INCOSE DEIX Ontology Development with Protégé

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Outline

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Introduction

→ Ontology Development using Protégé and OWL 2

***Protégé** is a free, open-source software that allows you to create and manage ontologies for various domains and applications. It supports W3C standards, plug-ins, and web-based access to your knowledge.*

https://protege.stanford.edu/

*The **OWL 2 Web Ontology Language**, informally OWL 2, is an ontology language for the Semantic Web with formally defined meaning. OWL 2 ontologies provide classes, properties, individuals, and data values and are stored as Semantic Web documents.*

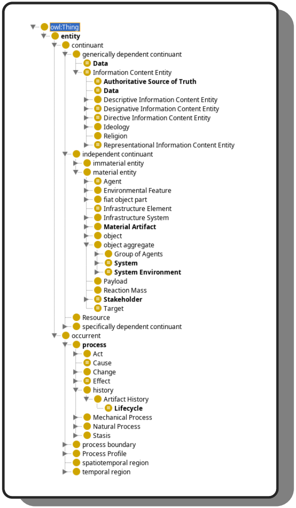
https://www.w3.org/TR/owl2-overview/

→ Imported Ontologies — BFO

Basic Formal Ontology[1] (BFO-2020 – ISO/IEC 21838) contains classes and relations representing content common to all areas of scientific investigation, e.g. object, process, etc. and is used as a top-level architecture by numerous ontologies in the Industrial Ontologies Foundry (IOF), and the **Common Core Ontologies** suite.

Ontologies conformant to BFO promote interoperability, standardization, and reuse among domain-level ontologies.

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



[1] ISO/IEC 2021

➞ Imported Ontologies — CCO (1)

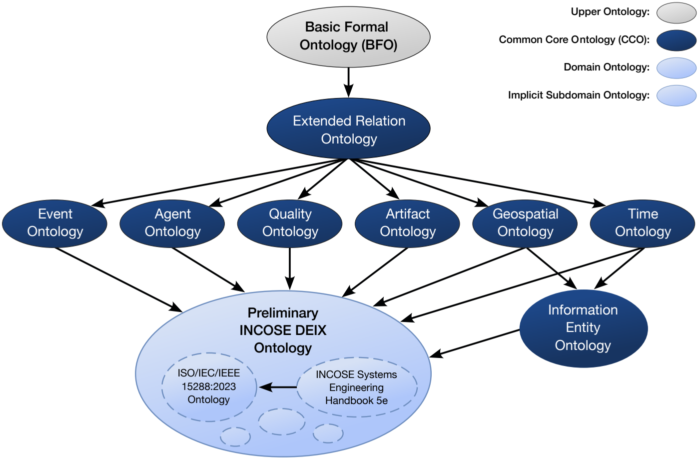
The **Common Core Ontologies** (CCO)[1] comprise twelve (12) ontologies that are designed to represent and integrate taxonomies of generic classes and relations across all domains of interest.

CCO is a mid-level extension of Basic Formal Ontology (BFO), an upper-level ontology framework widely used to structure and integrate ontologies.

https://github.com/CommonCoreOntology/CommonCoreOntologies

[1] CUBRC, Inc. et al. 2024a; Jensen et al. 2024

→ Imported Ontologies — CCO (2)



1

[1] Adapted from CUBRC, Inc. et al. 2024a

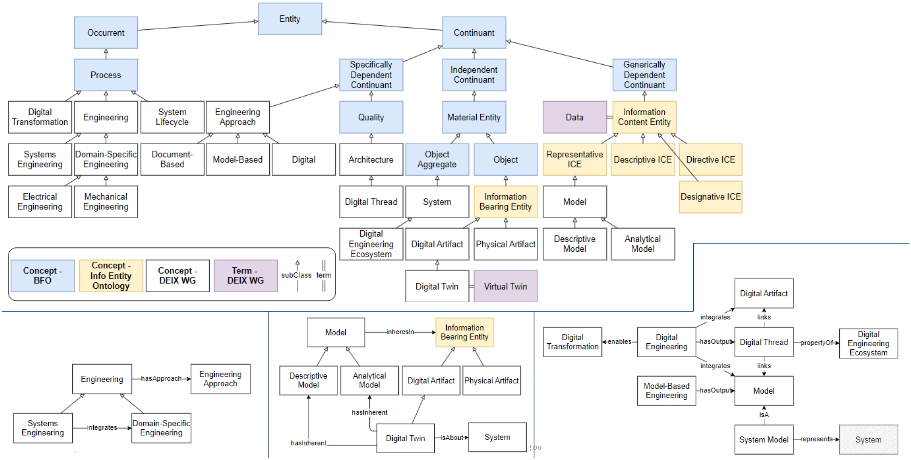
→ Sources for this DEIX ontology

Ontology classes were defined and modeled using the following sources:

- Prior INCOSE DEIX Taxonomy WG presentations
- **ISO/IEC/IEEE 15288:2023**[1]
- INCOSE Systems Engineering Handbook, Fifth Edition[2]
- Defense Acquisition University (DAU) glossary[3]
- INCOSE Needs and Requirements Manual (NRM) (2022)[4]
- Wikipedia *(where standard definitions do not exist or have not been sourced)*

[1] ISO/IEC/IEEE 2023 [2] INCOSE 2023 [3] Defense Acquisition University 2024 [4] Wheatcraft et al. 2022

→ Preliminary DEIX Taxonomy



1

[1] Source: 'Defining ASOTs' – DEIX Taxonomy WG Internal Presentation, ca. June 4, 2024

→ Overview of this DEIX ontology

The following presented ontology was built with Protégé and OWL 2, has one direct import, and **successfully validates** using the ELK 0.6.0 Protégé reasoner. It defines:

- **110** classes
- **69** 'equivalent class' axioms
- **68** English definitions with **66** definition sources
- **0** object properties
- **0** data properties
- **0** individuals (temporarily removed 5 to simplify automatic reasoning)
- **1** direct import (CCO – AllCoreOntology)
- **18** indirect imports from CCO (including BFO-2020)

This DEIX ontology combines canonical English definitions of Digital Engineering concepts and newly written axioms that relate those concepts using standard BFO and CCO ontological relations.

②

Concepts

→ Digital Engineering

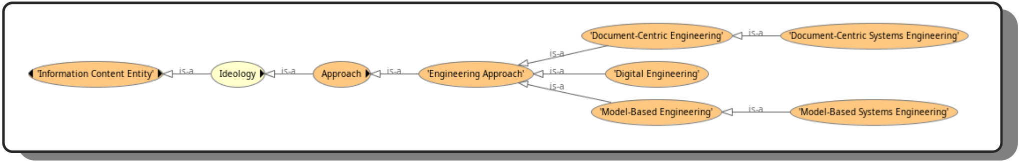
Definition (Digital Engineering)

An integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.[1]

Listing 1: 'Digital Engineering' is a subclass of 'Engineering Approach' and equivalent to:

```
    'Engineering Approach'
and ('is concretized by' some 'Digital Transformation')
and ('is about' some 'Digital Thread')
```

OWL 2 Manchester Syntax



[1] Defense Acquisition University 2024

→ Act of Engineering

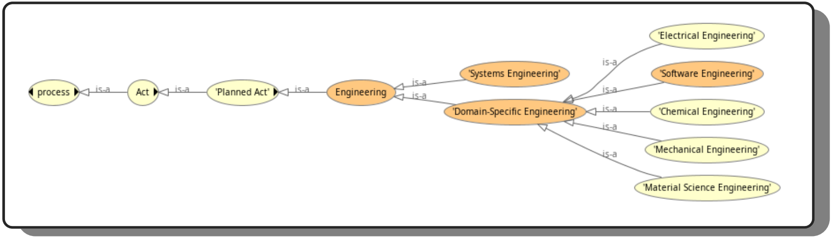
Definition (Act of Engineering)

TBD

Listing 2: 'Act of Engineering' is a subclass of 'Planned Act' and equivalent to:

```
    'Planned Act'
and (concretizes some 'Engineering Approach')
and ('is part of process' some Lifecycle)
```

OWL 2 Manchester Syntax



→ (System) Lifecycle

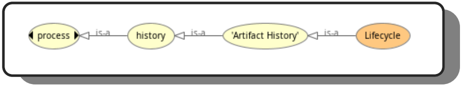
Definition (Lifecycle)

evolution of a System, Product, Service, Project or other human-made entity from conception through Retirement[1]

Listing 3: 'Lifecycle' is a subclass of 'Artifact History' and equivalent to:

```
'history of' some System
```

