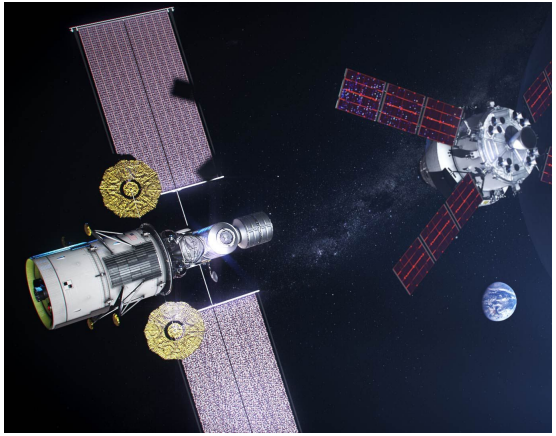
Supporting NASA Human Spaceflight Engineering with Knowledge Graphs

ARTEMIS

Lunar Outpost

Human Lander System

Advanced Exploration (AES)



Exploration Systems (ESD)

Space Launch System

Orion

Exploration Ground Systems (EGS)

The Team:

- Systems Engineers
- Designers (CS)
- Developers
- Administrators
- Testers
- Analysts
- Network Specialists

...from across the agency, from industry, and across the country.

Ian Maddox | MSFC | ESSCA

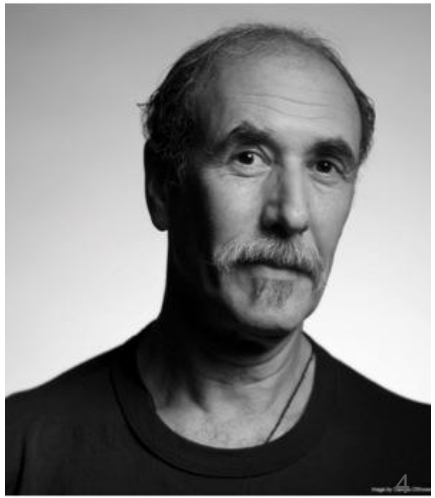
Deputy, NASA Artemis Data Integration

Senior Systems Engineer, Jacobs Technology

Andrew Schain | HQ | Stardog

Manager, NASA ESD Data Integration (Retired)

Senior Consultant, Stardog



GLOBAL PRODUCT DATA INTEROPERABILITY SUMMIT 2019

How do we help? ...the right data to the right people at the right time.

1. Help Engineering and Safety communities do their job more efficiently
    - Less time data gathering/munging/scrubbing; more time engineering and analyzing
2. Greater data fidelity so that engineers can be confident in their results
3. Quietly, implicitly inspire a migration from paper culture to data culture

We did it different & it's working:

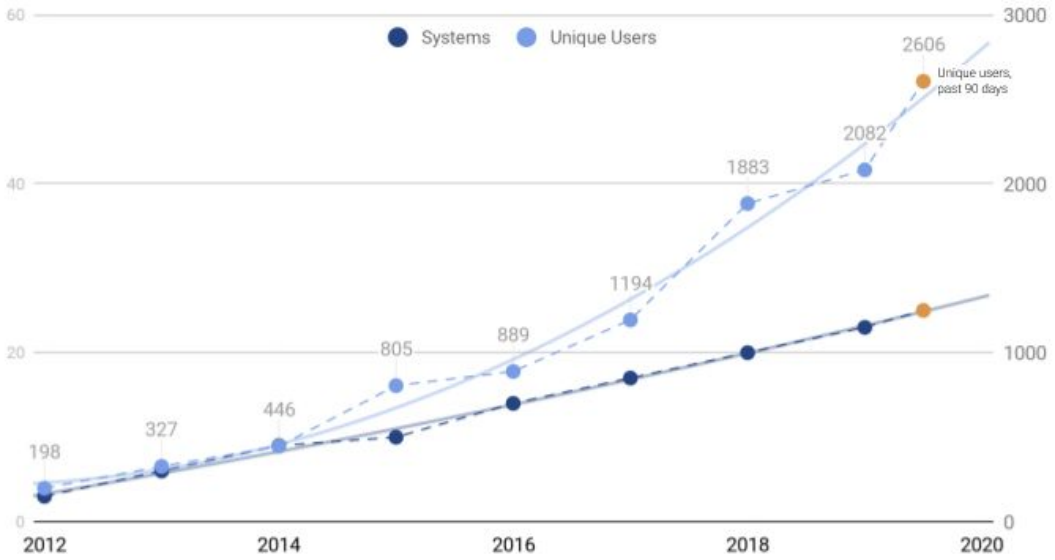
Traditional:

