dice them along different directions:

- all data about *this part (instance)*
- all data about parts of *this type*
- all data about parts from *this supplier*
- all data about *this supplier*
- all data about *costs* associated with parts of this type from this supplier

Ontoview Report Builder

Enter an aircraft tail number

Ontoview returns all assertions related to that aircraft

Each activity represented as a hyperlink

Assertions are formed by linking one hyperlink to the next

artifact:Aircraft Tail-# SPAF91415	info:correlates	local:SerialNumber_7000000456
local:SerialNumber_7000000456	ro:participates_in	local:Maint_1718388407…
local:Maint_1718388407…	ero:occurs_on	local:TimeInterval_2015-12-1706:05…
local:TimeInterval_2015-12-1706:05	info:designated_by	local:MaintDurationMeasure…
local:MaintDurationMeasure…	ero:inheres_in	local:MaintDurationHrsToken…
local:MaintDurationHrsToken…	has_integer_value	n

Ontoview Report Builder

SPARQL Query: Return the 25 engines having the longest durations of unscheduled maintenance during 2016

Start with ‘engines’

Create list of assertions

Filter to those assertions relating to ‘unscheduled maintenance’

Output start and end times of unscheduled maintenance for each engine

Calculate stasis hours between end and start times

Rank order

Output list of engines as ranked

Or output list of *types* of engines as ranked

BUILDING AN ONTOLOGY-BASED DIGITAL TWIN FOR THE AIRCRAFT/ENGINE PRODUCT LIFE CYCLE

Sketch of a PLC ontology framework that remains constant across different types of aircraft, engines, operations, systems, data, software tools …

Rooted in tested ontology approaches, including Joint Doctrine Ontology

with thanks to Dimitris Kiritsis, Lausanne

Digital Thread/Digital Twin initiative

Advanced Research and Development of Digital Thread / Digital Twin (DT/DTw) Applications for Next Generation (Gen) and Legacy Aerospace Systems and Engines

Goal: To address the stovepipe problems resulting from the fact that airforce bases import data, models, and information from a huge variety of different sources, all of which use their own local terminologies and data models

RELATION TO TIME / MULTI-SCALE	CONTINUANT				OCCURRENT
	INDEPENDENT		DEPENDENT		
AIRCRAFT	Fleet Ontology		Design Specification Attribute Ontology		Air Operations Ontology
	Aircraft Ontology				
AIRCRAFT COMPONENT	Aircraft Subsystem Ontologies: Airfame, Propulsion, Energy Storage …		System Function Ontology	Realized Attribute Ontology	Air Sustainment Ontology
	Aircraft Component Ontology	Sensor Ontology	Structural Mechanics Ontology	Fault Ontology	Test Ontology
MOLECULE	Materials Ontology		Materials Attribute Ontology		Materials Process Ontology

Draft of a set of ontology modules for air force logistics

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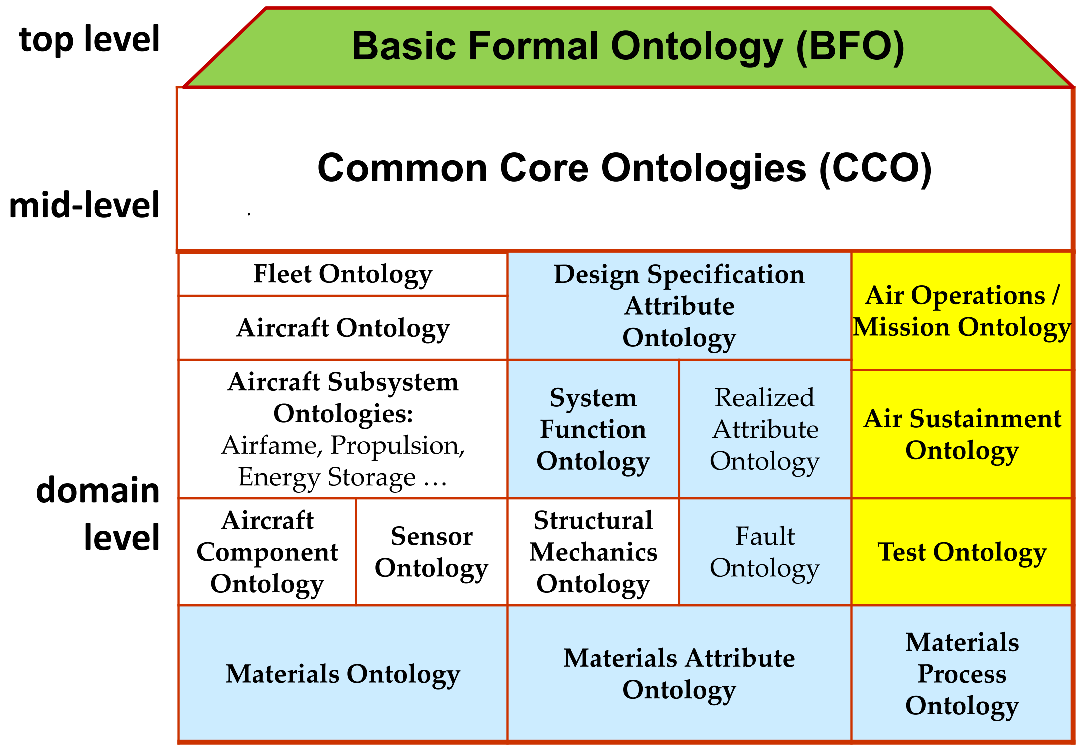

All ontologies descend from BFO + CCO

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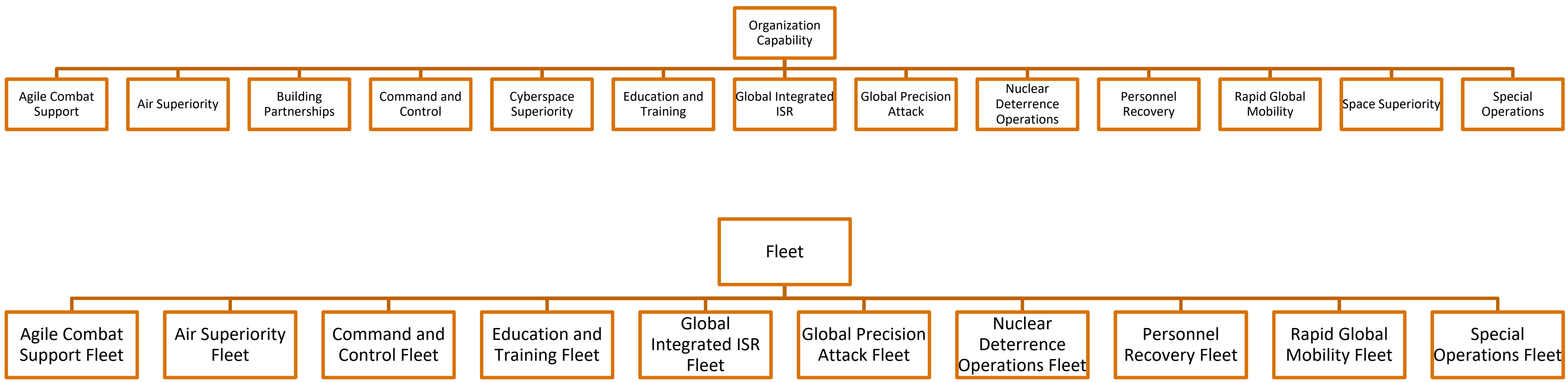
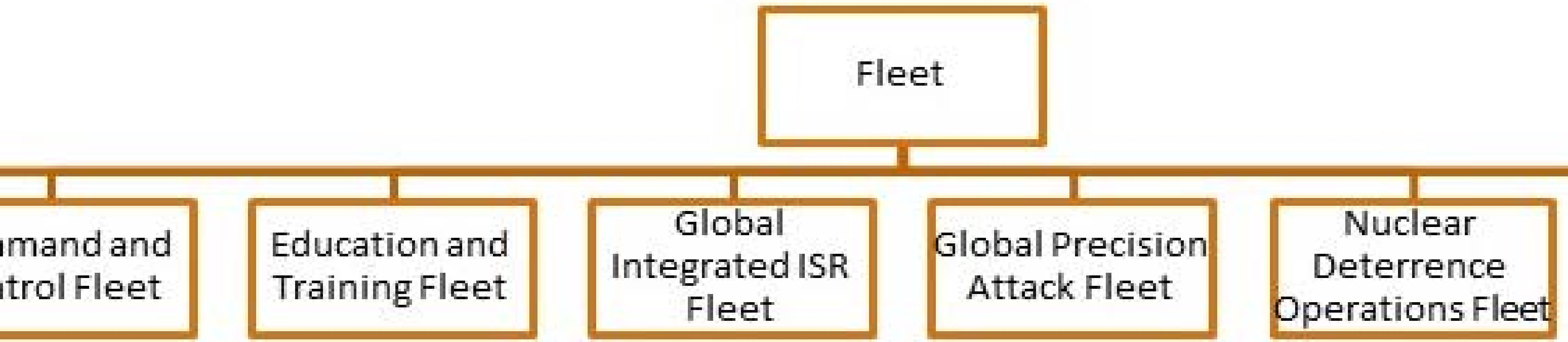
Air Force Core Functions and Fleets

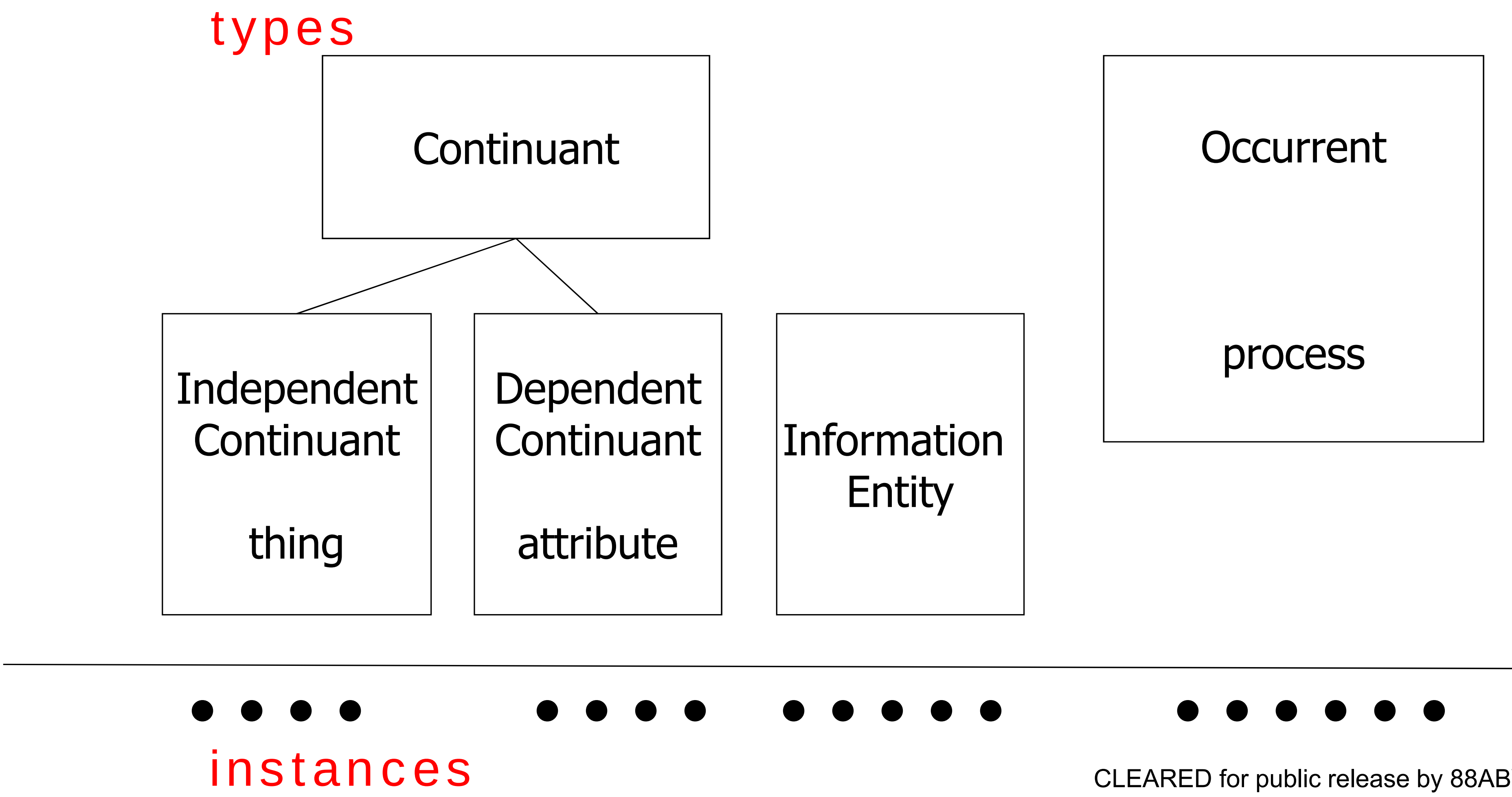
Core functions are subtypes of Organization Capability and together with Acts of Organizational Control are used to classify Fleets



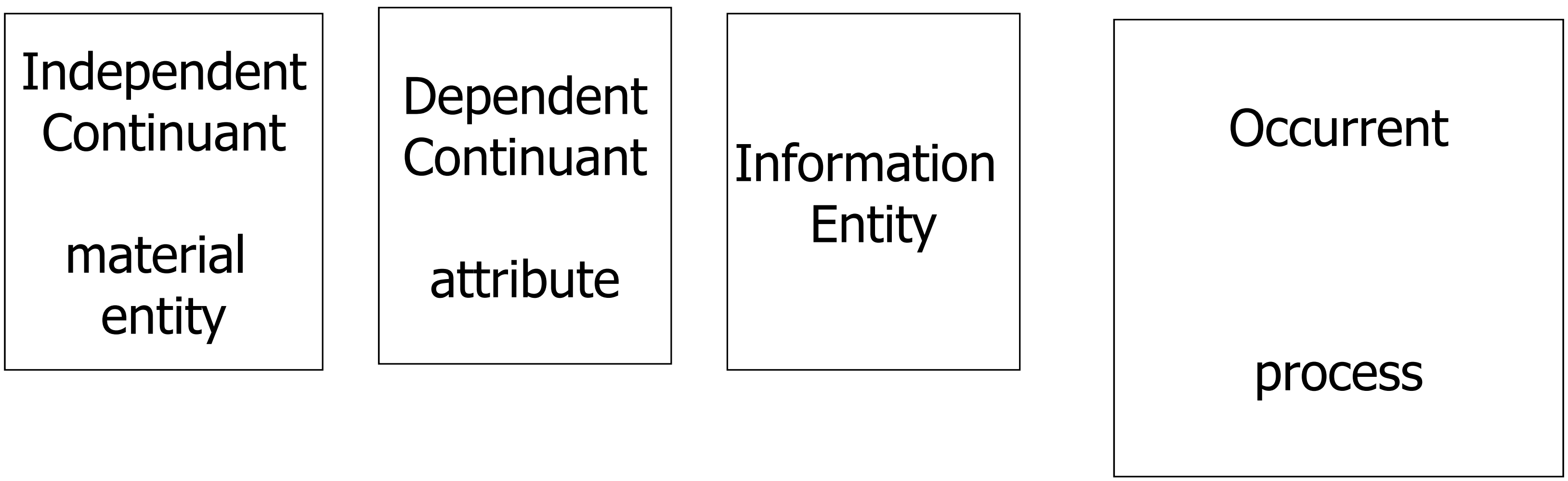

Organization Capability
Command and Control
Cyberspace Superiority
Education and Training
Global Integrated ISR
Global Precision Attack
Nuclear Deterrence Operations


Fleet
mand and trol Fleet
Education and Training Fleet
Global Integrated ISR Fleet
Global Precision Attack Fleet
Nuclear Deterrence Operations Fleet