OWL 2 Manchester Syntax



[1] ISO/IEC/IEEE 2023

Digital Transformation

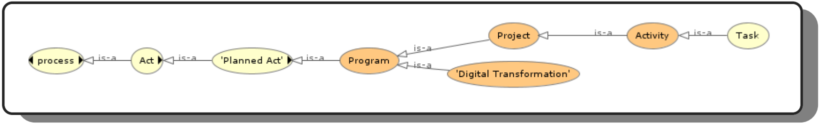
Definition (Digital Transformation)

Digital transformation (DT) is the process of adoption and implementation of digital technology by an organization in order to create new or modify existing products, services and operations by the means of translating business processes into a digital format.[1]

Listing 4: 'Digital Transformation' is a subclass of 'Program' equivalent to:

```
    Program
and ('occurs in' some Organization)
and ('has output' some 'Digital Environment')
and ('is interest of' some Stakeholder)
```

OWL 2 Manchester Syntax



[1] Wikipedia 2024(b)

→ Digital Engineering Environment

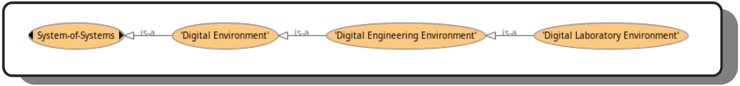
Definition (Digital Engineering Environment)

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.[1]

Listing 5: 'Digital Engineering Environment' is a subclass of 'Digital Environment' equivalent to:

```
    'Digital Environment'
and ('has continuant part' some
        ('Digital Thread' and 'Digital Tool'))
and ('has continuant part' some 'Engineering Methodology')
and (environs some Engineering)
and ('is used by' some 'Project Team Member')
```

OWL 2 Manchester Syntax



[1] 'Digital Engineering Ecosystem' — Defense Acquisition University 2024

→ Digital Environment

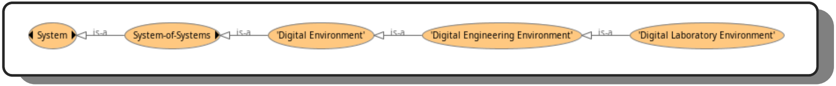
Definition (Digital Environment)

A digital environment is an integrated communications environment where digital devices communicate and manage the content and activities within it.[1]

Listing 6: 'Digital Environment' is a subclass of 'System-of-Systems' and equivalent to:

```
    ('continuant part of' some Organization)
and ('has continuant part' some
       (Computer and 'Computer Network' and Database))
and (environs some 'Computing Process')
and ('accessory in' some Activity)
and ('is used by' some User)
```

OWL 2 Manchester Syntax



[1] Wikipedia 2024(a)

Engineering Methodology

Listing 7: ‘**Engineering Methodology**’ is a subclass of ‘**Methodology**’ equivalent to:

```
    Methodology
and (prescribes some Engineering)
```

OWL 2 Manchester Syntax

Listing 8: ‘**Methodology**’ is a subclass of ‘**Plan**’ is a subclass of ’**Directive ICE**’ equivalent to:

```
    ('has continuant part' some Method)
and (prescribes some 'Act of Tool Use')
```

OWL 2 Manchester Syntax

Listing 9: ‘**Method**’ is a subclass of ‘**Plan**’ is a subclass of ’**Directive ICE**’ equivalent to:

```
prescribes some 'Planned Act'
```

OWL 2 Manchester Syntax

→ Digital Engineering Ecosystem

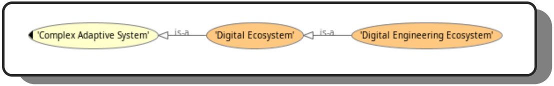
Definition (Digital Engineering Ecosystem)

A digital ecosystem encompassing some shared market(s) of organizations and their products and services, whose digital environments, including Digital Engineering Environments, are networked to share resources, artifacts, and information.

