Towards a Digital Engineering Ontology to Support Information Exchange

INCOSE IS 7/28/2025

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Department of Systems & Industrial Engineering

Co-chair: Clarence (Moe) Moreland

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Contents

- **Digital Engineering Challenges**
- Ontology as a Solution
- DEIX Overview
- DE Ontology
- Next Steps

Digital Engineering

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What is Modeling [1]?

- Precise language for effective communication,
- Mathematical abstractions that empower analysis,
- Effective automation to reduce error.

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ASOT [1]: an entity such as a person, governing body, or system that applies expert judgement and rules to proclaim a digital artifact is valid and originates from a legitimate source.

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ASOT [2]: the single, definitive source of a given piece of information that all consumers of that information should reference to mitigate the risk of relying on outdated, inconsistent, or inaccurate information.

[1] https://www.omgwiki.org/MBSE/doku.php?id=mbse:authoritative_source_of_truth (accessed 7/27/2025)

[2] U.S. Space Force. (2021). U.S. Space Force Vision for a Digital Service.

DE Environment / Ecosystem

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DE Ecosystem [1]: The interconnected infrastructure, environment, and methodology (process, methods, and tools) used to store, access, analyze, and visualize evolving systems' data and models to address the needs of the stakeholders.

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DE Environment [3]: A DE Environment enables the interconnected data, people, processes, and technology used to store, access, analyze, and visualize evolving systems' data and models to address the needs of enterprise-wide stakeholders.

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[2] https://www.sandia.gov/digital-engineering/de-ecosystem-governance (accessed 7/27/2025)
[3] McDermott, T. (2022). WRT-1051 Program Managers Guide to Digital and Agile Systems Engineering Process Transformation.

What is Modeling?

If **modeling** means the following:

- Precise language for effective communication,
- Mathematical abstractions that empower analysis,
- Effective automation to reduce error.

Then:

- We need to first align our **conceptual** understanding (not just our data formats),
- We need to represent them **logically** (mathematically),
- We can leverage existing tools to **automate** reasoning across our digital information.

- Digital Engineering Challenges
- **Ontology as a Solution**
- DEIX Overview
- DE Ontology
- Next Steps

What is Ontology?

Ontologies provide a means to represent that **precise language** [1].

- i.e., define what is meaningful to say within a particular domain.

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Example 1

- System *s1* has mass 100 kg. ✅
- Function *f1* has mass 100 kg. ❌

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Example 2

- VerificationCase *v1* verifies Requirement *r1*. ✓
- Requirement *r1* verifies VerificationCase *v1*. ✗

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Example 3
- DEEnvironment *e1* contains DigitalArtifact *d1*. ?

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Ontological Reasoning

If we model *what we know* using ontologies,
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- Every *SystemRequirement* must be verified by at least one *VerificationActivity*.
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- A *DigitalTwin* must carry a *SystemView* produced by a *MeasurementProcess*.
- If *artifact123* does not: Reasoner says it's not a valid *DigitalTwin*.

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Powerful way to:

- Catch modeling errors or inconsistencies early.
- Ensure that artifacts meet necessary criteria.
- Automatically detect redundant or missing artifacts.
- Enforce traceability or coverage (e.g., "does each artifact address a stakeholder need?").

Specifically, why is this relevant to DE?

- Digital Engineering Challenges
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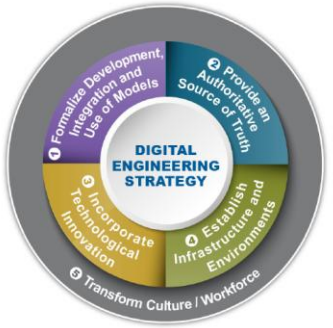
What is the DEIX WG?

- Digital Engineering Information Exchange WG
- Formed as INCOSE Working Group in 2018
- Collaboration between:
  - International Council of Systems Engineers (INCOSE)
  - National Defense Industrial Association (NDIA)
  - Office of the Under Secretary of Defense for Research and Engineering (DoD OUSD(R&E))

- The DEIXWG:

"supports the strategic objective of accelerating digital engineering transformation by characterizing the content and relationships involved in the exchange of digital artifacts between stakeholders of various disciplines throughout the engineering lifecycle"



Use the authoritative source of truth to produce digital artifacts, support reviews, and inform decisions

As the technical baseline matures, preserving the knowledge across programs and lifecycle phases is essential. Technical reviews can be conducted from the authoritative source of truth on a continuous basis. Stakeholders will generate digital artifacts, representing multiple views and various perspectives from the authoritative source of truth. Digital artifacts provide visibility of appropriate information across functional domains, disciplines, and organizations.

--- DoD Digital Engineering Strategy, 2018

What is the DEIX WG?