- Achieve management needs (e.g. metrics, reporting) by mandating tools/processes
- Lead with technology, tools, programming languages
- Data architecture defined with minimal engineering community engagement (usually admins)
- Define the exhaustive data architecture first; implement only once baselined
- Information system leads approve all changes

Now:

- Achieve management needs as a by-product of **addressing pain points at the working level**
- **Lead with process-analysis** and understanding of customer goals
- Engage in **constant contact** with end users; build personal relationships
- Implement **positive change early and often;** evolve data architecture
- Information system leads **define strategy; encourage autonomy** to project leads

NASA Adoption

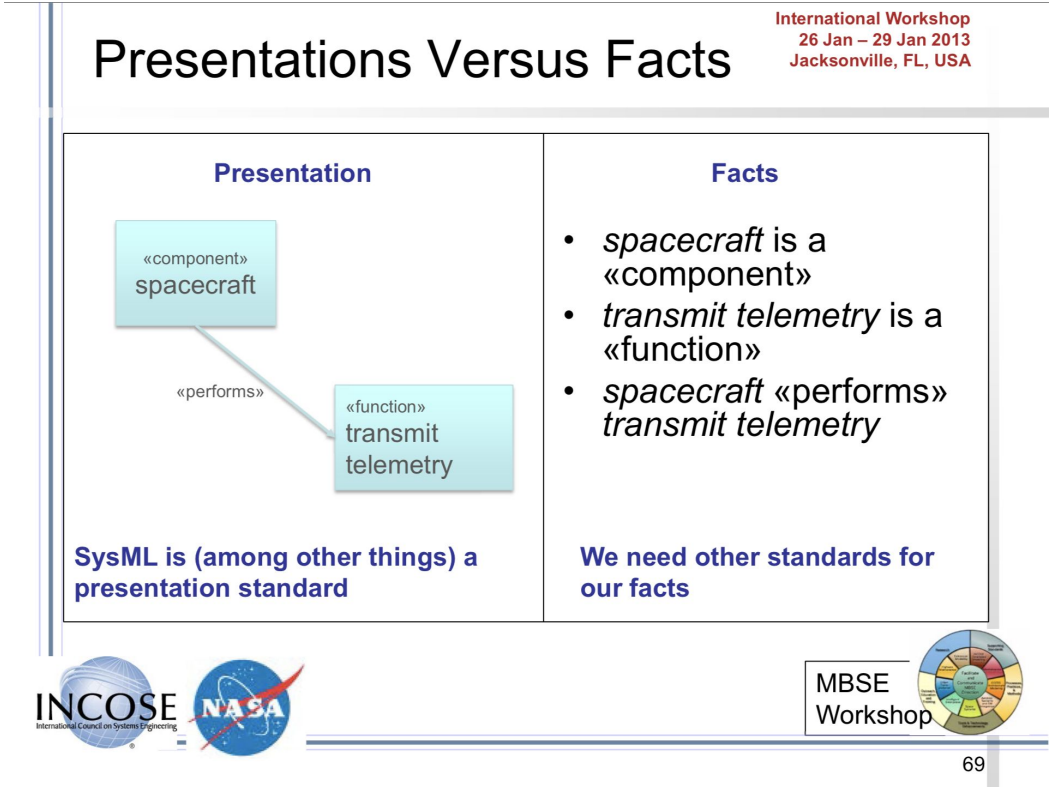


MBSE at NASA

- an implementer’s perspective.