Top level organization of BFO



Top level organization of BFO



Top Level organization of BFO

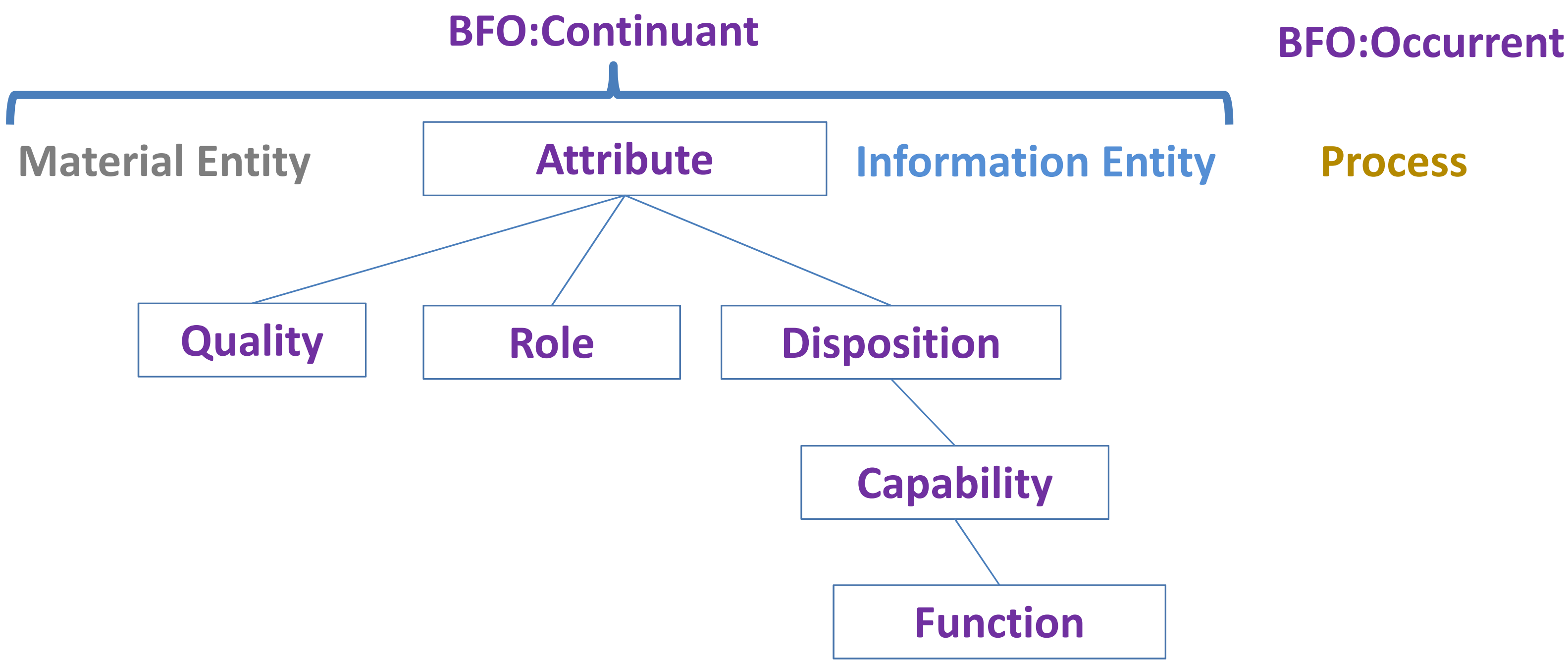
BFO:Continuant

Material Entity **Attribute** **Information Entity**

BFO:Occurrent

Process

Top Level organization of BFO



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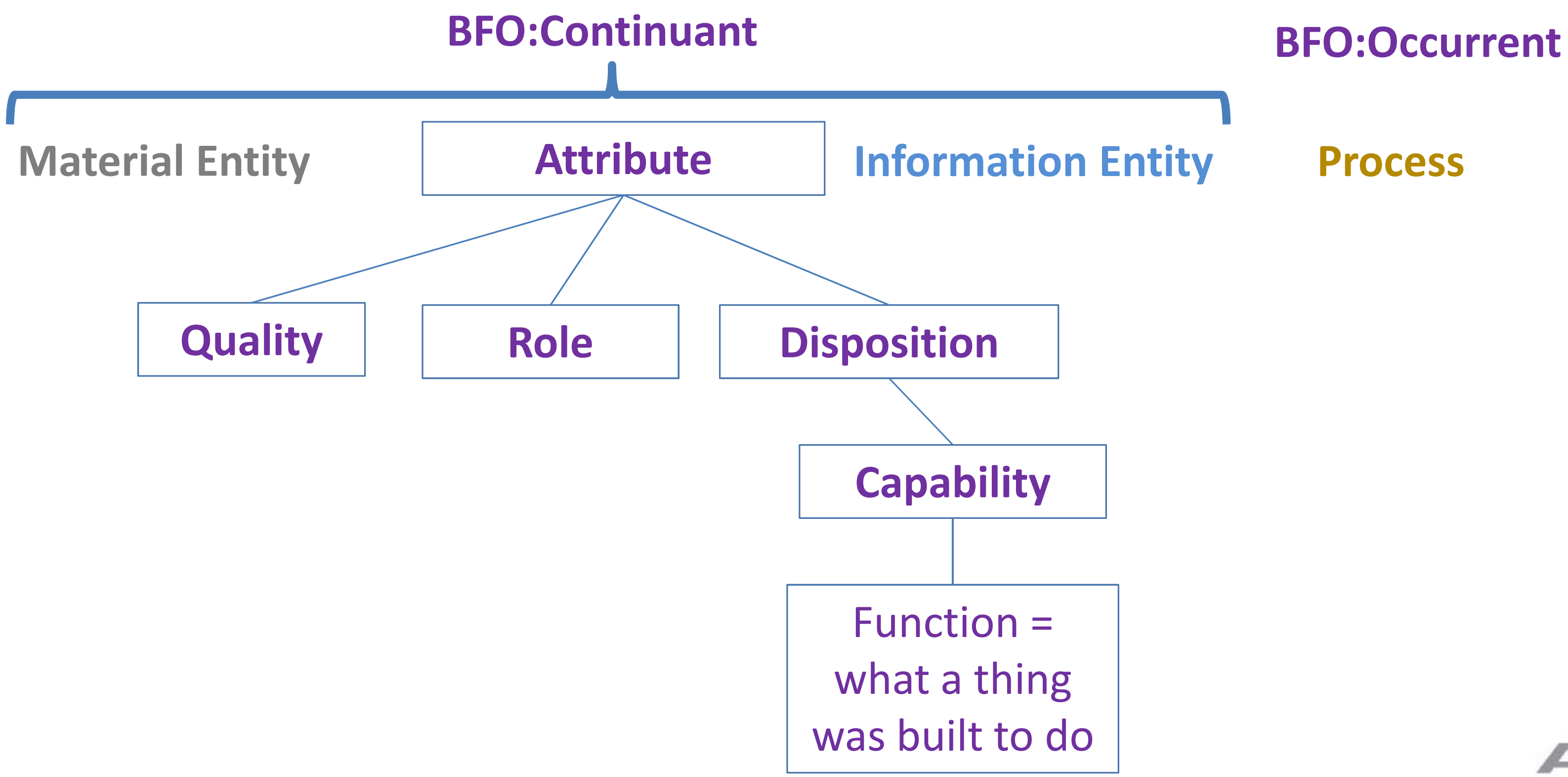
Top Level organization of BFO



Four major top-level categories in BFO

BFO:Continuant			BFO:Occurrent
Material Entity	**Attribute**	**Information Entity**	**Process**

Aircraft
Tail
Airframe
Engine
Sensor

Machine Tool

Airbase
Fuel Supply
System
IVHM System*

*Integrated Vehicle Health Management System

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Four major top-level categories in BFO

BFO:Continuant

BFO:Occurrent

Material Entity	**Attribute**	**Information Entity**	**Process**
Aircraft Tail Airframe Engine Sensor Machine Tool Airbase Fuel Supply System IVHM System	Crack Fault Discontinuity Status Productivity Quality Function Capability		

Material Entity **Information Entity** **Process**

Designer
Machinist
Engineer
Pilot

Aircraft
Tail
Airframe
Engine
Sensor

Machine Tool

Airbase
Fuel Supply System
IVHM System

We focus on these three BFO categories

Material Entity

Information Entity

Process

Joint Doctrine
Publication

Technical Manual

Requirement
Specification

Aircraft Design

Production Plan
Part List

Sensor Data

Maintenance Plan
Maintenance Report
Maintenance History

Material Entity

Information Entity

Process

Design Process
Production Process

Production Plan
Generation Process

Sortie
Taxi
Landing

Logistics Process

Flight Debrief
Inspection
Grounding
Assessment

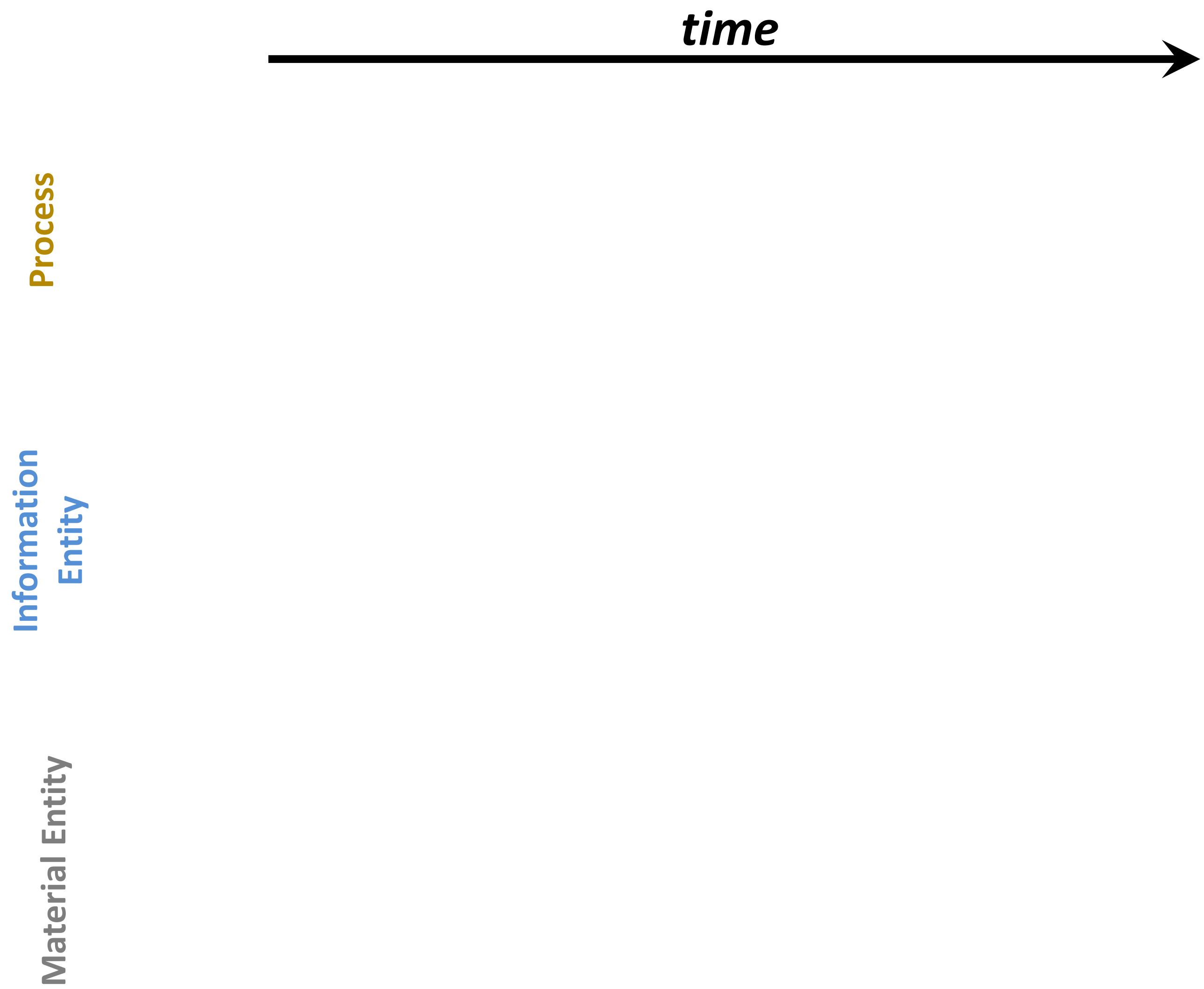
End Of Life Process

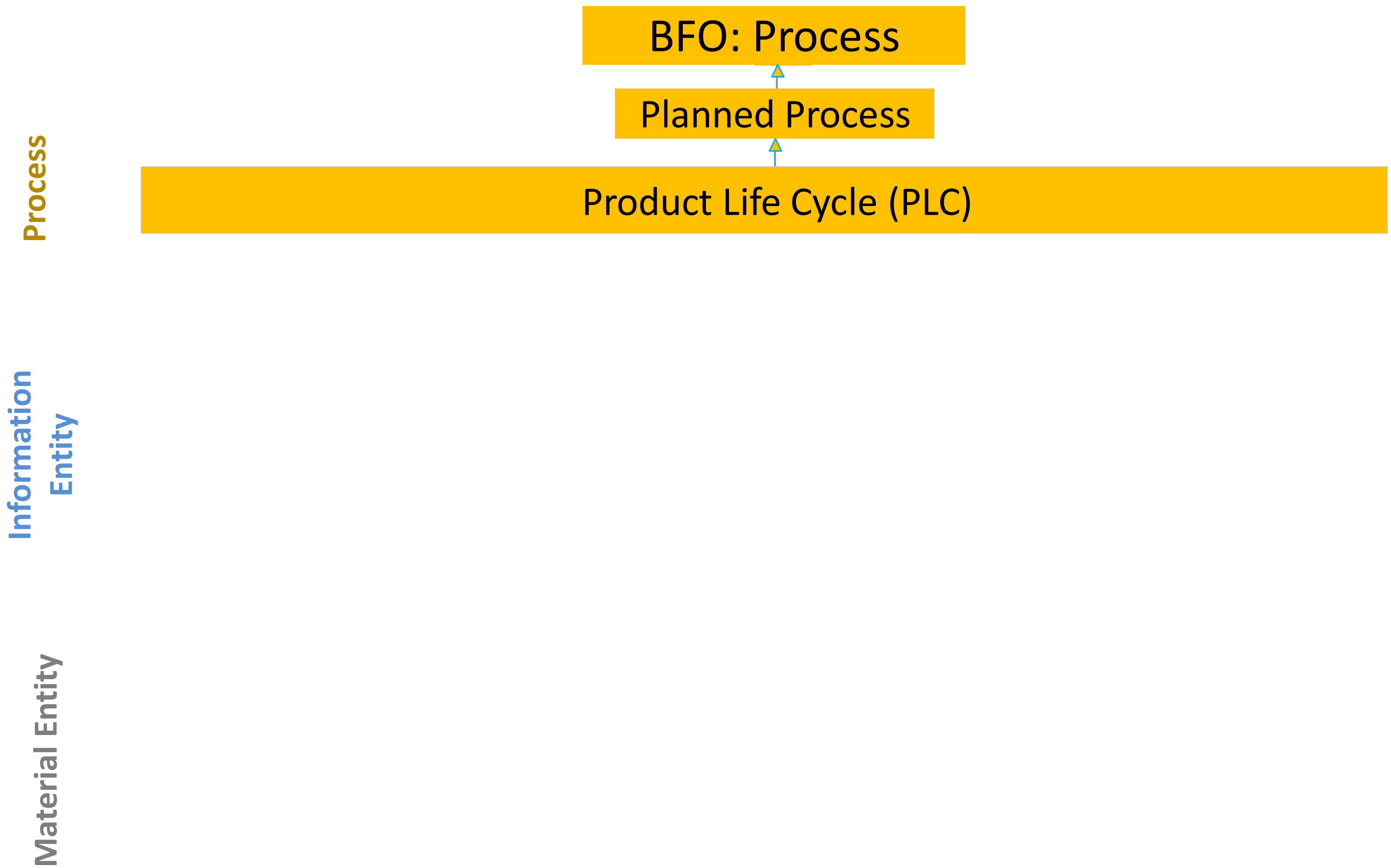
Material Entity Information Entity Process

Process

Information Entity

Material Entity


time
Process
Information Entity
Material Entity



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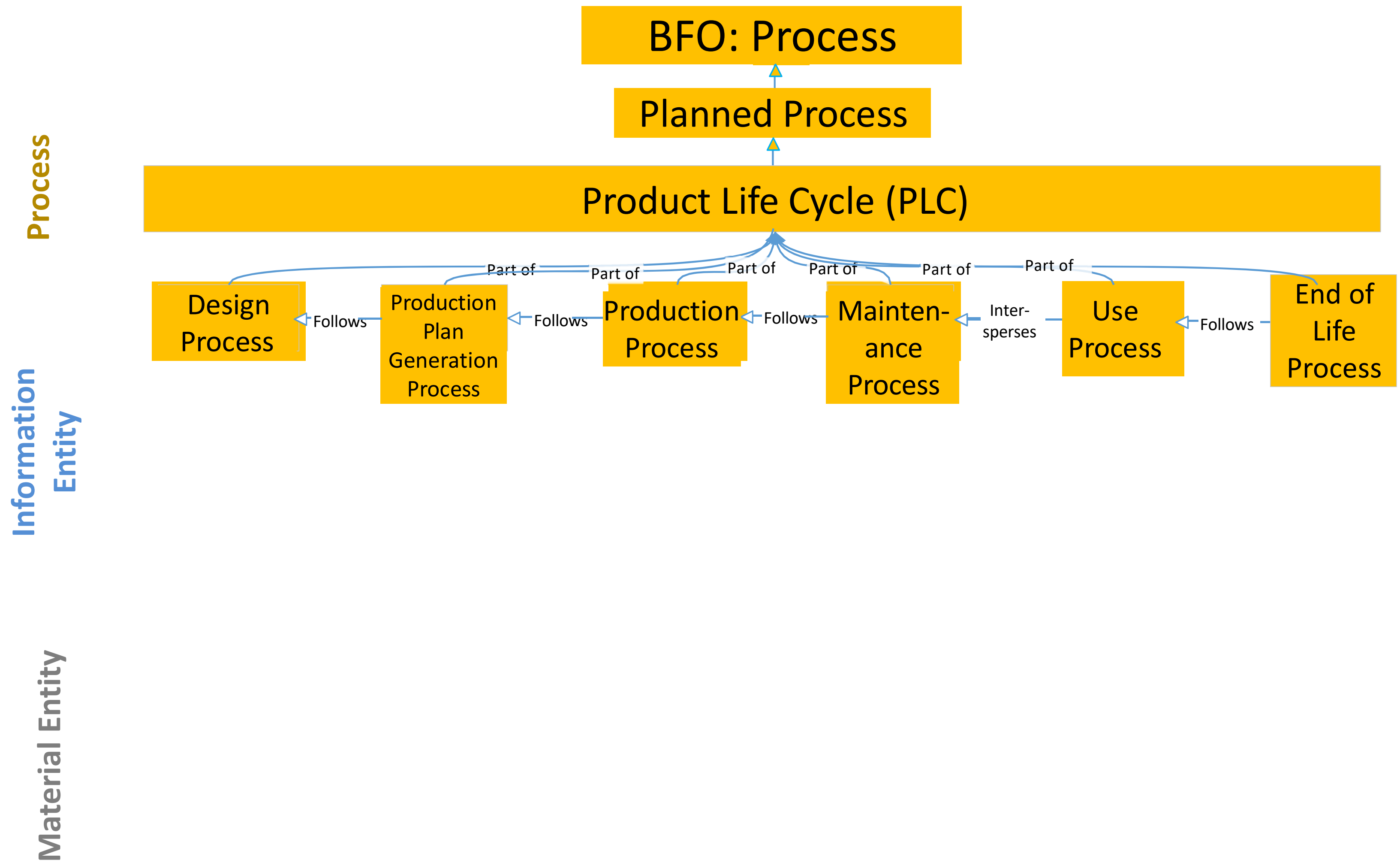

