

Semantically Enabled Dashboards to Support Systems Engineers

INCOSE IS – 7/30/2025

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

Co-authors: Visalakshi Iyer, Dr. Alejandro Salado



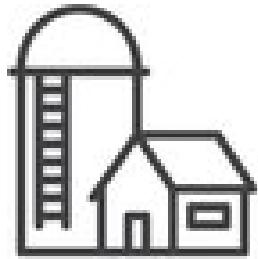
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Agenda

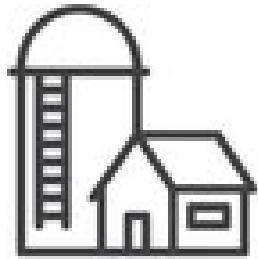
- Digital Engineering at UA
- Our Approach to DE
- DEF Workflow Example
- Next Steps

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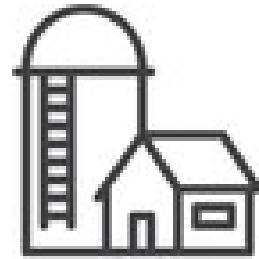
Digital Engineering



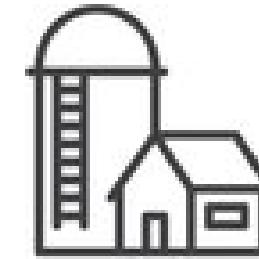
Software



Electronics

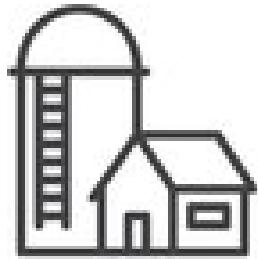


Aerodynamics

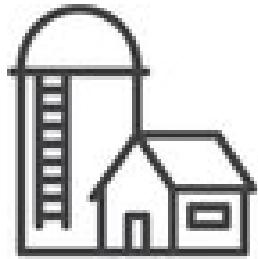


Mechanical

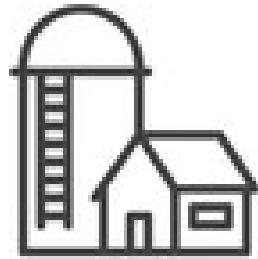
Digital Engineering



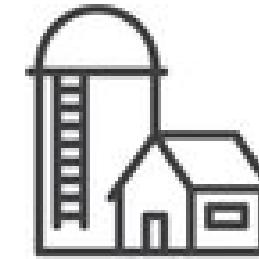
Software



Electronics



Aerodynamics

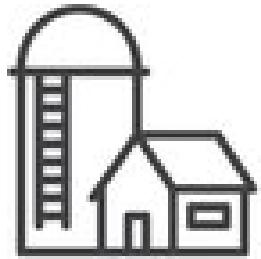


Mechanical

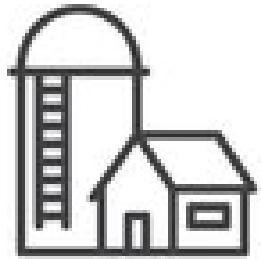
This is not good enough in **industry**!

But what do we do across engineering **curricula**?

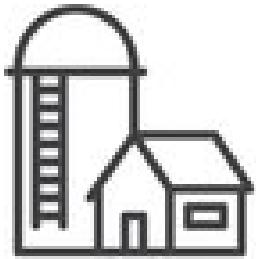
Digital Engineering



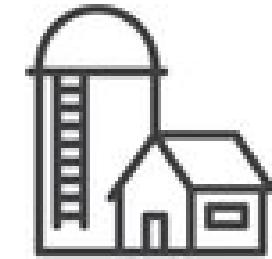
SIE 431



SFWE 302

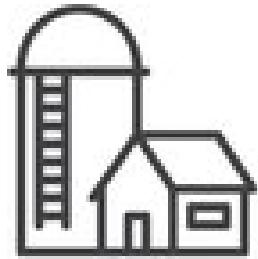


SIE 458

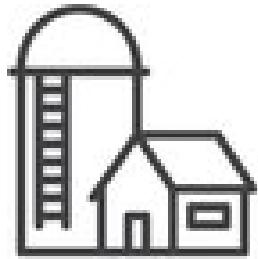


SFWE 403

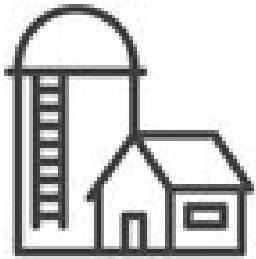
Digital Engineering



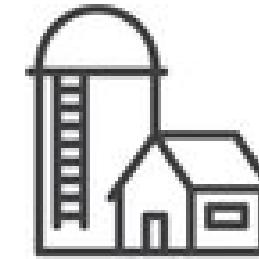
SIE 431



SFWE 302



SIE 458

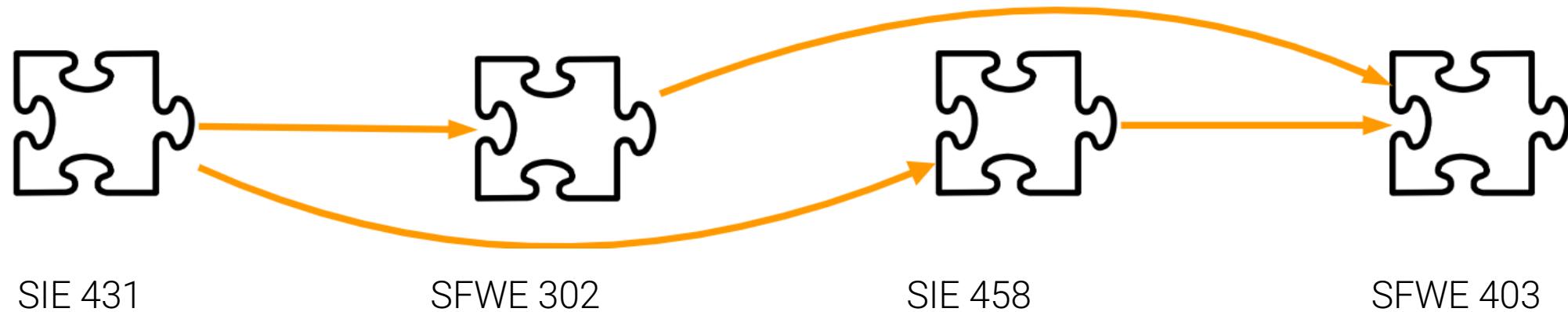


SFWE 403

Engineering courses are **silos**

- No downstream effects
- Data / effort duplication
- Limited scope for collaboration

Digital Engineering



Engineering courses are **silos**

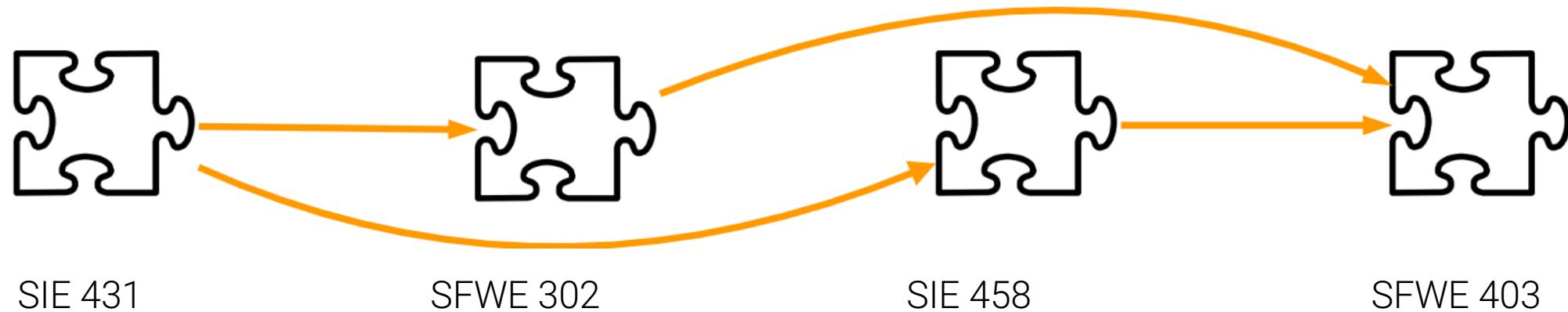
- No downstream effects
- Data / effort duplication
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Courses supported by **Digital Environment**

- Observe downstream effects
- Creation and management of Digital Thread
- Significant project opportunities

Digital Engineering



Engineering courses are **silos**

- No downstream effects
- Data / effort duplication
- Limited scope for collaboration



Courses supported by **Digital Environment**

- Observe downstream effects
- Creation and management of Digital Thread
- Significant project opportunities
- **BONUS:** Digital Env to explore **digitalization**

- Digital Engineering at UA
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DE at UA: Our Approach



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DE at UA: Our Approach

Technical Interoperability (DEF)

How do tools talk to each other?

DE at UA: Our Approach

Technical Interoperability (DEF)

How do tools talk to each other?