Lessons Learned from NASA JPL (via INCOSE)

- Vocabulary in SysML, UML, and other models provides a baseline of expressivity
- More nuance can be realized with an ontology
- When models collide, an ontology and logical constraints can help discern the relationships



90% Shared Goals and Intentions

- What's the impact? ...the rationale? ..the effect?
- How do you know you're done?
- Right data to right people at right time
- Data-centric; long-duration knowledge capture
- Distributed architecture
- Confidence of paper, but the benefits of technology

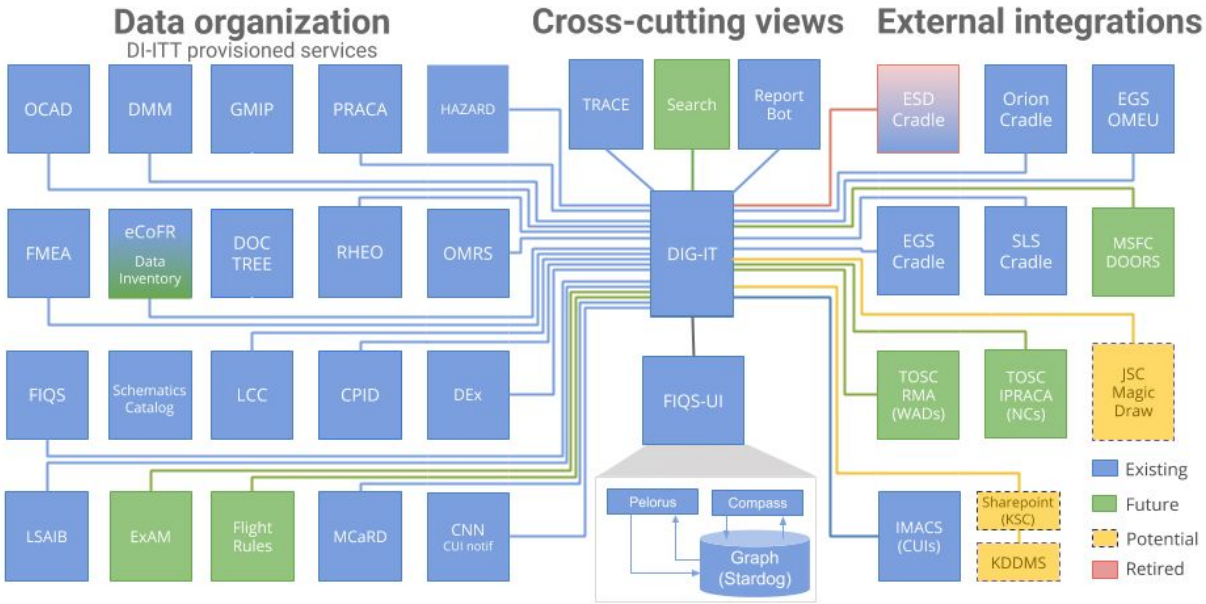
Traditional MBSE @ NASA

A prescriptive SE process for using models to understand structure and behavior of the system.

- Implemented in SysML via MagicDraw - barriers to entry tends to separate data from SMEs
- Models integrated via duplication and manual synchronizing - resulting in data duplication.
- Models feed centralized, monolithic “source of truth” - generally with access limited to the modelers.
- Modeling processes designed for small, homogenous teams - limited ability to support a large, distributed, heterogeneous, “light-touch” environment.

Knowledge Graph Support for MBSE

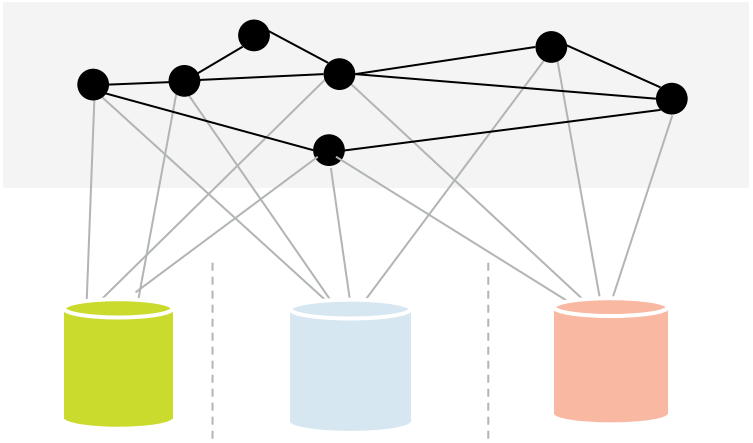
Not big data… heterogeneous data.