Chair: Terri Chan: terri.chan@incose.net

Deputy Chair: Celia Tseng: Celia.Tseng@3ds.com

Co-Chair (OSD Liaison): Frank Salvatore: Frank.J.Salvatore@SAIC.com

Co-Chair (NDIA Liaison): Chris Schreiber: Chris.Schreiber@LMCO.com

Tech Leads – Ontology: Joe Gregory joegregory@arizona.edu

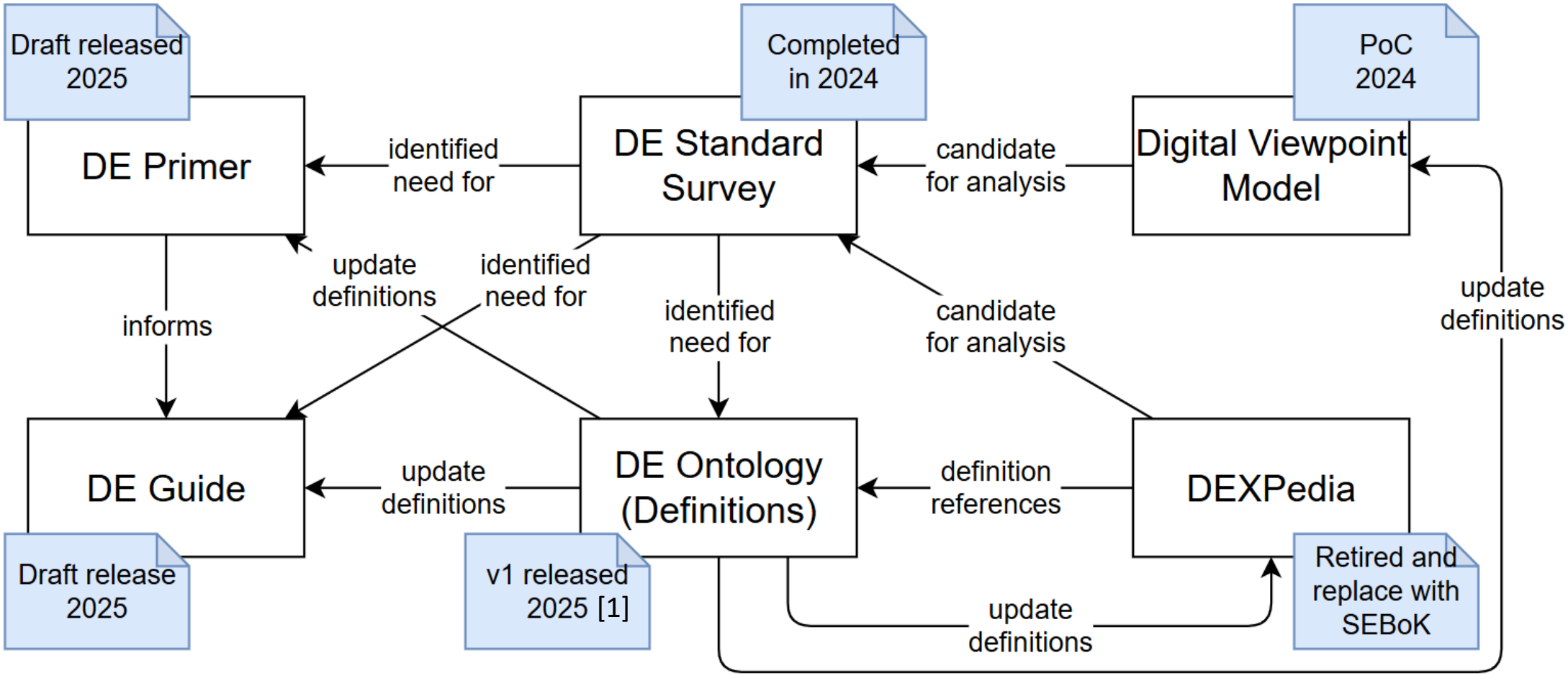
Moe Moreland moe.moreland@mtsi-va.com

DE Primer: Darryl Howell darryl.howell@pcgconsults.com

DE Guide: Melissa Wallace melissa.wallace@incose.net

Digital Viewpoint Model (DVM): Leqi (Ken) Zhang LeqiKen.Zhang@L3Harris.com

What is the DEIX WG?



[1] https://github.com/INCOSE/DEIX_Ontology

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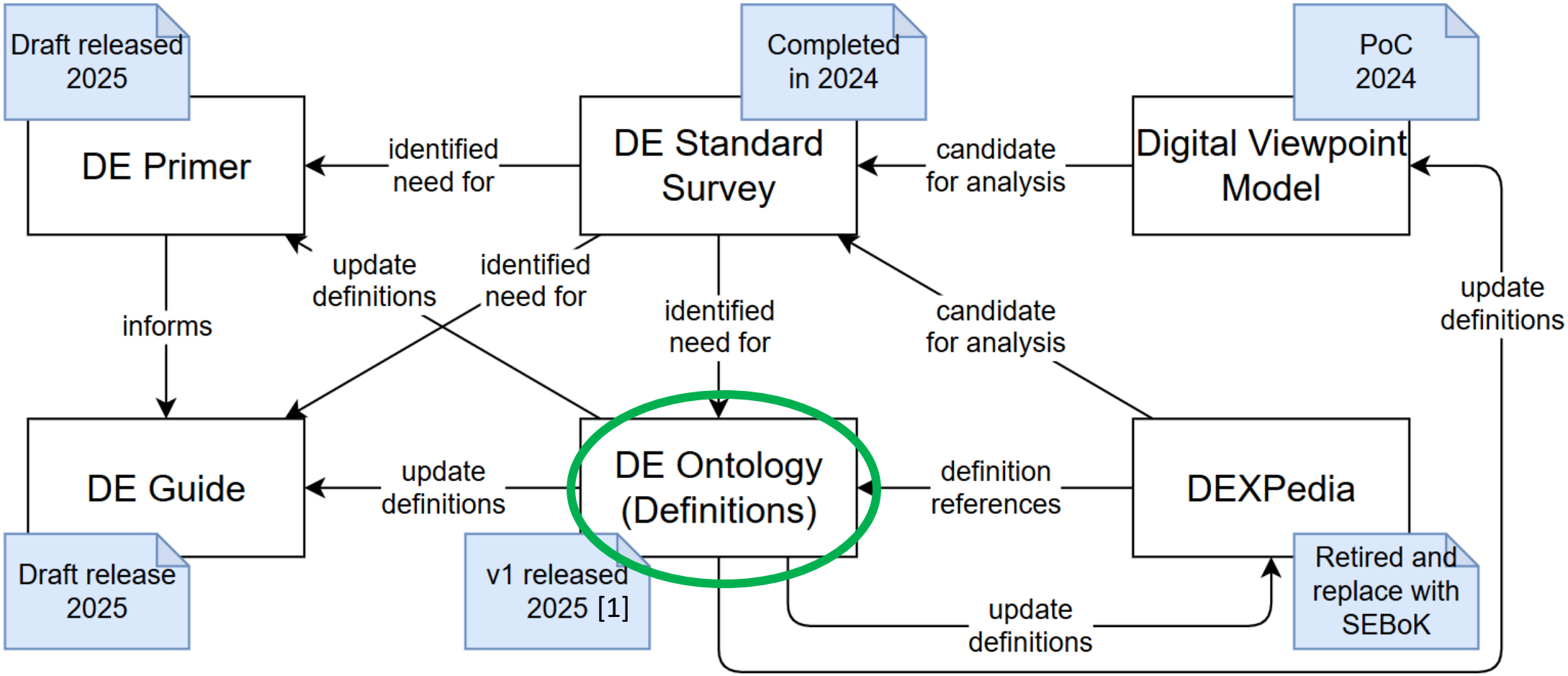