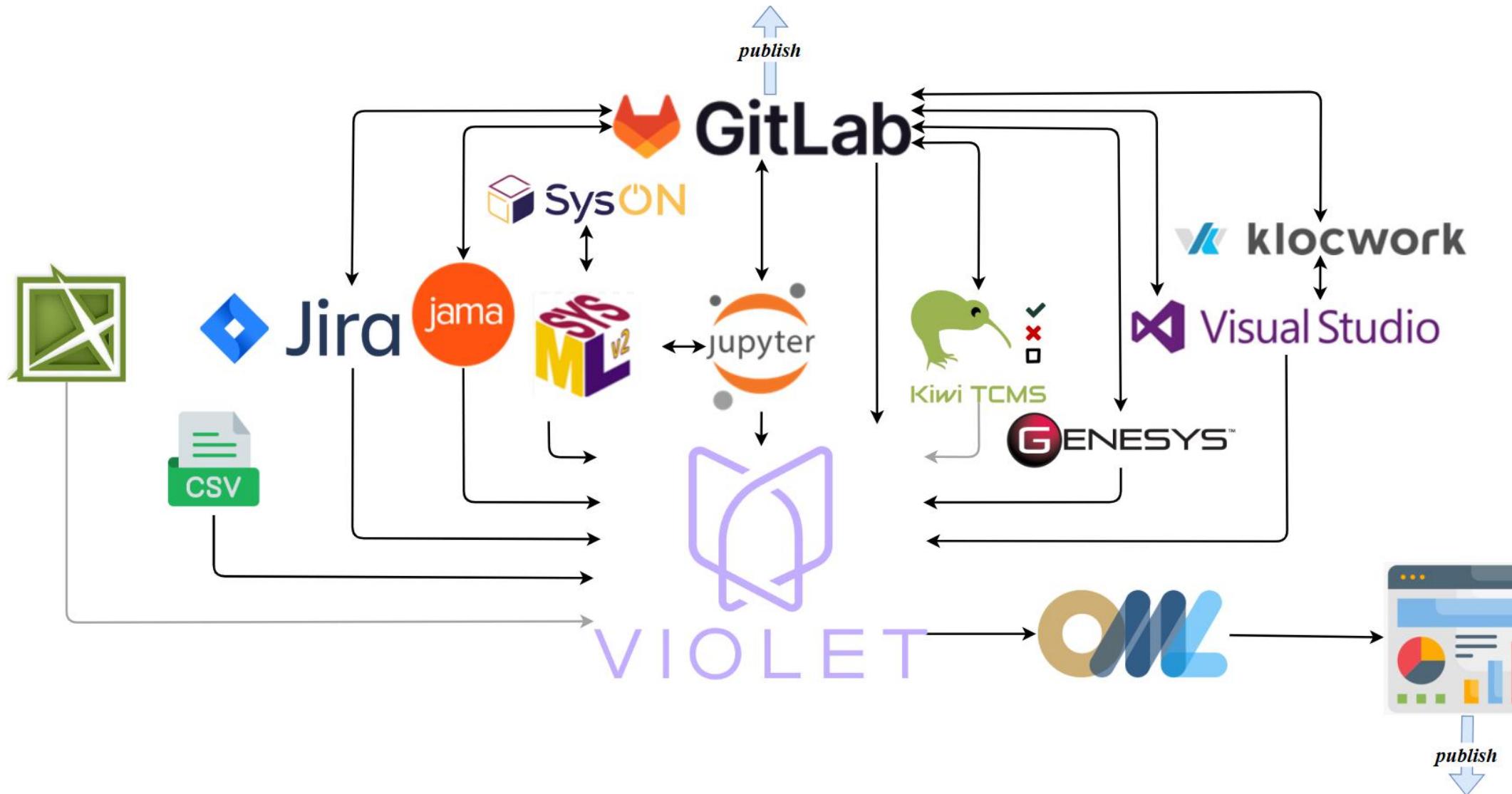
Data Interoperability (UAOS)

How do tools talk the same language?



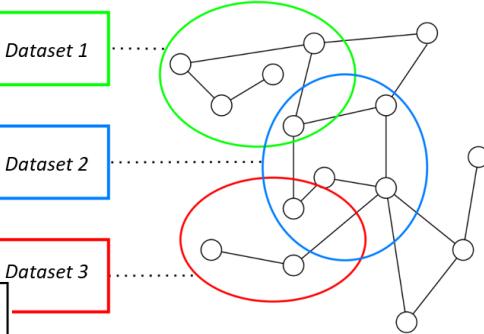
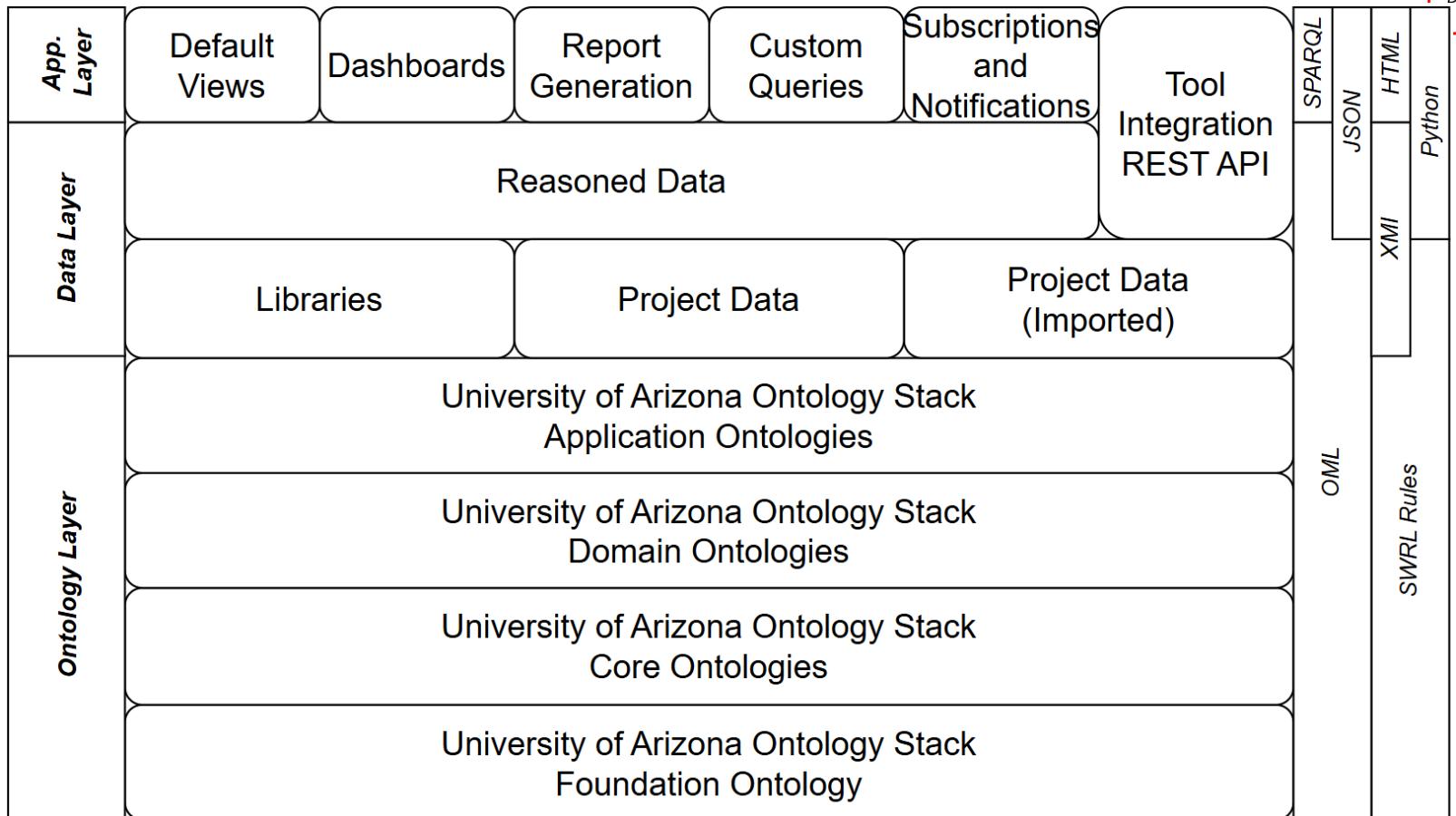
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DE at UA: The Digital Engineering Factory (DEF)