HOW TO BUILD A KNOWLEDGE GRAPH

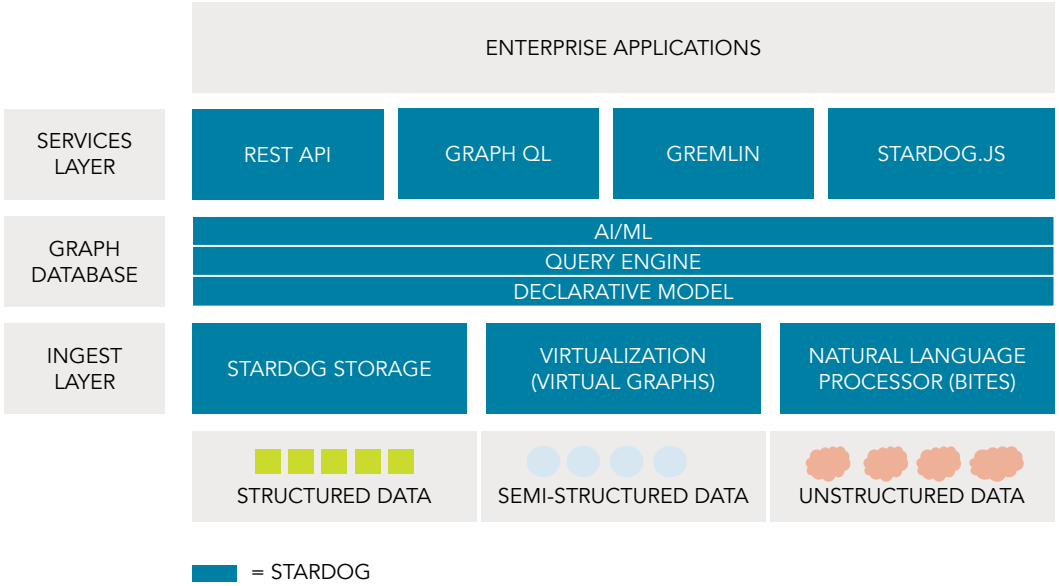
1. Solve the Data Silo Problem
2. Identify Relationships Between Data
3. Apply Machine Learning and Logical Reasoning to Gain Insight

A Knowledge Graph connects all data without moving or copying it.



STARDOG PULLS ALL THE DATA TOGETHER

Works with existing infrastructure for databases, BI, and analytics.



STARDOG is

- ✓ Delivered on premise or in the cloud
- ✓ Based on a reusable data model
- ✓ Capable of working across schemas
- ✓ Standards-based

STARDOG is not

- ✘ A data visualization tool
- ✘ A storage-only database

Digital Thread, the Systems Engineering Challenge

How do we look across all disciplines for a holistic and reusable view of the data?

Data Silo Problem Pervasive

Best of breed tools and point to point integrations means everyone has a different view, but none unified

Manual Effort to Create Cross Discipline Data

From verification closures to components and structures, the lack of a reusable and extensible data fabric means costly on-off efforts

Modeling Languages Don't Go Far Enough

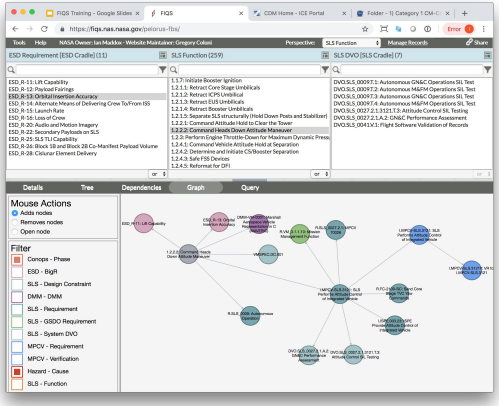
MBSE and SysML elevated basic record structures to a first approximation of modeling, but don't go far enough to capture differences