Listing 10: 'Digital Engineering Ecosystem' is a subclass of 'Digital Ecosystem' and equivalent to:

```
    'Digital Ecosystem'
and ('has continuant part' some 'Digital Engineering Environment')
```

OWL 2 Manchester Syntax



→ Digital Ecosystem

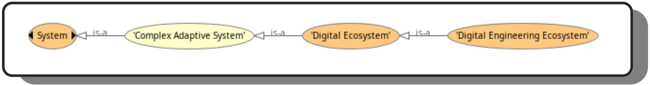
Definition (Digital Ecosystem)

Defined as a set of businesses functioning as a unit and interacting with a shared market for software and services, together with relationships among them. These relationships are frequently underpinned by a common technological platform and operate through the exchange of information, resources, and artifacts.[1]

Listing 11: 'Digital Ecosystem' is a subclass of 'Complex Adaptive System' and equivalent to:

```
    ('has continuant part' some
        ('Digital Environment' and Organization and Software_Product and 'Service Provider'))
and (environs some 'Act of Financial Instrument Use')
```

OWL 2 Manchester Syntax



[1] Wikipedia 2024(c)

Authoritative Source of Truth

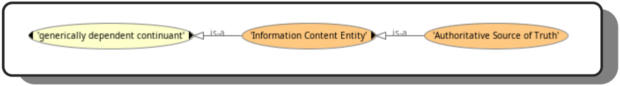
Definition (Authoritative Source of Truth)

The reference point for models and data across the system life cycle. The authoritative source of truth provides traceability as the system evolves, capturing historical knowledge and connecting configuration-controlled versions of models and data.[1]

Listing 12: 'Authoritative Source of Truth' is a subclass of 'ICE' and equivalent to:

```
    ('generically depends on' some
        ('Digital Engineering Environment' and 'Expert Authority'))
and ('has continuant part' some
        (Data and 'Digital View' and 'System Architecture'))
and ('is about' some Lifecycle)
and ('is output of' some 'Computing Process')
```

OWL 2 Manchester Syntax



[1] Defense Acquisition University 2024

Expert Authority

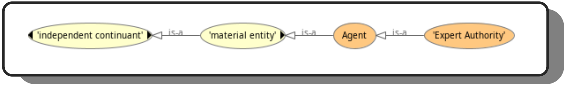
Definition (Expert Authority)

TBD

Listing 13: 'Expert Authority' is a subclass of 'Agent' and equivalent to:

```
    Agent
and ('aggregate has role' some 'Authority Role')
and ('has interest in' some Lifecycle)
```

OWL 2 Manchester Syntax



→ Digital View

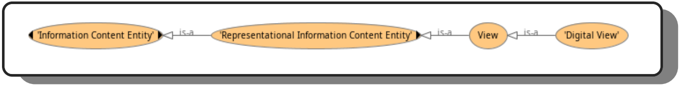
Definition (Digital View)

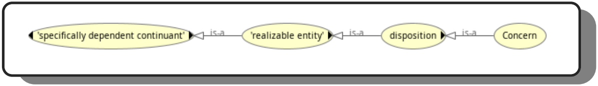
TBD

Listing 14: ‘Digital View’ is a subclass of ‘View’ and equivalent to:

```
    ('has continuant part' some Data)
and (represents some Concern)
and (represents some System)
```

OWL 2 Manchester Syntax





→ Digital Viewpoint

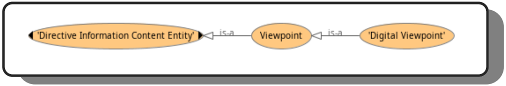
Definition (Digital Viewpoint)

TBD

Listing 15: ‘Digital Viewpoint’ is a subclass of ‘Viewpoint’ and equivalent to:

```
    ('has continuant part' some Data)
and (prescribes some View)
```

OWL 2 Manchester Syntax



→ Stakeholder (1)

Definition (Stakeholder)

individual or Organization having a right, share, claim, or interest in a System or in its possession of characteristics that meet their Needs and expectations[1]

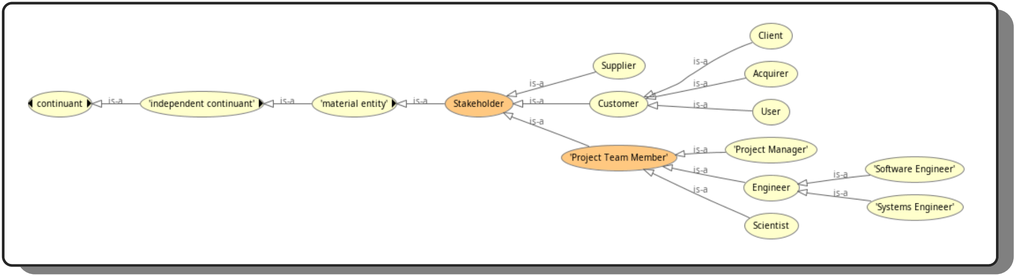
Listing 16: ‘Stakeholder’ is a subclass of ‘material entity’ and equivalent to:

```
    (Agent or Organization)
and (('agent in' some Lifecycle)
        or ('has interest in' some Lifecycle))
and ('aggregate bearer of' some Concern)
and ('is subject of' some Need)
```