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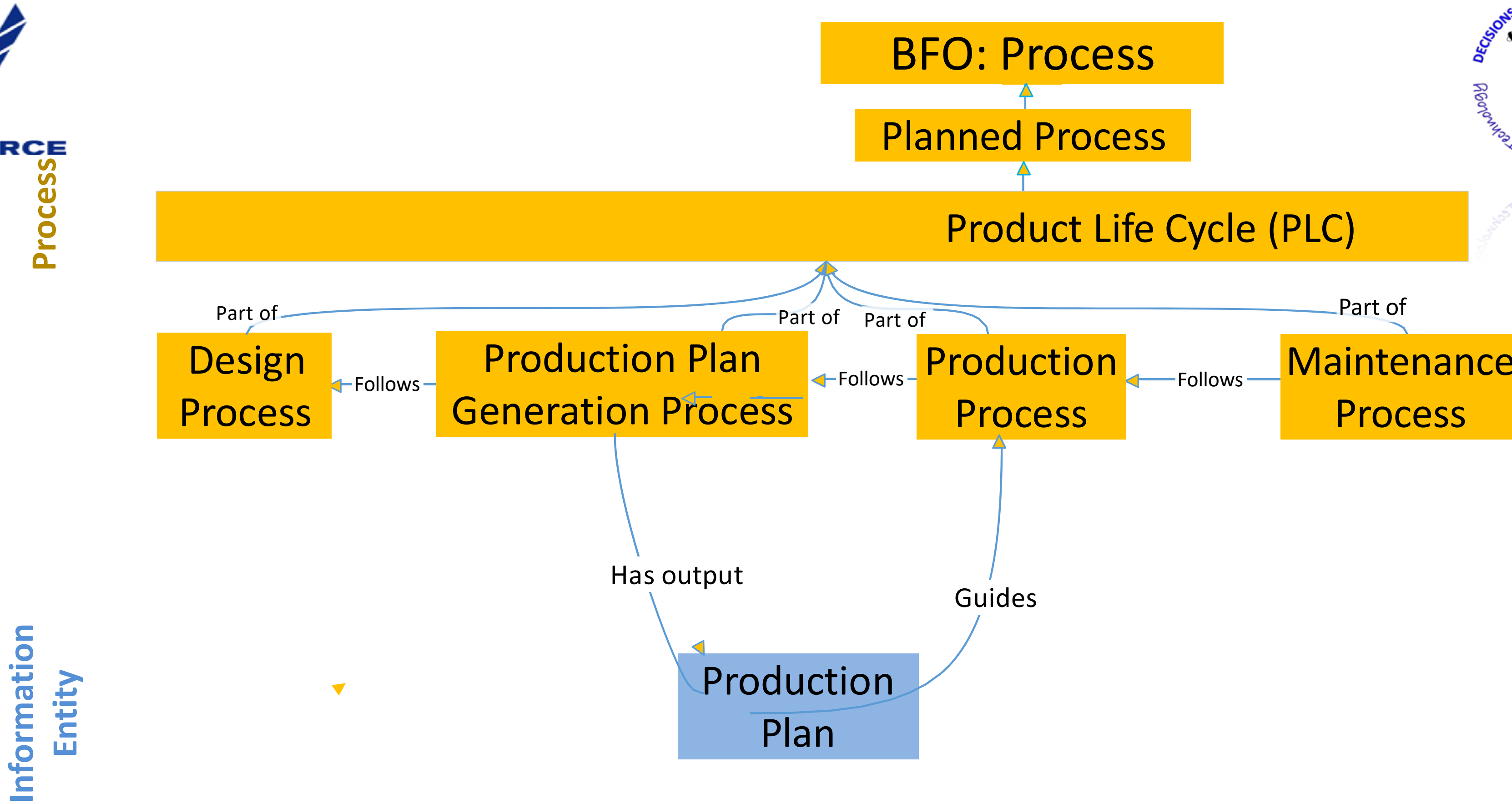

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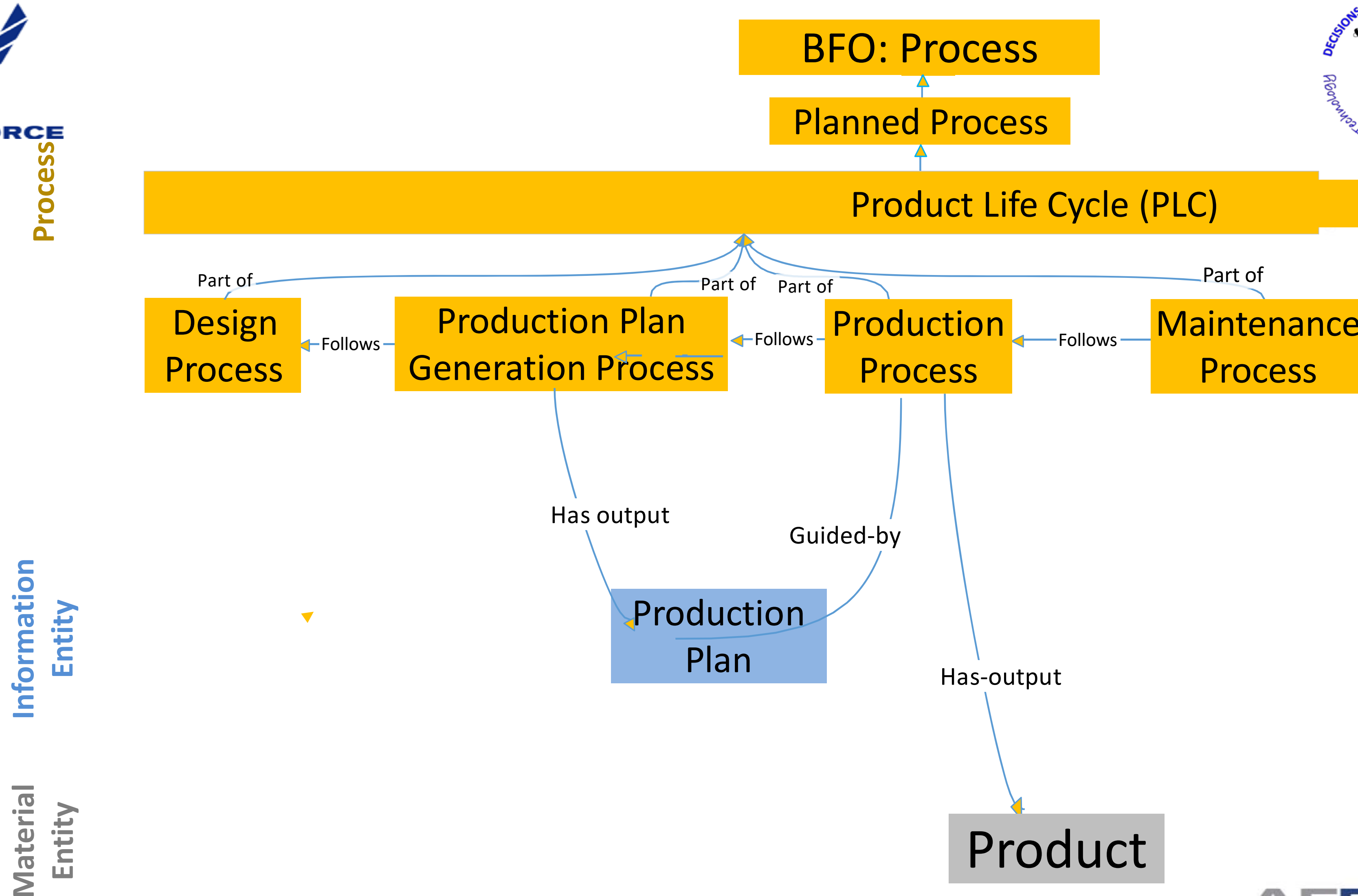
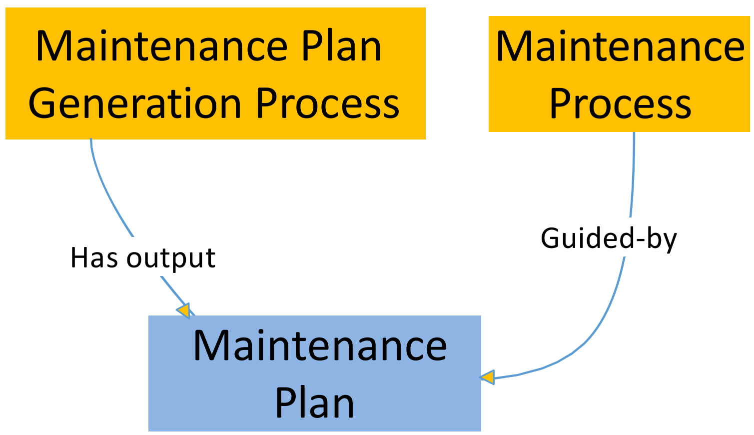
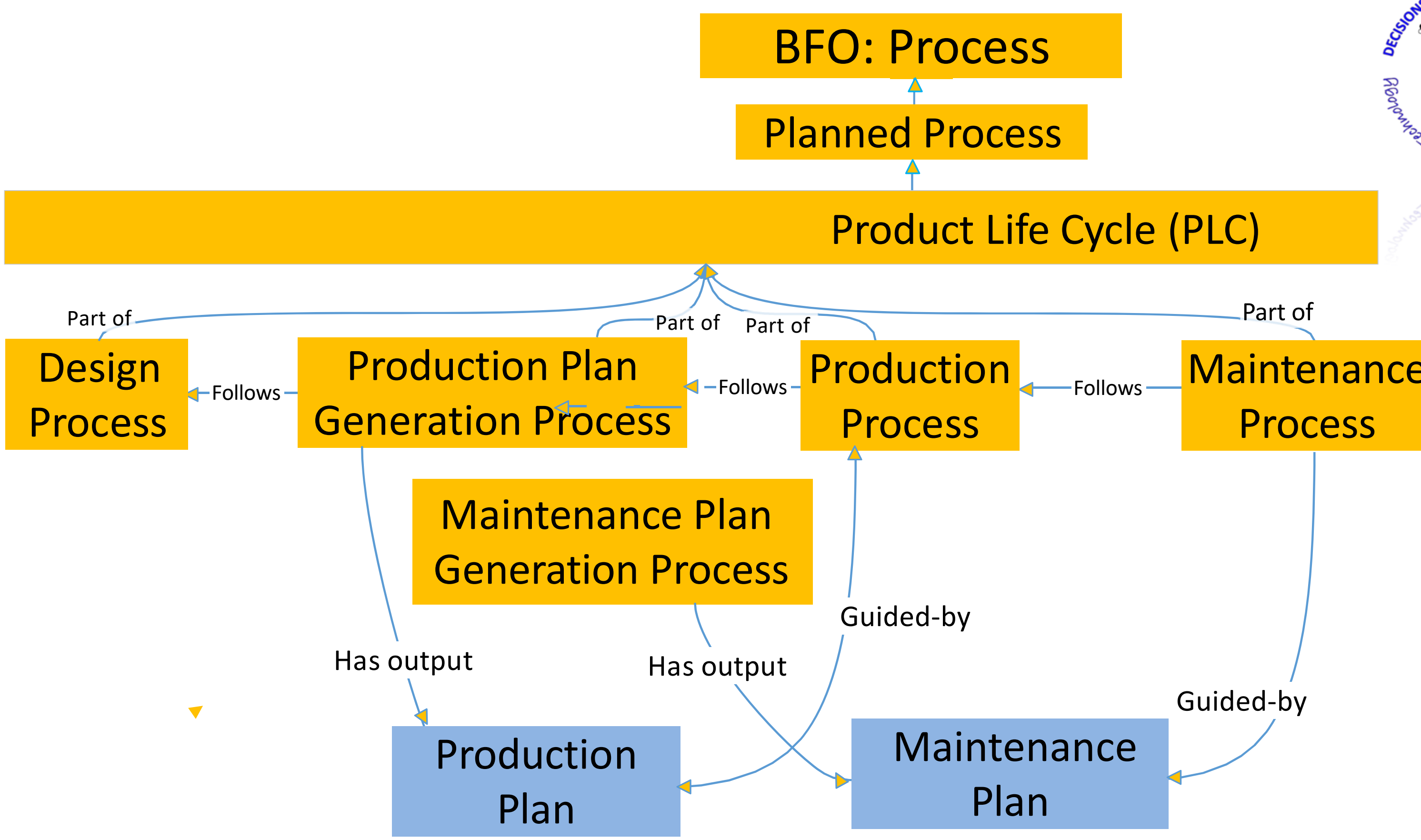

BFO: Process
Planned Process
Product Life Cycle (PLC)
Process
Part of
Part of
Part of
Part of
Design Process
Follows
Production Plan Generation Process
Follows
Production Process
Follows
Maintenance Process
Has output
Guided-by
Information Entity
Production Plan
Has-output
Material Entity
Product


Maintenance Plan Generation Process
Maintenance Process
Has output
Guided-by
Maintenance Plan

Process

Information Entity



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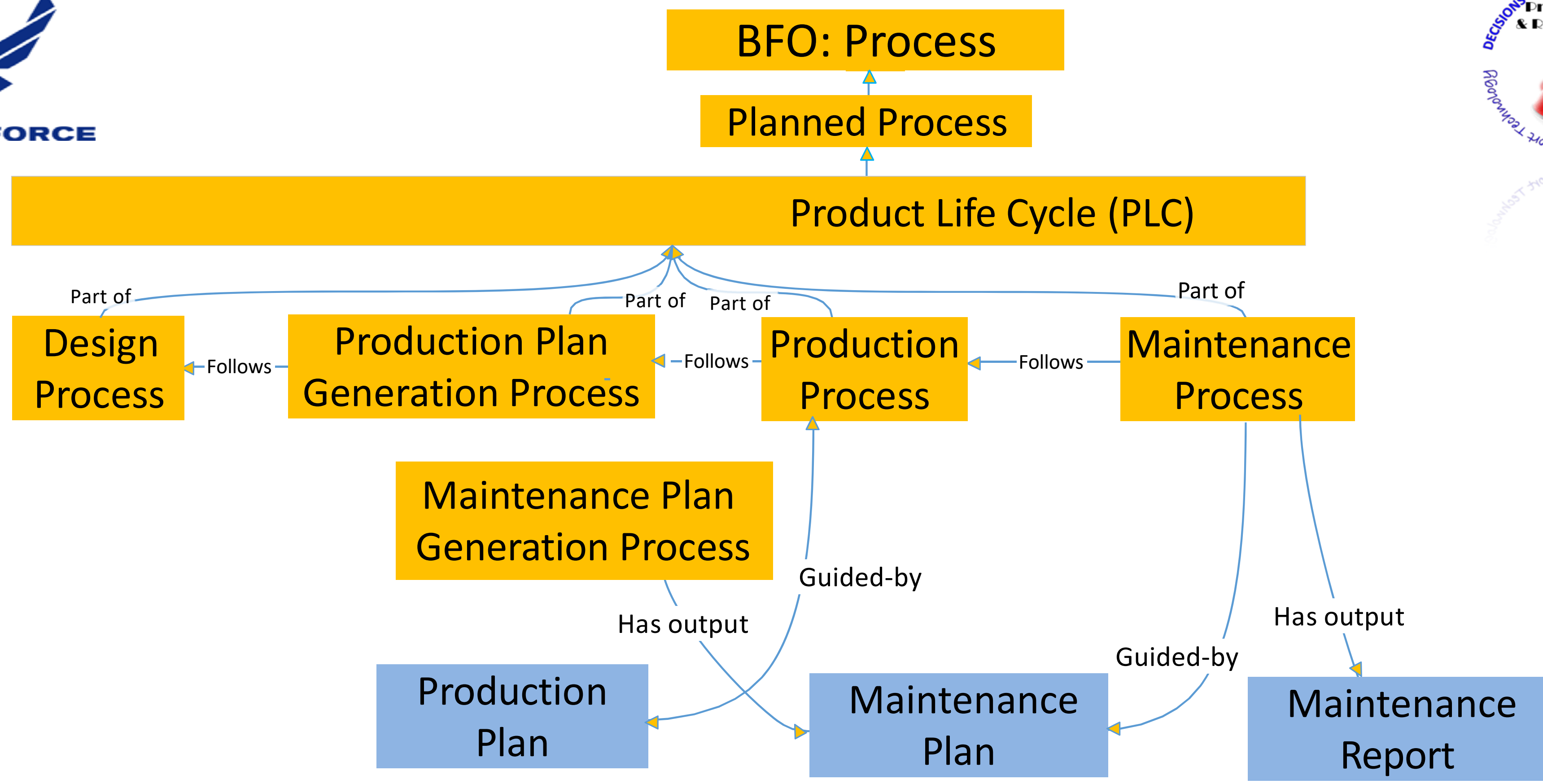