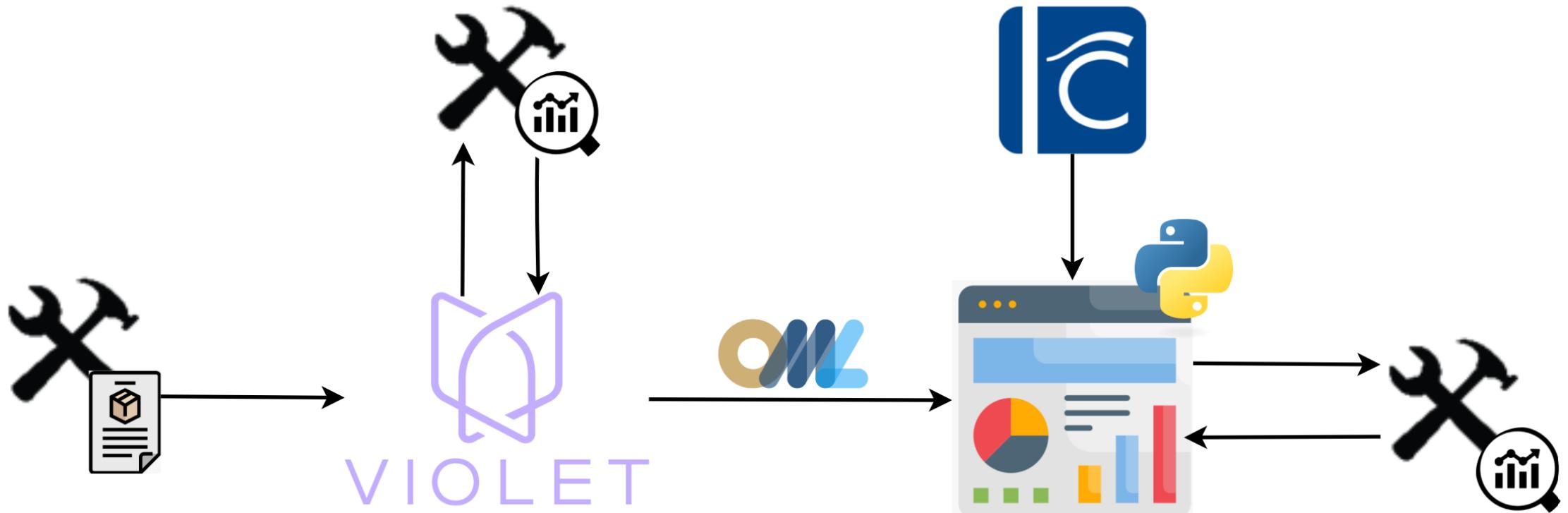
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DE at UA: The UA Ontology Stack (UAOS) [7]



- Digital Engineering at UA
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DE at UA: General Workflow



DE at UA: Example Workflow

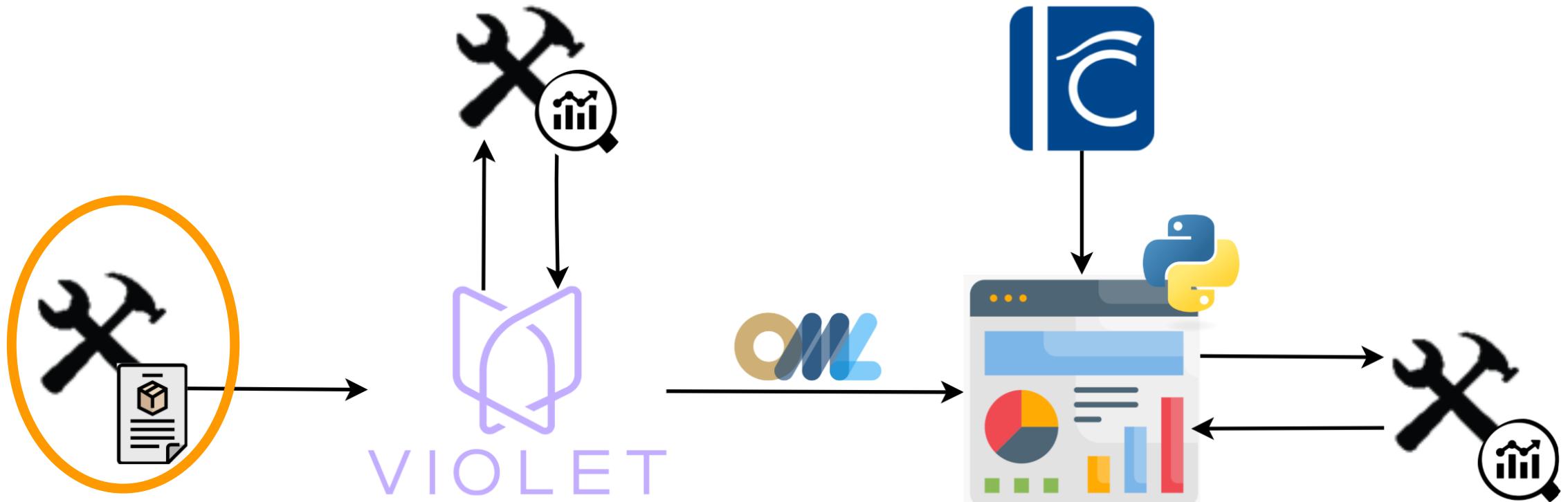


Notional cubesat, **Cloud Analysis and Tracking Satellite** (CATSAT)

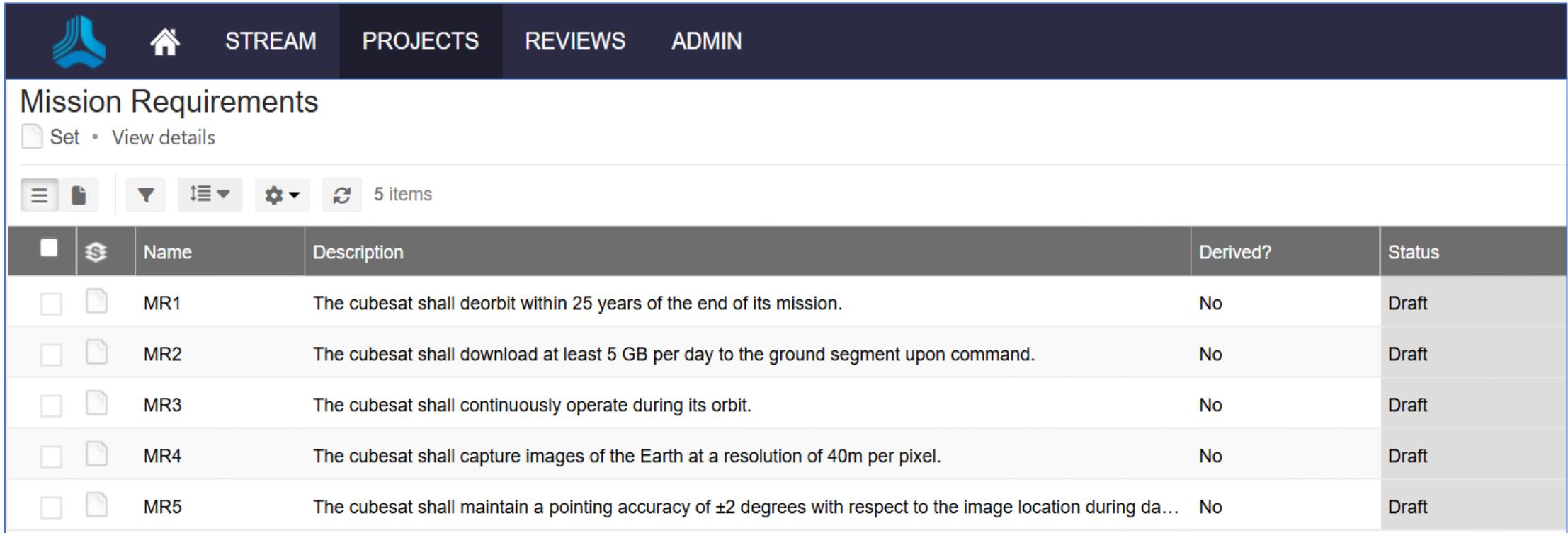
- Ascertain cloud types and monitor their movement from low-Earth orbit (LEO).
- The CATSAT mission has a corresponding set of mission requirements.
- 2U cubesat, dimensions of 20cm x 10cm x 10cm.
- One unit will contain the payload, a high-resolution camera.
- The other will contain the supporting systems.

Orbital Element	Value	Unit
Altitude	465	km
Inclination	55	degrees
Eccentricity	0	n/a
Longitude of Ascending Node	10	deg
Argument of Periapsis	0	deg

DE at UA: Example Workflow



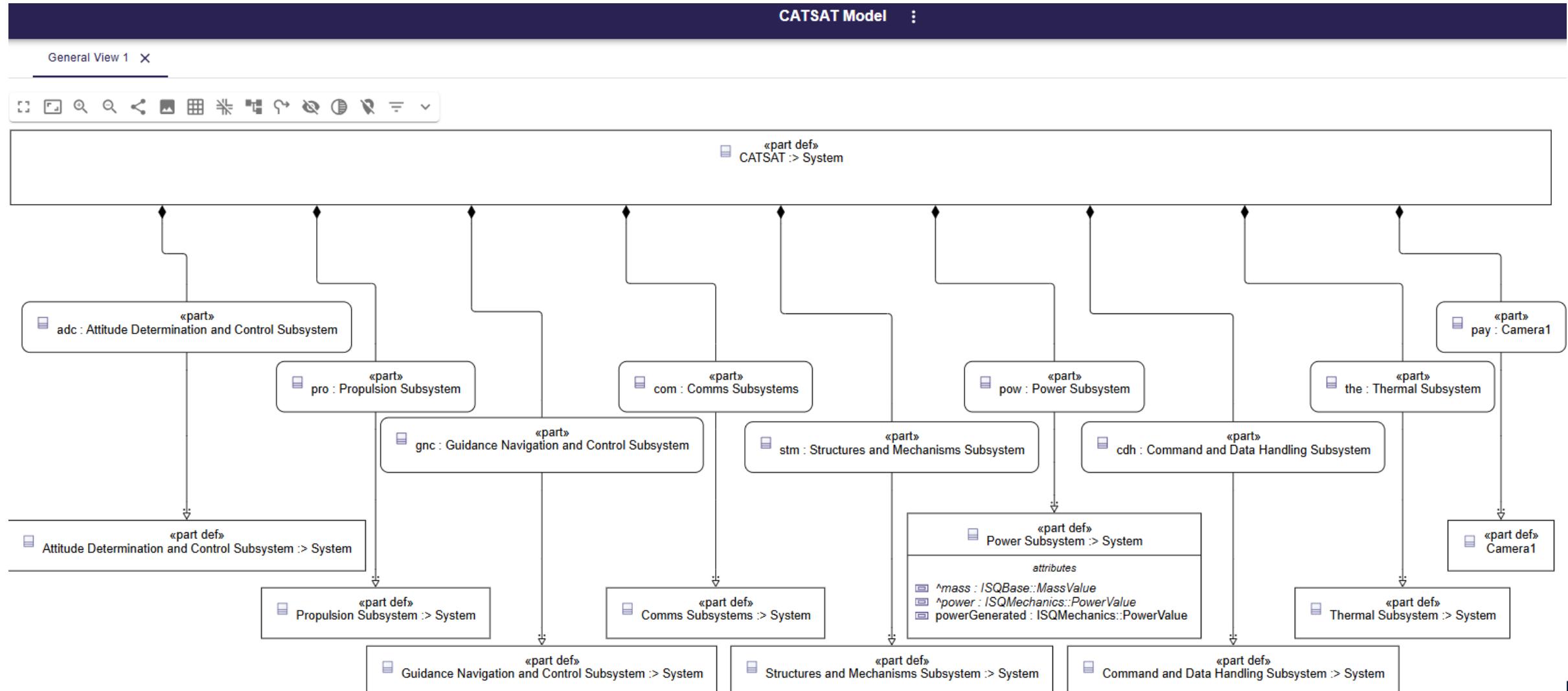
DE at UA: Example Workflow



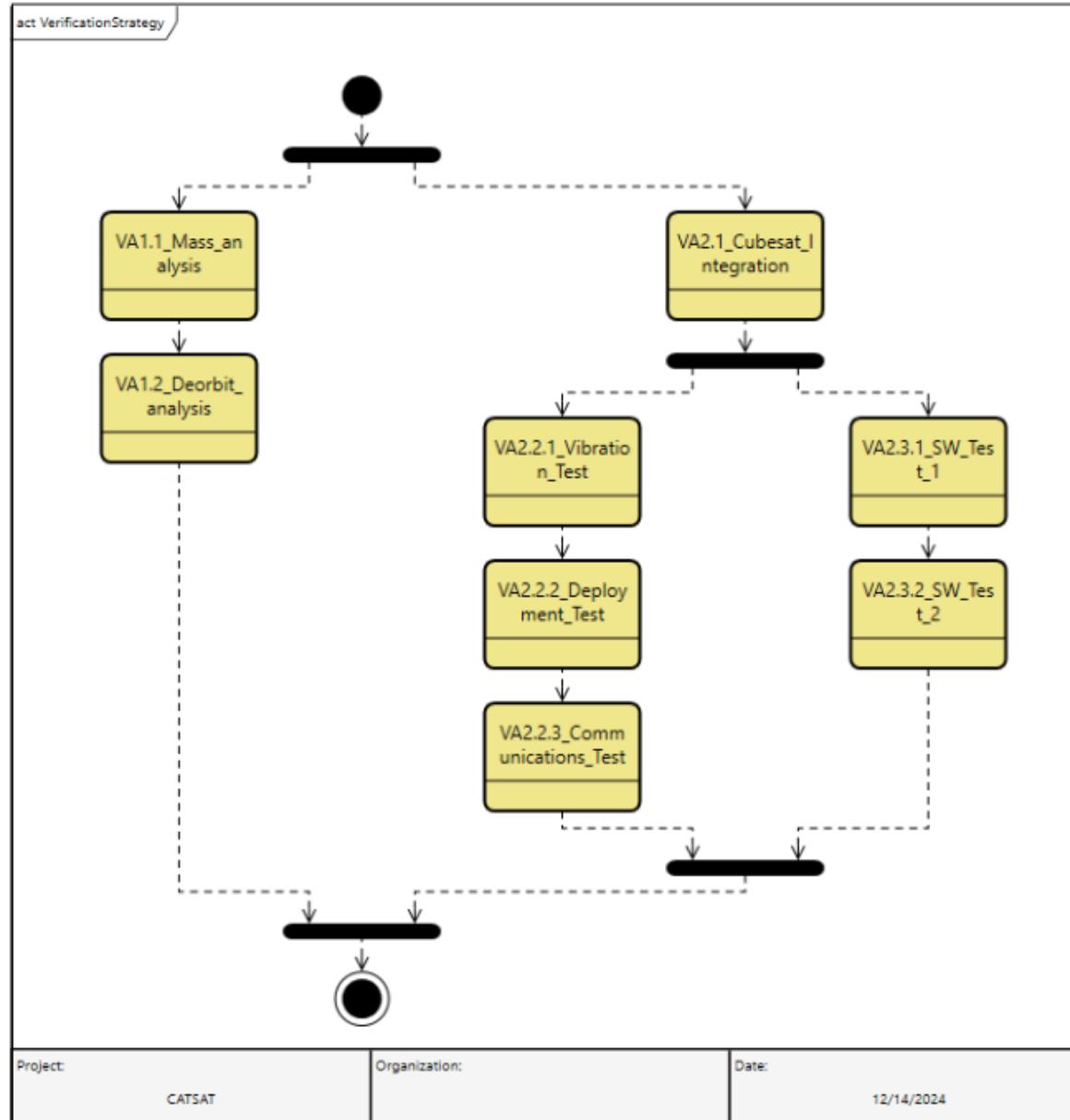
The screenshot shows a software interface for managing mission requirements. The top navigation bar includes icons for a house, Stream, Projects, Reviews, and Admin. The main section is titled "Mission Requirements" and displays a list of 5 items. Each item has a checkbox, a file icon, a name, a description, a "Derived?" column, and a "Status" column. The requirements are:

	Name	Description	Derived?	Status
<input type="checkbox"/>	MR1	The cubesat shall deorbit within 25 years of the end of its mission.	No	Draft
<input type="checkbox"/>	MR2	The cubesat shall download at least 5 GB per day to the ground segment upon command.	No	Draft
<input type="checkbox"/>	MR3	The cubesat shall continuously operate during its orbit.	No	Draft
<input type="checkbox"/>	MR4	The cubesat shall capture images of the Earth at a resolution of 40m per pixel.	No	Draft
<input type="checkbox"/>	MR5	The cubesat shall maintain a pointing accuracy of ± 2 degrees with respect to the image location during da...	No	Draft

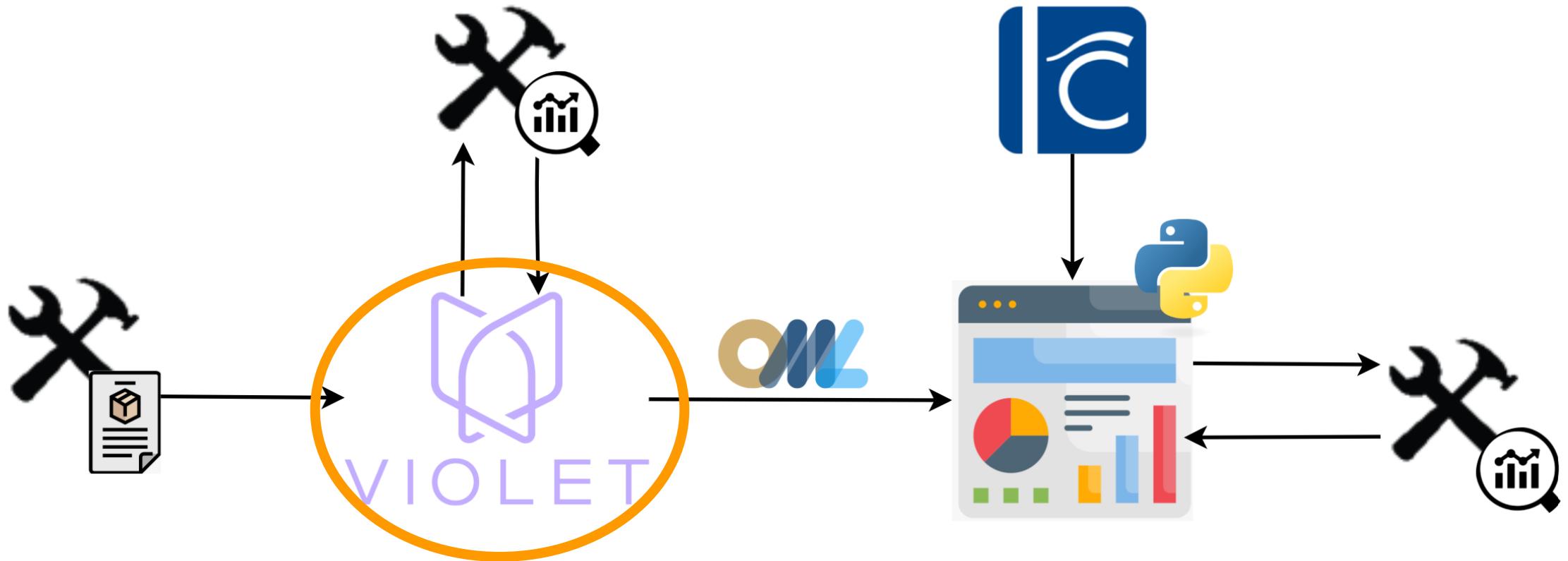
DE at UA: Example Workflow



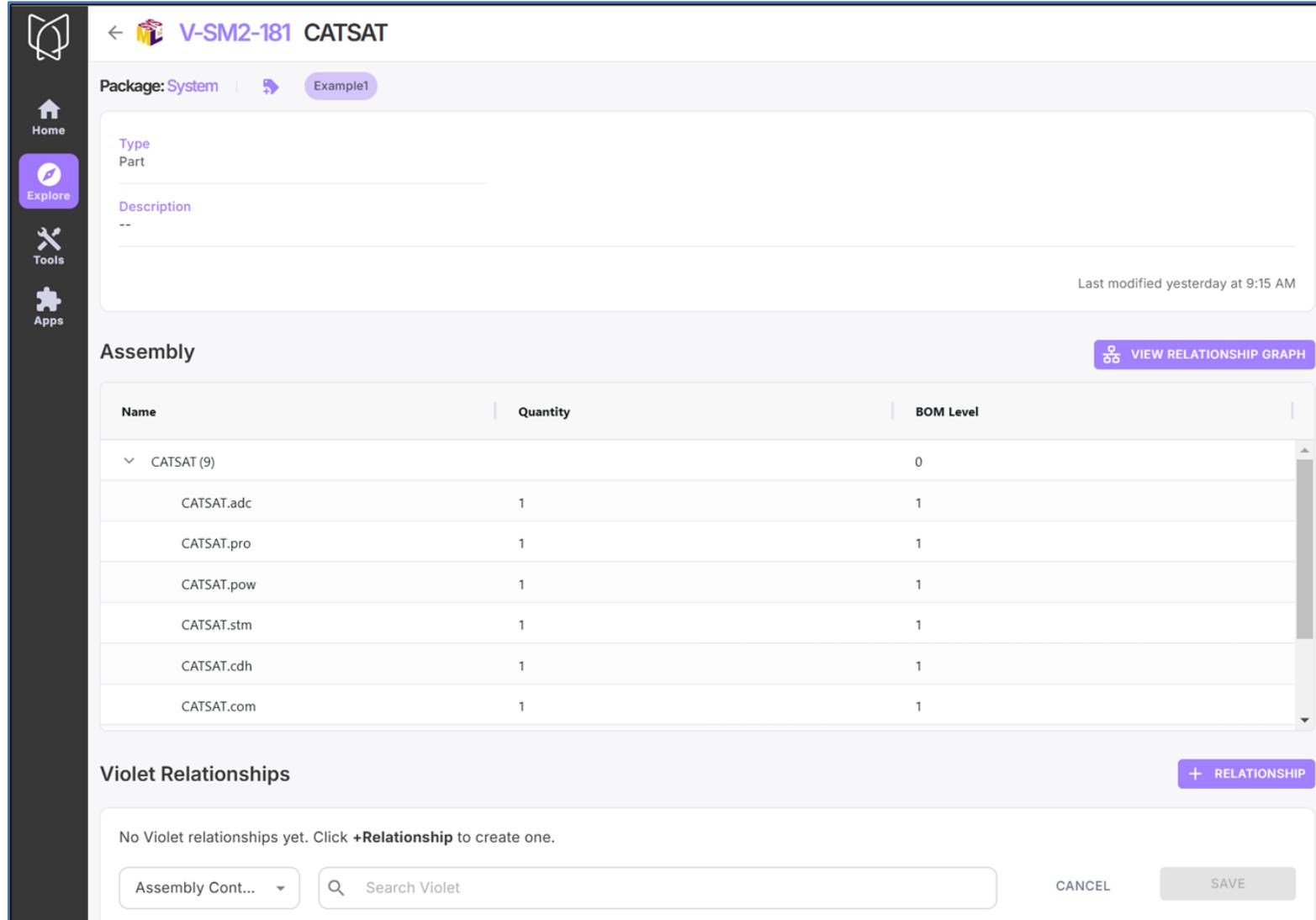
DE at UA: Example Workflow



DE at UA: Example Workflow



DE at UA: Example Workflow



The screenshot shows a software interface for managing product structures. The title bar indicates the project is 'V-SM2-181 CATSAT'. The left sidebar has icons for Home, Explore (selected), Tools, and Apps. The main area shows the following details:

- Type:** Part
- Description:** --
- Last modified:** yesterday at 9:15 AM

Assembly:

Name	Quantity	BOM Level
CATSAT (9)	1	0
CATSAT.adc	1	1
CATSAT.pro	1	1
CATSAT.pow	1	1
CATSAT.stm	1	1
CATSAT.cdh	1	1
CATSAT.com	1	1

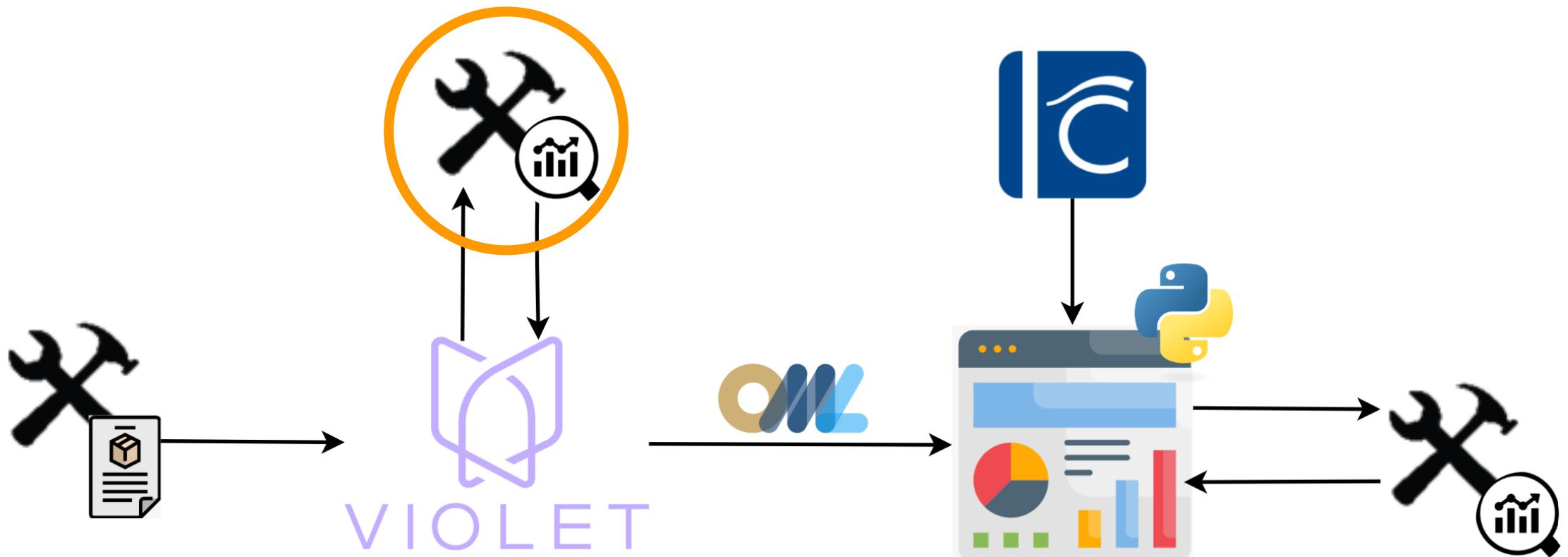
Violet Relationships:

No Violet relationships yet. Click **+Relationship** to create one.

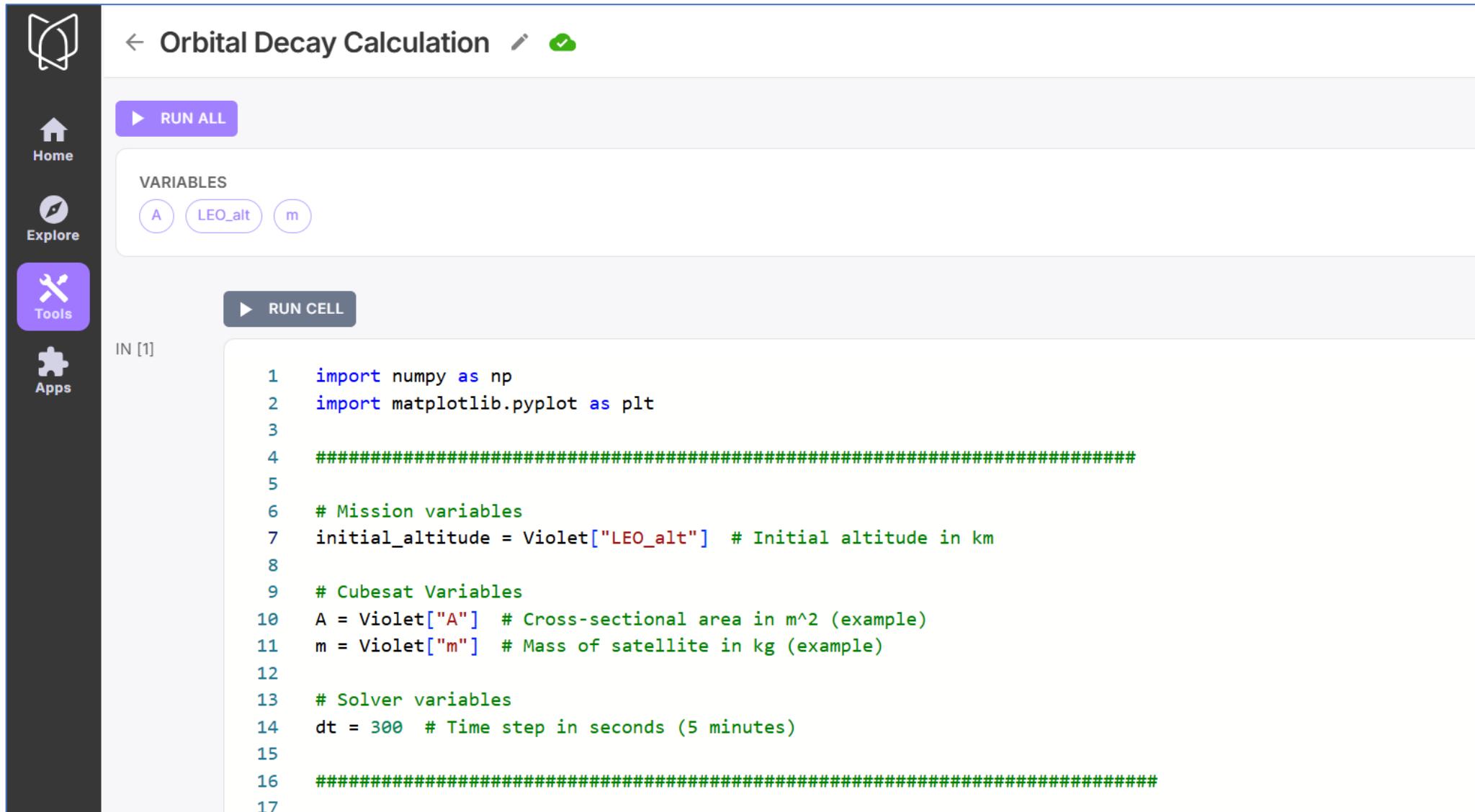
Buttons at the bottom: Assembly Cont..., Search Violet, CANCEL, SAVE.

- Assembly Contains
- Is Part Of Assembly
- Performs
- Performed By
- Predecessor
- Successor
- Satisfies
- Satisfied By
- Has Output
- Is Output Of
- Has Input
- Is Input Of
- Verifies
- Verified By
- Prescribes
- Prescribed By
- Describes
- Is Described By
- Participates In
- Has Participant
- Contains Properties Of
- Has Properties
- Allocated To
- Allocates
- Derives
- Is Derived From
- Decomposes

DE at UA: Example Workflow



DE at UA: Example Workflow

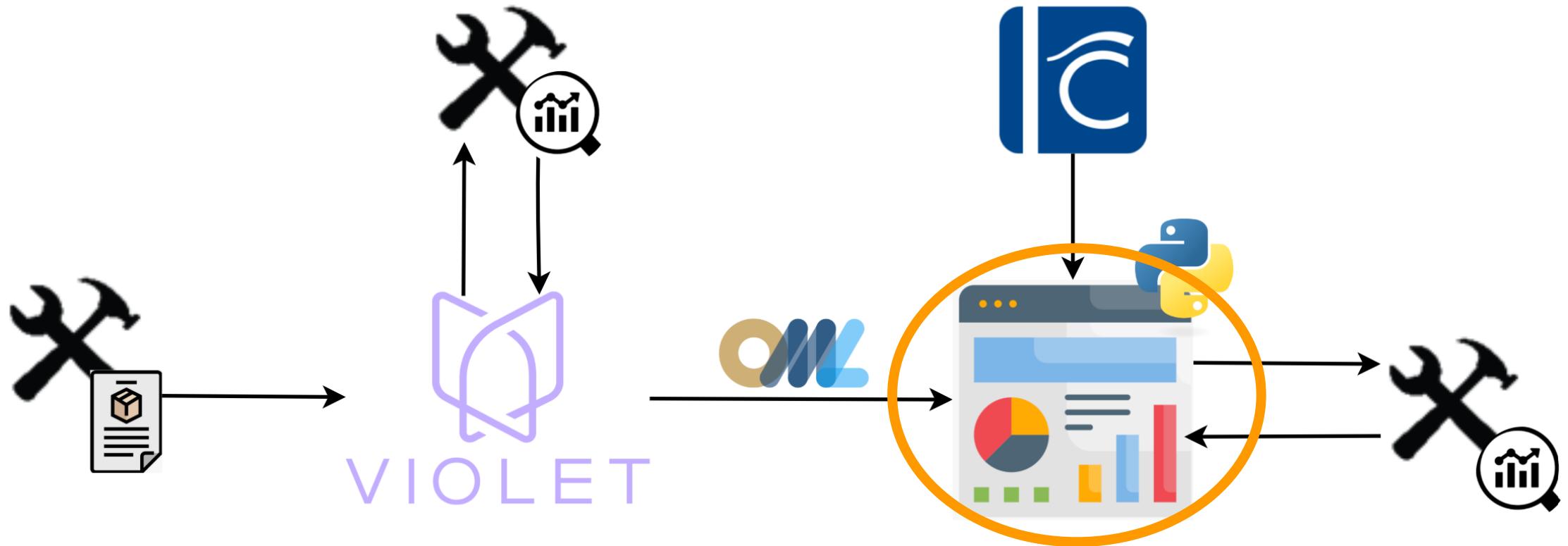


The screenshot shows a Jupyter Notebook interface with the following elements:

- Left Sidebar:** A dark sidebar with icons for Home (house), Explore (compass), Tools (wrench), and Apps (puzzle).
- Title Bar:** 'Orbital Decay Calculation' with a back arrow, a pencil icon, and a green checkmark icon.
- Buttons:** 'RUN ALL' (purple) and 'RUN CELL' (grey).
- VARIABLES:** A list of variables: A, LEO_alt, and m.
- Code Cell (IN [1]):** The code is as follows:

```
1 import numpy as np
2 import matplotlib.pyplot as plt
3
4 #####
5
6 # Mission variables
7 initial_altitude = Violet["LEO_alt"] # Initial altitude in km
8
9 # Cubesat Variables
10 A = Violet["A"] # Cross-sectional area in m^2 (example)
11 m = Violet["m"] # Mass of satellite in kg (example)
12
13 # Solver variables
14 dt = 300 # Time step in seconds (5 minutes)
15
16 #####
17
```

DE at UA: Example Workflow



DE at UA: Example Workflow

New Project Details x

Input new project details

Project Name

Description

Select Views

Home x Architecture x x v

You can change your selection of views later under 'Preferences' -> *Edit Project*

Create

DE at UA: Example Workflow

New Project Details ×

Input new project details

Project Name

Description

Select Views

Home × Architecture × ✖ ▾

You can change your selection of views later under 'Preferences' -> *Edit Project*

Create



Edit Data

CubeSat Mission Dashboard

[Home Page](#) [Test Facilities](#) [Requirements](#) [Architecture](#) [Orbit](#) [Test Strategy](#) [Test Results](#) [Issues/Warnings](#)

RDF Triple Count: 11839

Files used in each tab

Tab Name	Files Utilized
Home Page	TripleCount.json
Test Facilities	TestFacilities.json
Requirements	Requirements.json
Architecture	SystemArchitecture.json
Architecture	MissionArchitecture.json
Test Strategy	TestStrategy.json
Test Results	TestResults.json

DE at UA: Example Workflow

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<testsuites name="http://uaprojects.com/CubesatOrbit/bundle">
  <testsuite name="Consistency">
    <testcase name="http://uaprojects.com/CubesatOrbit/bundle">
      <failure message="Individual violates minimum cardinality restriction"><![CDATA[
Individual violates minimum cardinality restriction

// Class with restriction

<http://uaontologies.com/UA_Core/UA_Measurement#Measurement> <http://www.w3.org/2000/01/rdf-schema#subClassOf> [
  <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://www.w3.org/2002/07/owl#Restriction> .
  <http://www.w3.org/2002/07/owl#onProperty> <http://uaontologies.com/UA_Core/UA_Measurement#hasUnit> .
  <http://www.w3.org/2002/07/owl#minQualifiedCardinality> 1 .
  <http://www.w3.org/2002/07/owl#onClass> <http://uaontologies.com/UA_Core/UA_Measurement#Unit> .
] .
// Violating individual with conforming property values

<http://uaprojects.com/CubesatOrbit/CatSAT#CatSAT_Power_Battery_Capacity_Measurement> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type> <http://uaontologies.com/UA_Core/UA_Measurement#Measurement> <http://uaprojects.com/CubesatOrbit/CatSAT#CatSAT_Power_Battery_Capacity_Measurement> <http://www.w3.org/2002/07/owl#minQualifiedCardinality> 1 .
] ]></failure>
    </testcase>
  </testsuite>
  <testsuite name="Satisfiability">
    <testcase name="http://uaontologies.com/UA_Domain/UA_Requirements#Objective"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_SystemArchitecture#Interface"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Agent#Consumer"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#IdentifiedEntity"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#Object"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Agent#Plan"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_Requirements#Constraint"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Agent#Agent"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_Requirements#VerificationMethod"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_SystemArchitecture#ConnectsTo"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_OrbitsAndTrajectories#Orbital_INC"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_SystemArchitecture#HasItemFlow"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#ImmaterialEntity"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_Software#SoftwareAgent"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Measurement#Unit"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_Requirements#Satisfies"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Agent#IsRoleOf"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#Function"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_Requirements#KPP"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#GenericallyDependentContinuant"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Information#Describes"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_ModelingAndSimulation#Simulation"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Event#OccursBefore"/>
    <testcase name="http://uaontologies.com/UA_Core/UA_Agent#Person"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_Mission#Mission"/>
    <testcase name="http://uaontologies.com/UA_Domain/UA_ProjectManagement#Task"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#TemporalRegion"/>
    <testcase name="http://uaontologies.com/UA_Foundation/UA_Foundation#Site"/>
  </testsuite>
</testsuites>
```

DE at UA: Example Workflow

Violation

A **Measurement** must have at least one **hasUnit** relation to **Unit**. Individual **CatSAT_Power_Battery_Capacity_Measurement** violates this.

Item	Value
(1) Class	Measurement
(2) Object property	hasUnit
(3) Object property range	Unit
(4) Ontology	UA_Measurement
(5) Instance	CatSAT_Power_Battery_Capacity_Measurement
(6) Description	CatSAT

DE at UA: Example Workflow

 **CubeSat Mission Dashboard**

[Requirements](#) [Architecture](#) [Orbit](#) [Test Strategy](#) [Warnings/Issues](#)

Requirements Summary

Requirement ID	Requirement Name	Description	Satisfied By	Verified By
MR1	Deorbit	The cubesat shall deorbit within 25 years of the end of its mission	CATSAT_Mission	VA1.2_Deorbit_Analysis
MR2	Downlink	The cubesat shall download at least 5 GB per day to the ground segment upon command	CATSAT_Mission	None
MR3	Power	The cubesat shall continuously operate during its orbit	CATSAT_Mission	None
MR4	Image Resolution	The cubesat shall capture images of the Earth at a resolution of 40m per pixel	CATSAT_Mission	None
MR5	Pointing Accuracy	The cubesat shall maintain a pointing accuracy of ± 2 degrees with respect to the imaged location during data collection	CATSAT_Mission	None

CubeSat Mission Dashboard

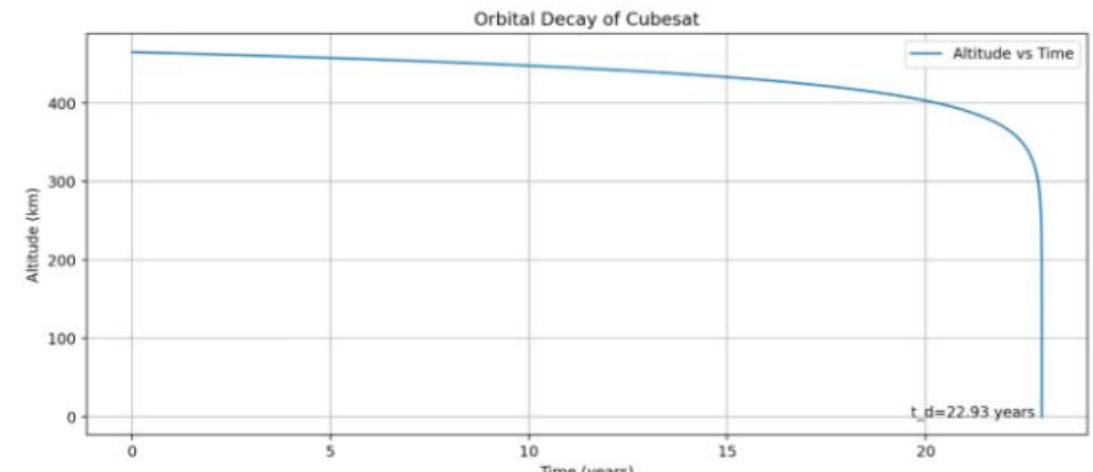
Requirements Architecture **Orbit** Test Strategy Warnings/Issues

Orbital Details



CubeSat Orbit Details

Orbit Properties	Values
Altitude (km)	465
Semi-major axis (km)	6,843
Inclination (deg)	55
Eccentricity	0
Longitude of Ascending Node (deg)	10
Argument of periapsis (deg)	0
Period (s)	5,633.701



DE at UA: Example Workflow

CubeSat Mission Dashboard

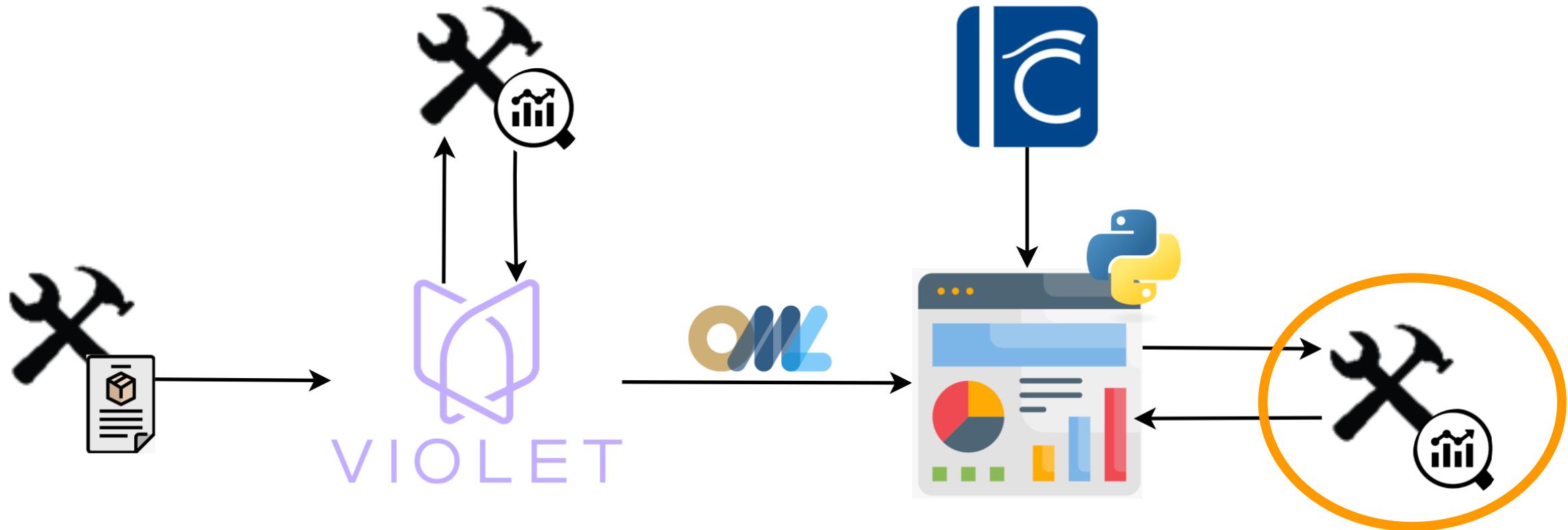
Home Page Test Facilities Requirements Architecture Orbit **Test Strategy** Test Results Issues/Warnings

Total Test Duration	Total Test Cases	Total Tests
64 days	12	3
Total Test Facilities	Total Test Equipment	Total Test Procedures
2	11	6

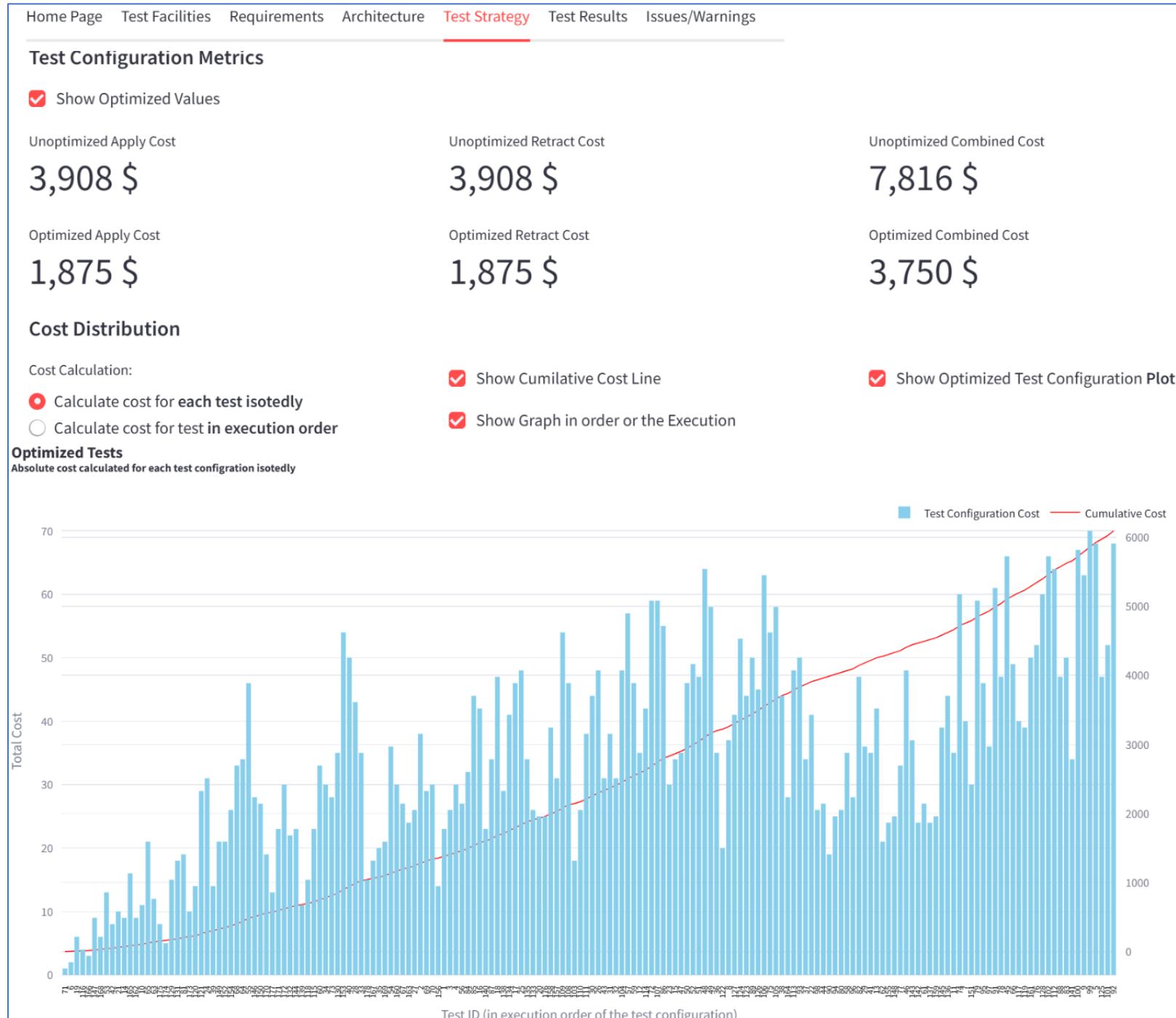
Warnings/Issues

- ⚠ The test duration is more than 60 days
- ❗ The Equipment VT_Stopwatch for Test Case T2_1 is not available at the assigned facility UA_TestFacility
- ❗ The Researcher UA_Researcher for Test Case T3_3 is not available at the assigned facility VT_TestFacility

DE at UA: Example Workflow



DE at UA: Example Workflow



- Digital Engineering at UA
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- **Next Steps**

Next Steps

- Continue development
 - Domain ontologies (Mission, System, Test – JHU APL)
 - Dashboard features (make ontological reasoning convenient)
- **Research:** Expand digitalized workflows
 - Build approval workflow into dashboards
 - Improve UI with supporting ontologies
 - Develop workflow to incorporate dynamic updates, decisions and reporting
- **Education:** Deploy in other courses
 - Currently used in SIE 250 (Intro to SE), SIE 523 (Advanced T&E), and multiple SW

Supporting Work

Model-Based Test and Evaluation

- Gregory, J., & Salado, A. (2024). An Ontology-based Digital Test and Evaluation Master Plan (dTEMP) Compliant with DoD Policy. *Systems Engineering*.
- Gregory, J., & Salado, A. (2024). dTEMP: From Digitizing to Modeling the Test and Evaluation Master Plan. *Naval Engineers Journal*.
- Gregory, J. & Salado, A, "Model-Based Integration and Test Planning: Automating the Propagation and Verification of Expert Knowledge using Ontologies," in *SECESA 2024*, Strasbourg, France, 2024.
- Gregory, J., & Salado, A., "Spacecraft Test and Evaluation using Semantic Web Technologies," in *AIAA SciTech*, Orlando, FL, USA, 2024.

Verification Strategies as Bayesian Networks

- Gregory, J., & Salado, A., "Model-Based Verification Strategies Using SysML and Bayesian Networks," in *CSER*, Hoboken, NJ, USA, 2023.
- Gregory, J., & Salado, A., "A Semantic Approach to Spacecraft Verification Planning using Bayesian Networks," in *IEEE Aerospace Conference*, Big Sky, MT, USA, 2024.
- Gregory, J., Jackson, B., Salado, A., "Automated Generation of Bayesian Verification Strategies using Semantic Web Technologies," in *CSER*, Long Beach, CA, USA, 2025.

In the Classroom

- Gregory, J., & Salado, A., "A Digital Engineering Factory for Students," in *CSER*, Tucson, AZ, USA, 2024.
- Gregory, J. & Salado, A, "Connecting Systems Engineering Artifacts in the Classroom , " in *SECESA 2024*, Strasbourg, France, 2024.

Overviews

- Gregory, J., et al., "The Digital Engineering Factory: Considerations, Current Status, and Lessons Learned," in *INCOSE International Symposium*, Dublin, Ireland, 2024.
- Gregory, J., & Salado, A., "Towards a Systems Engineering Ontology Stack," in *INCOSE International Symposium*, Dublin, Ireland, 2024.

Acknowledgments

This material has been produced using funds provided by the
Arizona Technology and Research Initiative Fund.

Violet Labs

for continued support of the DEF project

www.violetlabs.com

hello@violetlabs.com

UA Eng IT Team

for continued work on hardware configuration

UA SFWE Students

for continued work on DEF development

THANK YOU

joegregory@arizona.edu

References

- [1] A. Patel and S. Jain, "Present and future of semantic web technologies: a research statement," *Int. J. Comput. Appl.*, pp. 1–10, 2019.
- [2] W3C, "Resource Description Framework (RDF) Concepts and Abstract Syntax", 2014. [Online]. Available <https://www.w3.org/TR/rdf11-concepts/>. [Accessed 24 August 2024]
- [3] W3C, "OWL 2 Web Ontology Language Document Overview (Second Edition)", 2012. [Online]. Available <https://www.w3.org/TR/owl2-overview/>. [Accessed 24 August 2024]
- [4] W3C, "SPARQL 1.1 Query Language", 2013. [Online]. Available <https://www.w3.org/TR/sparql11-query/>. Accessed [24 August 2024]
- [5] Violet Labs, 2023. [Online]. Available: <https://www.violetlabs.com>. [Accessed 24 August 2024].
- [6] OpenCAESAR, "Ontological Modeling Language 2.0.0 Living Standard", 2023. [Online]. Available <https://www.opencaesar.io/oml/>. [Accessed 24 August 2024].
- [7] Gregory, J., & Salado, A., "Towards a Systems Engineering Ontology Stack," in INCOSE International Symposium, Dublin, Ireland, 2024.

Backup

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Semantic Web Technologies

provide an approach to the structuring and understanding of data [1].

Resource Description Framework (RDF) [2]

- Triple structure: **subject-predicate-object**
- Makes information **machine-readable**



Web Ontology Language (OWL) [3]

- Ontology: defines what is meaningful to say: i.e., allowable concepts and relations in a domain
- Provides **context** to information
- Enables validation of RDF graphs



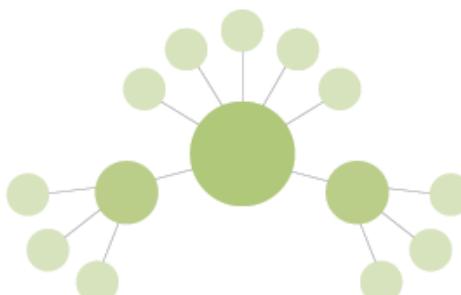
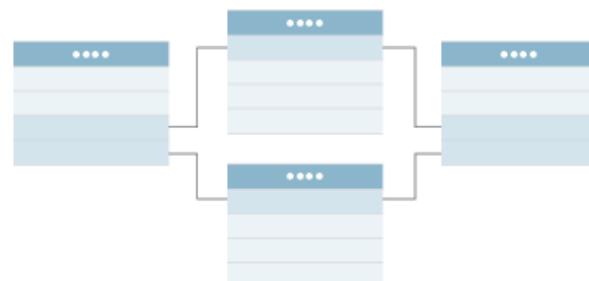
SPARQL [4]

- 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