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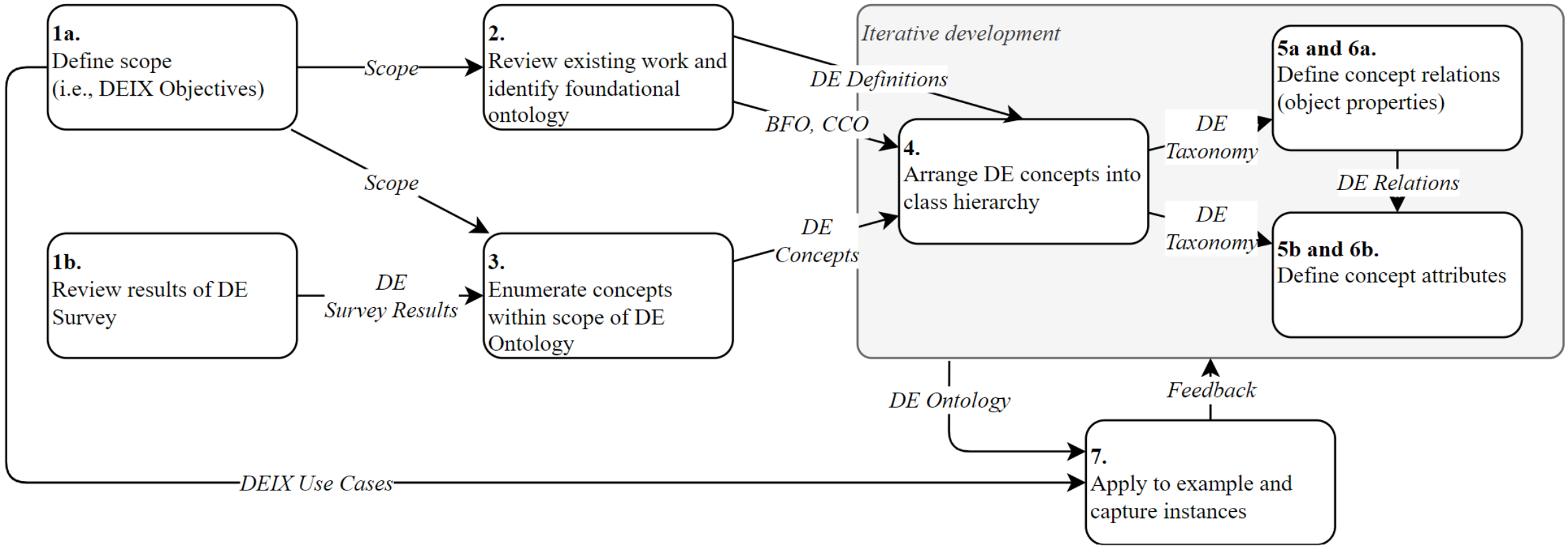
Our Approach



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Goals

"Support the DEIX WG (the **Digital Viewpoint Model**, the **DE Guide** and the **DE Primer**) by providing clear, concise, consistent definitions of DE concepts"

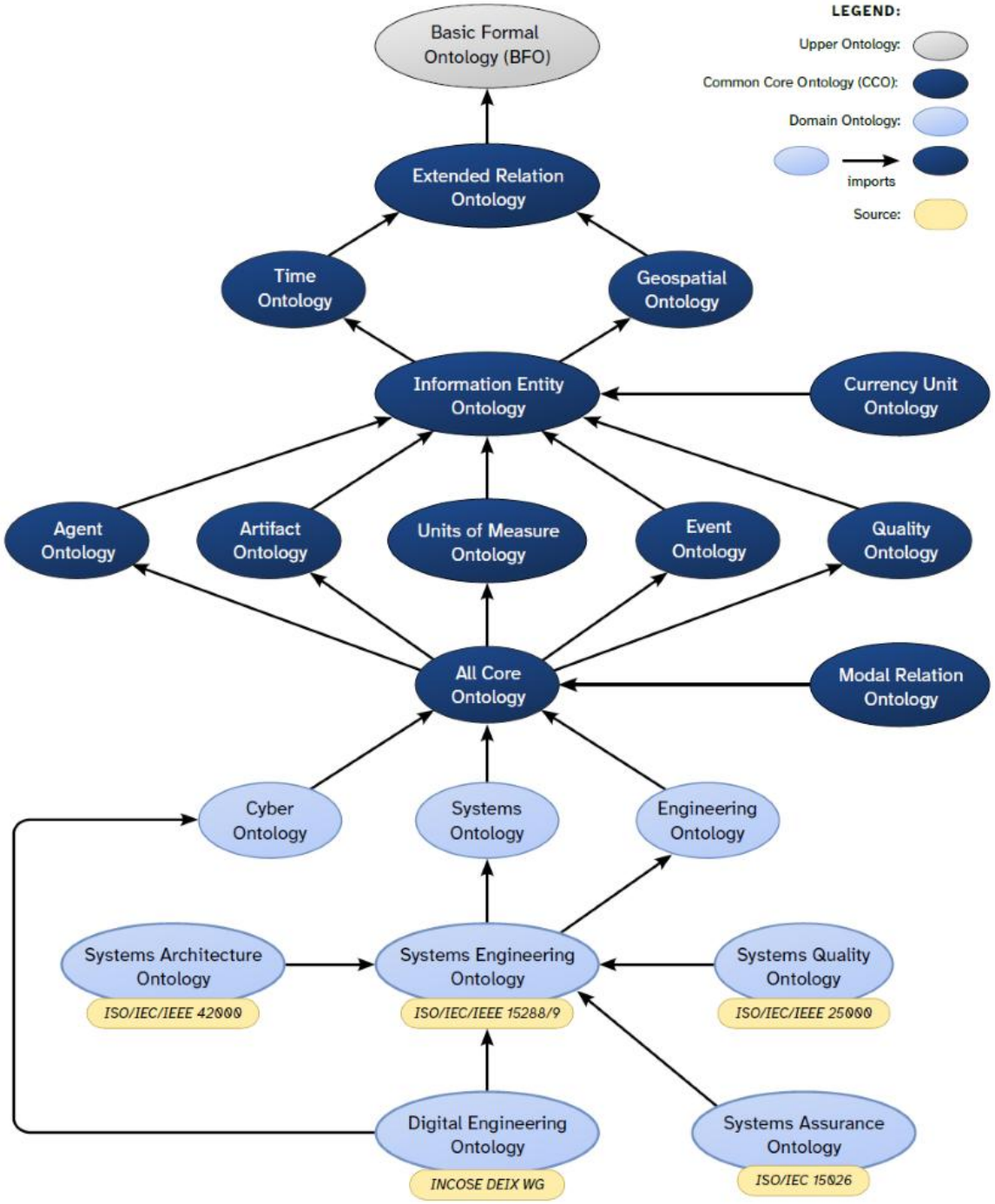
- **Concept-based**
  - i.e., focus on definition of the *concept* rather than specific *terminology*
  - This allows us to define synonyms / mappings between domains

- **Focus on definitions to support relevant domains**
  - Reached by consensus, and aligning with standards from relevant domains
  - Concepts are defined by their relationships

- **Machine-readable**
  - Web Ontology Language (OWL) or similar
  - Protégé or similar

Goals

- **Align with similar work in other areas**
  - Built on Basic Formal Ontology (BFO) and Common Core Ontologies (CCO)
  - Industrial Ontology Foundry (IOF) SE Working Group
  - OntoCommons



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- **1. Classification Reasoning**
  - What concept is this instance typed by?
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- **2. Reusability Criteria**
  - Is this artifact suitable for reusability, given the context I wish to reuse it in?
    - Considers *Reusable Asset Criteria* (RAS), from OMG Model-Based Acquisition WG
    - Criteria generally includes metadata as well as content.