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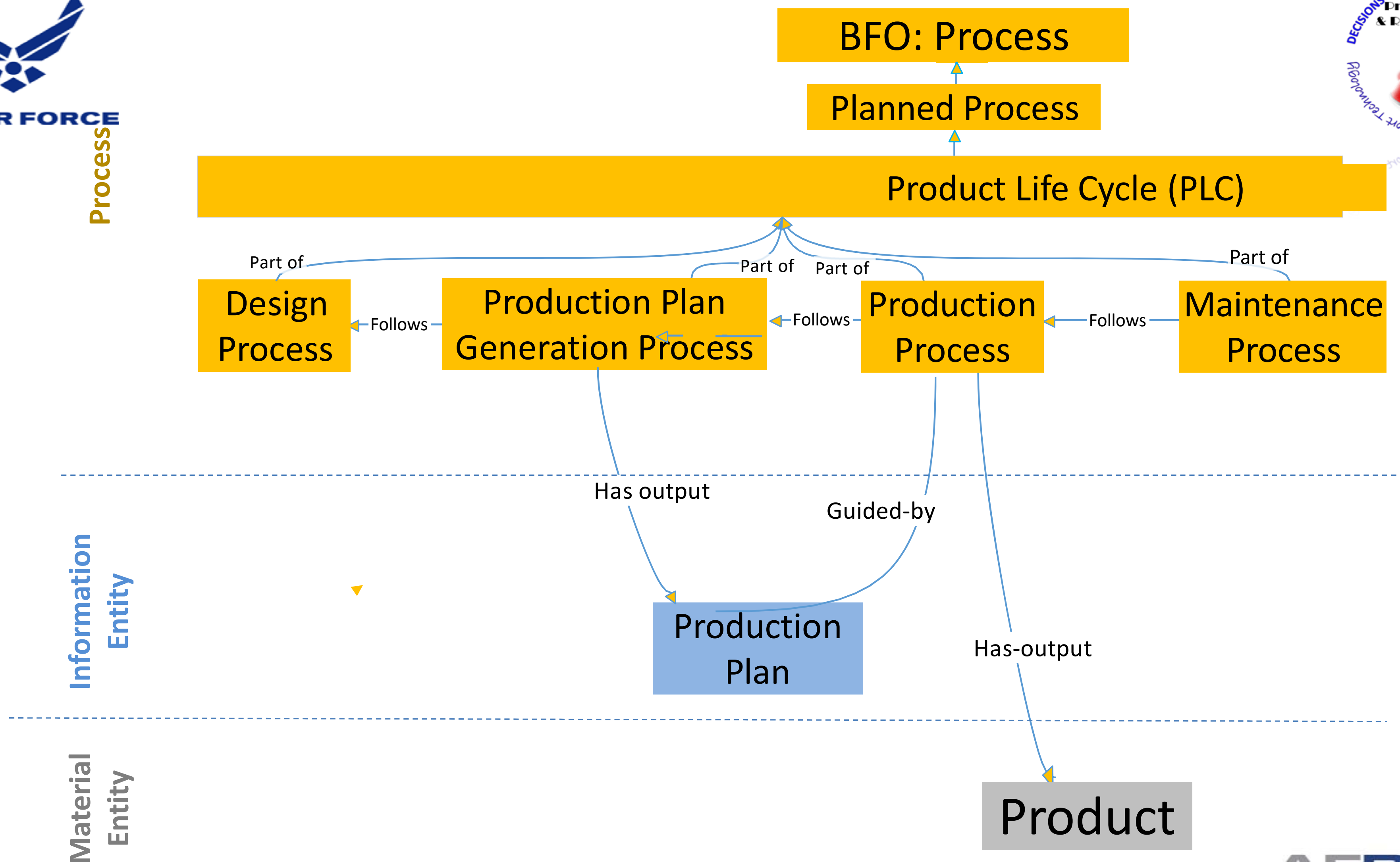
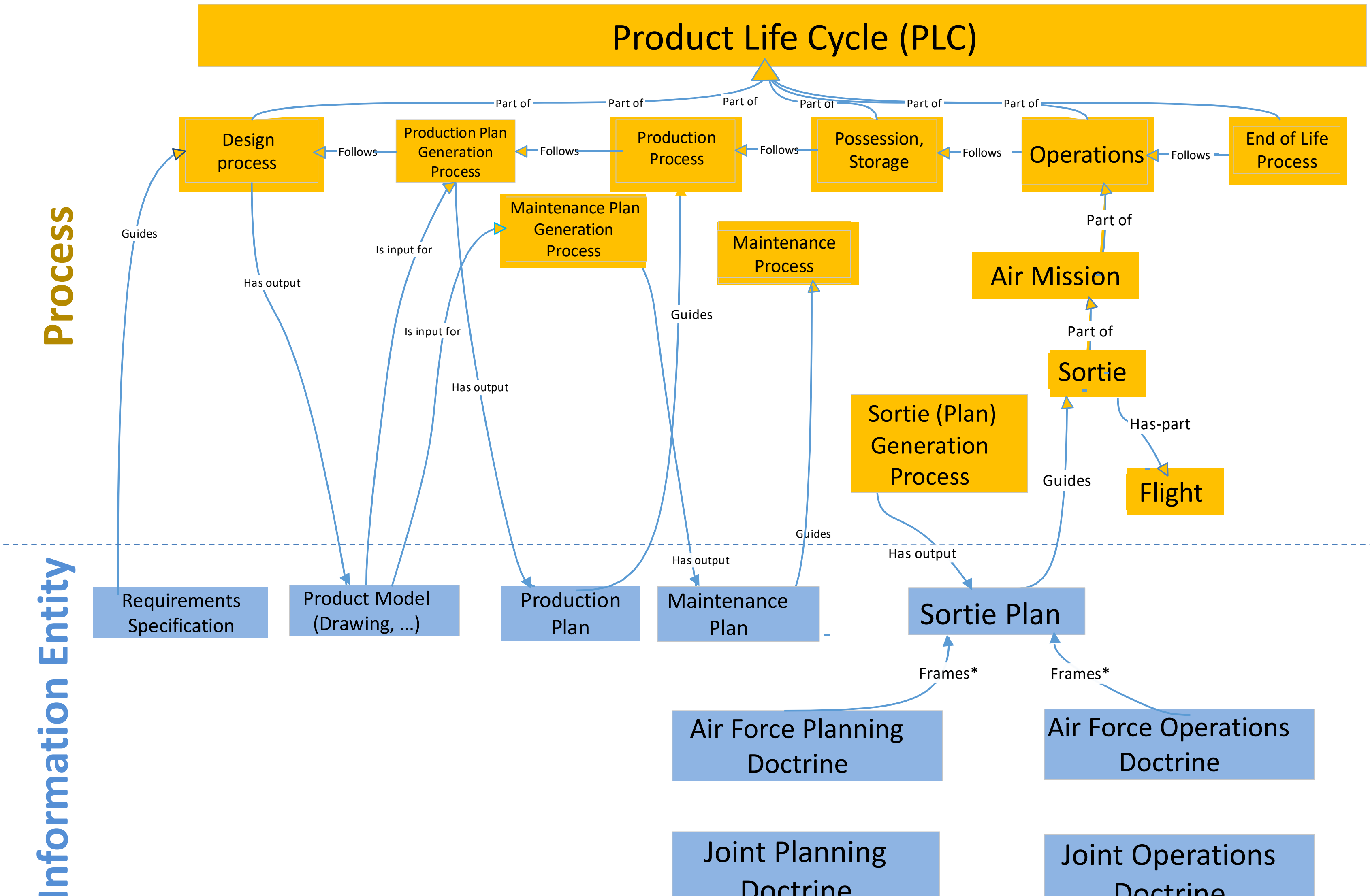


BFO: Process
Planned Process
Product Life Cycle (PLC)
Process
Part of
Part of
Part of
Part of
Design Process
Follows
Production Plan Generation Process
Follows
Production Process
Follows
Maintenance Process
Has output
Guided-by
Information Entity
Production Plan
Has-output
Material Entity
Product



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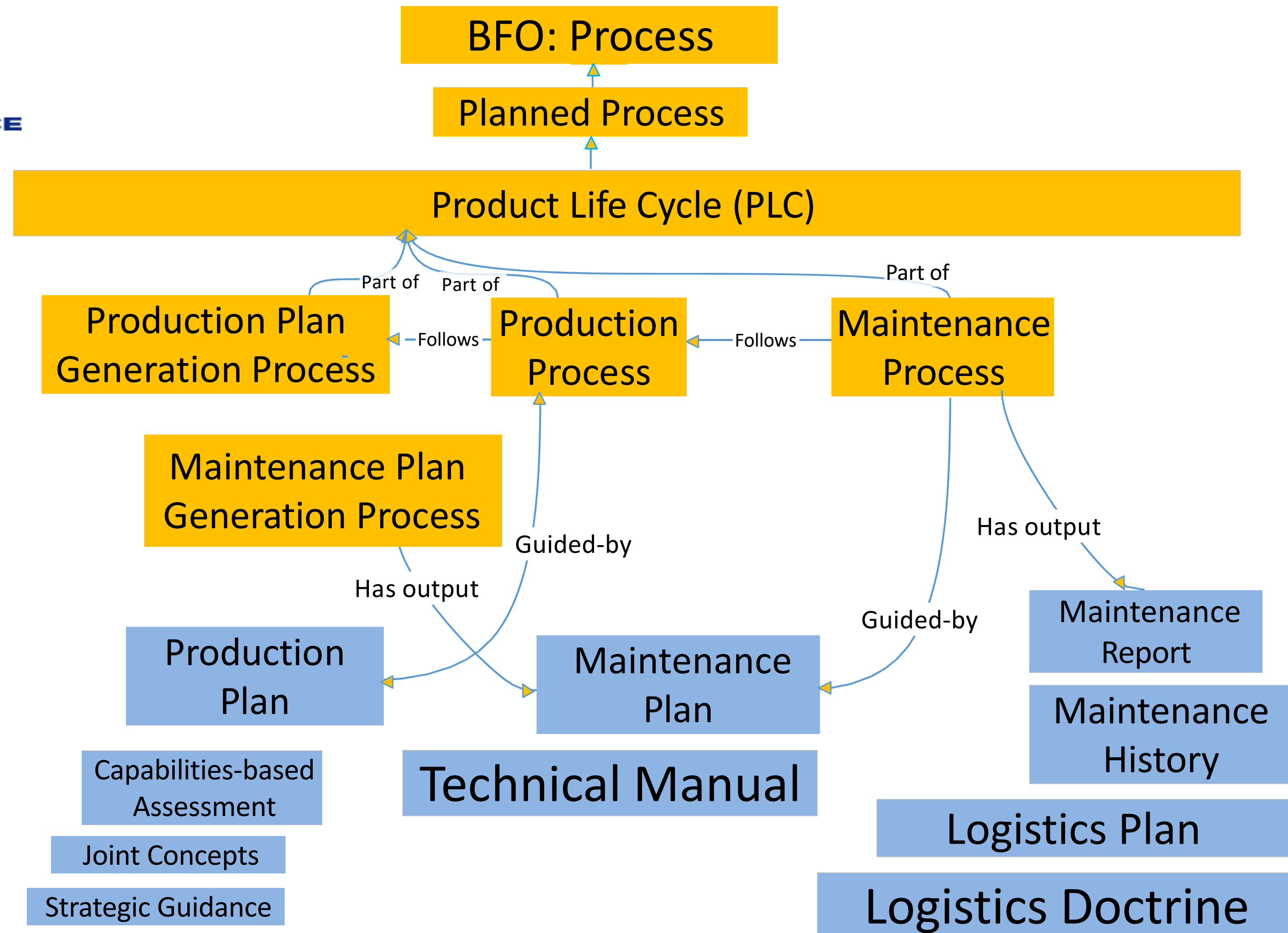
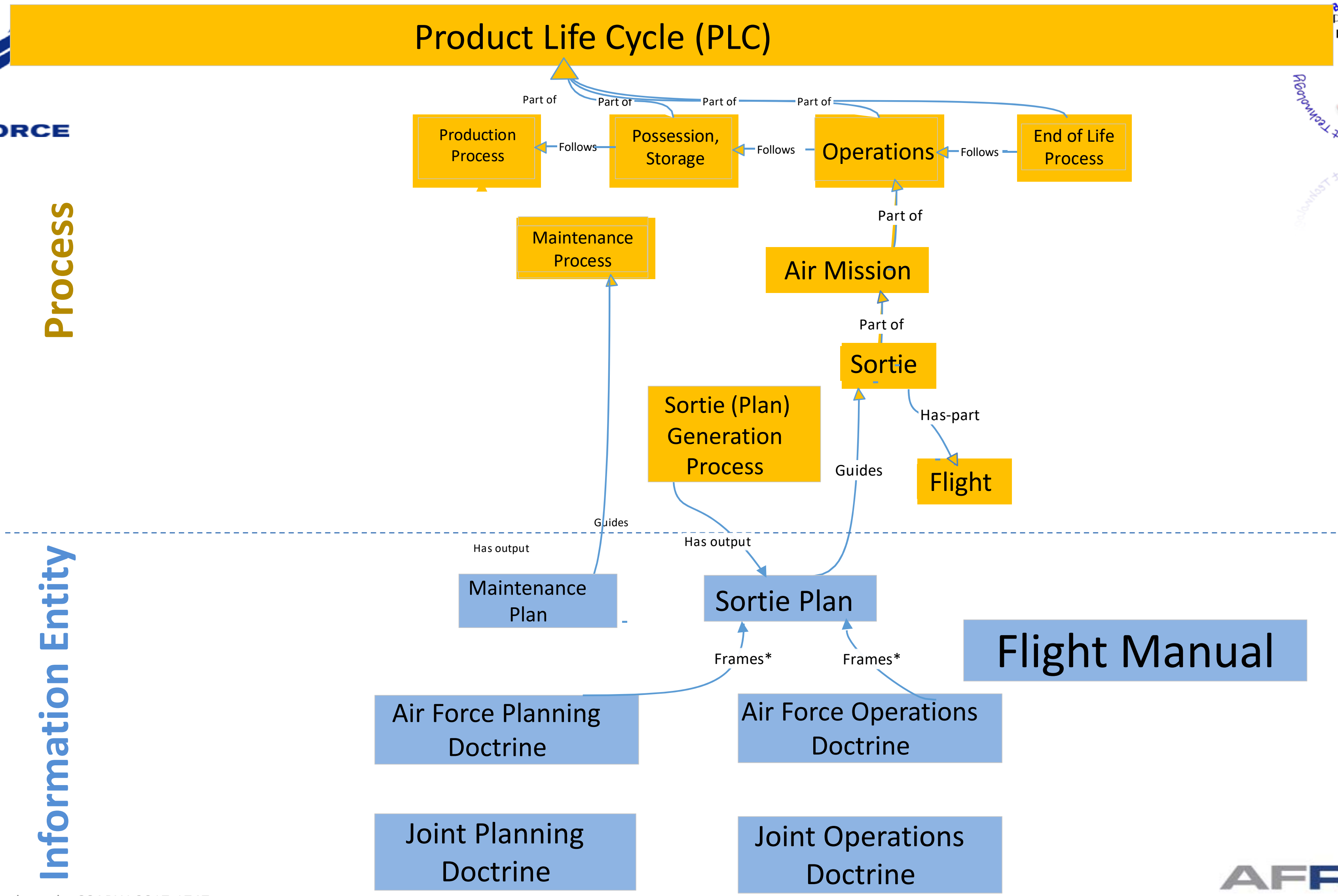

BFO: Process
Planned Process
Product Life Cycle (PLC)
Part of
Part of
Part of
Production Plan Generation Process
Follows
Production Process
Follows
Maintenance Process
Maintenance Plan Generation Process
Guided-by
Has output
Has output
Guided-by
Production Plan
Maintenance Plan
Maintenance Report
Maintenance History
Capabilities-based Assessment
Technical Manual
Joint Concepts
Strategic Guidance
Logistics Plan
Logistics Doctrine