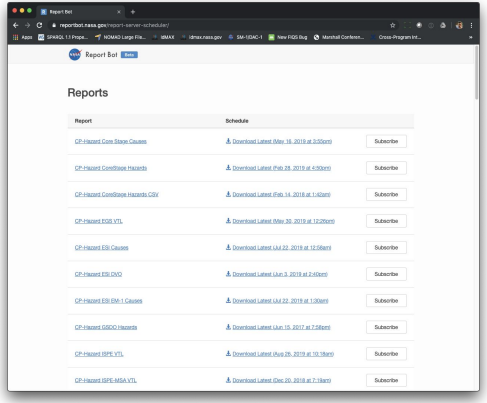
Knowledge Graphs accelerate Systems Engineering

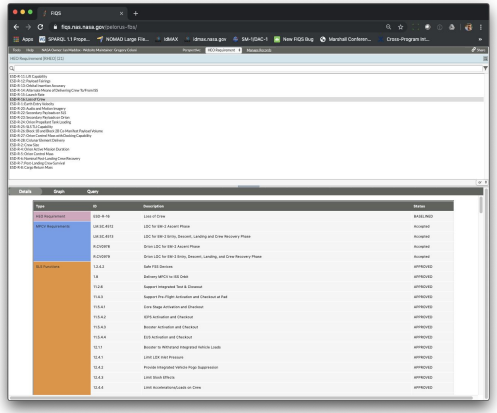
- Knowledge graphs can unify the disparate systems
  - Virtual Graphs over in-situ data
  - Direct alignment with engineering tool standards (e.g. OSLC)
- Ontologies provide a complementary modeling capability
  - Expressivity to align various model concepts and relationships
  - Domain specific reasoning to avoid undecidable or intractable relationships
  - Quality tools (e.g. using Stardog Integrity Constraint Validation)
- Drive standards based integration
  - W3C standards for the data format (RDF), query language (SPARQL) and ontology (OWL) in the knowledge graph
  - OSLC standards for Linked Data for engineering lifecycle tools

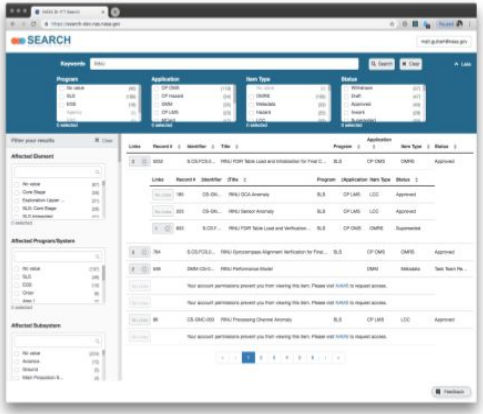
Results for Artemis Data Integration

A suite of solutions… all built off the graph

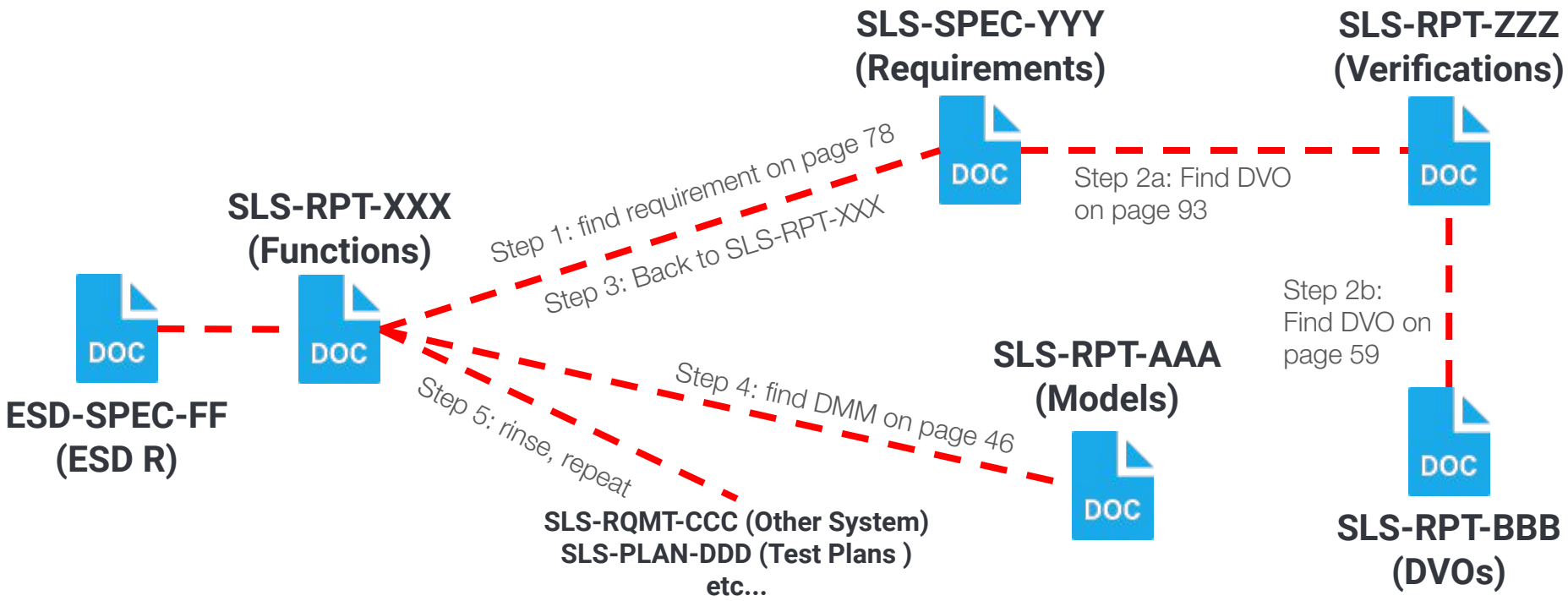






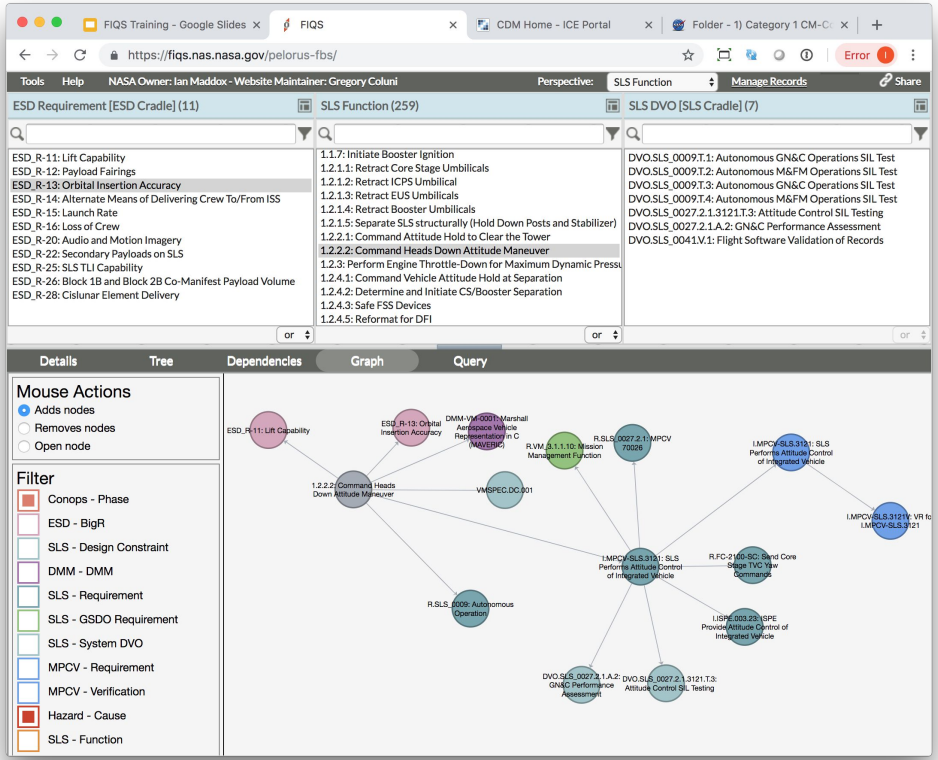


Case Study: FIQS (before; “simplified” view)

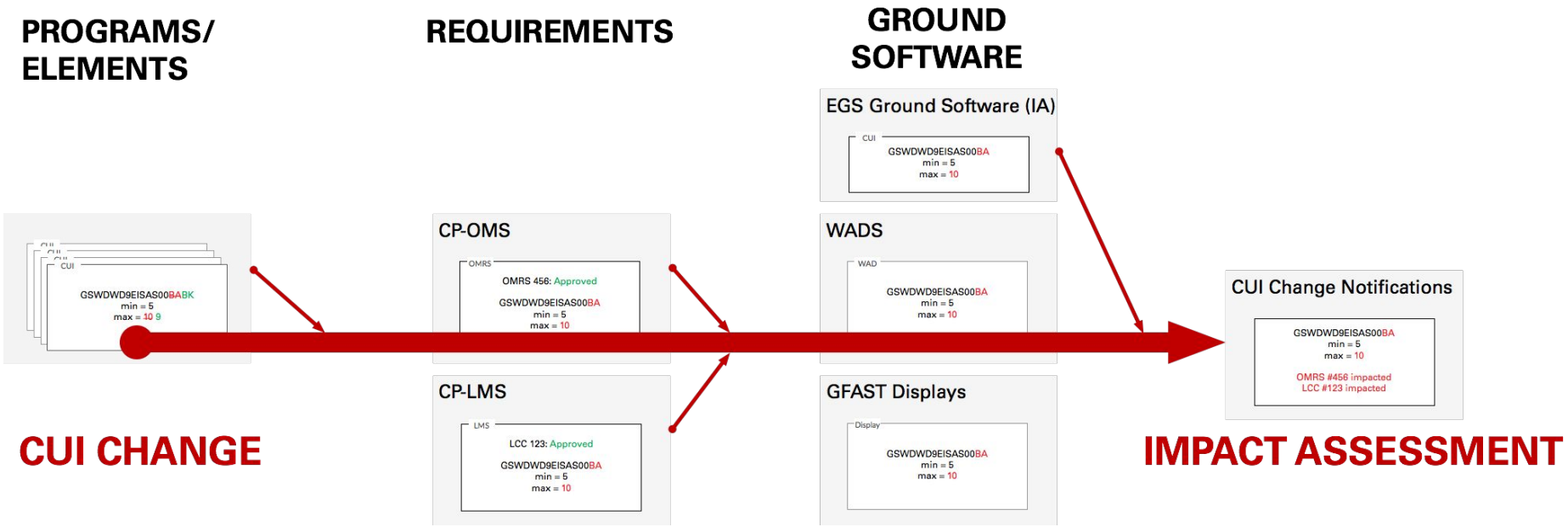


Case Study: FIQS (after)

- Leverages web services to tie into **13 different source data systems** and **40+ data objects**
- Models **SME-managed data** and **bidirectional links** in a knowledge graph to show a single view of NASA design & flight certification.
- Enables users to navigate all of the source data **instantaneously** (minutes instead of days).
- Some traces that were simply unavailable can now be easily seen.



Case Study: Compact Unique Identifiers (After)



Customer Response

Reporting based on this capability has identified large numbers of mismatches, each of which may force rework or failures in ground console development or integrated testing.

~200

requirements referencing data that can't be found in the end product

8000+

References that don't resolve to any actual data (e.g. "TBD", etc)

Getting Off The Stage

...how's it going?

The presence of OMS and LMS and the capabilities we designed in to these tools is HUGE. **Light-years ahead of what we had for SSP**... As a result, the **standing army** of Requirements Project Engineers (RPE's) USA employed during SSP **no longer need to exist** in the TOSC contract. In SSP, we had 8-12 folks who worked full time on managing the OMRS and LCC data, **chasing paper signatures, developing products for boards**, etc.

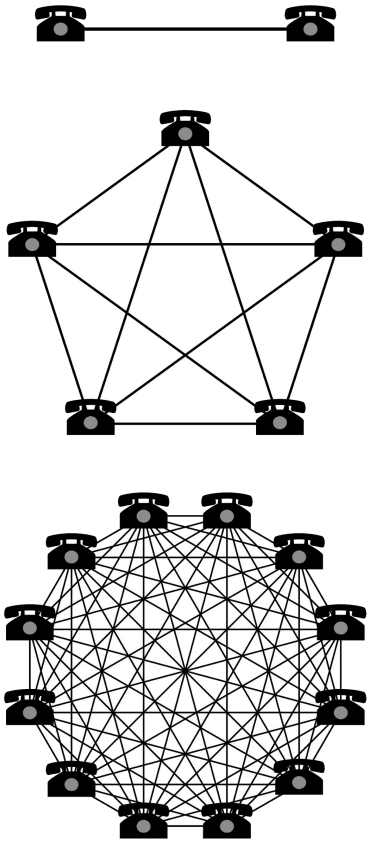
- Operational Requirements Panel Lead (June 2016)

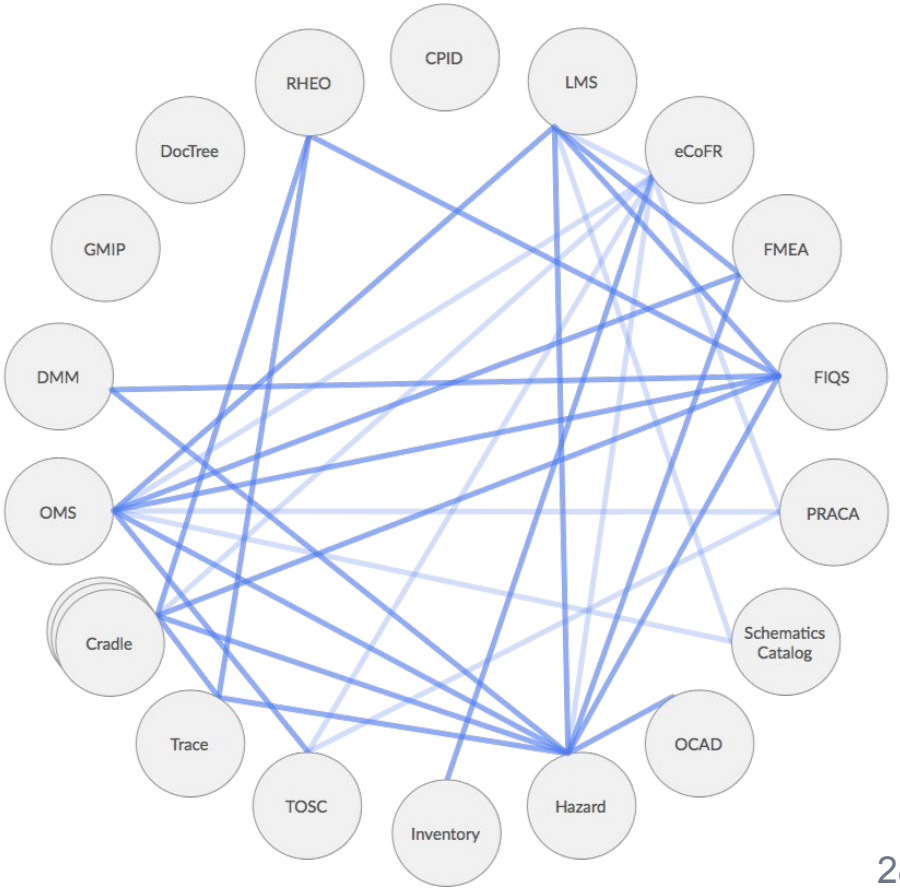
The “Big Picture” Is Federated

1. Of the data in the ESD/M2M graph, less than 30% is created by SE.
2. For non-SE content, over 80% have a known relationship to an SE product.
3. Of cross-system reports developed for ESD design and build certification, nearly all reference SE-generated data.

...we approach MBSE as one part of this larger problem.

Metcalfe's Law: Value is in the Network



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