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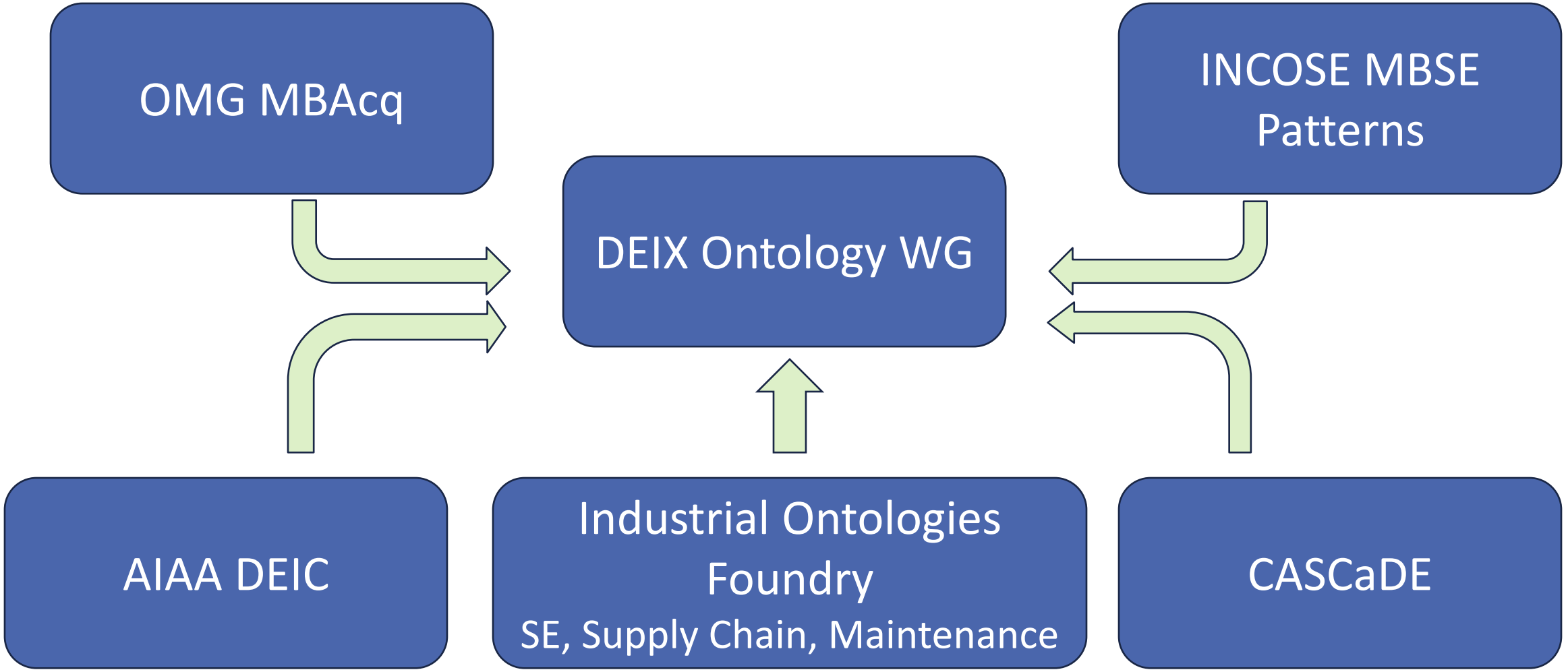
- **3. Asset Utility**
  - Does this asset address a particular need?
    - Analogous to traceability from system component, through function and requirement, to need
    - Reverse the question: impact analysis for particular business / use cases. How many artifacts?

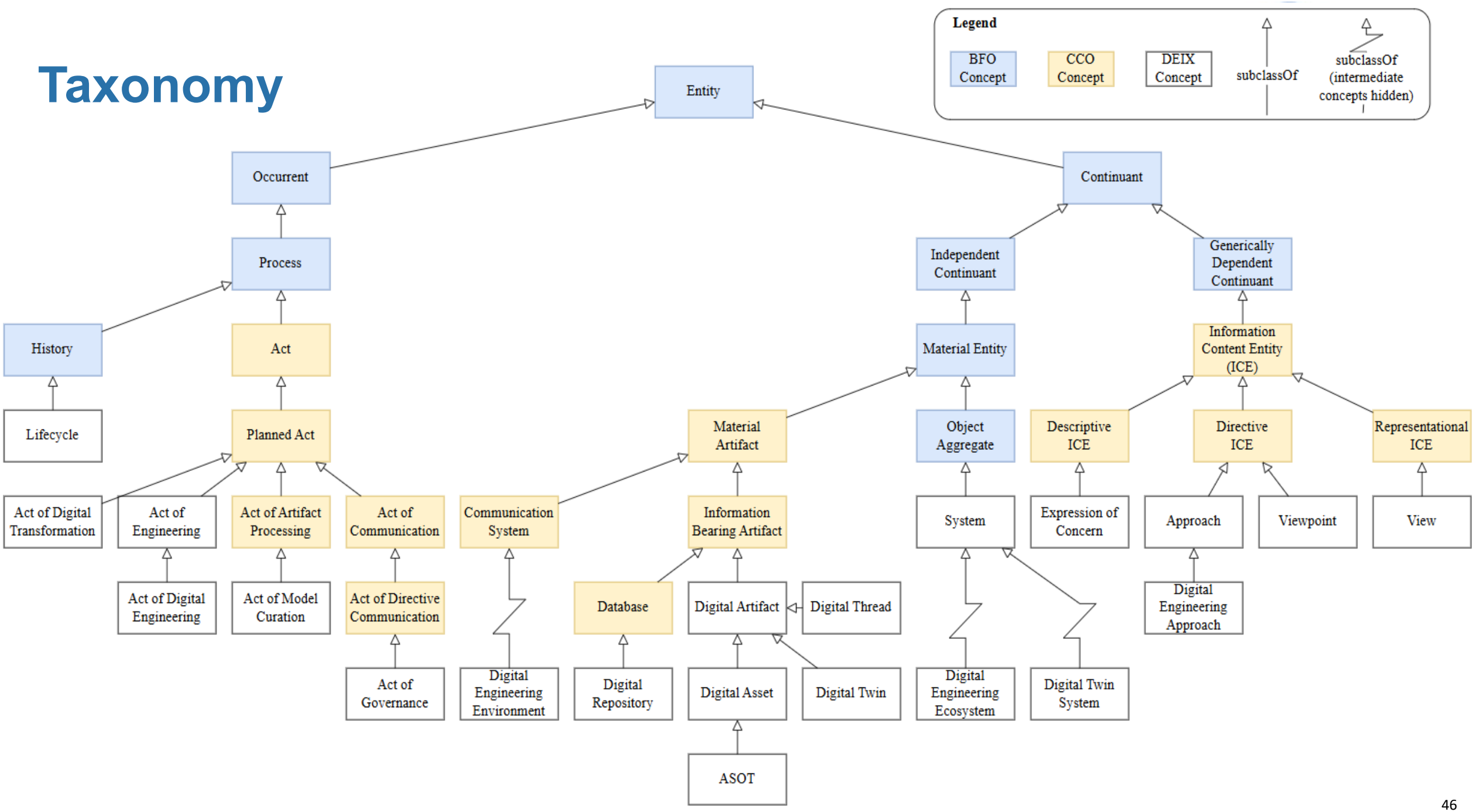
Related WGs


OMG MBAcq
INCOSE MBSE Patterns
DEIX Ontology WG
AIAA DEIC
Industrial Ontologies Foundry
SE, Supply Chain, Maintenance
CASCaDE