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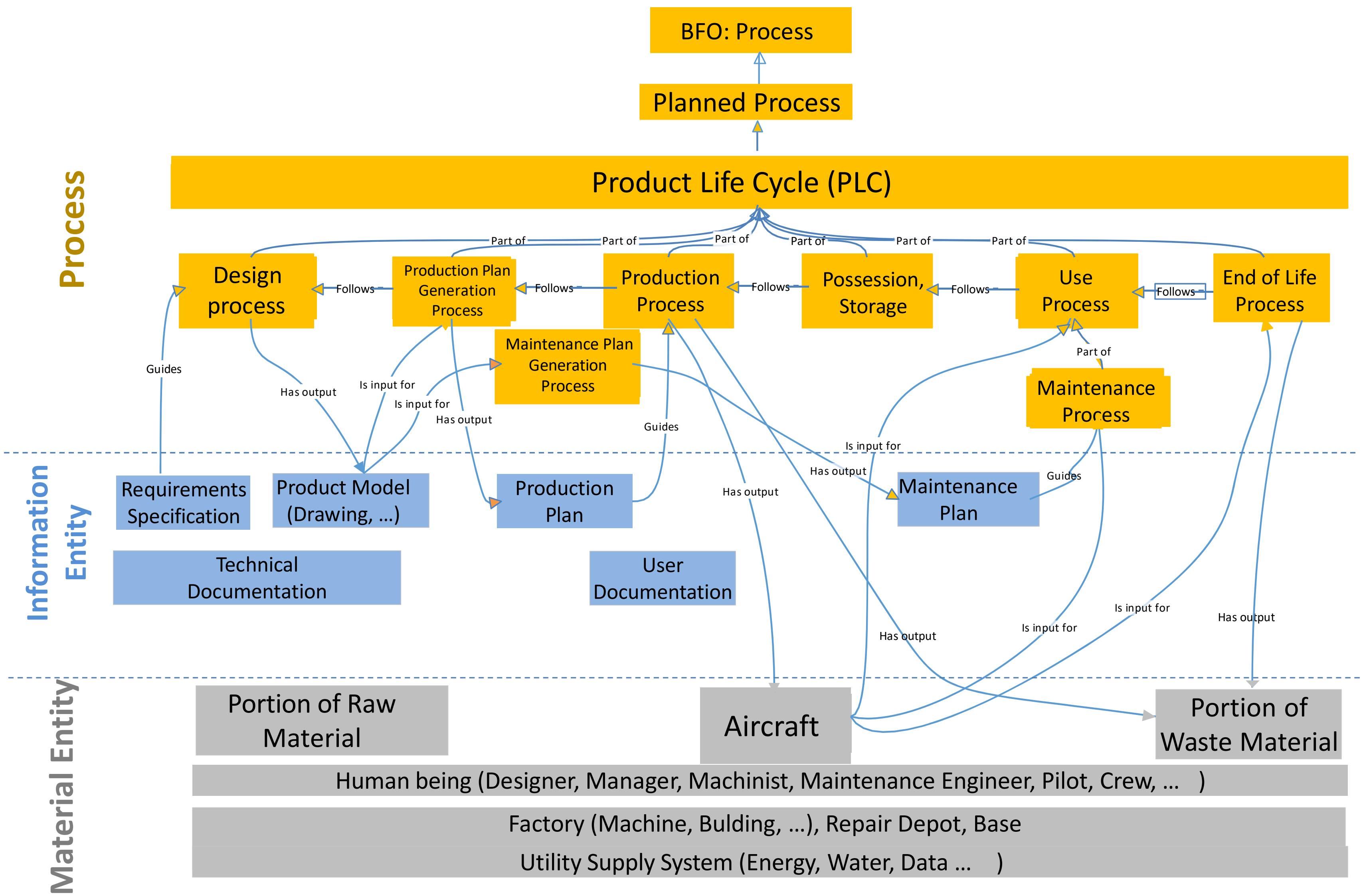
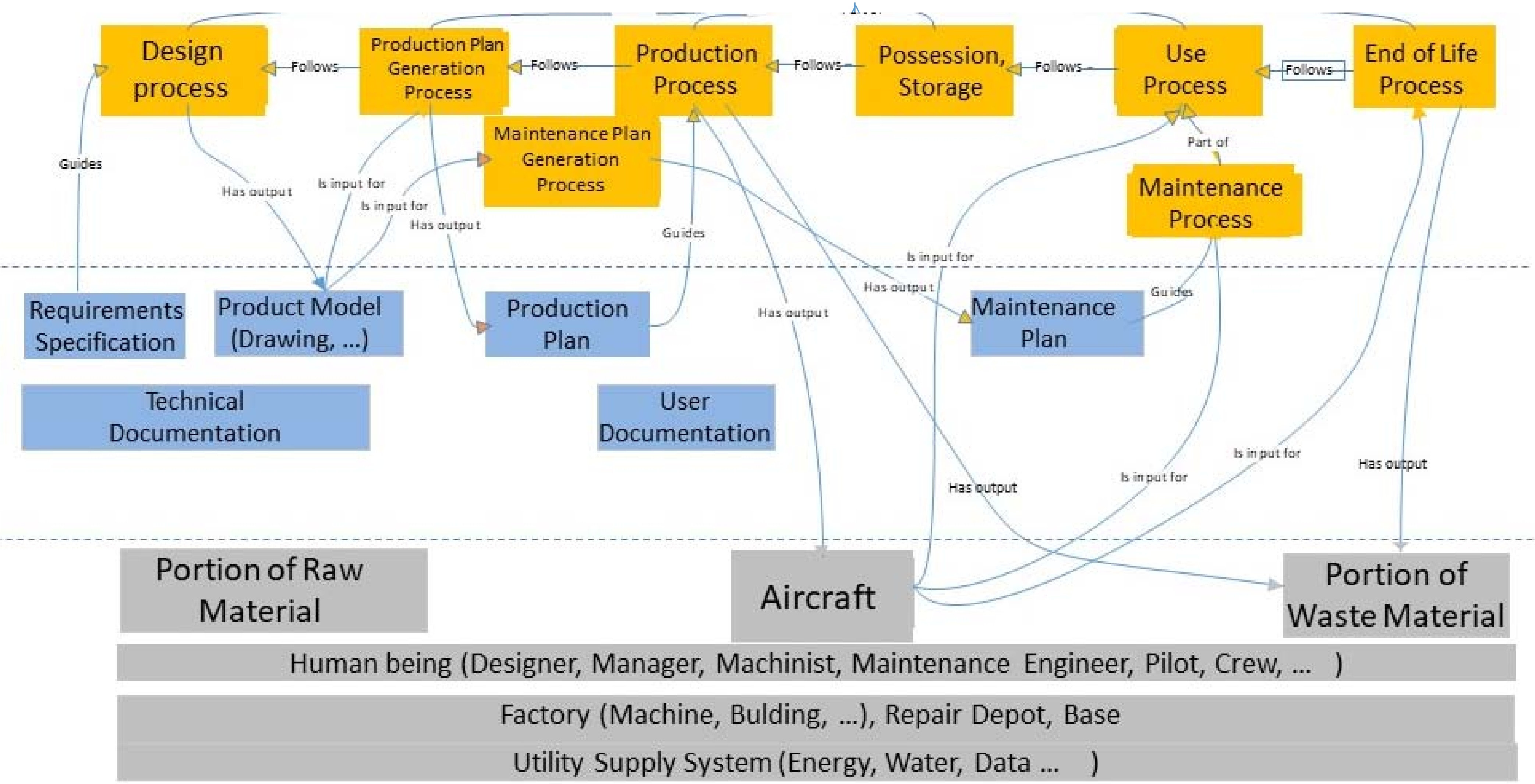


BFO: Process
Planned Process
Product Life Cycle (PLC)
Process
Part of
Design process
Production Plan Generation Process
Production Process
Possession, Storage
Use Process
End of Life Process
Follows
Maintenance Plan Generation Process
Maintenance Process
Guides
Has output
Is input for
Information Entity
Requirements Specification
Product Model (Drawing, …)
Production Plan
Maintenance Plan
Technical Documentation
User Documentation
Material Entity
Portion of Raw Material
Aircraft
Portion of Waste Material
Human being (Designer, Manager, Machinist, Maintenance Engineer, Pilot, Crew, …)
Factory (Machine, Bulding, …), Repair Depot, Base
Utility Supply System (Energy, Water, Data …)


Design process
Production Plan Generation Process
Production Process
Possession, Storage
Use Process
End of Life Process
Follows
Follows
Follows
Follows
Follows
Maintenance Plan Generation Process
Part of
Maintenance Process
Guides
Has output
Is input for
Is input for
Has output
Guides
Is input for
Has output
Has output
Guides
Requirements Specification
Product Model (Drawing, ...)
Production Plan
Maintenance Plan
Technical Documentation
User Documentation
Has output
Is input for
Is input for
Has output
Portion of Raw Material
Aircraft
Portion of Waste Material
Human being (Designer, Manager, Machinist, Maintenance Engineer, Pilot, Crew, ...)
Factory (Machine, Bulding, ...), Repair Depot, Base
Utility Supply System (Energy, Water, Data ...)

Material Entities

Aircraft

Engine

Airframe

Weapon System

Fuel

Ammunition

Procurement Staff
Designer
Production Engineer…

Pilot, Crew
Maintenance Engineer…

Disposal Engineer

Design Shop, Factory,

Airbase, Repair Depot

Disposal Facility

Material Entities, including Systems

Aircraft

Engine

Airframe

Weapon System

Fuel

Ammunition

Procurement Staff
Designer
Production Engineer…

Pilot, Crew
Maintenance Engineer…

Disposal Engineer

Design Shop, Factory,

Airbase, Repair Depot

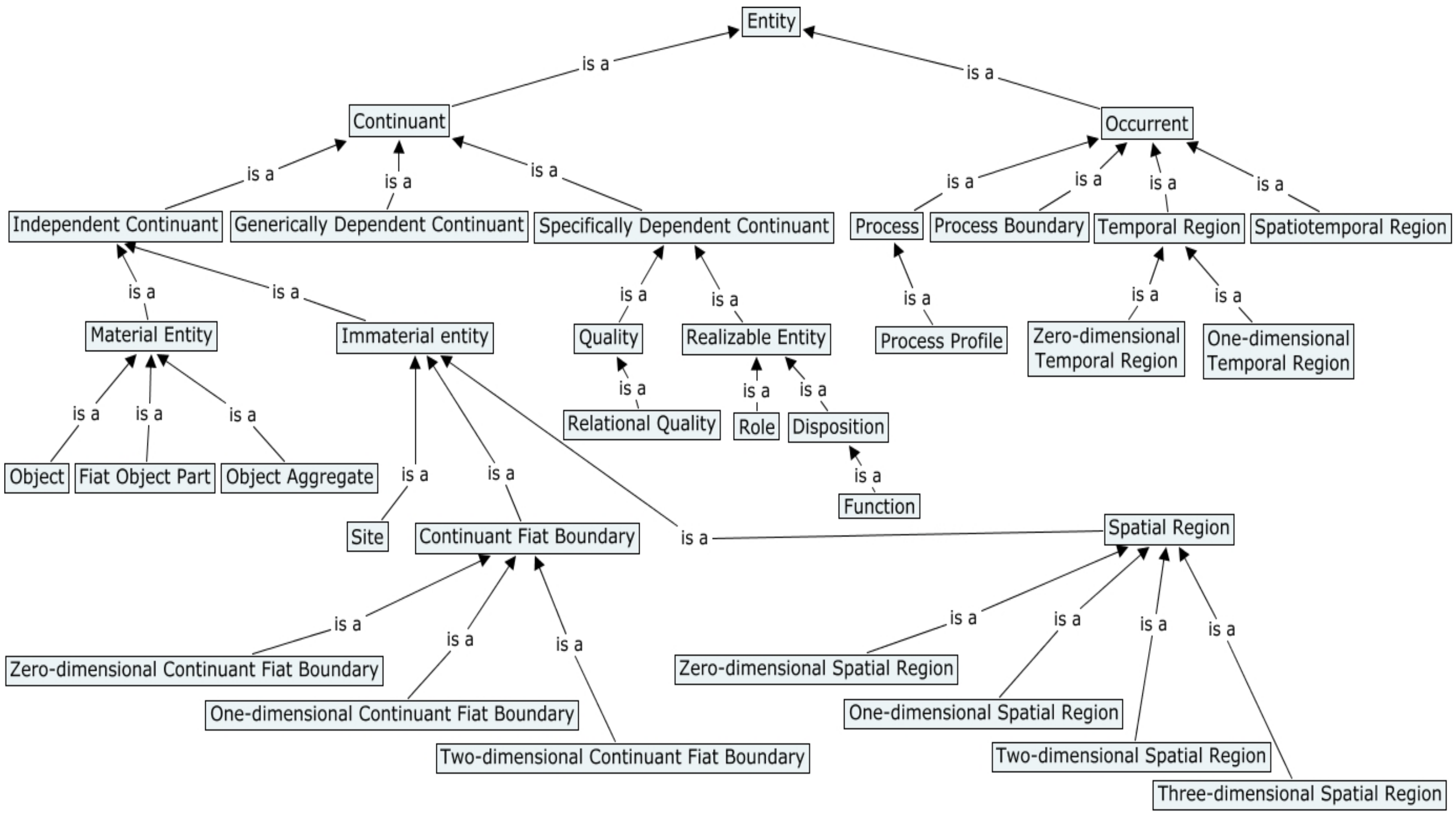
Disposal Facility

Maintenance (IVHM) System

Supply System (Fuel, ….)

Utility System (Energy, Water, Data / IT …   )

Infrastructure (Transport / Delivery System …   )


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
Process Profile
Zero-dimensional Temporal Region
One-dimensional Temporal Region
Relational Quality
Role
Disposition
Function
Object
Fiat Object Part
Object Aggregate
Site
Continuant Fiat Boundary
Spatial Region
Zero-dimensional Continuant Fiat Boundary
One-dimensional Continuant Fiat Boundary
Two-dimensional Continuant Fiat Boundary
Zero-dimensional Spatial Region
One-dimensional Spatial Region
Two-dimensional Spatial Region
Three-dimensional Spatial Region

Commodities, services and infrastructure (systems)

with thanks to Wolfgang Grassl

Basic Dichotomy between Commodities and Services

- Commodities are continuants
  - material things, software
  - deliberately created and such as to survive their act of creation
  - can be stored, bought, sold, rented,
- Services are occurrents

They are processes; but what sorts of processes?

Traditional examples of services

- haircutting
- consulting
- (aircraft) maintenance
- prostitution
- teaching
- transport (taxi)
- rock concert
- restaurant

What do all these have in common?

- haircutting
- consulting
- (aircraft) maintenance
- prostitution
- teaching
- transport (taxi)
- rock concert
- restaurant

A service is a realization of a capability?

- haircutting
- consulting
- (aircraft) maintenance
- prostitution
- teaching
- transport (taxi)
- rock concert
- restaurant

Production and consumption *coincide*

- haircutting
- consulting
- (aircraft) maintenance
- prostitution
- teaching
- transport (taxi)
- rock concert
- restaurant

Production and consumption *coincide*

- haircutting
- consulting
- (aircraft) maintenance
- prostitution
- teaching
- transport (taxi)
- rock concert
- restaurant

This is why services cannot be stored or rented

What are you paying for when you pay your monthly phone bill?

1. The phone itself
2. The process of using the phone
3. The capability of the phone to receive calls even when you’re not using it
4. The telephone network – a system

Two Kinds of Commodities (Manufactured Goods)

1. consumable (bananas)
2. non-consumable
   – physical infrastructure: roads, sewers, fiber-optic cable networks, …
   – digital instrastructure: internet contents, software on the net, ...

The latter *afford* (allow) services as an ocean affords swimming

Rental "services"

- When you rent an apartment you are buying the apartment, but only month by month.
- (Ultimate ownership remains with the landlord, but apartment rental is still not a matter of services, but a matter of goods.)

(Services of cleaning, … – may of course be included in your payment)

(Services of buying, selling, negotiating … may also be included)

Genuine services

are characterized by the fact that **renting is impossible**.

