Towards a Systems Engineering Ontology Stack

INCOSE IS 2024

7/4/2024

PRESENTER Dr. **Joe Gregory** *Postdoctoral Research Associate*
Department of Systems & Industrial Engineering

Co-author: Dr. Alejandro Salado

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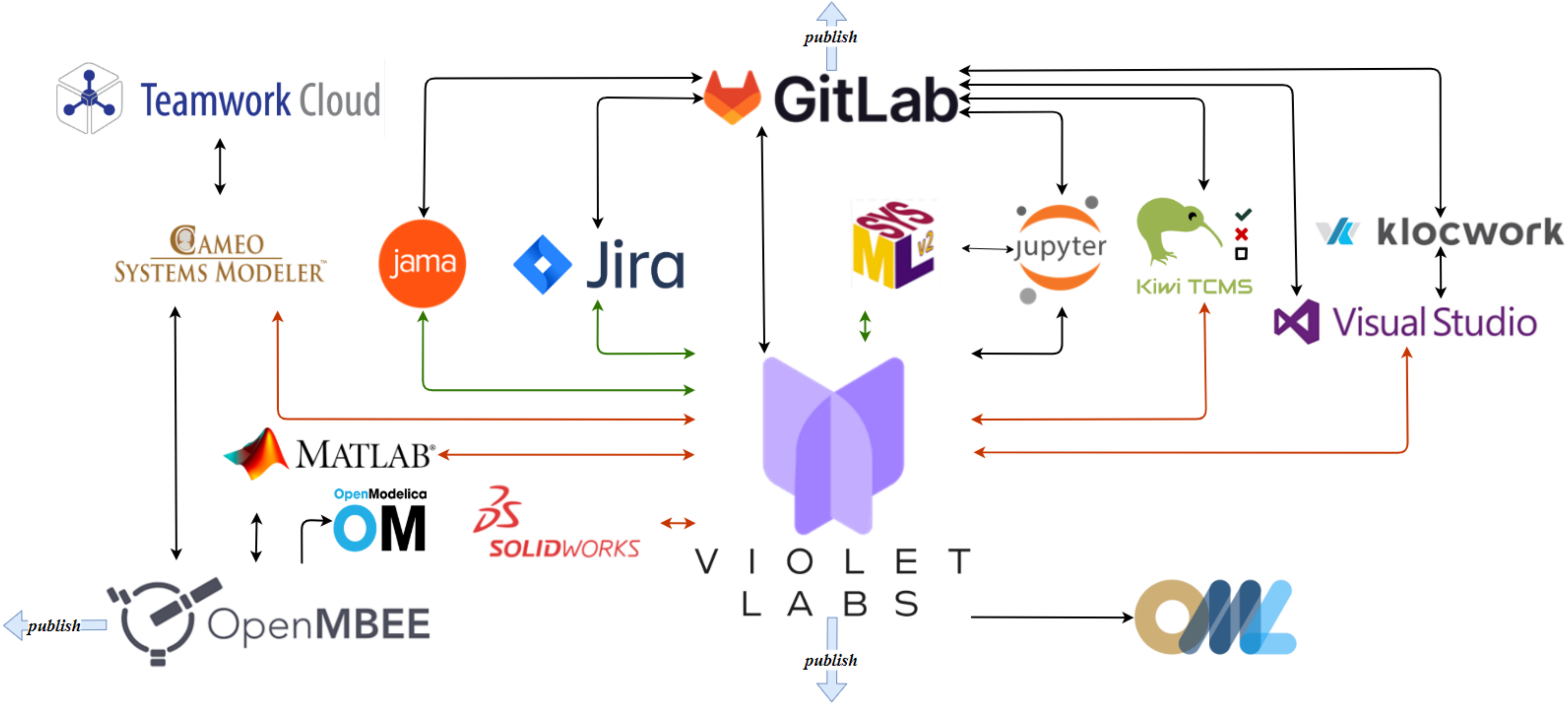
Digital Engineering at UA

Integration complete
Integration currently one-way
Integration under development

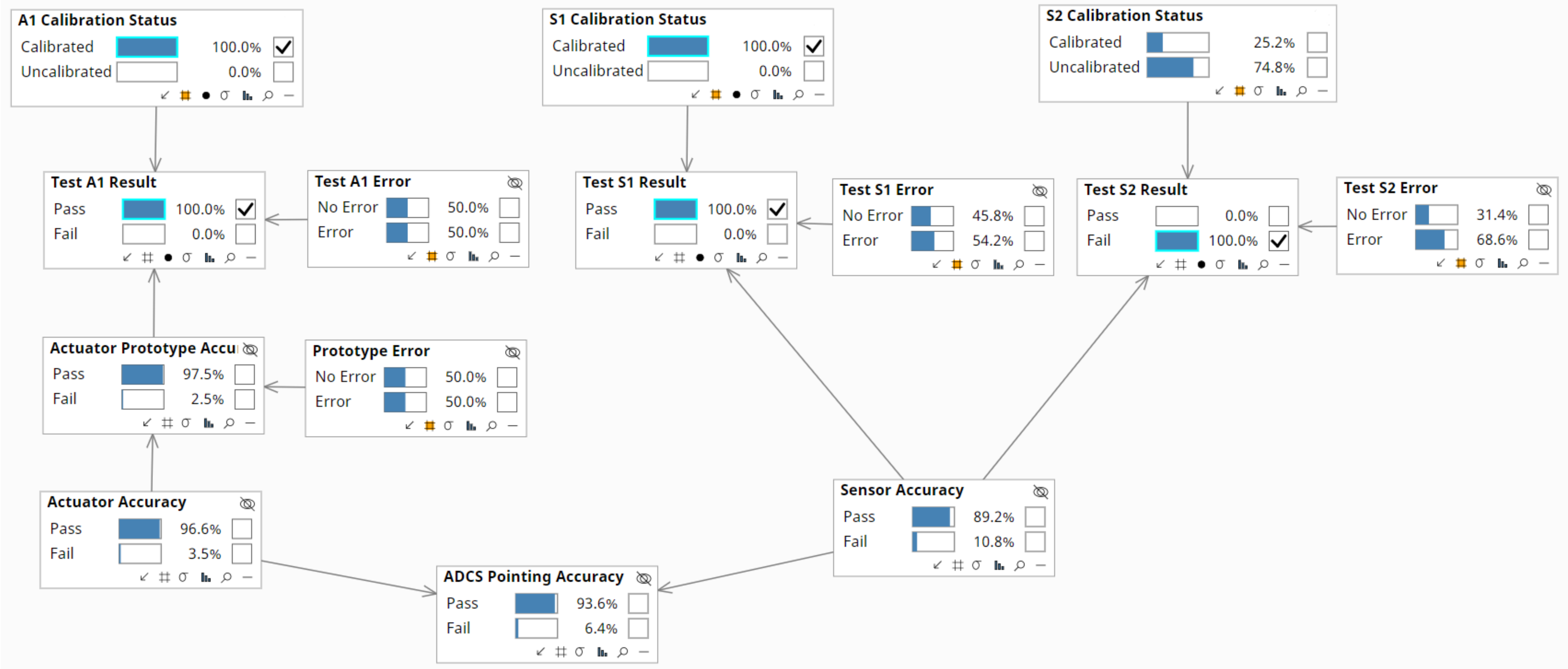


Digital Engineering at UA

Digital Engineering Factory

- Support Systems and SW Engineering Students
- Requirements, Architecture, Design, Verification
- Domain-specific Analysis
- Support Instructor Grading

Digital Engineering at UA



Digital Engineering at UA

DoD Instruction 5000.89

Test and Evaluation

Originating Component: Office of the Under Secretary of Defense for Research and Engineering
Originating Component: Office of the Director, Operational Test and Evaluation

Effective: November 19, 2020

Releasability: Cleared for public release. Available on the Directives Division Website

Digital Engineering at UA

Digital Engineering Factory

- Support Systems and SW Engineering Students
- Requirements, Architecture, Design, Verification
- Domain-specific Analysis
- Support Instructor Grading

Digital Test and Evaluation

- Novel T&E Methods
- Bayesian Representation of Strategy
- Digital T&E Master Plan (dTEMP)
  - Digital DoDI 5000.89

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Why Semantic Web Technologies?

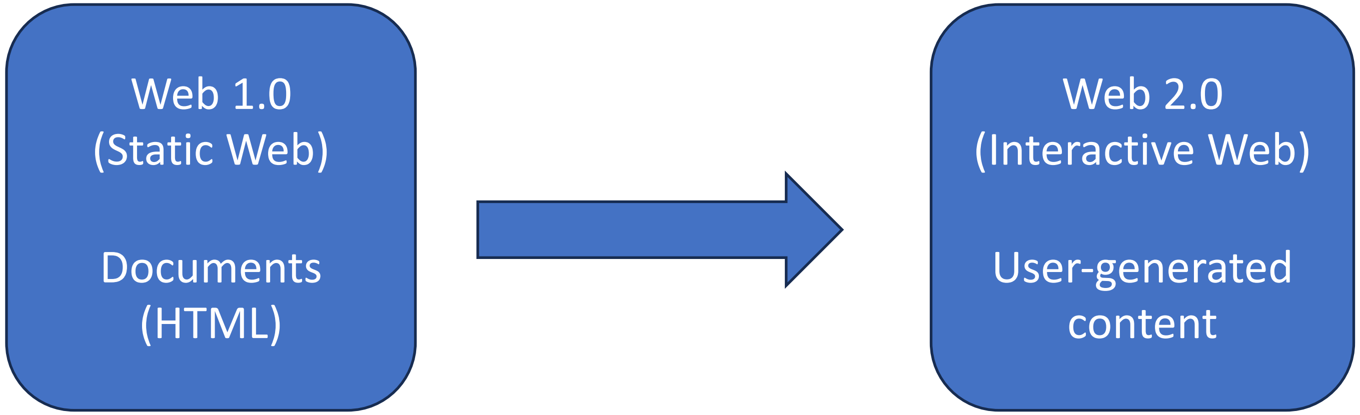
What are Semantic Web Technologies?

Web 1.0
(Static Web)

Documents
(HTML)

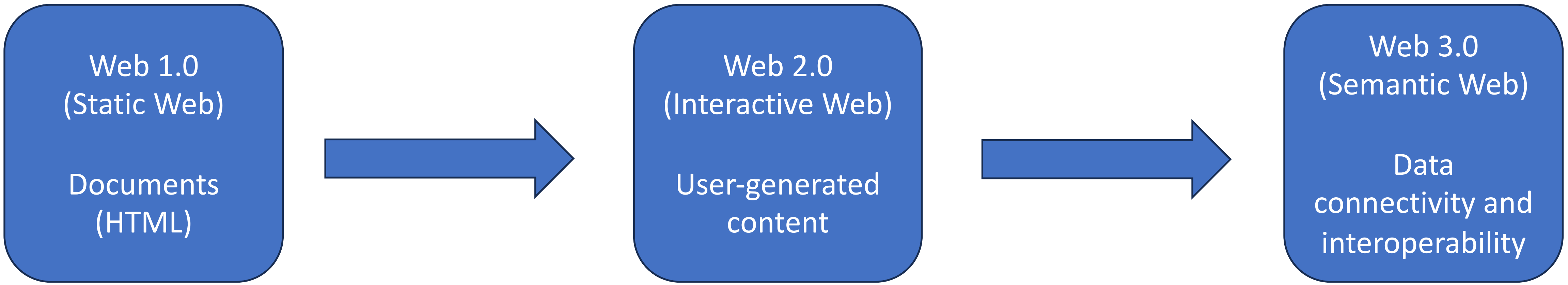
Why Semantic Web Technologies?

What are Semantic Web Technologies?



Why Semantic Web Technologies?

What are Semantic Web Technologies?



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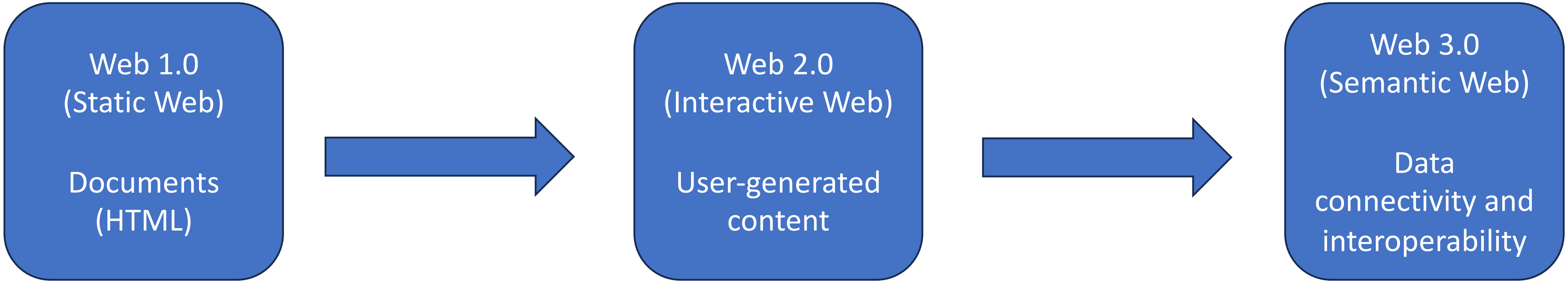
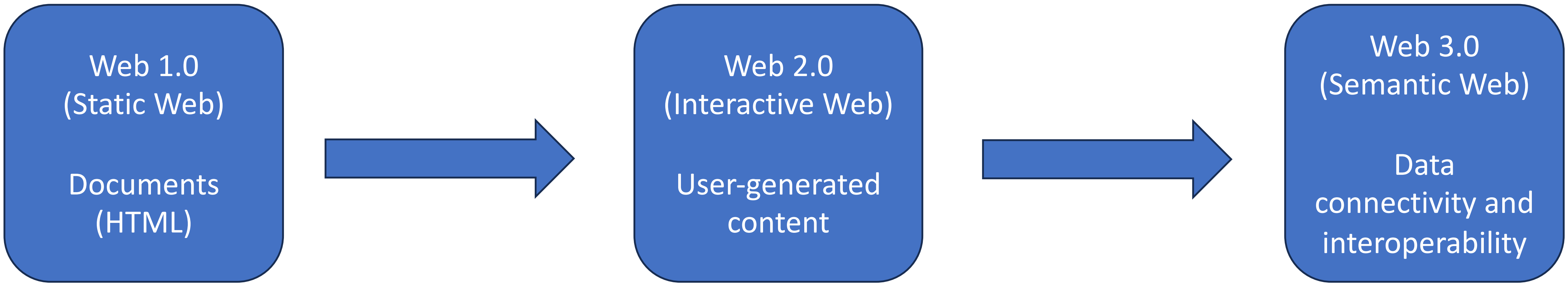


Consider the evolution of a ‘keyword search’

Why Semantic Web Technologies?

What are Semantic Web Technologies?



Consider the evolution of a ‘keyword search’

We want to leverage Semantic Web Technologies in our domains of interest

Why Semantic Web Technologies?

Provide an approach to the structuring and understanding of data.

Resource Description Framework (RDF)

- Triple structure: subject-predicate-object
- It is possible to combine data into large graphs
- Makes information machine-readable

Web Ontology Language (OWL)

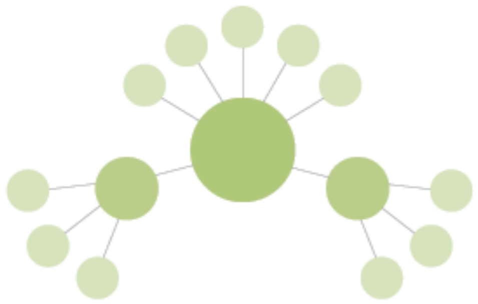
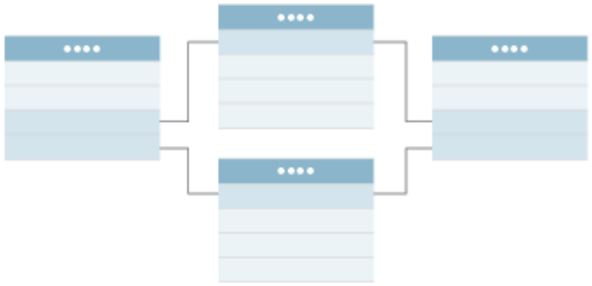
- Ontology: Network representation of allowable concepts (nodes) and relations (edges) in a domain
- Provides context to information
- Enables inference and validation capabilities

SPARQL

- Enables users to query RDF graphs

Why Semantic Web Technologies?

Relational Databases vs Graph Databases [6]

	Graph database	Relational database
FORMAT	Nodes and edges	Tables with rows and columns
RELATIONSHIPS	Considered data, represented by edges between nodes	Related across tables, established using foreign keys between tables
COMPLEX QUERIES	Run quickly and do not require joins	Require complex joins between tables
TOP USE CASES	Relationship-heavy use cases, including fraud detection and recommendation engines	Transaction-focused use cases, including online transactions and accounting
EXAMPLE		

- Graph Databases also suited to distributed data (horizontal scaling)
- Suited to 'multi-hop' queries
- Flexible when working with evolving schema

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Commentary | Published: May 2000

Gene Ontology: tool for the unification of biology

Michael Ashburner, Catherine A. Ball, Judith A. Blake, David Botstein, Heather Butler, J. Michael Cherry, Allan P. Davis, Kara Dolinski, Selina S. Dwight, Janan T. Eppig, Midori A. Harris, David P. Hill, Laurie Issel-Tarver, Andrew Kasarskis, Suzanna Lewis, John C. Matese, Joel E. Richardson, Martin Ringwald, Gerald M. Rubin & Gavin Sherlock

Nature Genetics **25**, 25–29 (2000) | Cite this article

Genomic sequencing has made it clear that a large fraction of the genes specifying the core biological functions are shared by all eukaryotes. Knowledge of the biological role of such shared proteins in one organism can often be transferred to other organisms. The goal of the Gene Ontology Consortium is to produce a dynamic, controlled vocabulary that can be applied to all eukaryotes even as knowledge of gene and protein roles in cells is accumulating and changing. To this end, three independent ontologies accessible on the World-Wide Web (http://www.geneontology.org) are being constructed: biological process, molecular function and cellular component.

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- Why do we need an Ontology Stack?
- Methodology
- UAOS – Current Status
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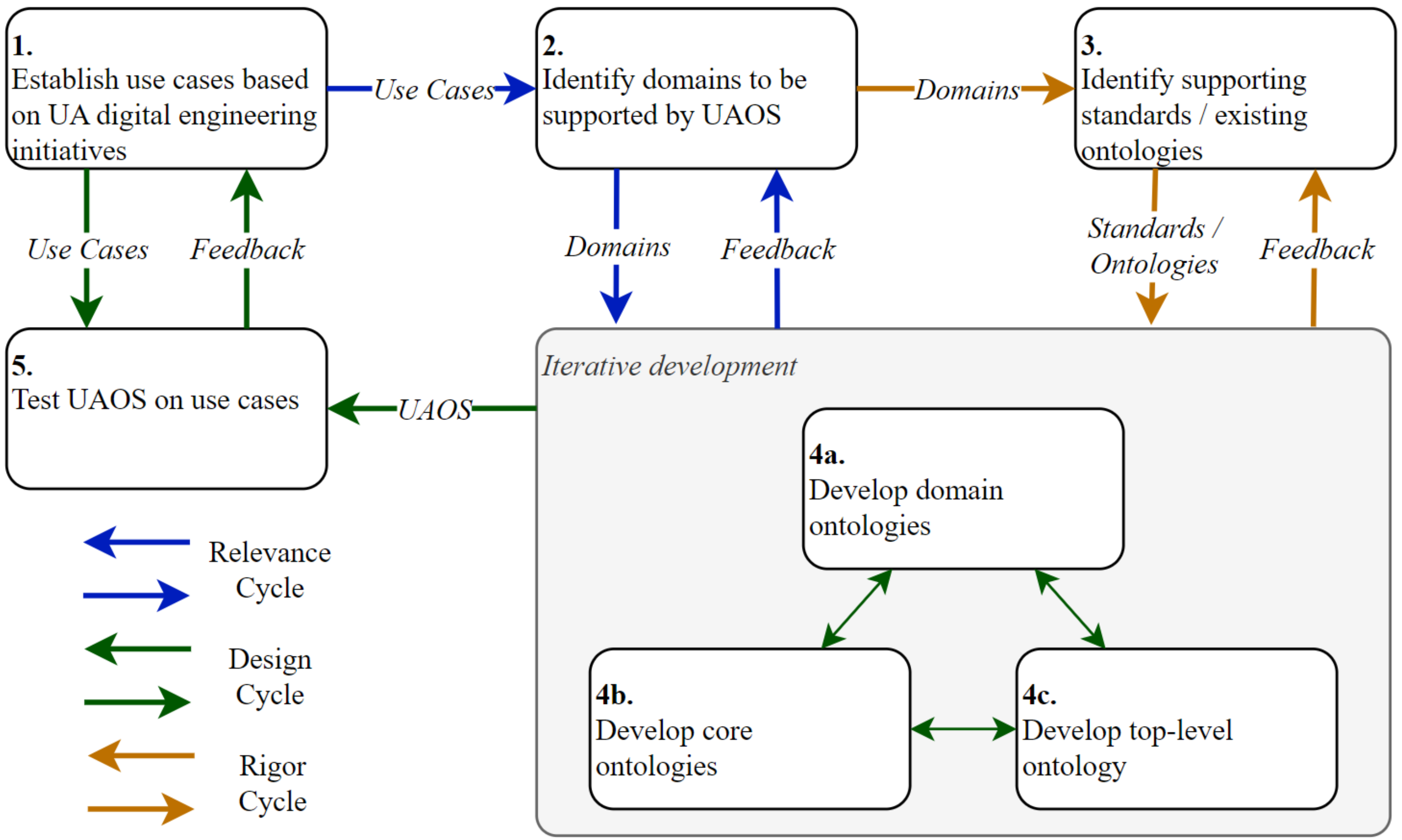
- Next Steps
- Conclusions

Methodology



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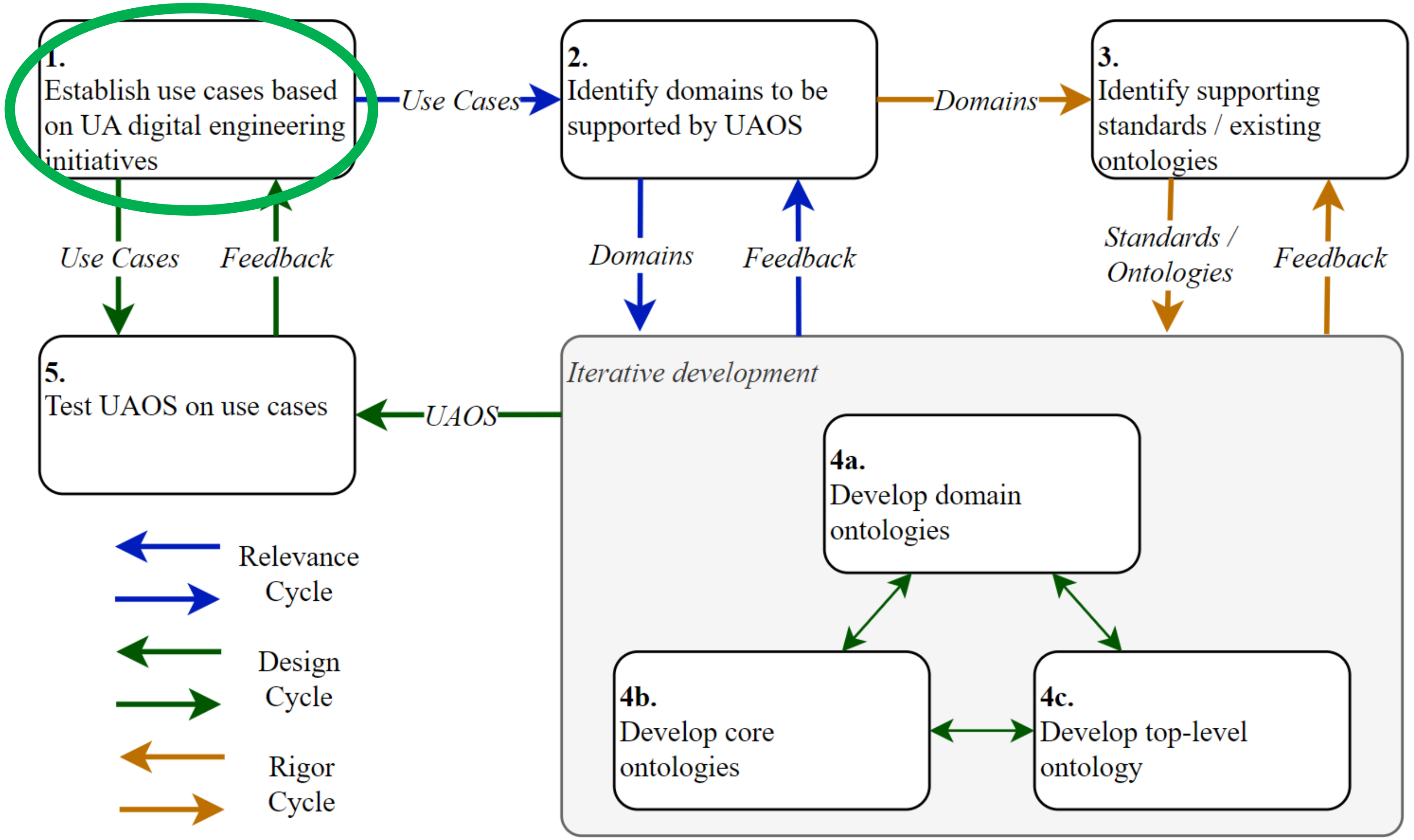
Methodology



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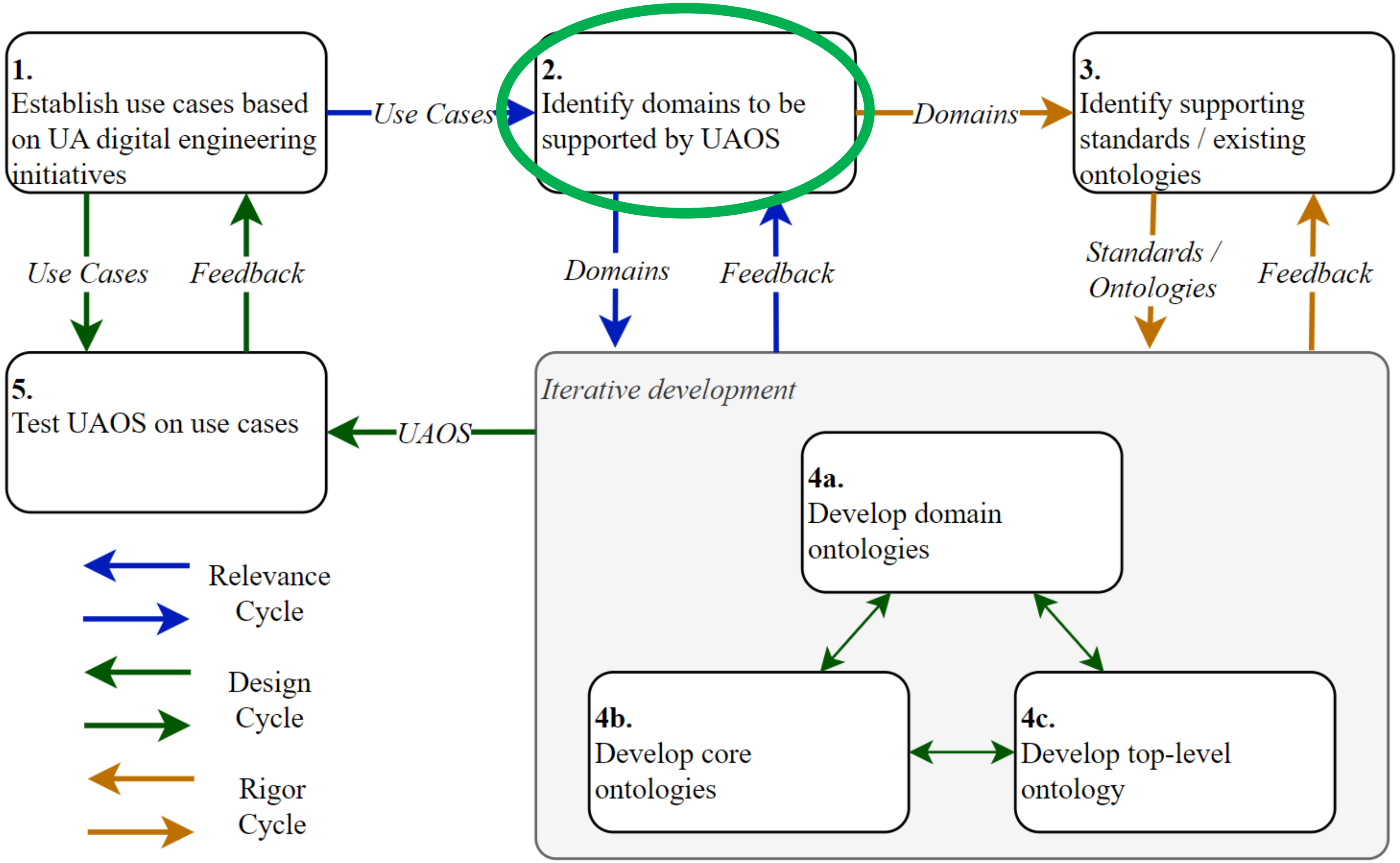
Methodology



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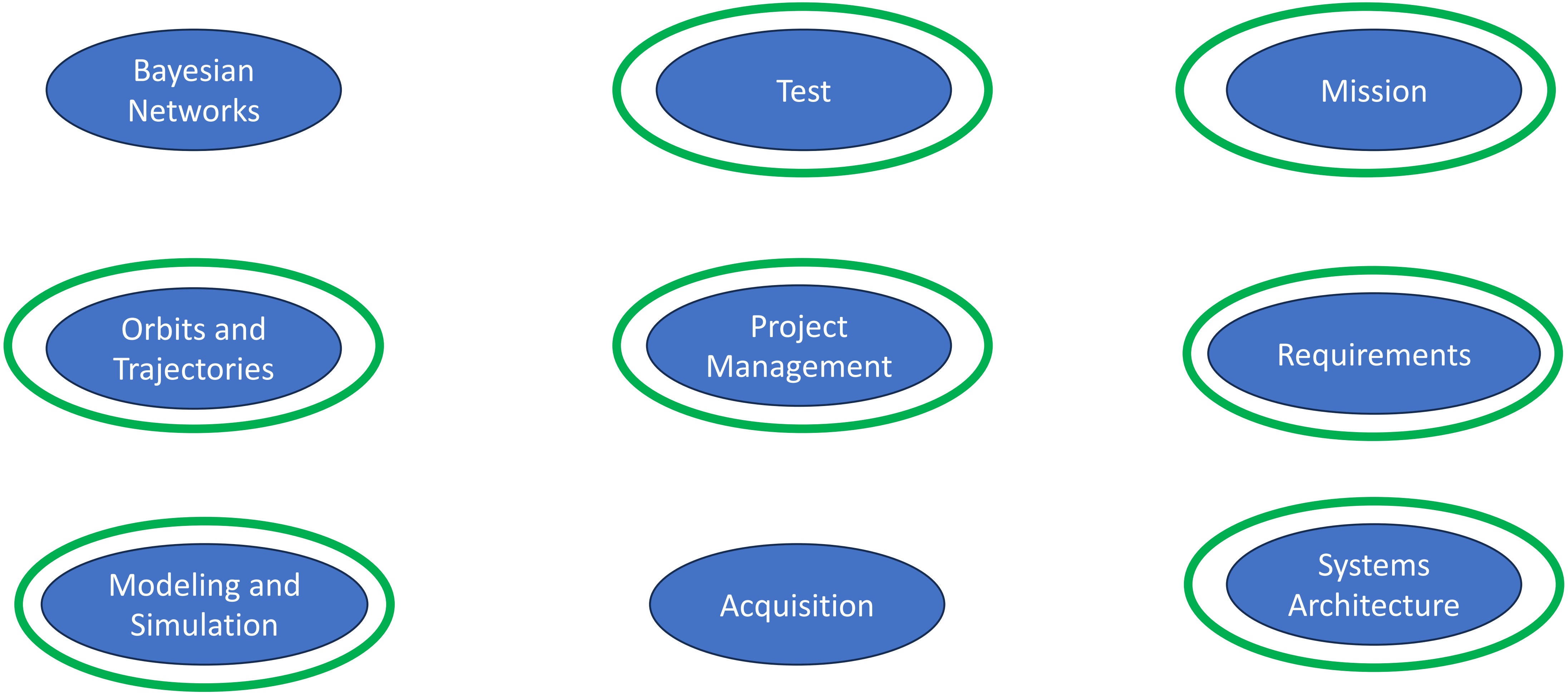
Methodology

- Bayesian Networks
- Test
- Mission
- Orbits and Trajectories
- Project Management
- Requirements
- Modeling and Simulation
- Acquisition
- Systems Architecture

Methodology



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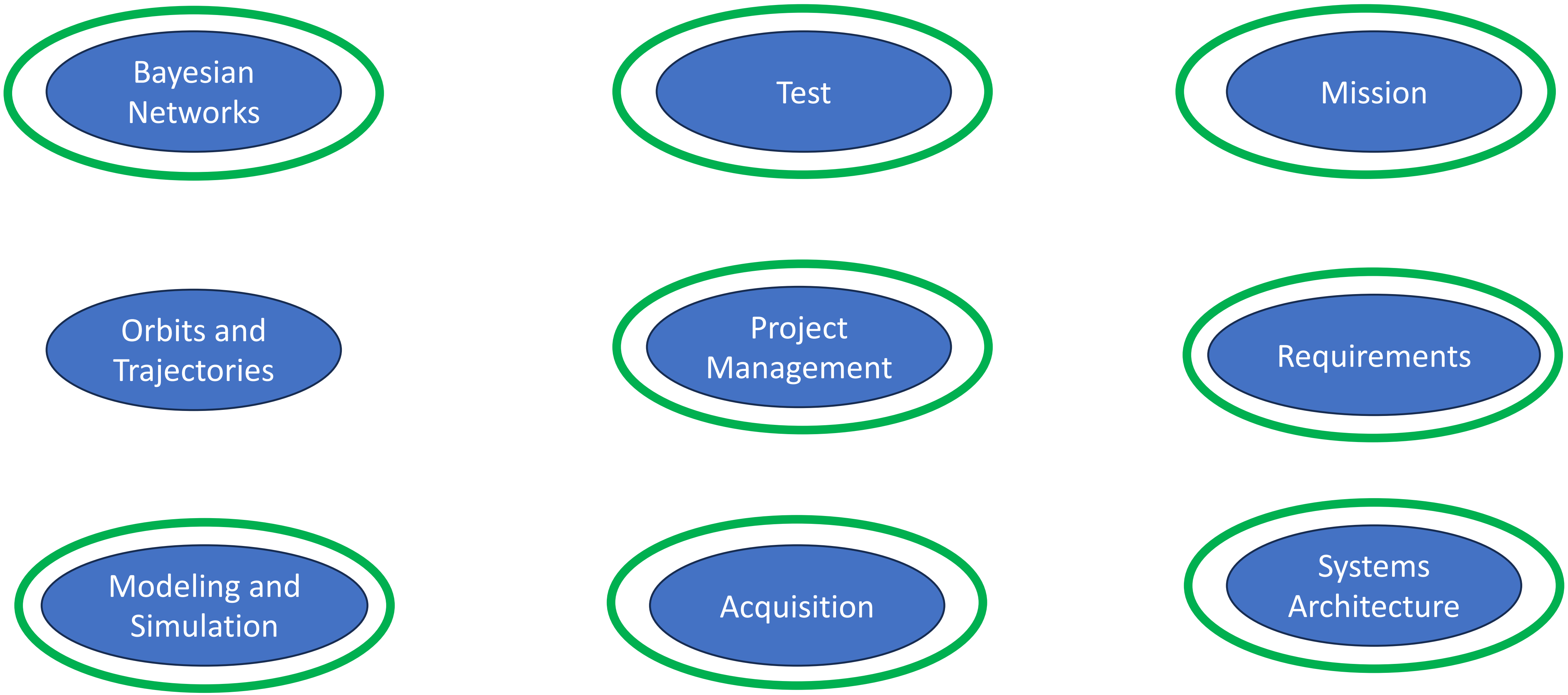

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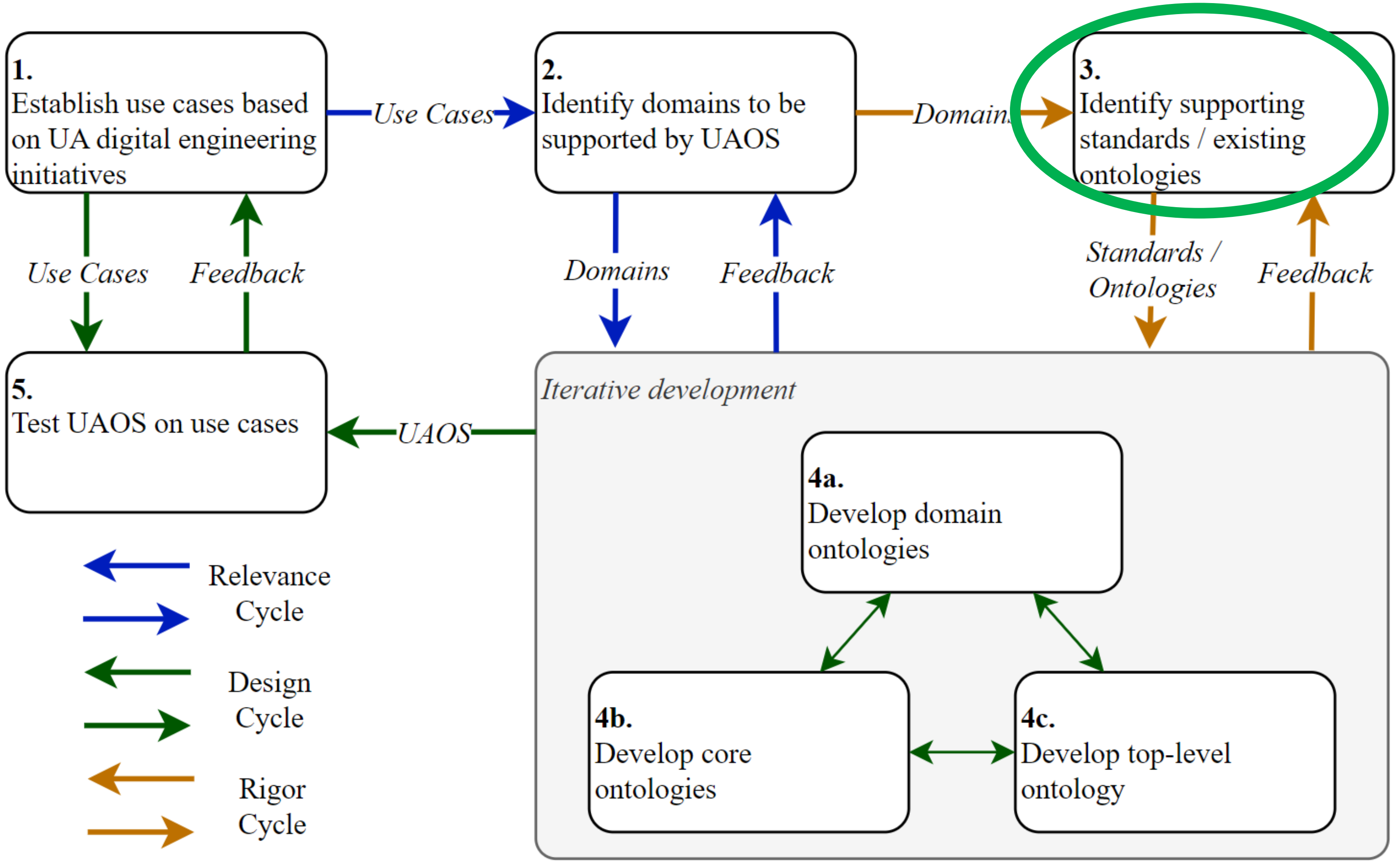

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Methodology

Methodology

The Space Object Ontology

Alexander P. Cox, Christopher K. Nebelecky,
Ronald Rudnicki, William A. Tagliaferri
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CUBRC
Buffalo, NY, USA
alexander.cox@cubrc.org

John L. Crassidis, Barry Smith
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Department of Philosophy
University at Buffalo, State University of New York
Buffalo, NY, USA
johnc@buffalo.edu

Methodology

The Space Object Ontology

Alexander P. Co
Ronald Rudni
Inform

Bu
alexar

electronics MDPI

Article

An Integrated Framework for Traceability and Impact Analysis in Requirements Verification of Cyber–Physical Systems

Alachew Mengist *, Lena Buffoni and Adrian Pop

Methodology

The Space Object Ontology

Alexander P. Co
Ronald Rudni
Inform
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electronics

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PROMONT – A Project Management Ontology as a Reference for Virtual Project Organizations

Sven Abels[3], Frederik Ahlemann[2], Axel Hahn[1], Kevin Hausmann[1], and Jan Strickmann[4]

Methodology

The Space Object Ontology

Alexander P. Co
Ronald Rudni
Inform

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alexar

electronics

MDPI

Article

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in Requ

Alachew Me

PROMONT – A Project Management Ontology as a Reference for Virtual Project Organizations

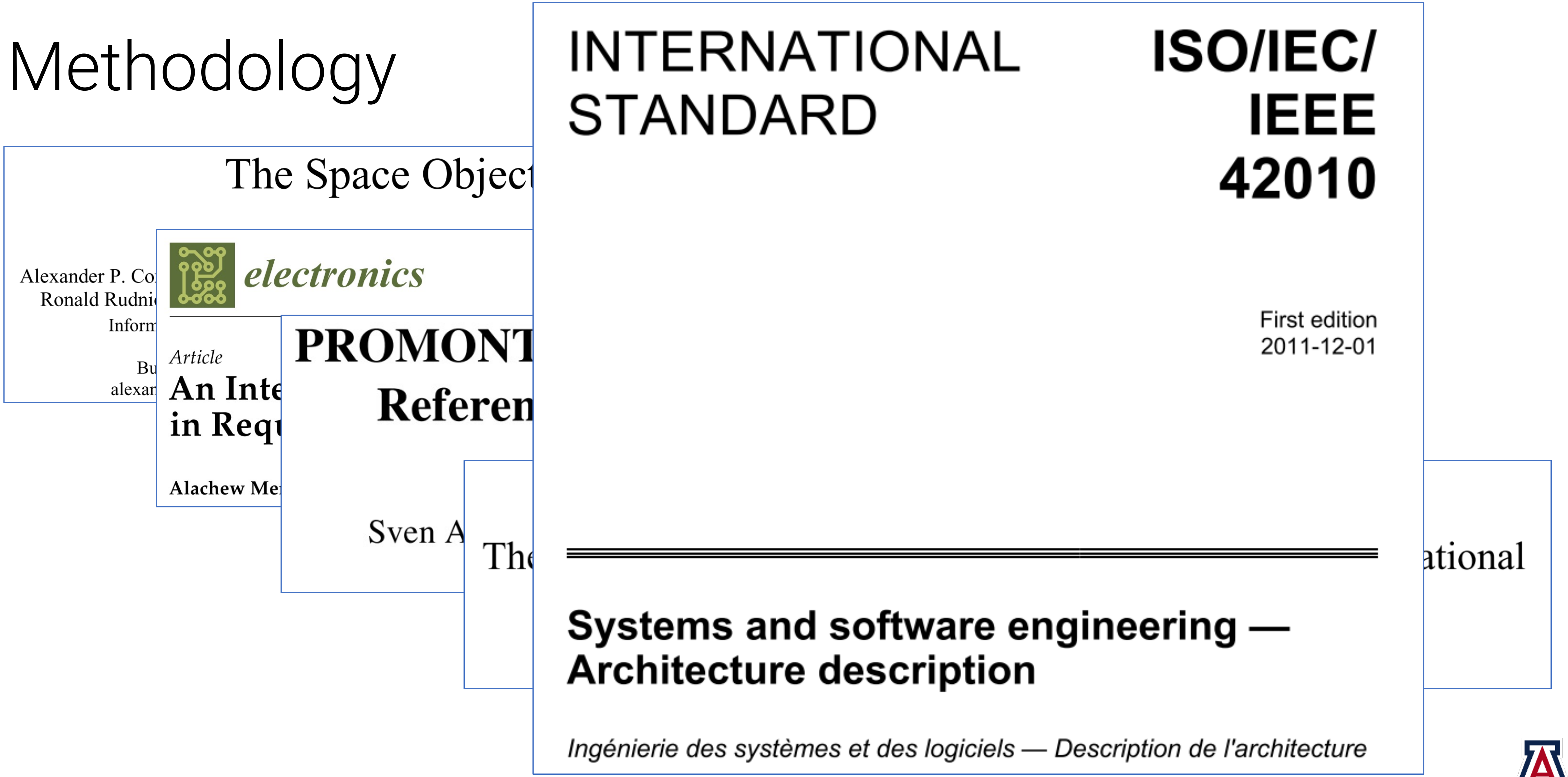
Sven A

17th Annual Conference on Systems Engineering Research (CSER)

The Ontology of Systems Engineering: Towards a Computational Digital Engineering Semantic Framework

Douglas Orellana[a]*, William Mandrick[a]

Methodology



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Methodology

The Space Object

Alexander
Ronald

INTERNATIONAL STANDARD

ISO/IEC/IEEE 42010

dition
12-01

Systems and software engineering — Architecture description

Ingénierie des systèmes et des logiciels — Description de l'architecture

ational

Received: 21 April 2018 | Revised: 4 June 2018 | Accepted: 27 July 2018

DOI: 10.1002/sys.21463

RESEARCH PAPER

WILEY

A mathematical model of verification strategies

Alejandro Salado PhD[1] | Hanumanthrao Kannan PhD[2]

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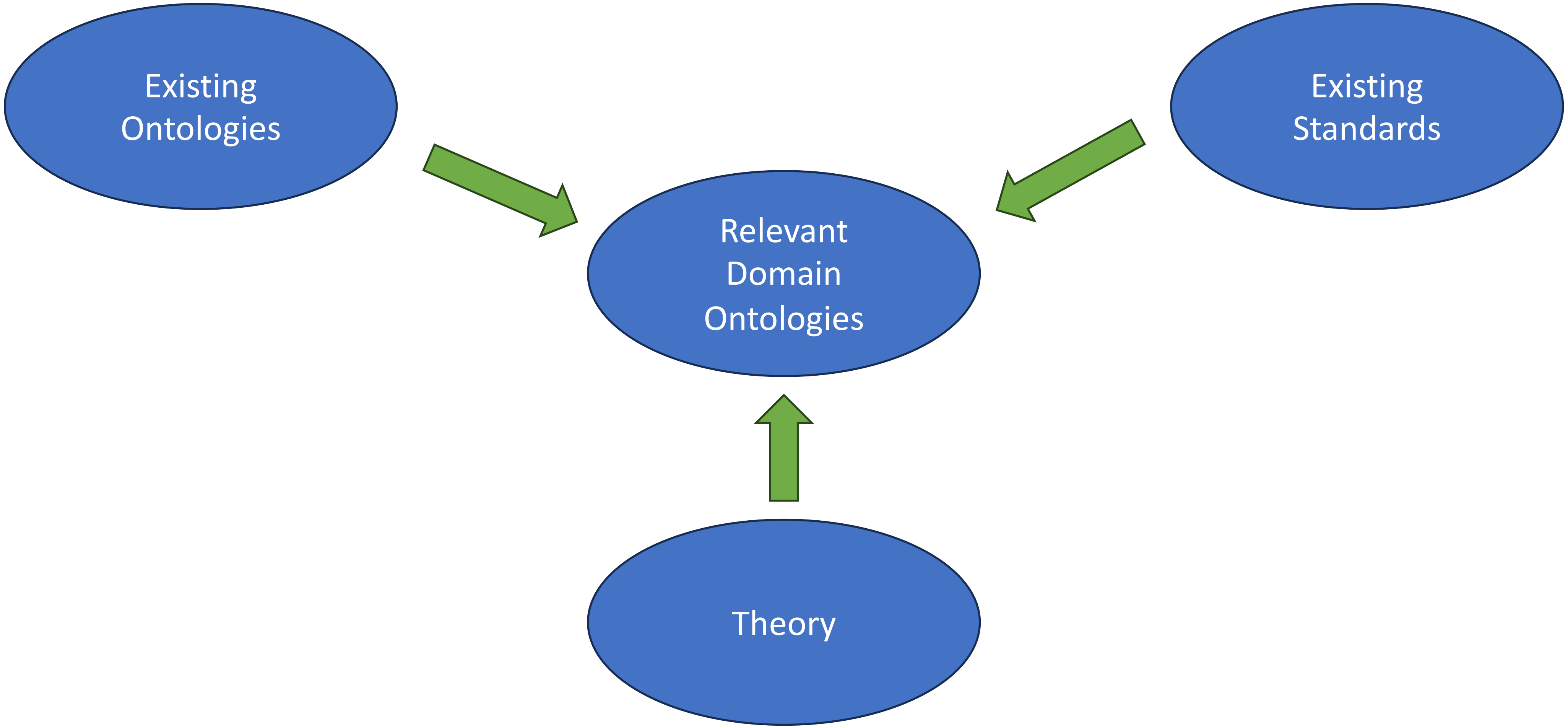
Methodology

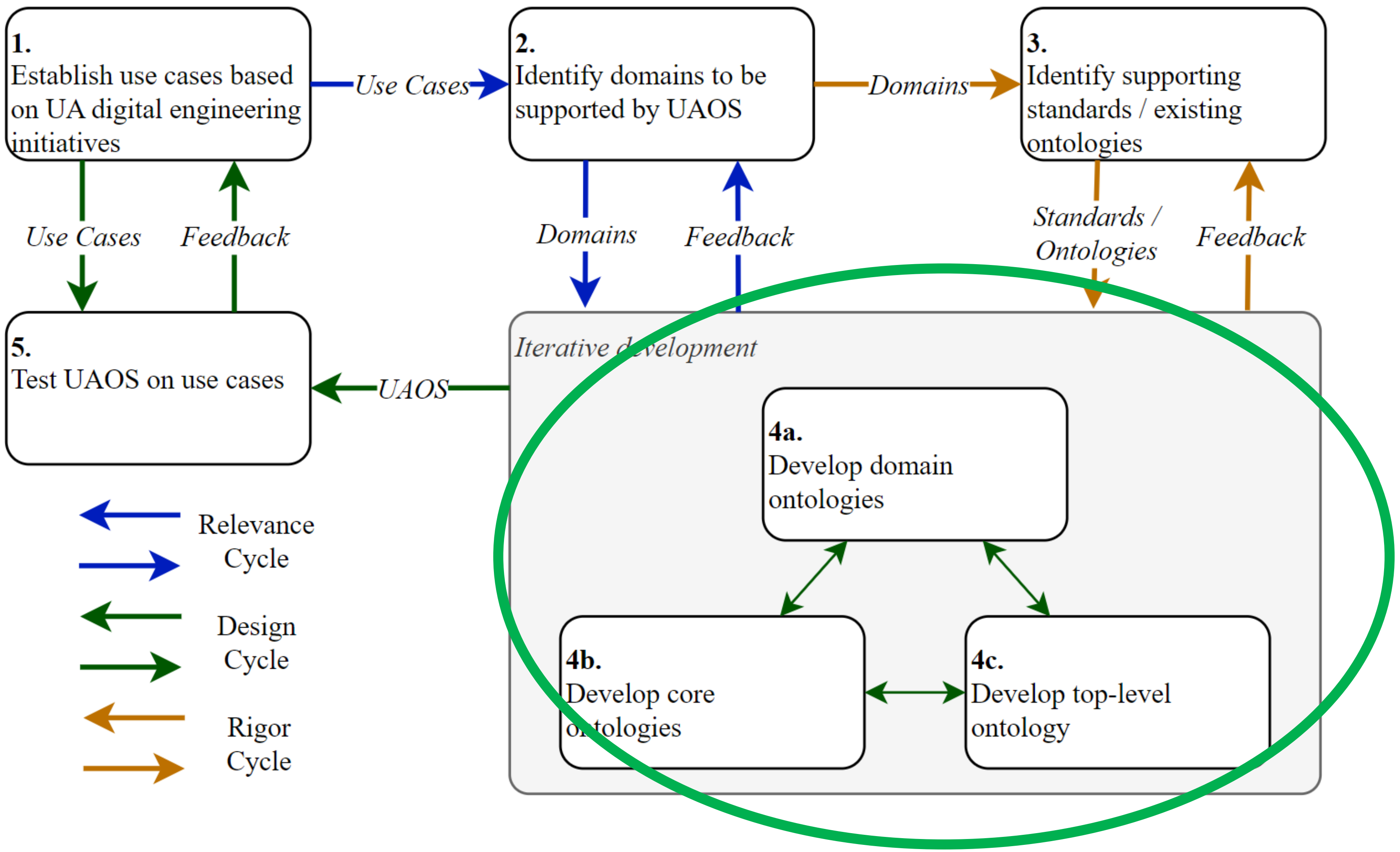


Methodology

How do we capture all of these concepts?

- How do we structure these concepts consistently?
- In what language do we capture this?

Methodology



Methodology

Consistency

- Use a foundational ontology
- Identify and capture repeating patterns

Methodology

Consistency

- Use a foundational ontology
- Identify and capture repeating patterns (Core)

The MIT Press

Building Ontologies with Basic Formal Ontology

Robert Arp, Barry Smith, and Andrew Spear

CUBRC

An Overview of the Common Core Ontologies

12 February 2019

Prepared by:
CUBRC, Inc.
4455 Genesee St., Buffalo, NY 14225
POC: Ron Rudnicki, Senior Research Scientist
716-204-5208

Methodology

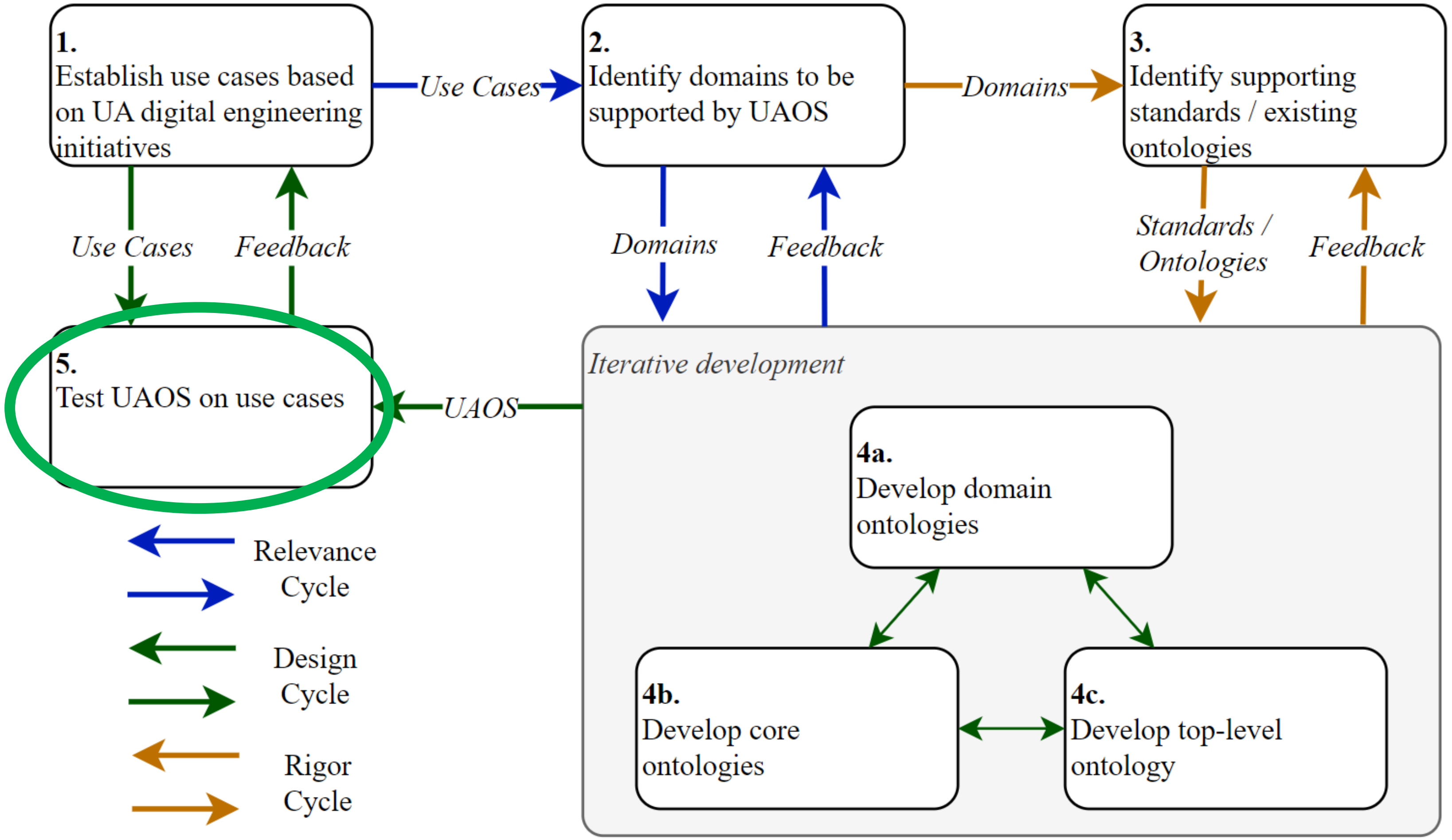
Ontological Modeling Language (OML)

- Thin extension to OWL 2 DL
- Developed as part of the OpenCAESAR initiative (JPL)
- Enables reification of relations
- Allows users to ‘bundle’ descriptions and apply the Closed-World Assumption (CWA)
- Convenient Eclipse-based tool (OML Rosetta) – open-source!
- We can use Semantic Web Rule Language (SWRL) and SPARQL

opencaesar/**oml-rosetta**

An Eclipse IDE that supports OML natively

Methodology



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Supporting Work and Use Cases

Overviews

- J. Gregory and A. Salado, “A Digital Engineering Factory for Students,” in CSER, Tucson, AZ, USA, 2024.
- J. Gregory and A. Salado, “The Digital Engineering Factory: Considerations, Current Status, and Lessons Learned,” in INCOSE International Symposium, Dublin, Ireland, 2024.

Mars rover student project

- J. Gregory and A. Salado, “Implementing a Student Rover Design Exercise in the Digital Engineering Factory,” in IEEE Aerospace Conference, Big Sky, MT, USA, 2024.

Cubesat verification

- J. Gregory and A. Salado, “Spacecraft Test and Evaluation using Semantic Web Technologies,” in AIAA SciTech, Orlando, FL, USA, 2024.

Bayesian representation of a verification strategy

- J. Gregory and A. Salado, “Model-Based Verification Strategies Using SysML and Bayesian Networks,” in CSER, Hoboken, NJ, USA, 2023.
- J. Gregory and A. Salado, “A Semantic Approach to Spacecraft Verification Planning using Bayesian Networks,” in IEEE Aerospace Conference, Big Sky, MT, USA, 2024.

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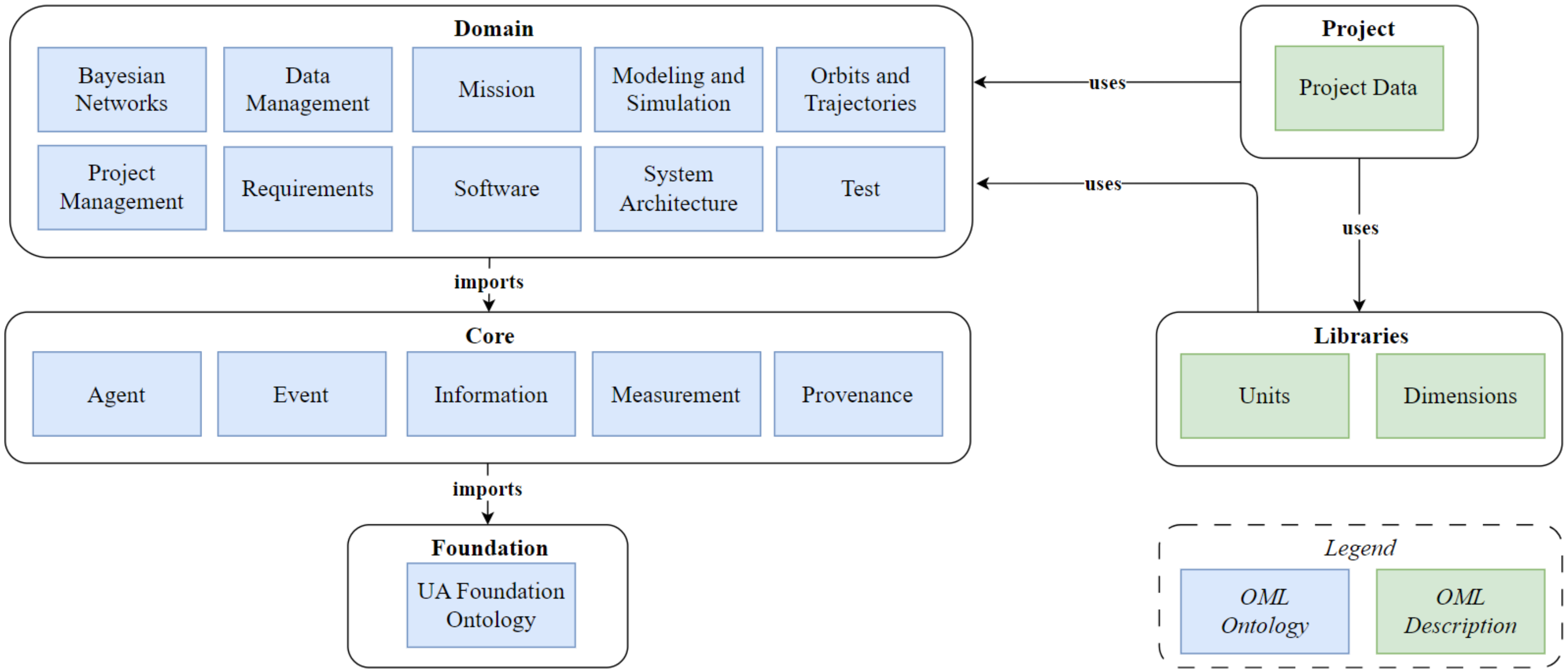
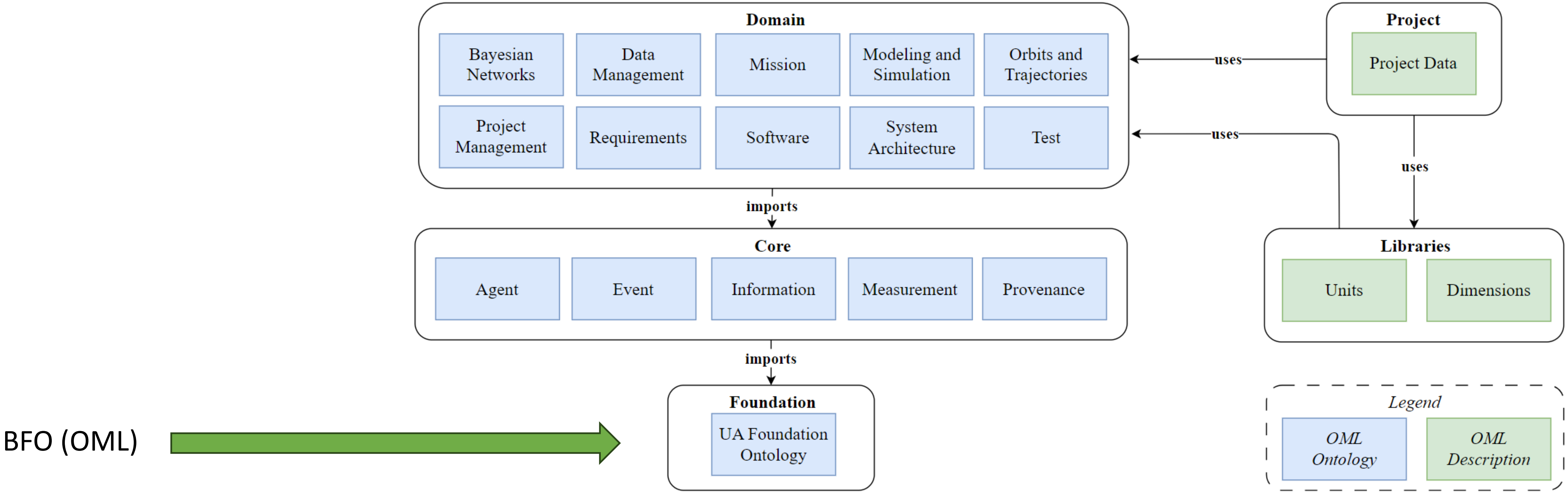
University of Arizona Ontology Stack (UAOS)



University of Arizona Ontology Stack (UAOS)



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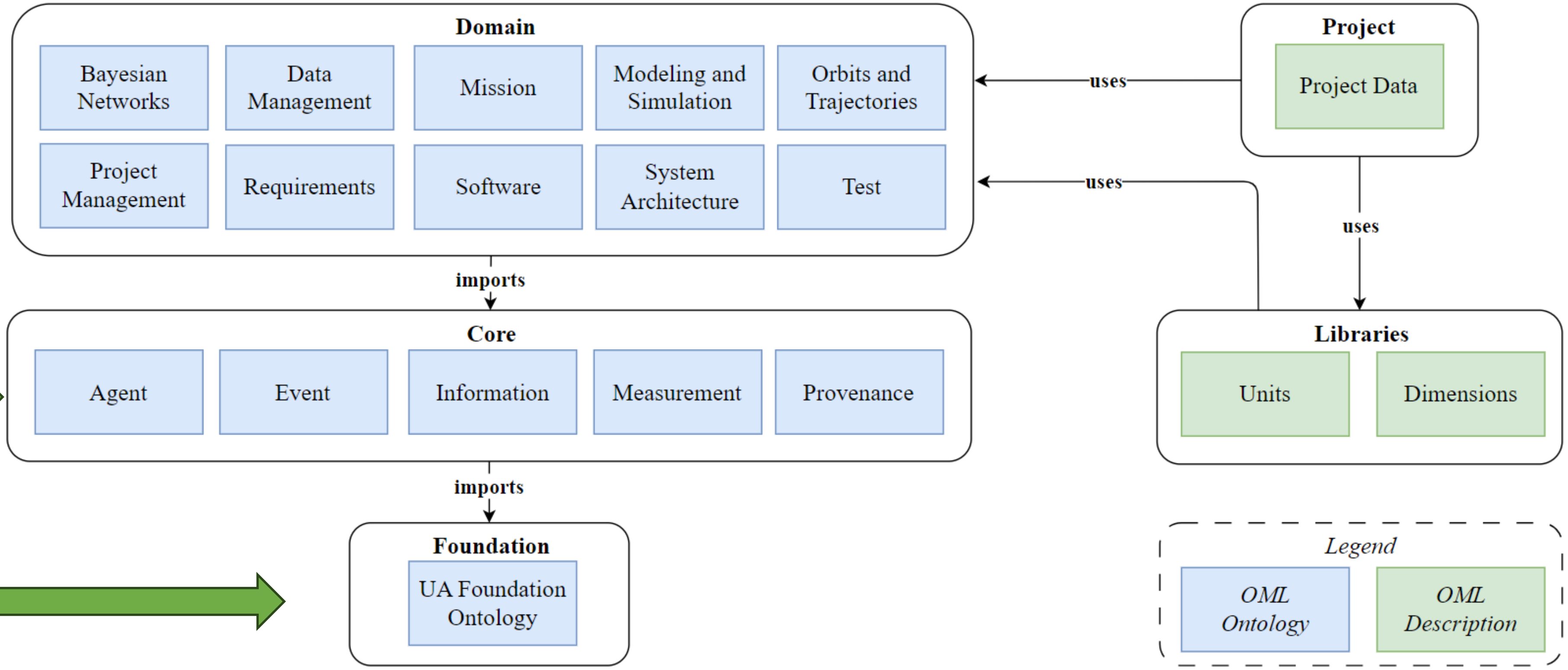
University of Arizona Ontology Stack (UAOS)

Common Core (OML)
PROV-N [1]

BFO (OML)



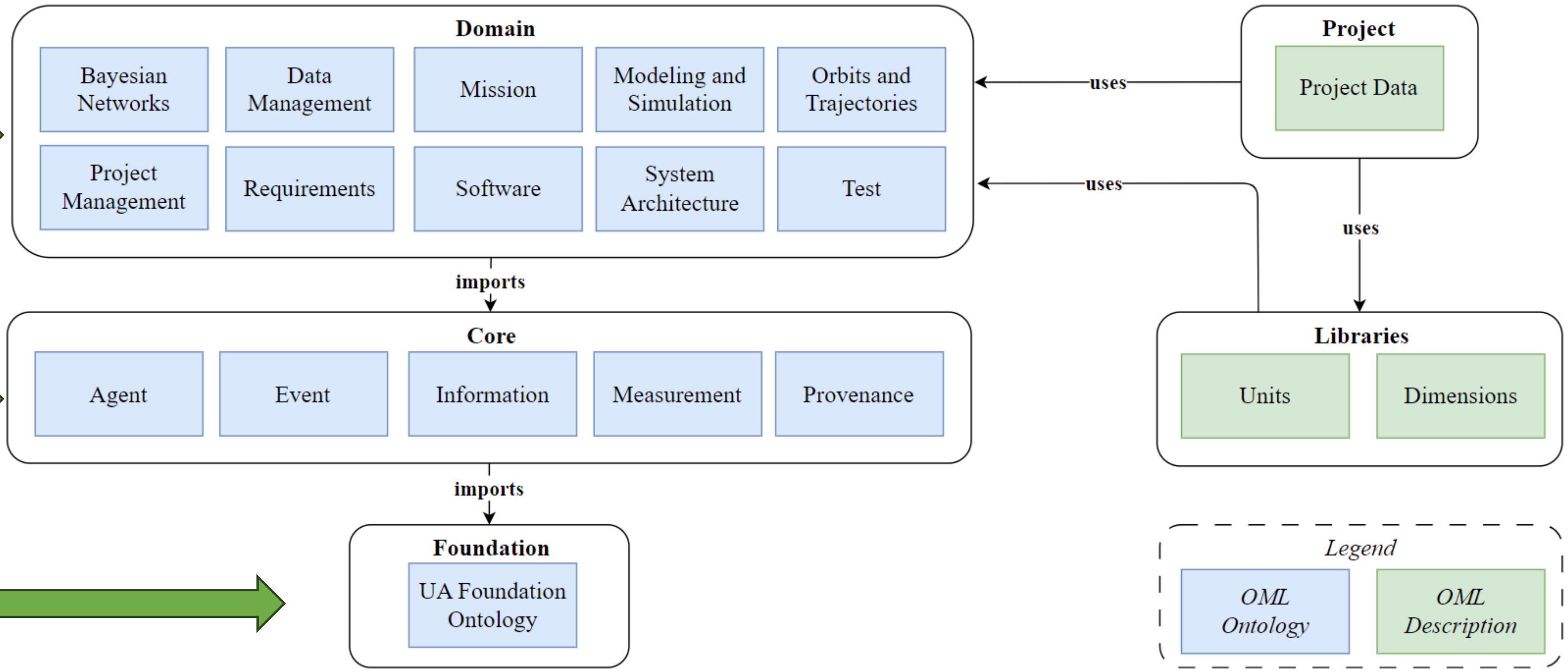
[1] Moreau, L., Missier, P., Cheney, J., & Soiland-Reyes, S. (2013). PROV-N: The Provenance Notation. *W3C Recommendation*, *April*, 1–34. http://www.w3.org/TR/2013/REC-prov-n-20130430

University of Arizona Ontology Stack (UAOS)

Existing Ontologies
Existing Standards
Theory

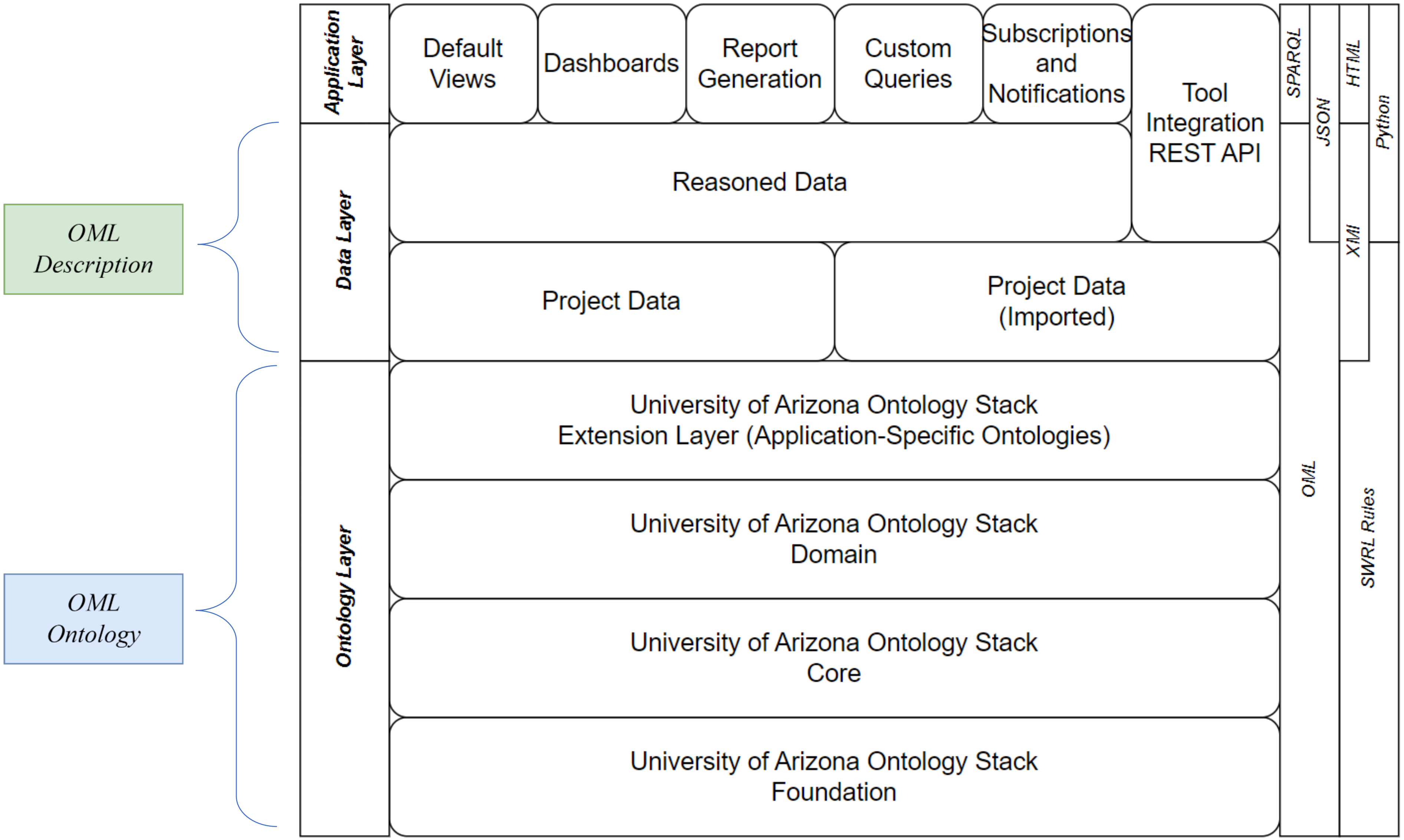
Common Core (OML)
PROV-N [1]

BFO (OML)



[1] Moreau, L., Missier, P., Cheney, J., & Soiland-Reyes, S. (2013). PROV-N: The Provenance Notation. *W3C Recommendation*, *April*, 1–34. http://www.w3.org/TR/2013/REC-prov-n-20130430

University of Arizona Ontology Stack (UAOS)



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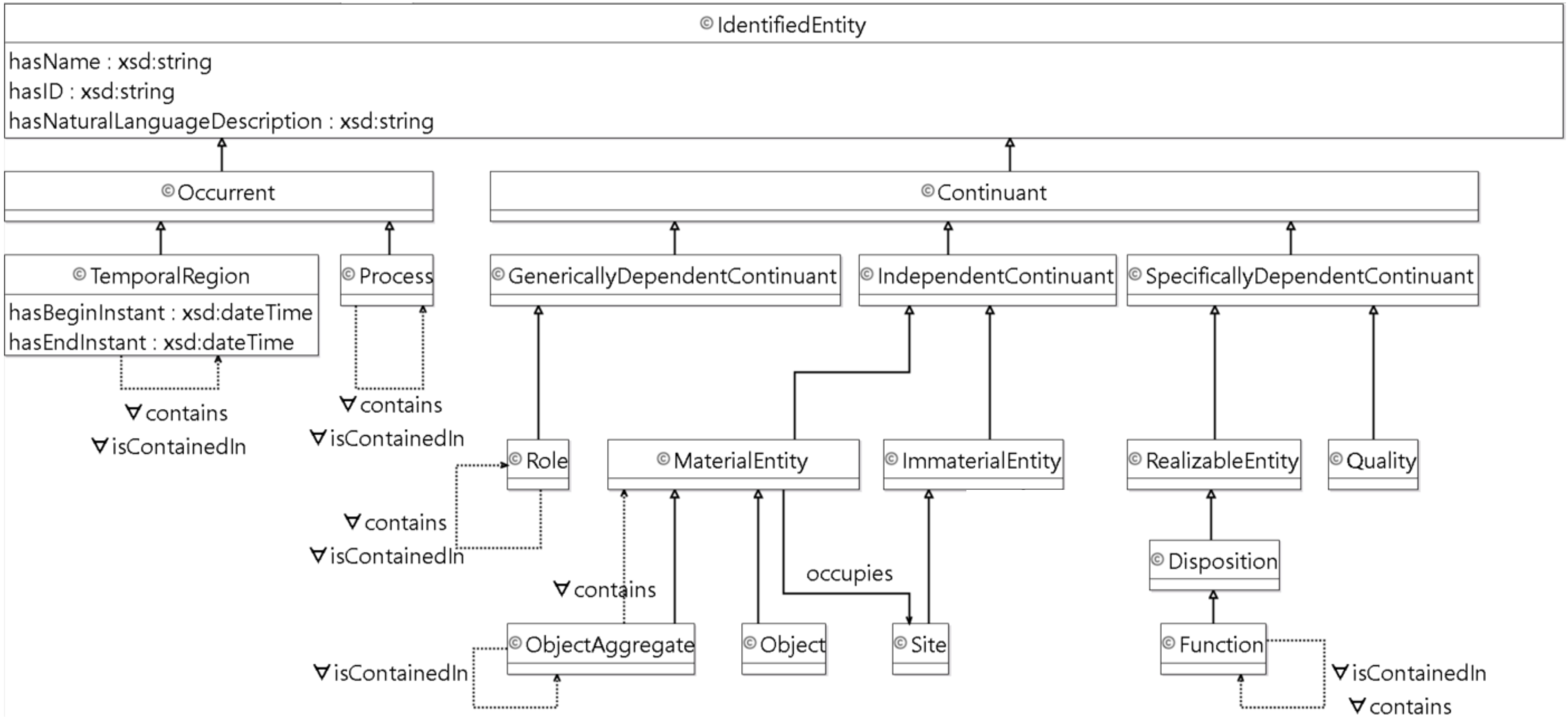
University of Arizona Ontology Stack (UAOS)

UA foundation Ontology – based on BFO



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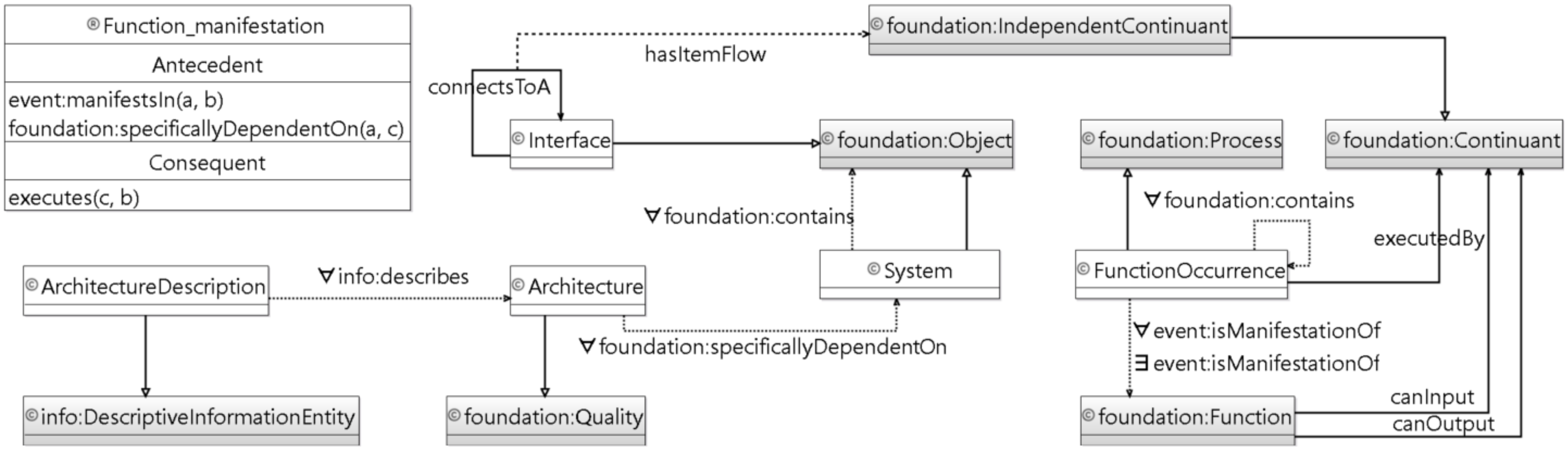
University of Arizona Ontology Stack (UAOS)
System Architecture Ontology – based on ISO 42010



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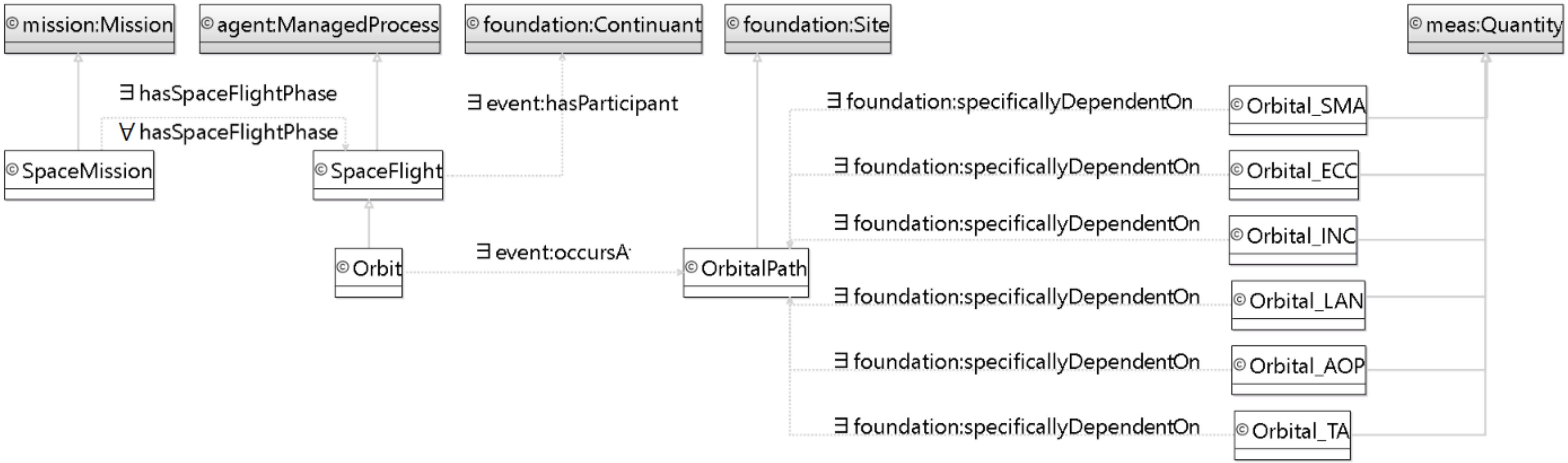
University of Arizona Ontology Stack (UAOS)

Orbits and Trajectories Ontology – based on SOO



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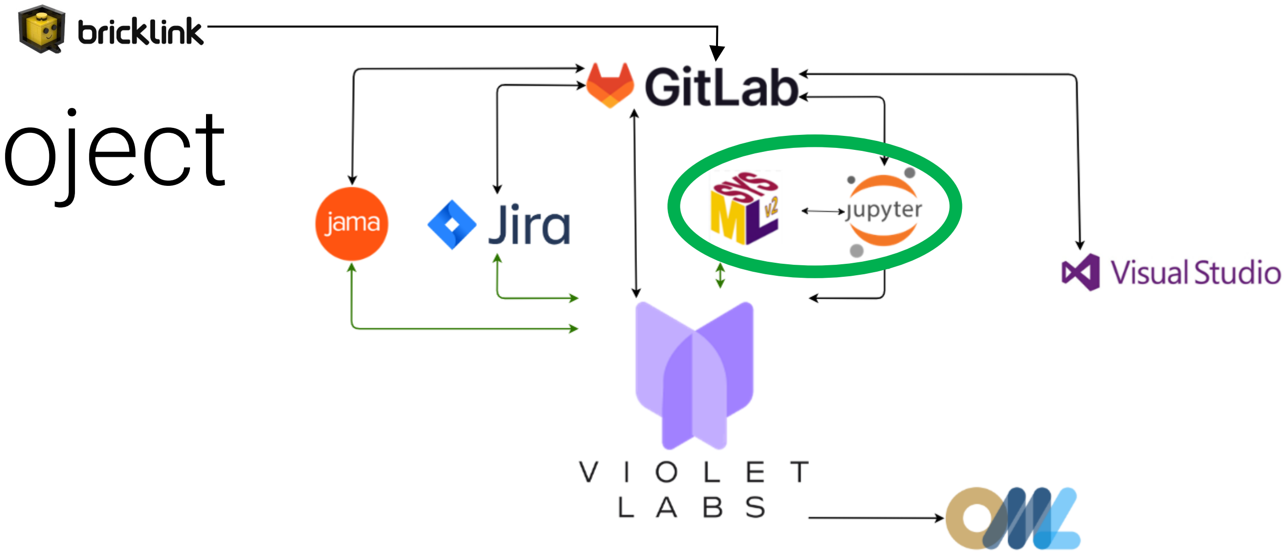
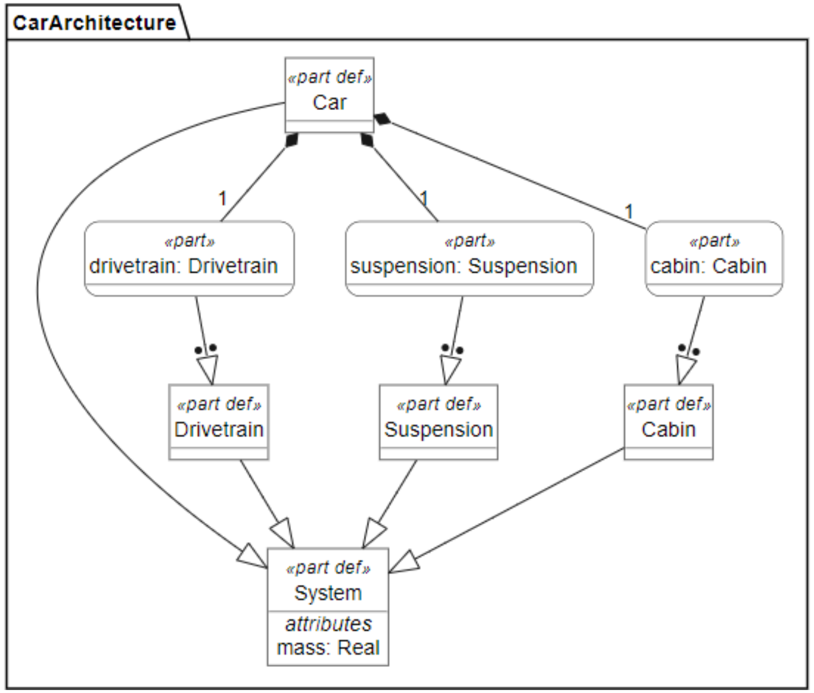
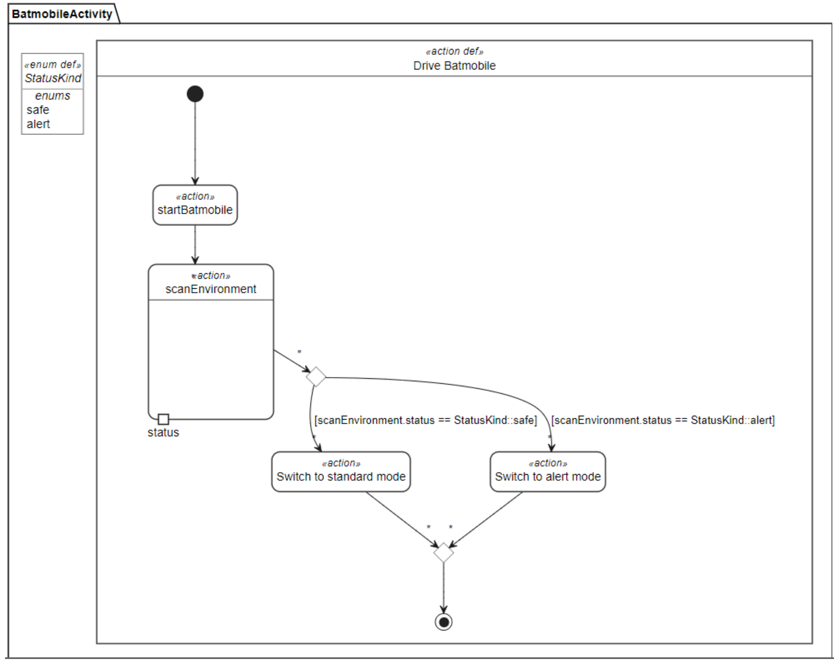
Applications – Student Project



- Manage Architecture (*SysML v2 Manual*)
- Manage Test Plans (*SysML v2 Manual*)





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Applications – Student Project

Tasks Table

TaskID	Description	StudentName	Outputs
SIE2501-10	Import SYSMLV2 Files into Violet	Emily Nguyen	
SIE2501-16	Create a Verification Plan for the System	Aisha Thompson	Rover_Verification_Strategy
SIE2501-17	Create a detailed Hardware design (CAD model) for System	Sofia Rivera	SIE250_CADModel
SIE2501-22	Construct Rover and all Hardware Components	Hassan Johnson	
SIE2501-23	Integrate all hardware and software to complete system architecture	Hassan Johnson	
SIE2501-24	Run Verification Tests according to Verification Plan	Aisha Thompson	
SIE2501-27	Complete mass analysis verification activity	Michael Carter	
SIE2501-3	Define System Requirements	Michael Carter	Terrain Requirement, Trash Requirement, Autonomous Requirement, Remote Control Requirement, Cargo Requirement, Spinning Requirement, Mass Requirement
SIE2501-4	Refine Stakeholder Needs	Michael Carter	
SIE2501-7	Create a System Architecture	Sofia Rivera	ProvideRoverPropulsion, Group1_Rover
SIE2501-9	Create and Assign Jira Tasks	Declan Arnold	

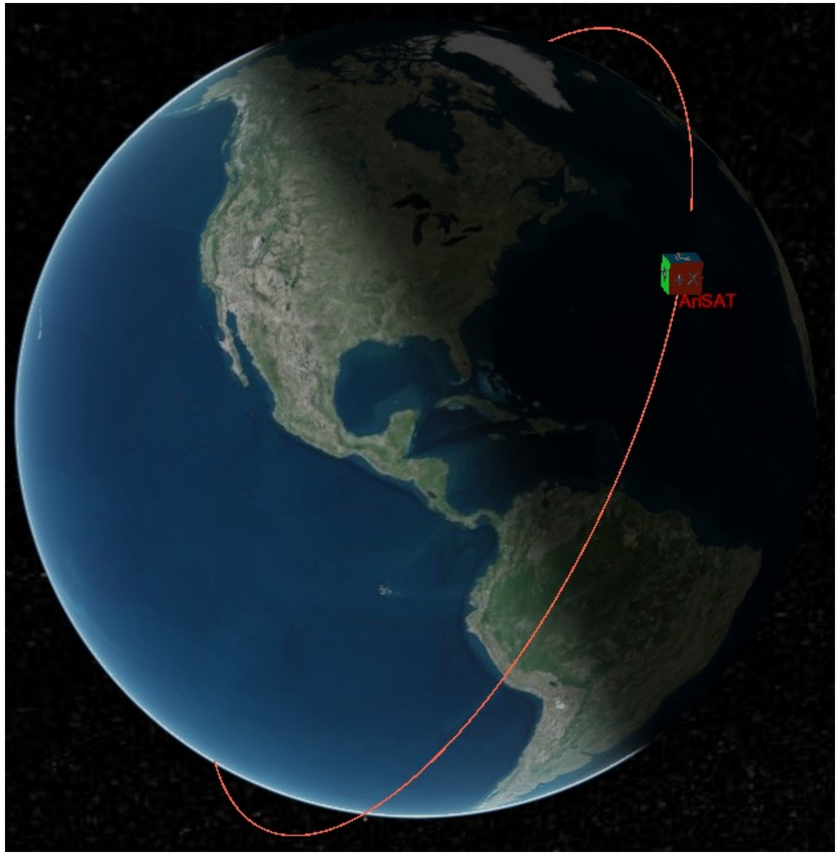
Applications – AIAA SciTech

Requirements ×

http://127.0.0.1:3000/J1_Requirements.html

Summary of Requirements

Requirements				Verification Method		Verification Status
ID	Name	Text	Source	Name	Source	
AriSAT-SYSRQ-1	System Mass Requirement	The system shall have a mass lower than 20 kg	Jama			
AriSAT-SYSRQ-2	Payload Requirement	The system shall measure Earth's gravitational field strength continuously	Jama	EclipseAnalysis	JupyterLab	true
AriSAT-SYSRQ-3	Communications Requirement	The system shall provide Earth's gravitational field strength's measurements to the Ground Station	Jama			
AriSAT-SYSRQ-4	Accuracy Requirement	The system shall measure Earth's gravitational field strength with XYZ accuracy	Jama			



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Applications – Digital TEMP (NEJ)

Rover TEMP Report

Introduction

This document has been generated from the OML descriptions of the Rover sysytem and its associated test program.

Mission Overview

In this section, an overview of the mission is provided. This includes information regarding all mission participants and the environment in which the mission will take place.

Mission	Participant
Rover_Mission	Rover_System
Rover_Mission	MarsOrbiter

Mission	Environment	Environmental Entity
Rover_Mission	Rover_Environment_Nominal	LocalDebris
Rover_Mission	Rover_Environment_Nominal	LocalRadiation

System Overview

In this section, an overview of the system is provided. This includes information regarding all components and functions of the SOI.

System	Subsystem
Rover_System	Rover_Comms
Rover_System	Rover_Mobility

Milestone	Milestone Date	Test	Test Equipment	Acquisition	Acquisition Date
TestMilestoneA	2024-03-18T12:00:00	ElectricalTest_1	Rover_Prototype	Rover_Prototype_Acquisition	2024-03-01T12:00:00
TestMilestoneA	2024-03-18T12:00:00	ElectricalTest_1	ElectricalTestRig	ElectricalTestRig_Acquisition	2024-03-04T12:00:00
TestMilestoneA	2024-03-18T12:00:00	VibrationTest_1	Rover_Prototype	Rover_Prototype_Acquisition	2024-03-01T12:00:00

Contents

An opportunity to improve the status quo for systems engineering

- What are your costliest problems?
- What are your biggest time sinks?
- What are the most valuable things to connect?
- What other opportunities for improvement do you see?
- Help us to help you!

IOF Systems Engineering WG

OAGi

Opportunities and Challenges for a Systems Engineering Ontology

Section 1: Introduction and acknowledgement

This survey is Part 1 of a three-part study. Please read the overview provided below and acknowledge that you are willing to participate in all three parts of this study.

Part 1 (this survey):

You will be asked to write down any opportunities and challenges that you believe are relevant to the deployment of a Systems Engineering ontology in a Systems Engineering environment.

This survey is divided across four sections:

- Section 1 (this page): Introduction and Acknowledgement (approximately 2 mins to complete)
- Section 2: About you (approximately 5 minutes to complete)
- Section 3: Systems Engineering Challenges (approximately 15 minutes to complete)
- Section 4: Systems Engineering Ontology (approximately 15 minutes to complete)

Your responses to this survey will be used anonymously.

What we're doing:

- We created a survey to elicit where the most value lies
- The survey should only take about 30 minutes to complete
- We need ~40 total **SE experts** to have their say

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IOF Systems Engineering WG

OAGi

Opportunities and Challenges for a Systems Engineering Ontology

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- Section 4: Systems Engineering Ontology (approximately 15 minutes to complete)

Your responses to this survey will be used anonymously.

We need your help:

- Are you willing to take the survey?
- Could you recommend ~5 SE experts you respect?
- Would your company be interested in working towards solutions within the IOF?

- Please email us at:
  jlogan@ontogenesis-solutions.com
  joegregory@arizona.edu

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Contents

Conclusions

- UAOS – supporting SWT-enhanced SE!
  - This is Digitalization of SE

- Apply, Evaluate, Refine!
  - DEF: Large-scale class project
  - Digital TE: DoD TEMP Data
Extend Bayesian Capabilities

- IOF SE Survey
  - Please reach out if you can help

THANK **YOU**

joegregory@arizona.edu