Core DE Concepts

DE Concept	Definition Status
ASOT	v1 complete
ASOT Role	v1 complete
Digital Process	underway
Digital Artifact	v1 complete
Digital Asset	v1 complete
Digital Engineering (Act of)	v1 complete
Digital Engineering Ecosystem	v1 complete
Digital Engineering Environment	v1 complete
Digital Engineering Approach	v1 complete
Digital Repository	v1 complete
Digital Thread	underway
Digital Transformation	underway
Digital Twin	v1 complete
Digital Twin System	v1 complete
Digital Instance	not started
Digital Prototype	not started
Governance (Act of)	not started
Model Curation (Act of)	not started
Model-Based Engineering (Approach)	not started
Trusted Digital Repository	underway
View	v1 complete
Viewpoint	v1 complete

Taxonomy


Legend
BFO Concept
CCO Concept
DEIX Concept
subclassOf
subclassOf (intermediate concepts hidden)
Entity
Occurrent
Continuant
Process
Independent Continuant
Generically Dependent Continuant
History
Act
Material Entity
Information Content Entity (ICE)
Lifecycle
Planned Act
Material Artifact
Object Aggregate
Descriptive ICE
Directive ICE
Representational ICE
Act of Digital Transformation
Act of Engineering
Act of Artifact Processing
Act of Communication
Communication System
Information Bearing Artifact
System
Expression of Concern
Approach
Viewpoint
View
Act of Digital Engineering
Act of Model Curation
Act of Directive Communication
Database
Digital Artifact
Digital Thread
Digital Engineering Approach
Act of Governance
Digital Engineering Environment
Digital Repository
Digital Asset
Digital Twin
Digital Engineering Ecosystem
Digital Twin System
ASOT

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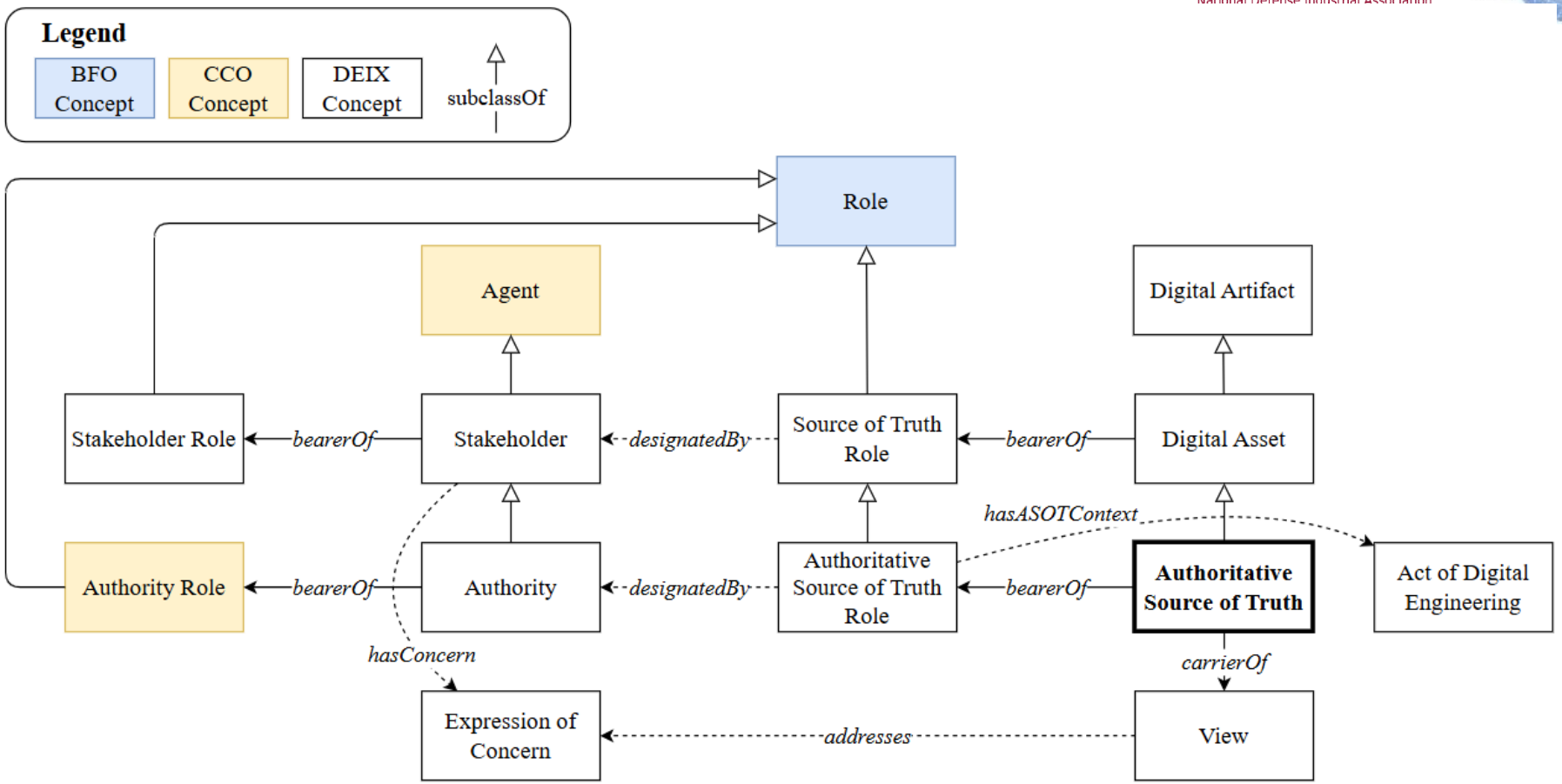

$$ASOT(x) \equiv DigitalAsset(x)$$
$$\wedge\ \exists a\ (ASOTRole(a) \wedge bearerOf(x,a))$$
$$\wedge\ \exists b\ (ActOfDigitalEngineering(b) \wedge hasASOTContext(a,b))$$
$$\wedge\ \exists c\ (Authority(c) \wedge designatedBy(a,c))$$
$$\wedge\ \exists d\ (View(d) \wedge carrierOf(x,d))$$

- Digital Engineering Challenges
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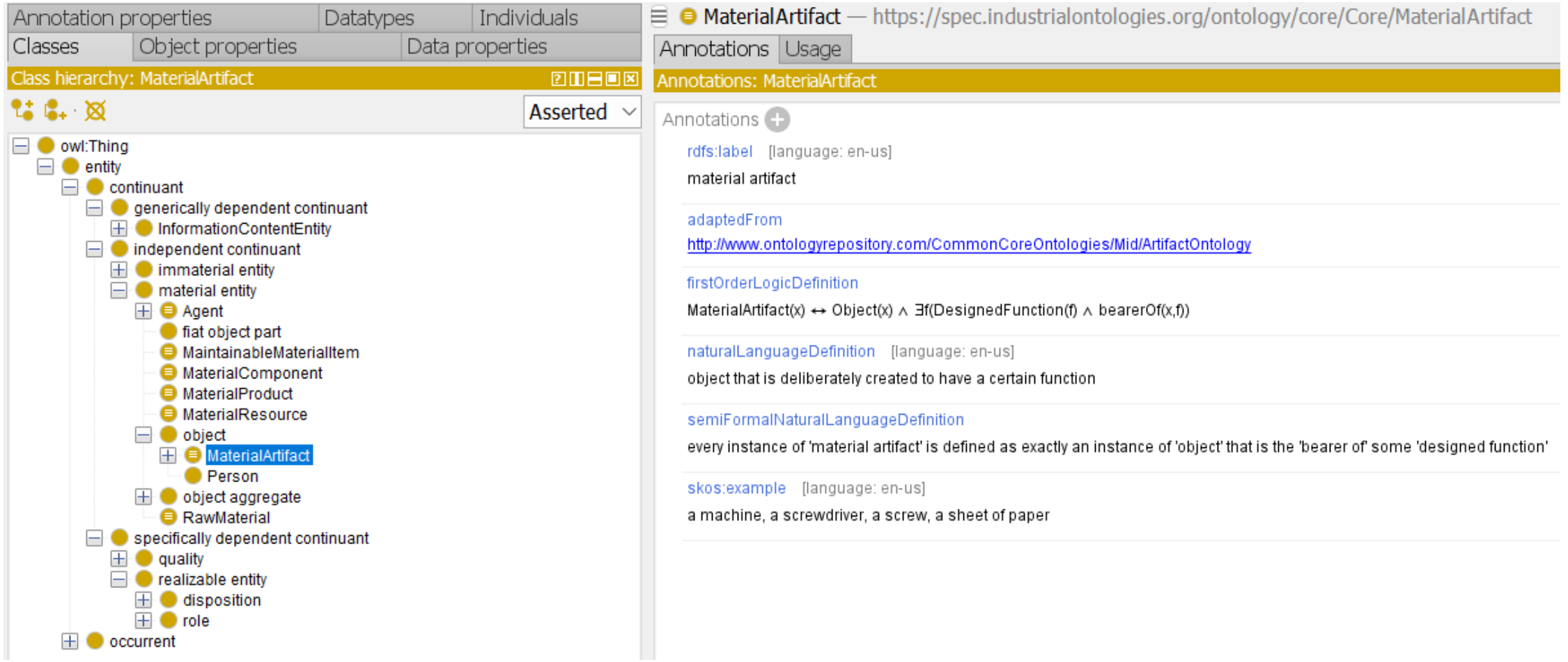
Invite Reviewers of OWL Model

- We are in the process of building in Protégé, on top of BFO/CCO



Proceed toward v2

Discuss next set of concepts
- Digital Thread
- Digital System Model
- …

Incorporate other works
- IOF SE, Supply Chain
- Systems Pattern
- SE Processes
- MBAcq metadata
- CASCaDE
- …

We need data
- Source data to test use cases

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ASOT	v1 complete
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View	v1 complete
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Thanks

- We have a core group of regular contributors – thanks to them all!

- If you are interested in contributing, reach out!
  - 1 hr / week.
  - Tend to focus on one concept for 2-3 weeks.
  - joegregory@arizona.edu

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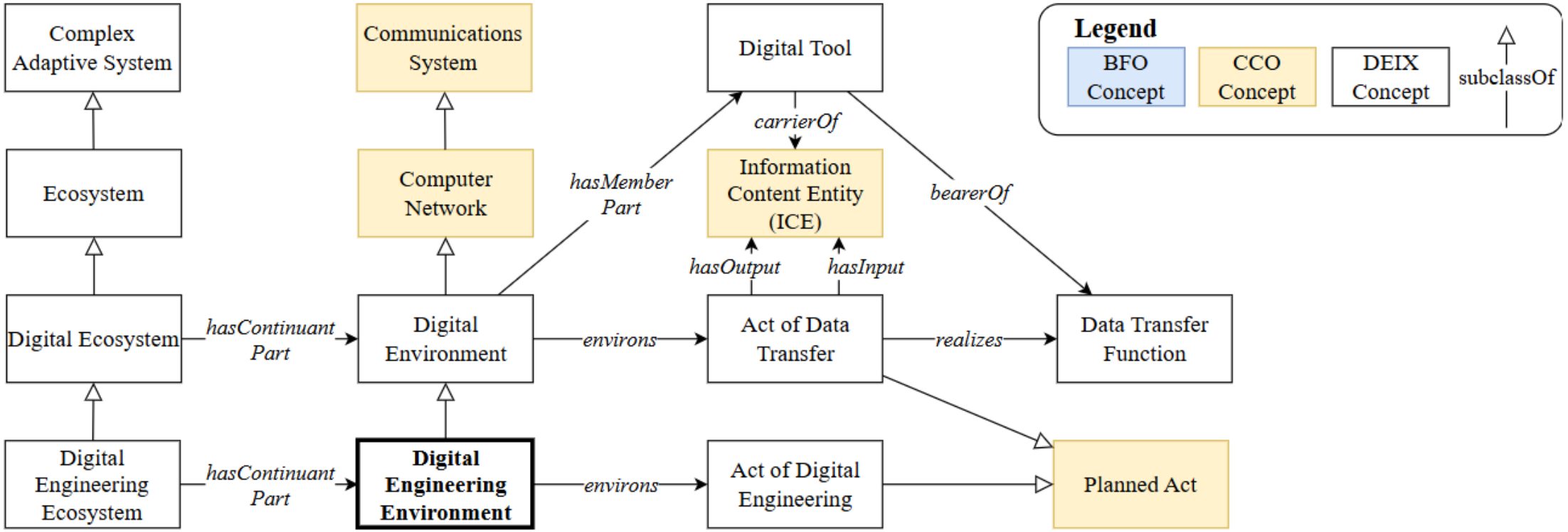
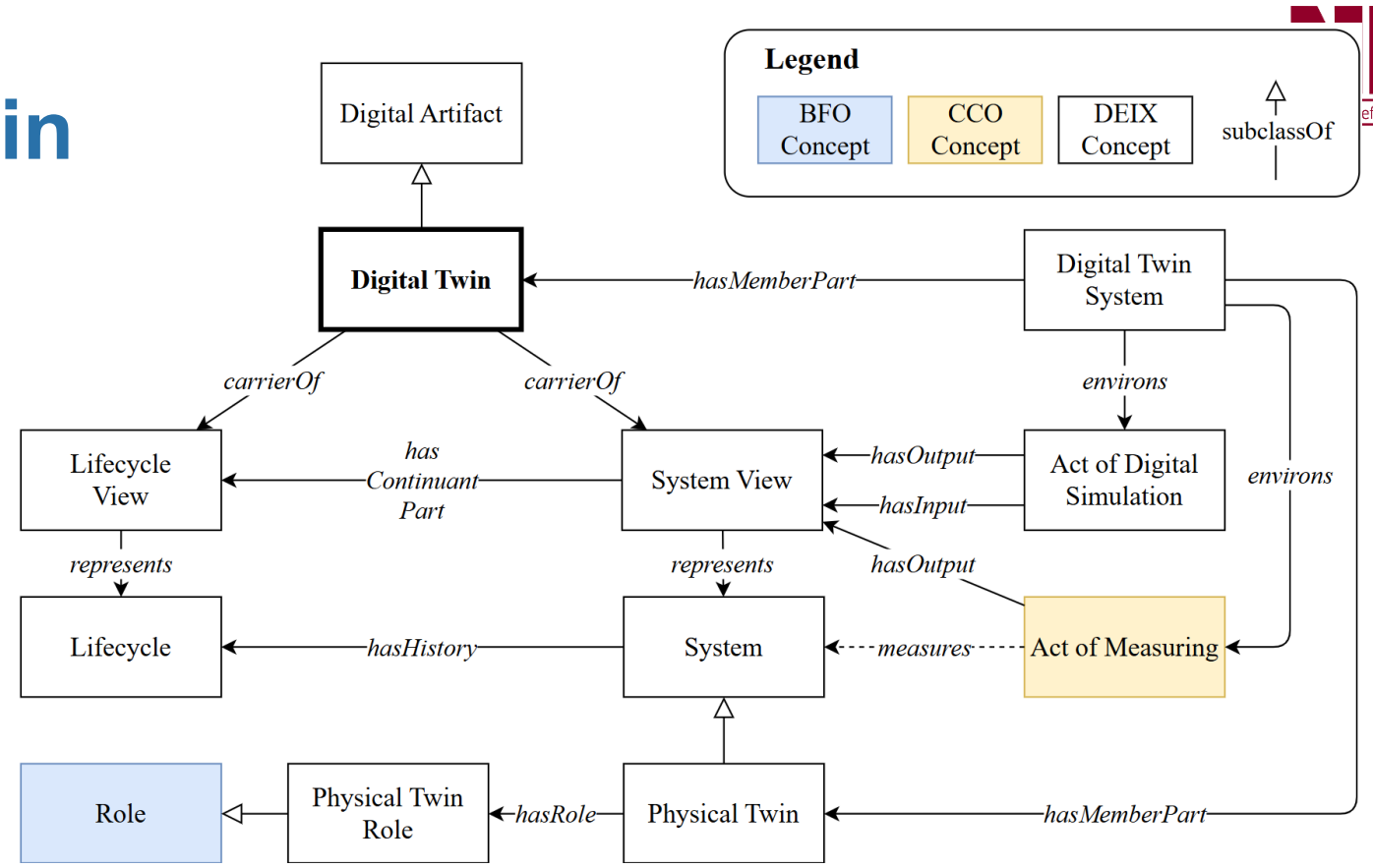
Backup