Services can only be **purchased**

Car Rental "Services"

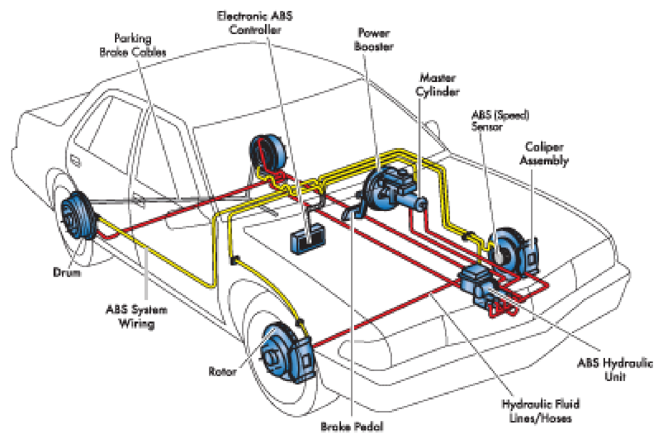
- When you rent a car, you are buying the car, but only for the next 3 days of its life

(Again, some services – of buying, selling, negotiating – will be included in the price)

(And behind these are further bodies of infrastructure – the legal system, the education system …)

A general feature of systems

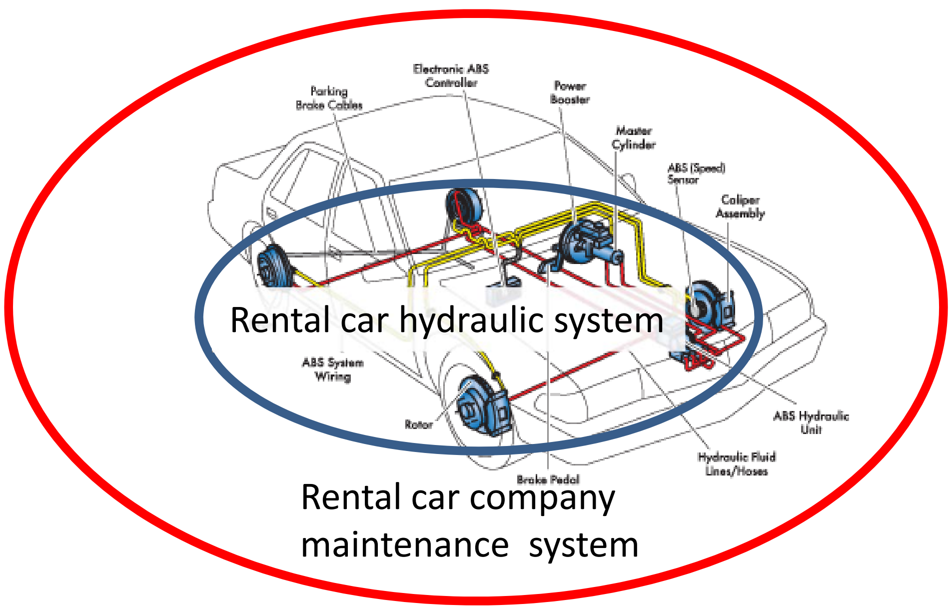
They tend to be embedded within larger systems



Rental car hydraulic system

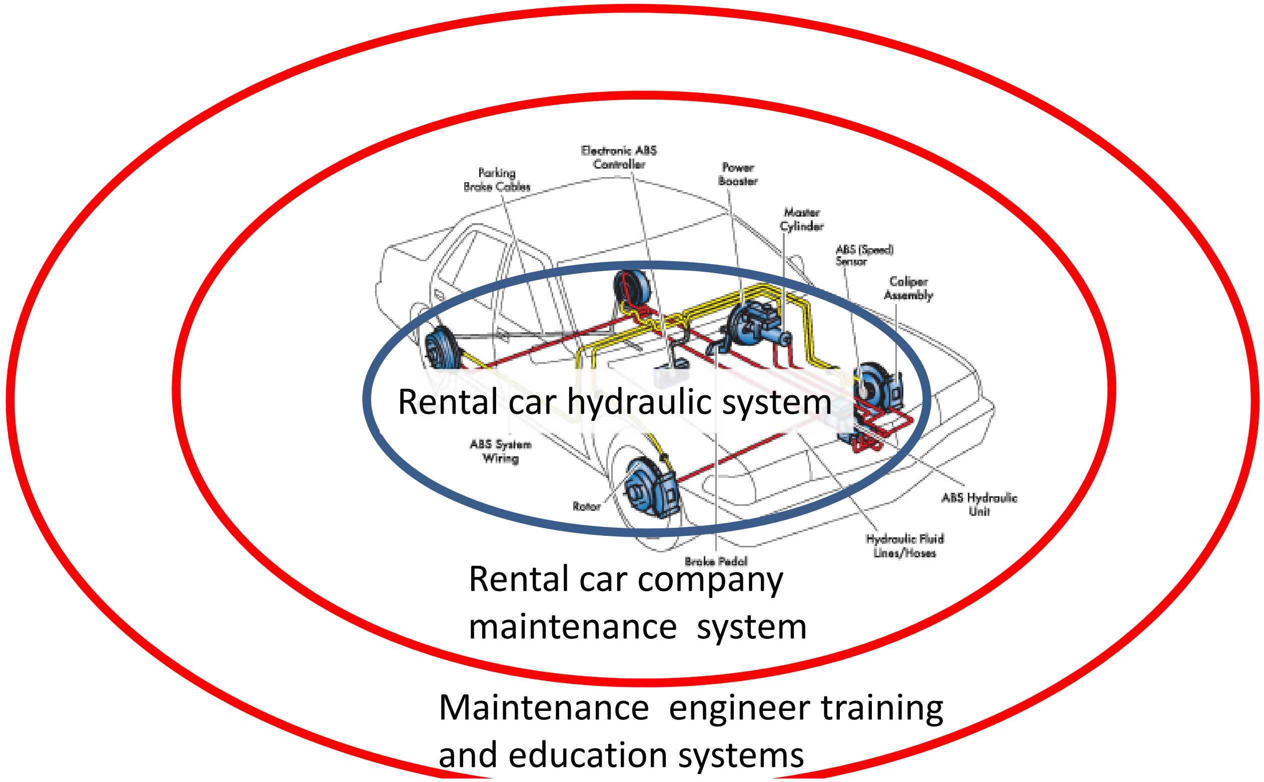
A general feature of systems

They tend to be embedded within multiple larger systems



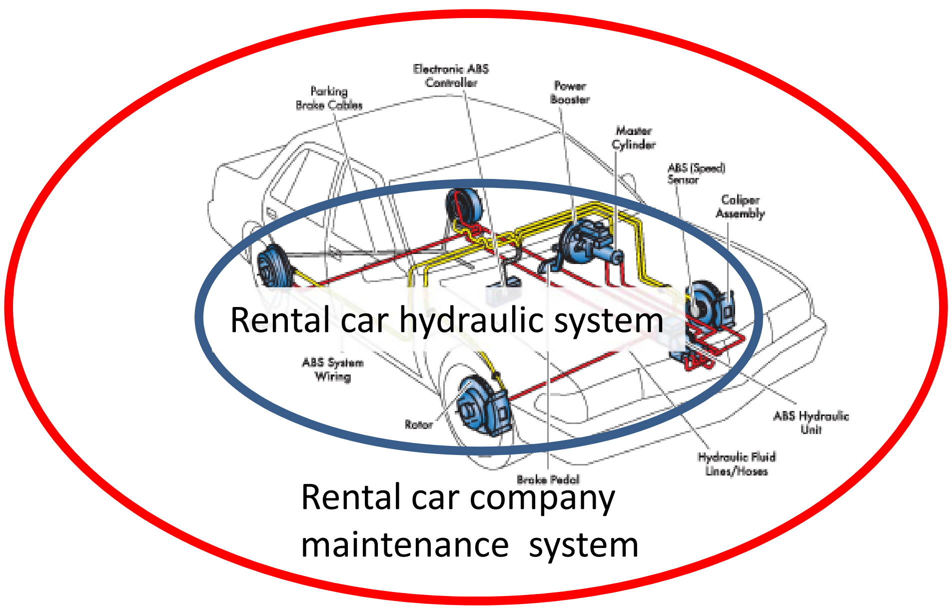
A general feature of systems

They tend to be embedded within multiple larger systems



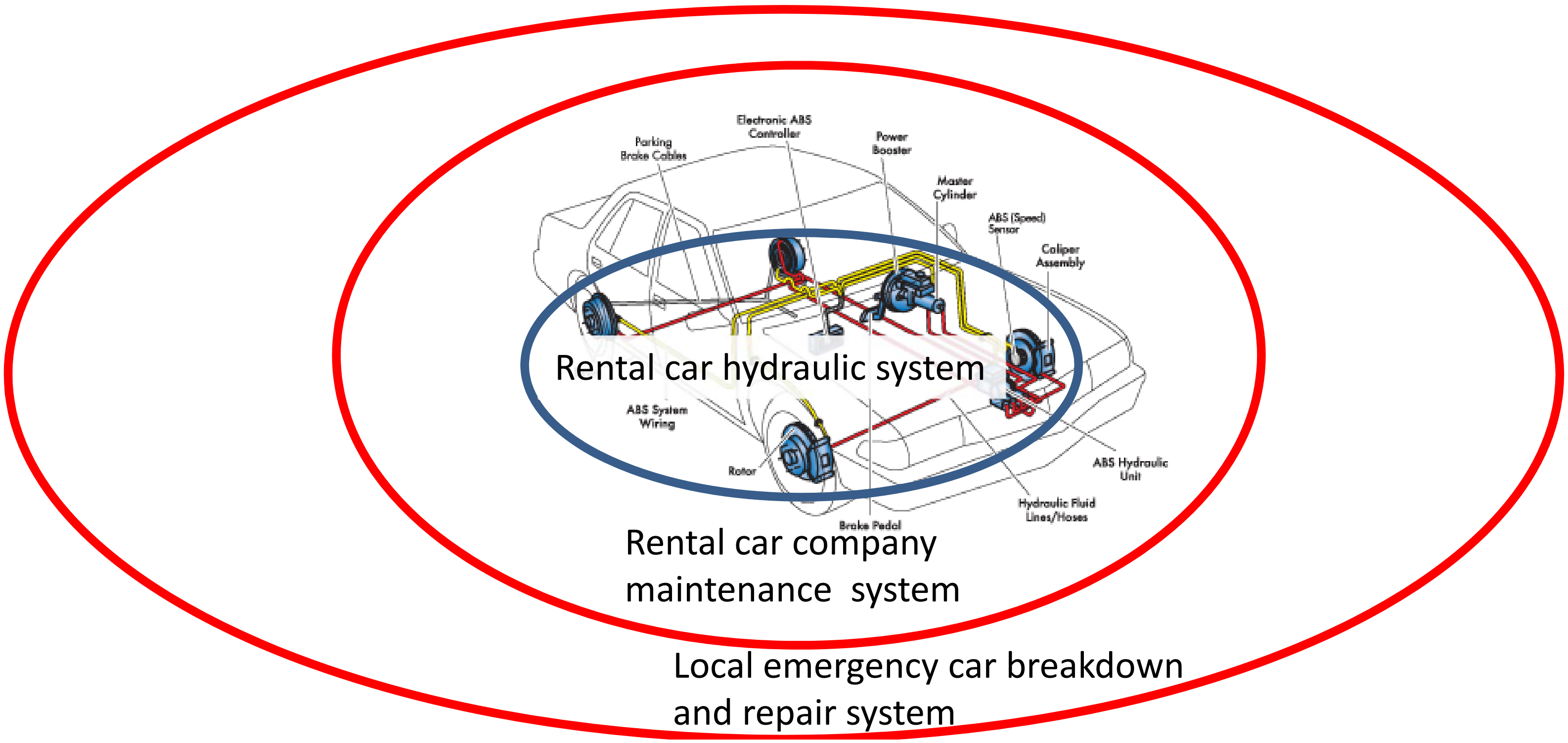
A general feature of systems

They tend to be embedded within multiple larger systems



A general feature of systems

They tend to be embedded within multiple larger systems



Is software a service

- When you buy a piece of shrink-wrapped software you sign a license agreement?
- Are things any different if you download the software from the internet?
- Is this *renting software,* if it becomes unusable after 30 days?

Selling systems

- that price of a service is dependent on the environment in which it is delivered
- the price of a commodity is dependent (in part) on the environment in which it is sold
- the ensemble of environmental features within which a purchase is made (environmental features which are relevant to the purchase)


CHANEL
CHANEL
The Ultimate Driving Machine.

Bundles of services

True services = production and consumption must coincide

Nearly every commodity goes hand in hand with bundles of:

greeting/welcoming/explaining services

for sales (when you buy a car in the showroom)

for delivery (the waiter in the restaurant)

for teaching (when the university administrator helps you enroll and pick your courses)

maintenance services (when you take your car back to be fixed)

When we think we are paying for a service we are nearly always paying primarily for infrastructure

- which means paying for something created which lasts through time even when not being consumed.
  - the internet (cables, …)
  - car rental
  - telephone service
  - transport (the highway system, the subway system)

  etc. etc.

Agenda

Time	Topic
3:00 PM	Break
3:15 PM	**Interactive session: Defining 'system'**
4:30 PM	Adjourn

Systems

Environment Ontology

Keywords: [ ] Search terms

Class: urban flooding

Term IRI: http://purl.obolibrary.org/obo/ENVO_01000718

Definition: Urban flooding is a flooding process in which land or property in a built environment, particularly in more densely populated areas, inundated due to the rate of water input exceeding that of water drainage provided by the environment's drainage systems. [database_cross_reference: https://en.wikipedia.org/wiki/Flood#Urban_flooding]

Annotations

- **editor note:** Relevant to built environments and can be linked to urban flows. Also relevant to water and sanitation SDGs.
- **in_subset:** environmental_hazards

Class Hierarchy

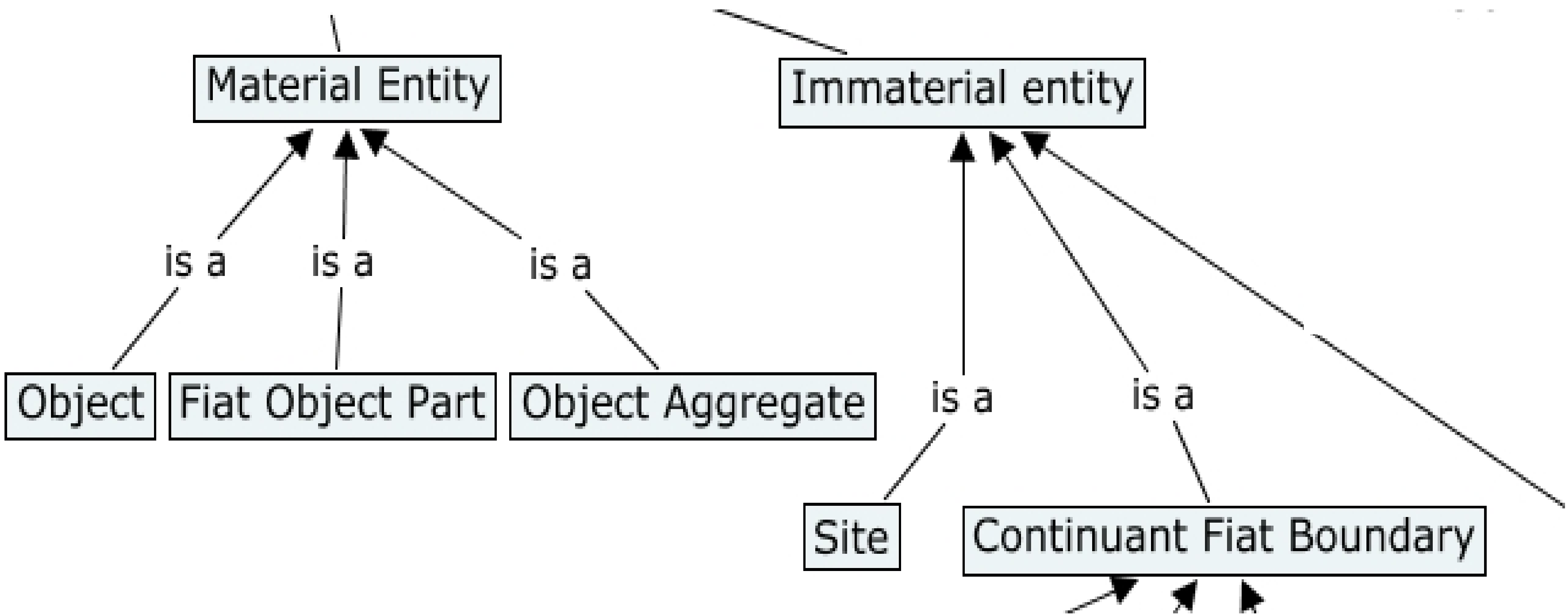
Thing
- + entity
  - + occurrent
    - + process

BFO

- + environmental system process
  - + hydrological process
    - + flooding
      - + coastal flooding
      - - riverine flooding
      - - flash flooding
      - - areal flooding
      - - urban flooding

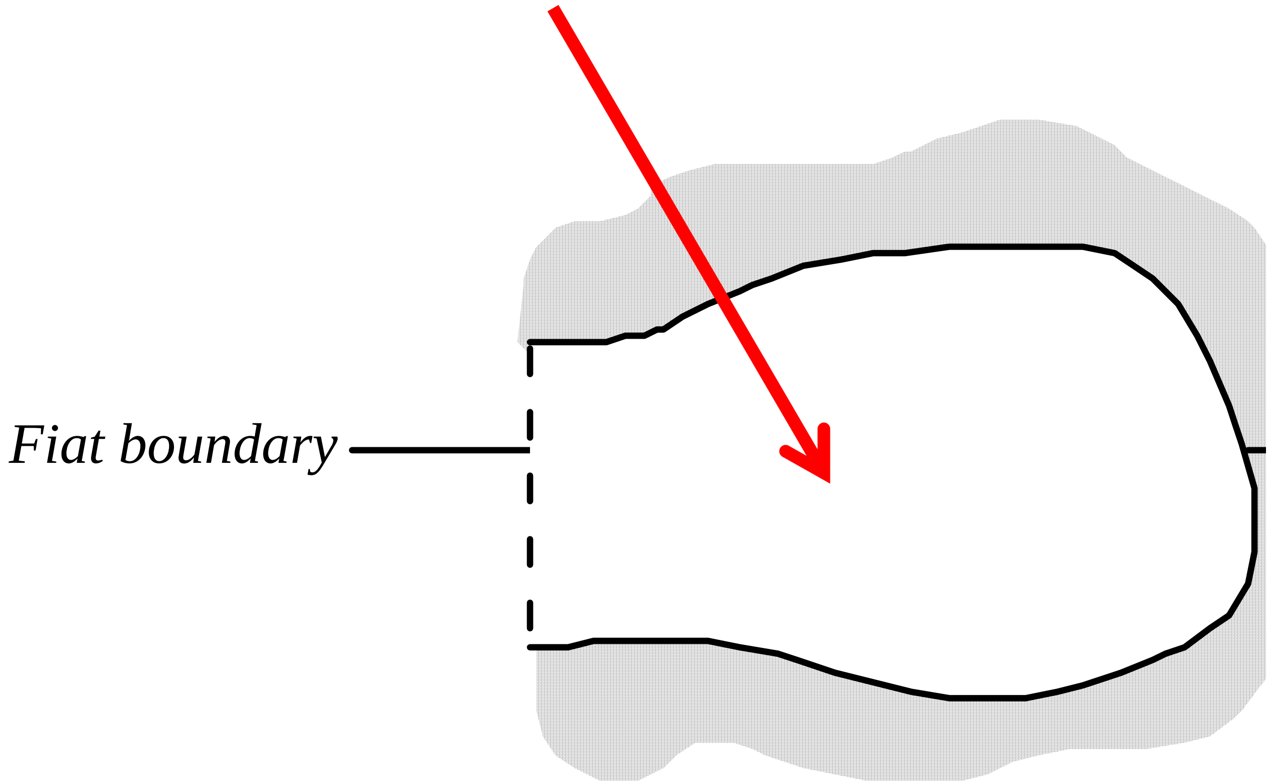
ENVO

BFO: site



Material Entity
Immaterial entity
is a
is a
is a
Object
Fiat Object Part
Object Aggregate
is a
is a
Site
Continuant Fiat Boundary