OWL 2 Manchester Syntax

[1] ISO/IEC/IEEE 2023

→ Stakeholder (2)



Digital Thread

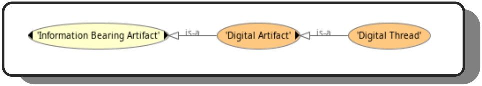
Definition (Digital Thread)

An extensible and configurable analytical framework that seamlessly expedites the controlled interplay of technical data, software, information, and knowledge in the digital engineering ecosystem, based on the established requirements, architectures, formats, and rules for building digital models. It is used to inform decision makers throughout a system's life cycle by providing the capability to access, integrate, and transform data into actionable information.[1]

Listing 17: 'Digital Thread' is a subclass of 'Digital Artifact' and equivalent to:

```
    ('continuant part of' some 'Digital Engineering Environment')
and ('has continuant part' some
        ('Digital Artifact' and Database))
```

OWL 2 Manchester Syntax



[1] Defense Acquisition University 2024

Digital Artifact

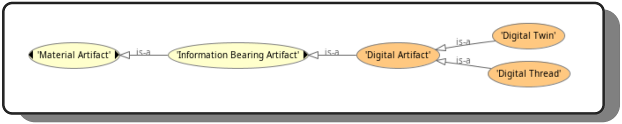
Definition (Digital Artifact)

A product or output, in computer (i.e., digital) format, created within or generated from the digital engineering ecosystem. Digital artifacts provide data for alternative views to visualize, communicate, and deliver data, information, and knowledge to stakeholders.[1]

Listing 18: 'Digital Artifact' is a subclass of 'Information Bearing Artifact' and equivalent to:

```
'is carrier of' some
    ('Authoritative Source of Truth'
        and Data
        and 'Digital View'
        and 'Information Content Entity')
```

OWL 2 Manchester Syntax



[1] Defense Acquisition University 2024

→ Digital Twin

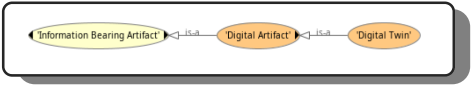
Definition (Digital Twin)

A virtual replica of a physical entity that is synchronized across time. Digital twins exist to replicate configuration, performance, or history of a system. Two primary sub-categories of digital twin are digital instance and digital prototype.[1]

Listing 19: 'Digital Twin' is a subclass of 'Digital Artifact' and equivalent to:

```
    ('is carrier of' some 'Digital View')
and ('has continuant part' some 'Authoritative Source of Truth')
and ('has history' some Lifecycle)
and ('is output of' some 'Act of Digital Simulation')
```

OWL 2 Manchester Syntax



[1] Defense Acquisition University 2024

→ Digital System Model

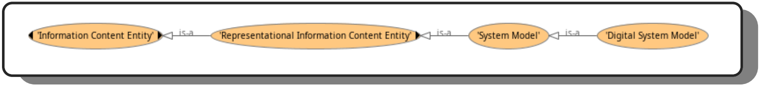
Definition (Digital System Model)

A digital representation of a system, generated by all stakeholders that integrates the authoritative technical data and associated artifacts which define all aspects of the system for the specific activities throughout the system lifecycle.[1]

Listing 20: 'Digital System Model' is a subclass of 'System Model' and equivalent to:

```
    ('has continuant part' some 'Authoritative Source of Truth')
and (represents some System)
```

OWL 2 Manchester Syntax



[1] Defense Acquisition University 2024

3

Individuals

→ Digital Engineering Factory

Listing 21: ‘**UA Digital Engineering Factory**’ is a type of ‘**Digital Engineering Environment**’:

```
'member part of' 'University of Arizona'
```

OWL 2 Manchester Syntax

Listing 22: ‘**University of Arizona**’ is a type of ‘**Educational Organization**’:

```
'has member part' 'UA Digital Engineering Factory'
```

OWL 2 Manchester Syntax

➞ Digital Laboratory Environment

Listing 23: ‘**AFRL Digital Laboratory Environment**’ is a type of ‘**Digital Laboratory Environment**’:

```
'member part of' 'US Air Force Research Laboratory'
```