DE Eosystem / Environment



$$DEEnvironment(x) \equiv ComputerNetwork(x)$$
$$\wedge \exists a\ (DigitalTool(a) \wedge hasMemberPart(x,a)\ )$$
$$\wedge \exists b\ (DigitalTool(b) \wedge hasMemberPart(x,b)\ )$$
$$\wedge \exists c\ (DataTransferFunction(c) \wedge bearerOf(a,c)\ )$$
$$\wedge \exists d\ (ActOfDataTransfer(d) \wedge realizes(c,d) \wedge environs(x,d)\ )$$
$$\wedge \exists e\ (ActOfDigitalEngineering(e) \wedge environs(x,e)\ )$$

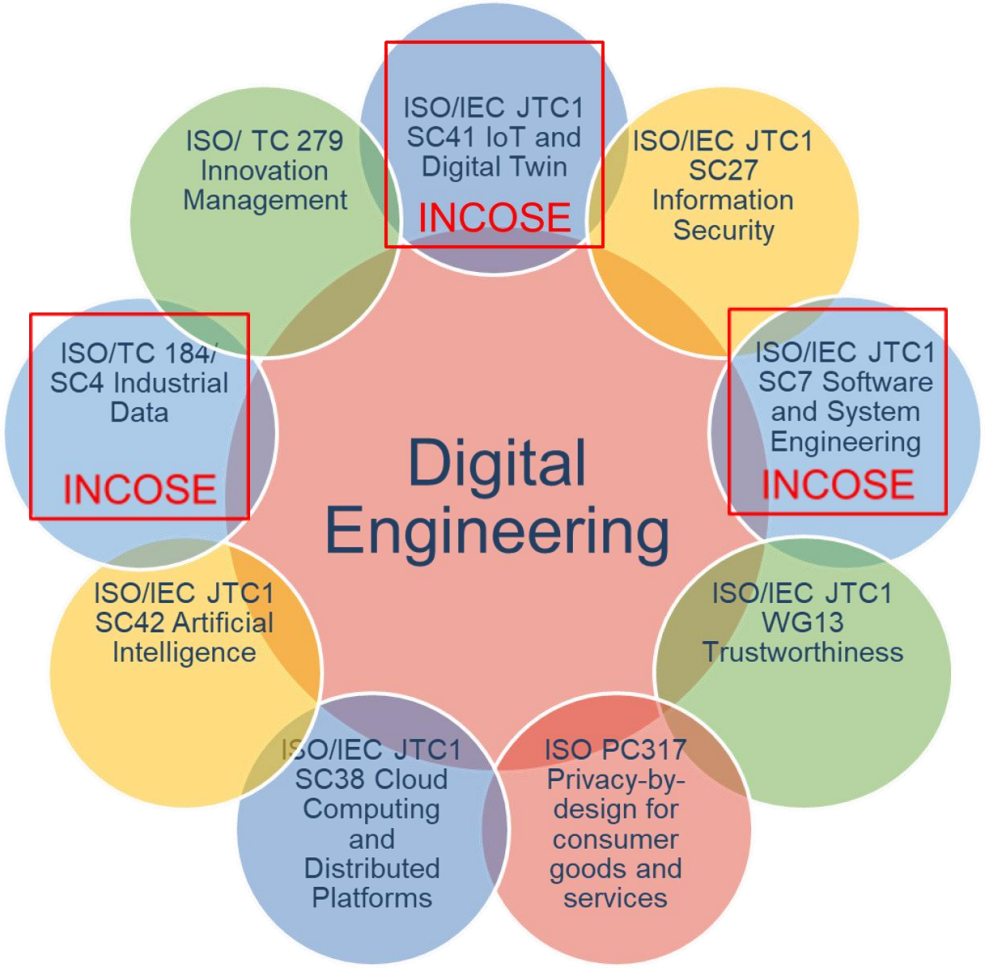
Digital Twin



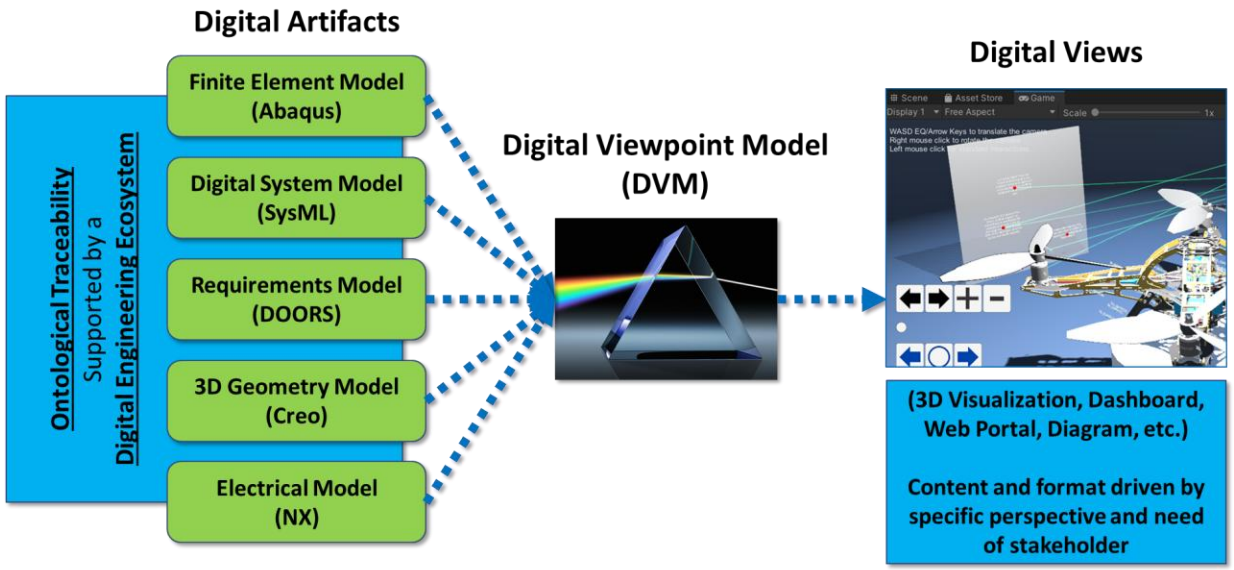
$$DigitalTwin(x) \equiv DigitalArtifact(x)$$
$$\wedge\ \exists a1\ (SystemView(a1) \wedge isCarrierOf(x,a1))$$
$$\wedge\ \exists a2\ (SystemView(a2) \wedge isCarrierOf(x,a2))$$
$$\wedge\ \exists a3\ (SystemView(a3) \wedge isCarrierOf(x,a3))$$
$$\wedge\ \exists b\ (System(b) \wedge represents(a1,b) \wedge represents(a2,b) \wedge represents(a3,b))$$
$$\wedge\ \exists d\ (ActOfDigitalSimulation(d) \wedge hasInput(d,a1) \wedge hasOutput(d,a2))$$
$$\wedge\ \exists e\ (ActOfMeasuring(e) \wedge measures(e,b) \wedge hasOutput(e,a3))$$
$$\wedge\ \exists f\ (LifecycleView(f) \wedge isCarrierOf(x,f))$$

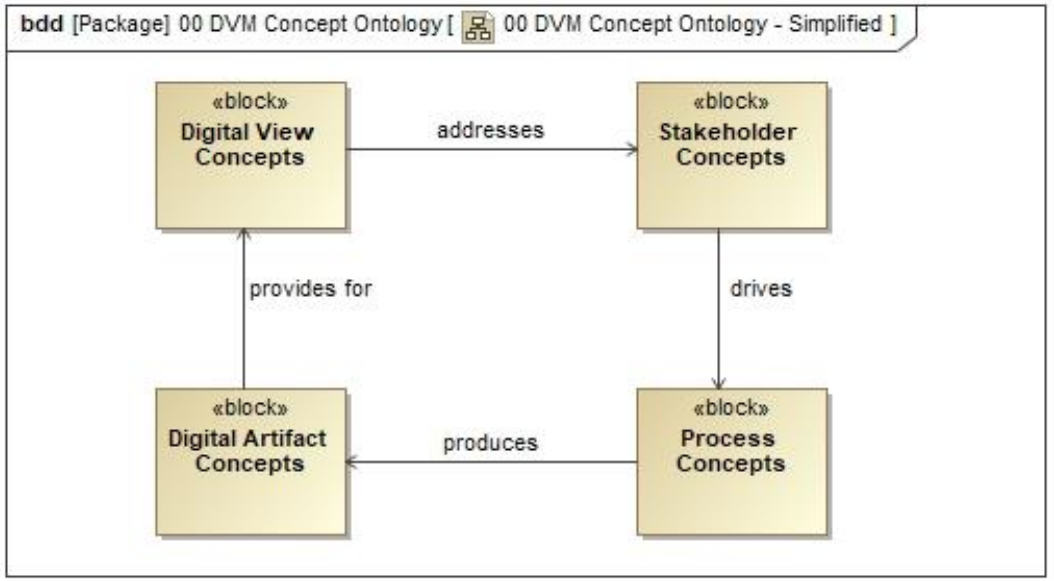
DE Standard Survey

- Scope: Collaboration with ISO/IEC JTC1 SC7 AHG 6 to provide analysis of the requirements of the market for DE standard development
  - Alignment of standardization needs identified in INCOSE SE Vision 2035
    - Presented in 2023 INCOSE IS
  - Alignment of ongoing standard development activities and identify standard gaps
  - Collect SE community input via DE survey
- Outcome: Analysis report completed in Dec 2023, 2 standards proposal accepted for draft development



Digital Viewpoint Model (Lead: Ken Zhang)





While the DVM is modeled using SysML, the concepts are agnostic of any particular language, tool, or infrastructure

- The Digital Viewpoint Model (DVM) is an **implementation-agnostic (platform independent), reference framework** developed from DEIXWG
- The DVM provides a high-level framework for describing sources of digital information in a digital engineering ecosystem (DEE)
- The DVM also conceptualizes how that information can be transferred, translated, transformed, and related for the purpose of exchanging digital information between stakeholders… who might not have the same DEE infrastructure or standards

DE Guide

Key areas of focus

- Tailors ISO/IEC/IEEE 15288 process to the unique challenges presented by digital engineering
- Clearly describes digital considerations across all system lifecycle stages
- Follows format of ISO/IEC/IEEE 21840

Objectives in terms of ISO alignment and industry impact

- Sets a foundation for cross-industry collaboration
- Provides general guidance for each ISO/IEC/IEEE 15288 process and process outcome in the context of DE
- Follows similar standards alignment to ISO/IEC/IEEE 21840

How the DE Guide aims to address current challenges and gaps in digital engineering

- Bridge gap between traditional systems engineering and digital engineering practices
- Provides adaptable guidelines that evolve with digital engineering practices