A cave (site)

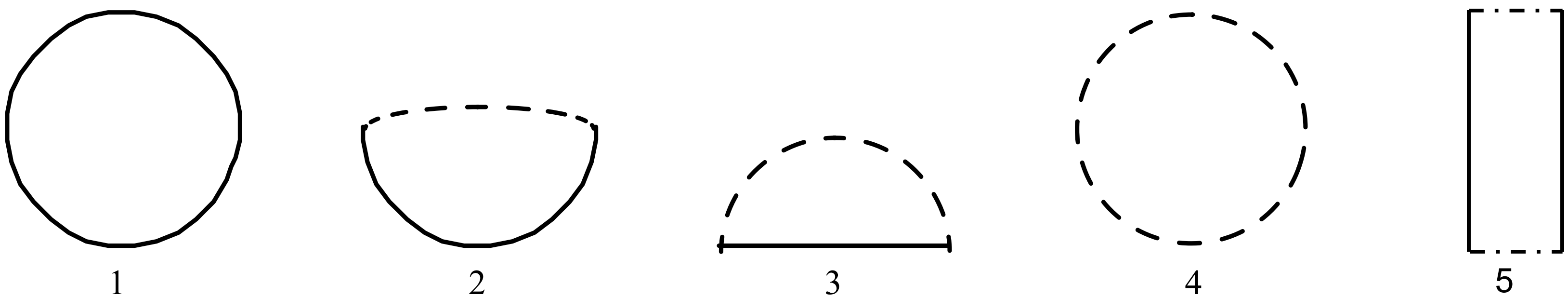


Ambiguity of ‘Manhattan’

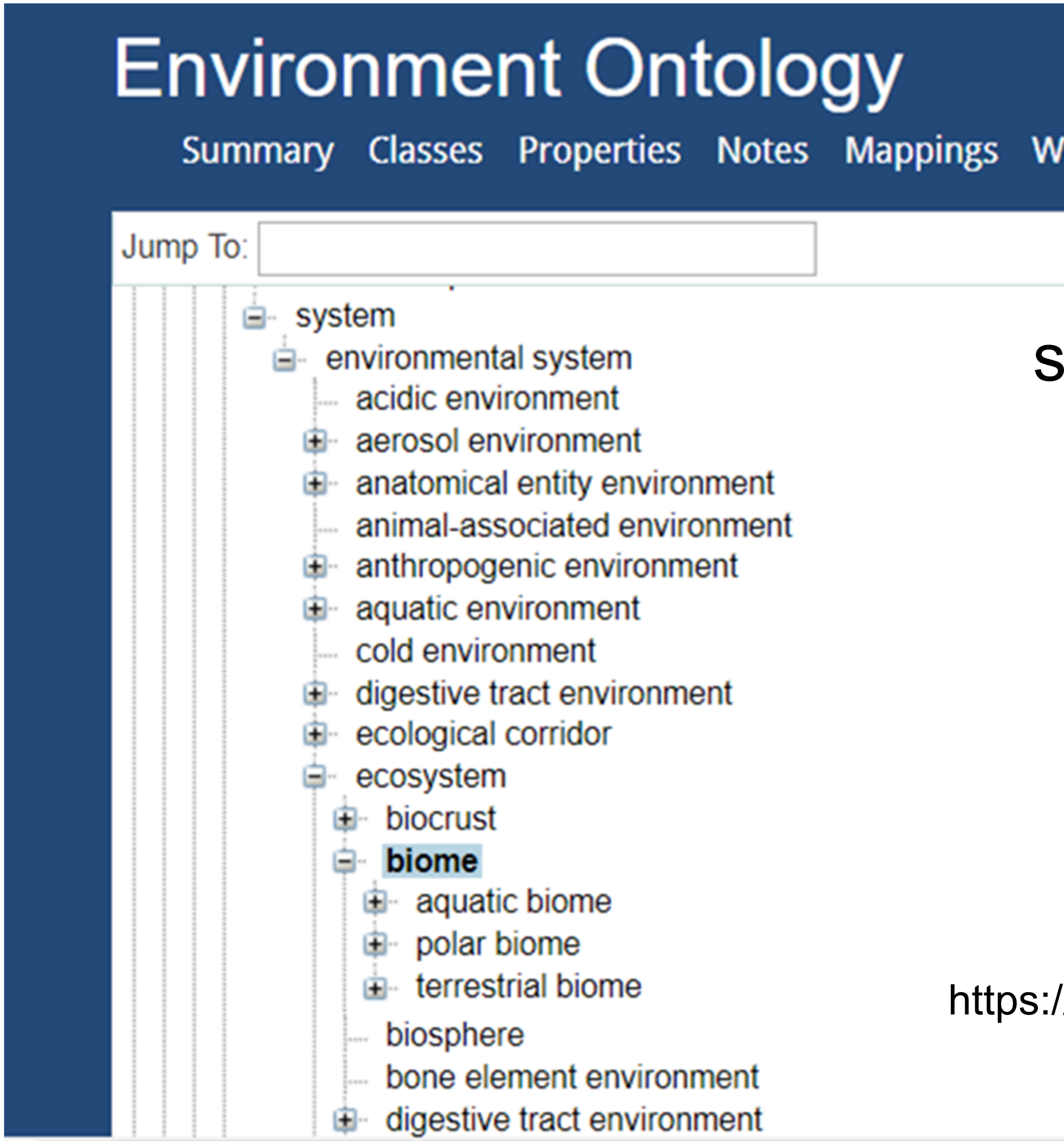
- Manhattan as material entity (a collection of bricks and rock and other solid matter)
- Manhattan as a complex site (the place where people actually live and move)
- Extended Manhattan = the sum of the above

analogously for cave, mouth, nostril, your car, your lab, your bed (getting *in*to bed …)

Five Basic Niche Types



1: a womb; an egg; a house (better: the interior thereof)
2: a snail’s shell;
3: the niche of a pasturing cow;
4: the niche around a circling buzzard (fiat boundary)
5. your digestive tract, the Mont Blanc tunnel



system

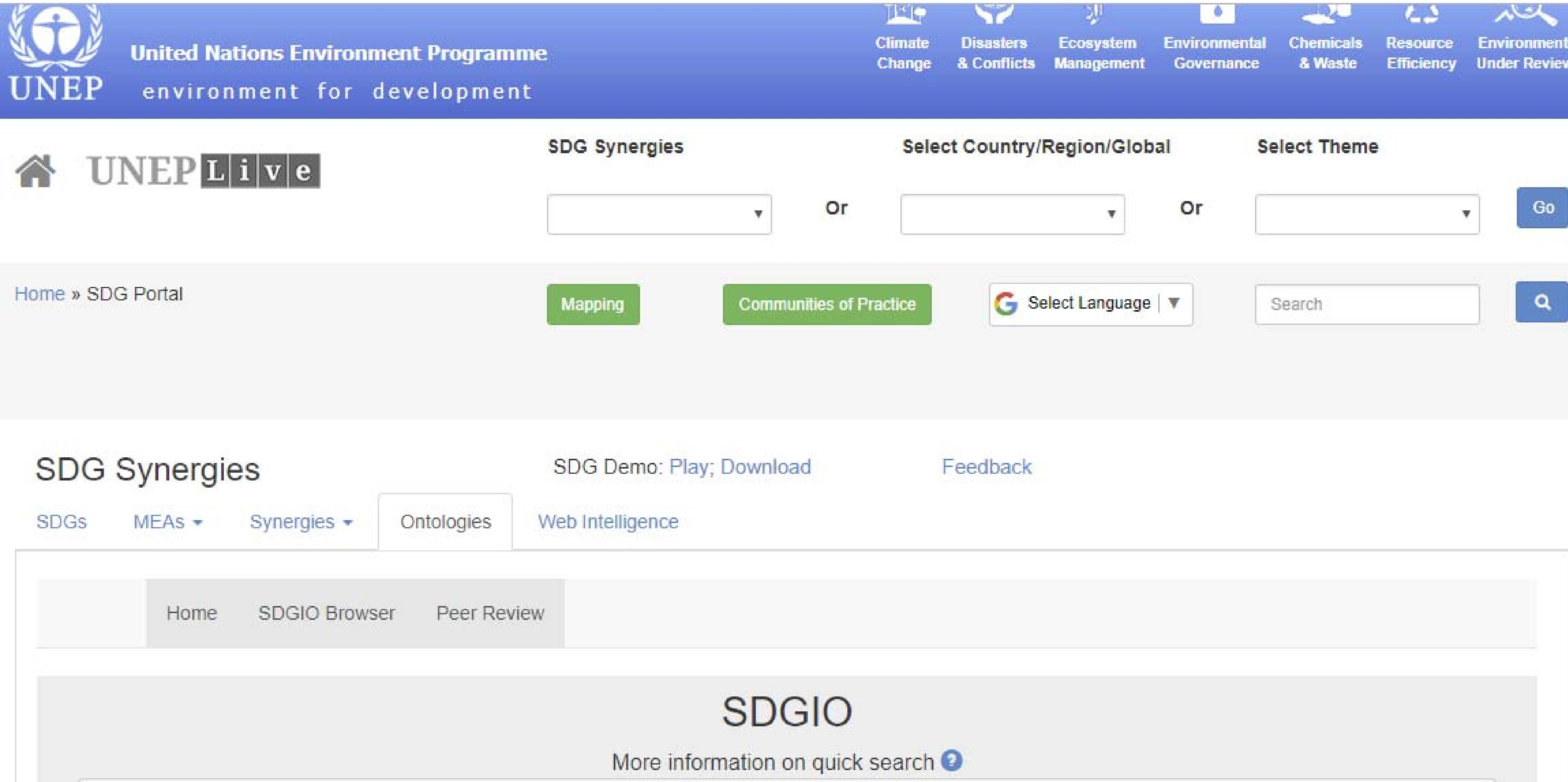
environmental system

ecosystem

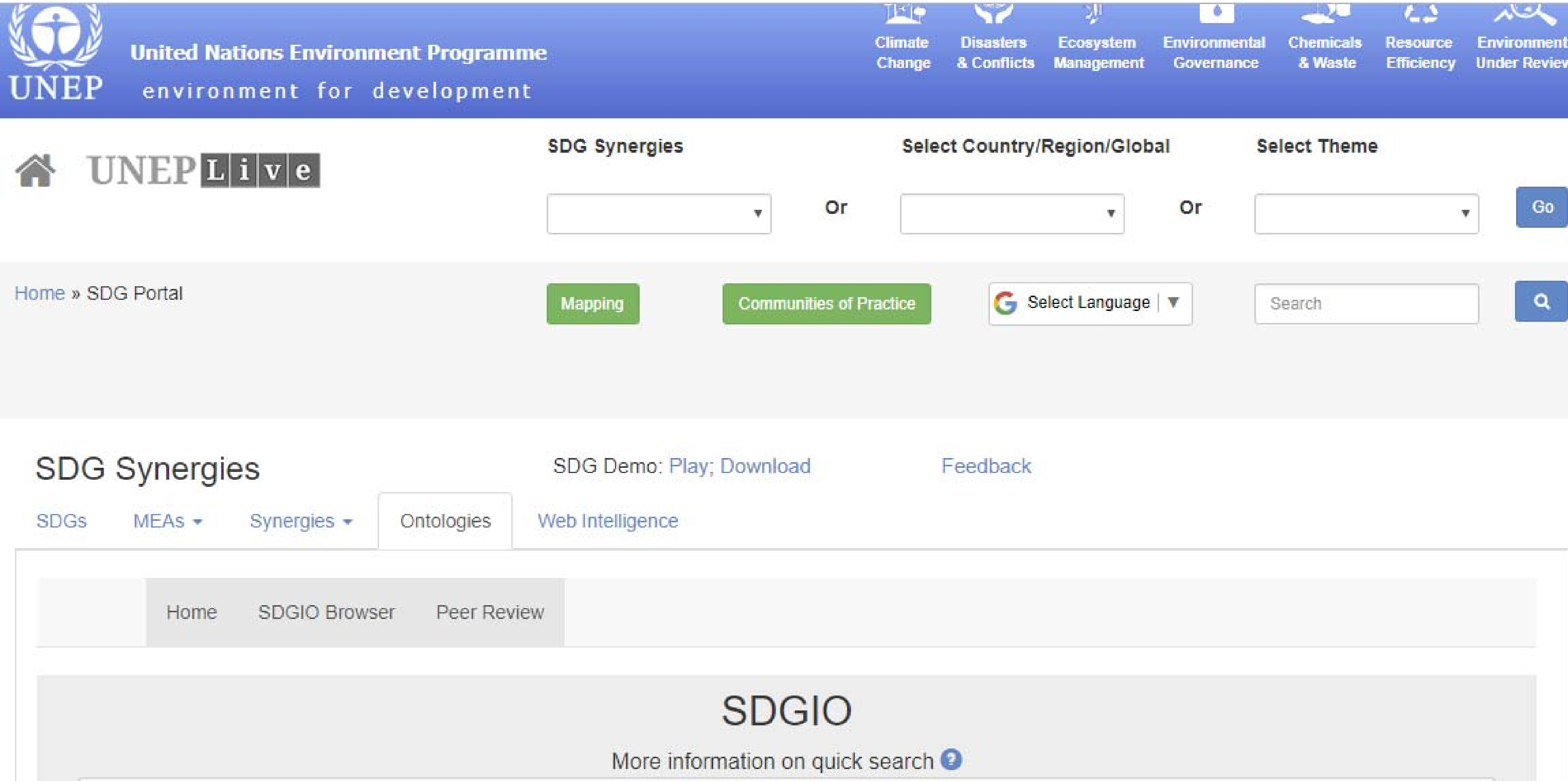
biome

microbiome

https://bioportal.bioontology.org/ontologies/ENVO



http://uneplive.unep.org/portal#ontologies



SDGIO = Sustainable Development Goals Interface Ontology (SDGIO)

ENVO Definition

system

=def. A material entity consisting of multiple components that are causally integrated

Examples: solar system, digestive system, forest ecosystem, subway system

Joint Doctrine Definition

system =def. A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole. (JP 3-0)

ENVO Definition

environmental system

= Def. A system which has the disposition to environ one or more material entities.

a environs *b* = Def. *a* includes *b* (partially or wholly) within its site and *a* causally influences *b*

Example: The Union Station lost-and-found system

The system includes, for example, the managers of the repository of found items.

ENVO Definition

system

environmental system

ecosystem

Def. an environmental system that environs living organisms

biome

microbiome

subtypes of ecosystem in ENVO

biome

biosphere

ecological corridor

habitat

mouth environment

skin environment

subtypes of ecosystem in ENVO

ecological corridor = Def. An ecosystem which bridges two or more adjoining ecosystems and through which organisms may move or propagate

habitat = Def. an ecosystem which can sustain and allow the growth of a population of organisms of a single species

biome

ENVO Definition

biome

=def. an ecosystem that is determined by an ecological community

determined by = def. A system is determined by an entity if the removal of that entity would cause the collapse of that system

(e.g. removing the corals from a coral reef ecosystem would cause that ecosystem to collapse)

Systems typically break if you take out their biggest parts.

Population and Community Ontology

- independent continuant
  - immaterial entity
  - material entity
    - environmental feature
    - environmental material
    - manufactured product
    - material anatomical entity
    - object aggregate
      - collection of organisms
        - community
          - **ecological community**
            - microbial community

community = Def. a collection of organisms connected by social or biological relations (biotic interactions).

ecological community = Def. a community of at least two different species living in a particular area.

1 "at least two different species" may be too narrow. It is possibly that one species but more than one strain. Also, do we consider two or more bacteria or humans (in one speceis) that form an ecological community?

Yongqun He, 11/10/2017

ENVO-based microbiome definition

system

- environmental system
  - ecosystem
    - biome
      - microbiome

Def. a biome determined by an ecological community of microbiota

biome is a system – includes both environment and inhabitants

Slide 398

1 I agree with your proposed short form, but I don't see what you objection is to the Def. as stated
Barry Smith, 11/4/2017

2 It's like saying "...determined by an ecological community of a microbial community" where it would be better to say "...determined by a an ecological community composed of microbes" or simply "...determined by a microbial community"

I added "microbial community" to PCO some weeks ago. Perhaps we can add "microbiota" as a synonym, as I think these are equivalent.
Pier Luigi Buttigieg, 11/4/2017

1 This doesn't sit well.
Microbiota constitute an ecological community. Perhaps rephrase to:

A biome which is determined by microbiota.