OWL 2 Manchester Syntax

Listing 24: ‘**US Air Force Research Laboratory**’ is a type of ‘**Government Organization**’:

```
'has member part' 'AFRL Digital Laboratory Environment'
```

OWL 2 Manchester Syntax

→ MATLAB

Listing 25: ‘**MATLAB**’ is a type of ‘**Digital Tool**’:

```
'member part of' 'MathWorks'
```

OWL 2 Manchester Syntax

Listing 26: ‘**MathWorks**’ is a type of ‘**Commercial Organization**’:

```
'has member part' 'MATLAB'
```

OWL 2 Manchester Syntax

➞ Microsoft Project

Listing 27: ‘**Microsoft Project**’ is a type of ‘**Digital Tool**’:

```
'member part of' 'Microsoft'
```

OWL 2 Manchester Syntax

Listing 28: ‘**Microsoft**’ is a type of ‘**Commercial Organization**’:

```
'has member part' 'Microsoft Project'
```

OWL 2 Manchester Syntax

4

Discussion

→ Quality Measurement

Follow the example of Financial Industry Business Ontology (FIBO)[1]:

- Every ontology element has a **label** and **definition**
- **ISO 704**: Terminology work – Principles and methods for terminology development
- **ISO 1087**: Terminology work and terminology science – Vocabulary
- Define standard ontology header information
- Compliant with OWL 2 DL subset[2]
- Continuous Integration with a SPARQL[3] test suite

And apply a quality measurement framework in **5** areas:[4]
Syntactic, Structural, Semantic, Pragmatic, Social

[1] Object Management Group 2024b [2] World Wide Web Consortium 2012 [3] World Wide Web Consortium 2013 [4] Wilson et al. 2021

→ Proposed Object Properties

Adding object properties to the DEIX domain ontology would help clarify concept relationships using standard systems engineering terminology. Ontology engineering best practice is to keep new object properties to a minimum, to encourage reuse and flexibility of queries.

- **constrains**
- **integrates**
- **mitigates**
- **verifies**
- **validates**

Propose we design a process for incorporating new object properties into the ontology. It should include proposed **definition, domain, range, ‘inverse of’, ’subproperty of’, and example use**.

→ Tradeoff Analysis of Imports

Alternatives: BFO[1] + CCO[2] *vs.* OMG Commons[3] + FIBO[4] *vs.* BFO + Information Artifact Ontology (IAO)[5] *vs.* Process Specification Language (PSL)[6]

- More imports increases reasoning time, but potentially improves the connectedness of our terms, and therefore expands its use cases
- More imports adds cognitive overhead (more base classes and properties to potentially use/misuse)
- Concept duplication (due overlap of mid-level ontologies) requires disciplined use and reduces the clarity of the ontology
- Redefinition of existing concepts: (1) adds conflicts to ontology reuse, (2) when few, may prevent a much larger import, (3) OTOO, may suit our domain as SE has very specific definitions for some common terms, e.g. Concept, View
- No open standard OWL ontology of ISO/IEC/IEEE 15288:2023[7] or INCOSE SE HB v5[8]) exists - but, many publications exist in this domain[9]

[1] ISO/IEC 2021 [2] CUBRC, Inc. et al. 2024a [3] Object Management Group 2024a [4] Object Management Group 2024b [5] CUBRC, Inc. et al. 2024b [6] ISO 2004 [7] ISO/IEC/IEEE 2023 [8] INCOSE 2023 [9] Yang, Cormican, and Yu 2019

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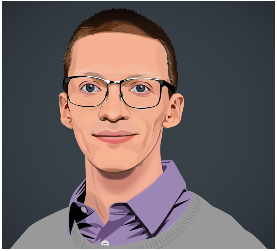
About the Presenter



James S. Wheaton

Herber Research Group

- Ph.D. Candidate in Systems Engineering at Colorado State University, advised by Dr. Daniel R. Herber
- Title of dissertation: “Bootstrapping a Trustworthy and Seamless Digital Engineering Appliance”
- Bachelor of Science, Mechanical Engineering from Purdue University (2011)
- Professional background in software engineering for e-commerce, and software engineering consulting for AI, big data, and blockchain systems at KPMG LLP
- Previously year-round student intern at NASA Jet Propulsion Laboratory (2023–2024) in Robotic Systems, model-based systems engineering and requirements engineering for Mars Sample Return