Where microbiota is a subclass of PCO ecological community (that can be added as a note under the "biome is a system" note)
Pier Luigi Buttigieg, 11/5/2017

2 I am happy with the shorter definition and with the use of as 'microbiota as synonym of 'microbial community'.Please adjust the slides to fit, so that we can remove these comments
Barry Smith, 11/5/2017

examples of systems

Natural

- solar system
- forest ecosystem
- digestive system

Engineered

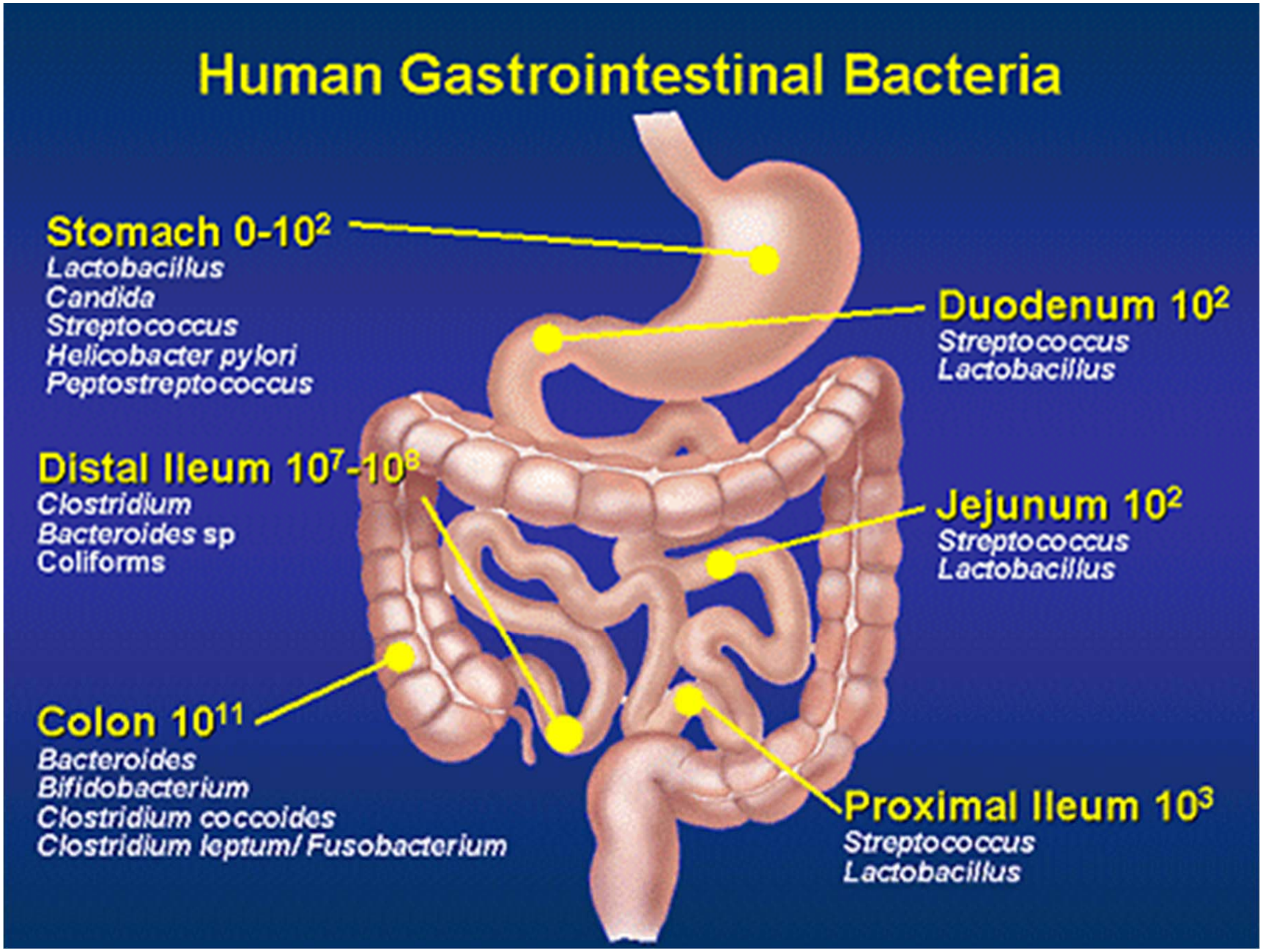
- subway system

Even a subway system is embedded in natural systems and has a variety of natural systems embedded within it

Dormant and activated Systems

- Trauma system is activated when message received that a patient is on the way

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5312685/


Human Gastrointestinal Bacteria
Stomach 0-10^2
Lactobacillus
Candida
Streptococcus
Helicobacter pylori
Peptostreptococcus
Duodenum 10^2
Streptococcus
Lactobacillus
Distal Ileum 10^7-10^8
Clostridium
Bacteroides sp
Coliforms
Jejunum 10^2
Streptococcus
Lactobacillus
Colon 10^{11}
Bacteroides
Bifidobacterium
Clostridium coccoides
Clostridium leptum/ Fusobacterium
Proximal Ileum 10^3
Streptococcus
Lactobacillus

ENVO-based microbiome definition

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- environmental system
  - ecosystem
    - biome
      - microbiome

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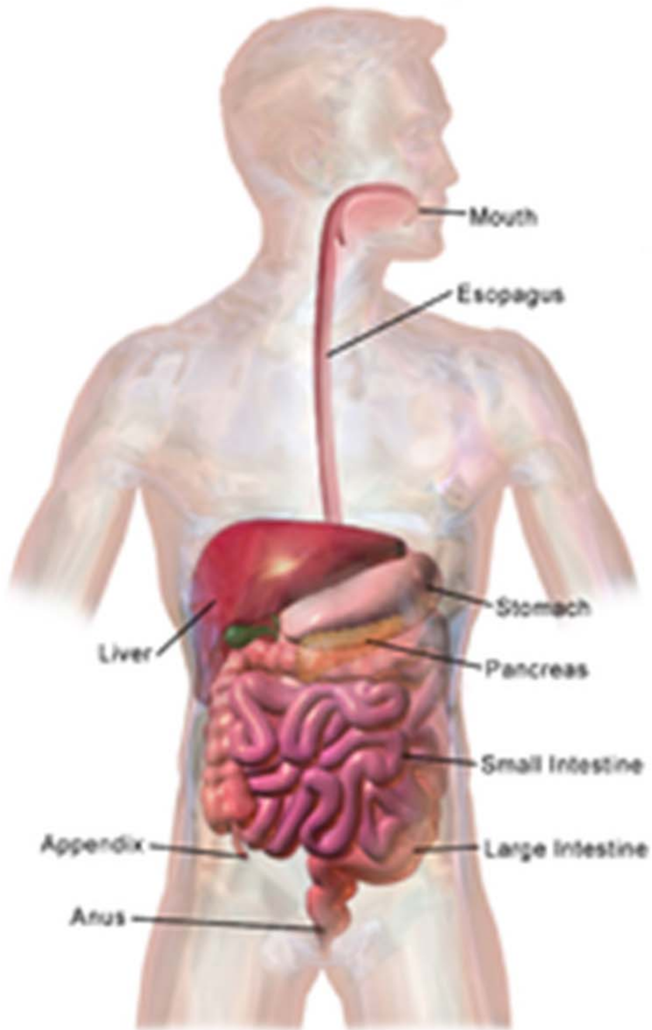
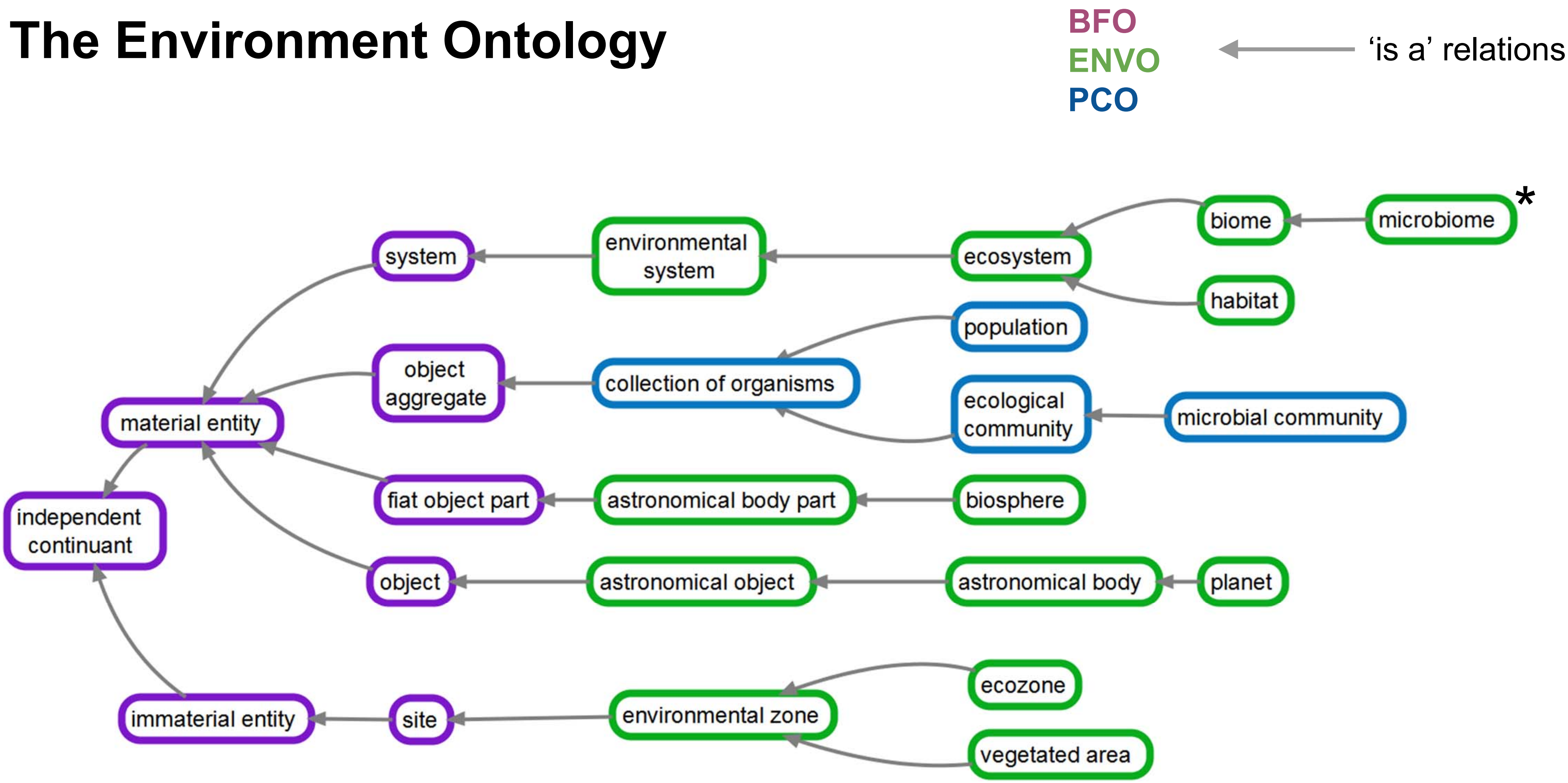
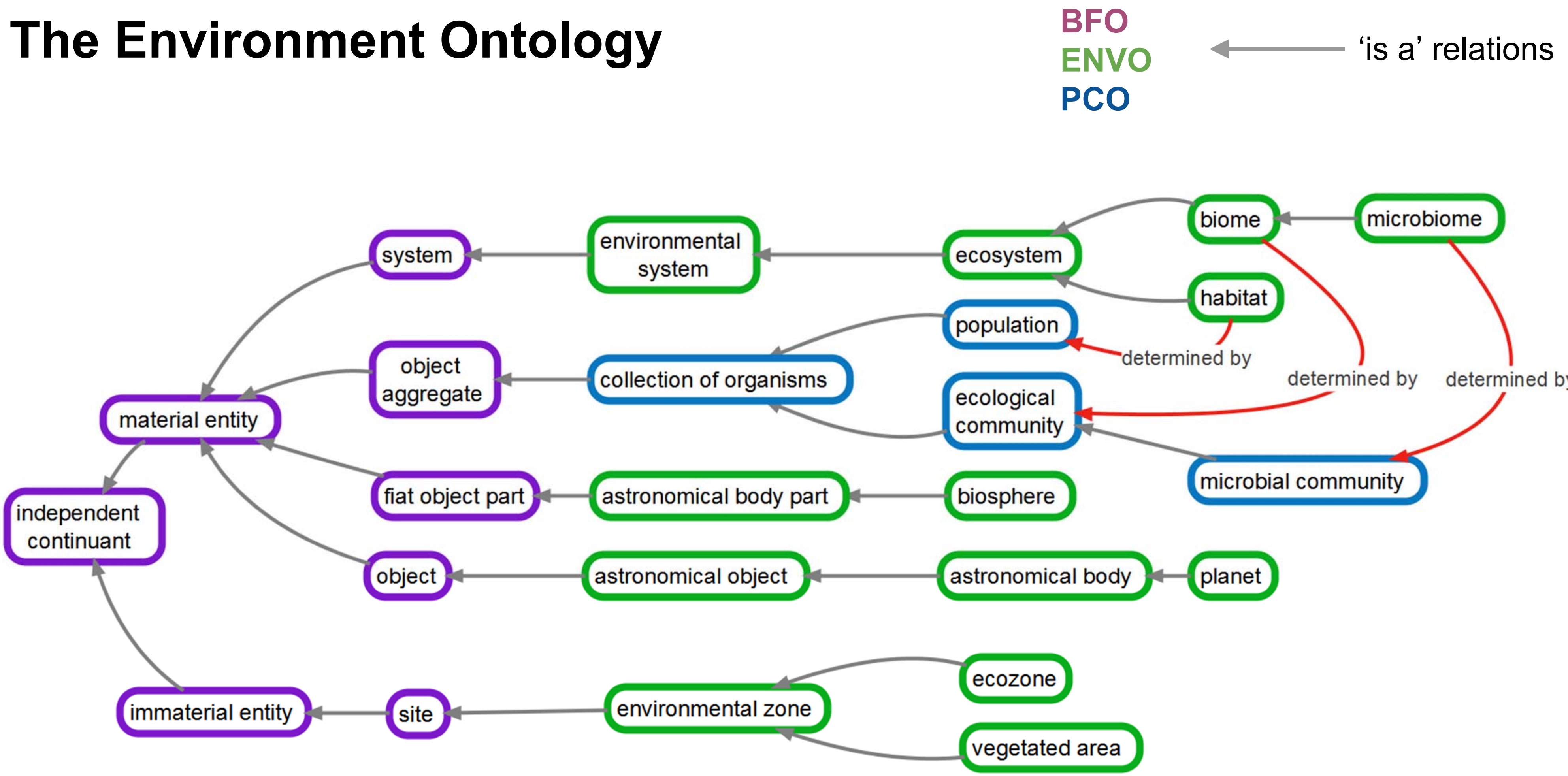


Digestive System

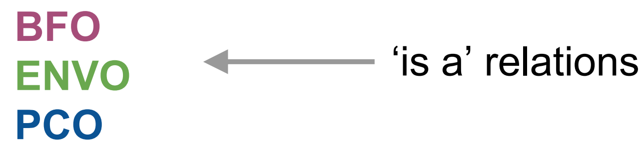
The Environment Ontology

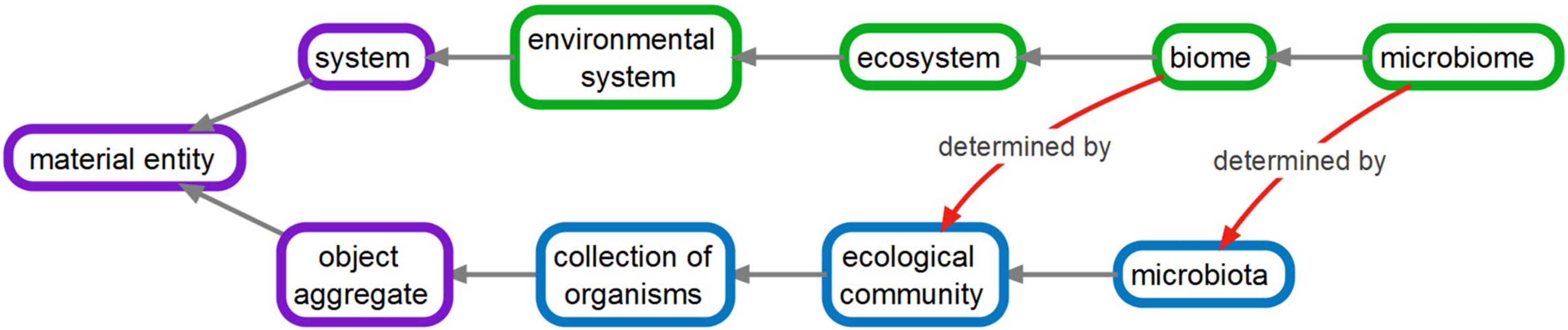


The Environment Ontology



Incorporating microbiome





Features of systems

Like patterns, systems have fiat boundaries

Are often parts of a larger systems

Often have smaller systems as parts

'Self-organizing' systems have something like homeostasis and repair mechanisms to restore homeostasis

An army is a system; the different units within the army influence each other positively

When two opposing armies fight, then they too form a system joined now by negative influence.

Systems Engineering, Definitions (ISO)

(1) Interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life. (ISO/IEC/IEEE 2010)

Systems Engineering, Definitions (INCOSE)

(2) An interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

Operations	Cost & Schedule
Performance	Training & Support
Test	Disposal
Manufacturing	

Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE 2012)

Systems Engineering, Definitions (SEBoK)

(revises to emphasize the inevitable on-going intertwining of system requirements definition and system design)

- Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal.