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# System Lifecycle Handler – *Spinning a Digital Thread for Manufacturing*

*INCOSE IS, Washington DC / July 12, 2018*

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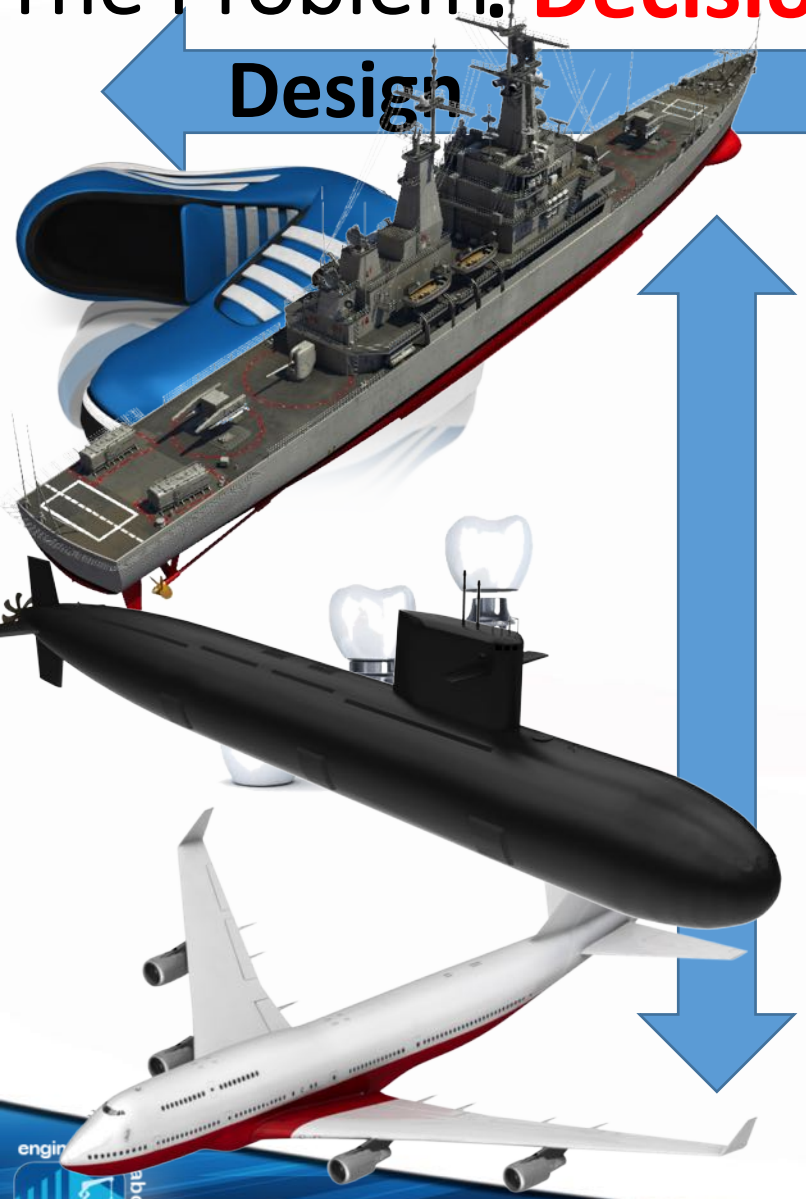
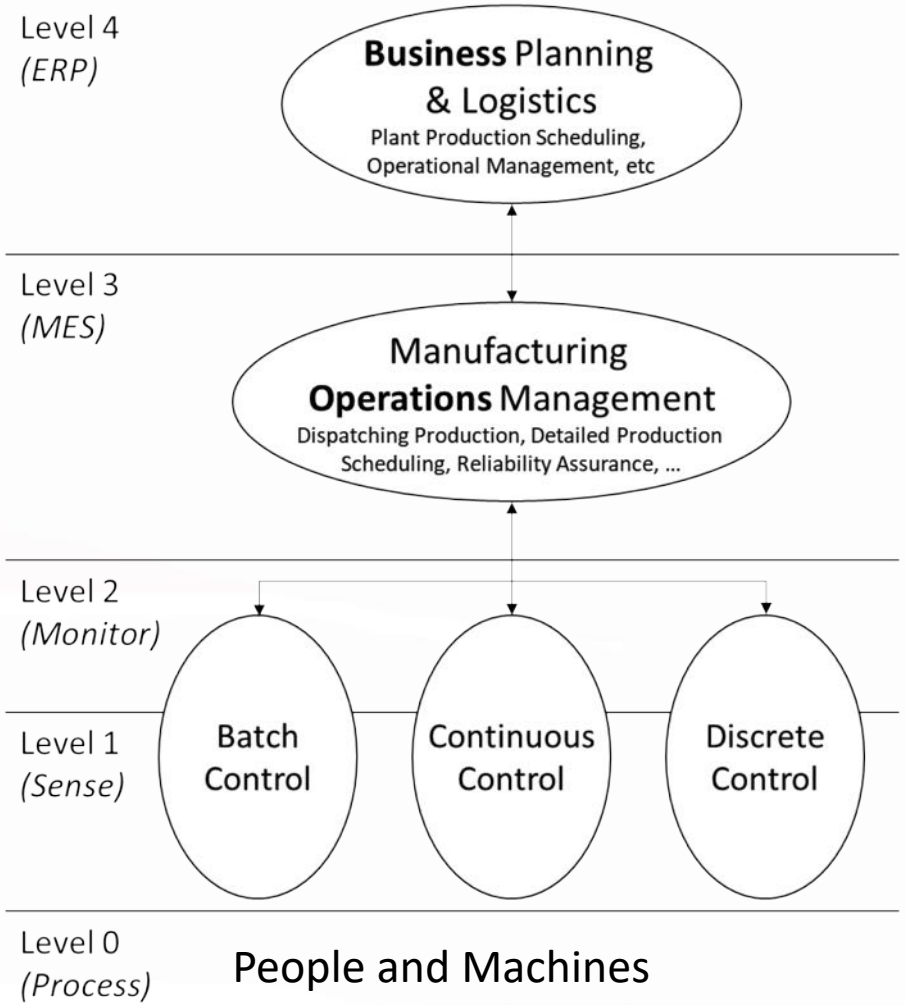
**Thomas Hedberg, Jr.**
Project Leader, Digital Thread for Smart Manufacturing, NIST

# Contents

# The Problem: Decision Making in Distributed Environments

**Design** → **Manufacturing** → **Sustainment**






# Why?

- Decentralized manufacturing –> OEMs = system integrators
- Industry wants and needs agility and flexibility [1]
- Simplicity through distributed complexity [2]
- Change in demand (lot size one, make it next door, on-demand ordering) [1, 3, 4]
- MRO/Sustainment needs distributed manufacturing to figure out what capabilities & capacities are located where and what is the topology of that distributed network
- Increased opportunities for MFGaaS –> $57 Million Annual Opportunity in simply better sensing and monitoring [5]


1. Gallaher, M. P., Oliver, Z. T., Rieth, K. T., and O'Connor, A. C., 2016. Economic analysis of technology infrastructure needs for advanced manufacturing: Smart manufacturing. Report NIST GCR 16-007, RTI International.
2. Mocker, M., Weill, P., & Woerner, S. (2014). Revisiting Complexity in the Digital Age. *MIT Sloan Management Review*. Retrieved from https://sloanreview.mit.edu/article/revisiting-complexity-in-the-digital-age/
3. Quan, T. and Williams, K., Product Variety, Across-Market Demand Heterogeneity, and the Value of Online Retail (November 17, 2016). Cowles Foundation Discussion Paper No. 2054. DOI: 10.2139/ssrn.2871513
4. Quan, T. and Williams, K., Product Variety, Across-Market Demand Heterogeneity, and the Value of Online Retail (June 26, 2017). Cowles Foundation Discussion Paper No. 2054R. DOI: 10.2139/ssrn.2993236
5. Anderson, G. (2016). *The Economic Impact of Technology Infrastructure for Smart Manufacturing* (NIST Economic Analysis Briefs 4). Retrieved from Gaithersburg MD: http://nvlpubs.nist.gov/nistpubs/eab/NIST.EAB.4.pdf

# Enter Digital Thread and Digital ~~Twins~~ Surrogates

- Digital Thread, *noun*
  - A connected information flow between standard interfaces for activities across the product lifecycle

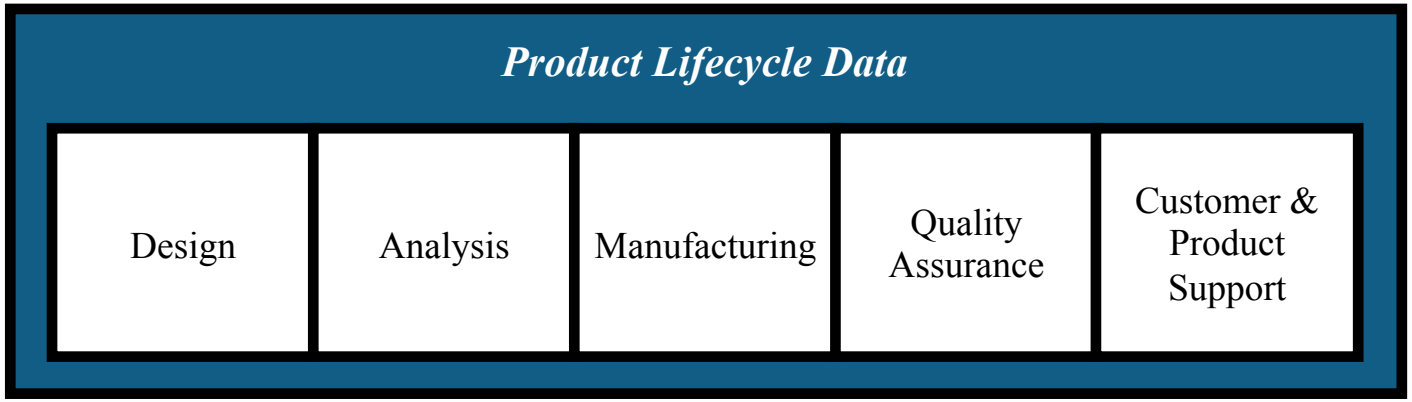
- Digital Surrogate, *noun*
  - An application of the digital thread to an environment where integrated information flows are leveraged to digitize systems and apply modeling and simulation to enable dynamic control

# Lifecycle Information Framework and Technology

*FROM INFORMATION SILOS…*


Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

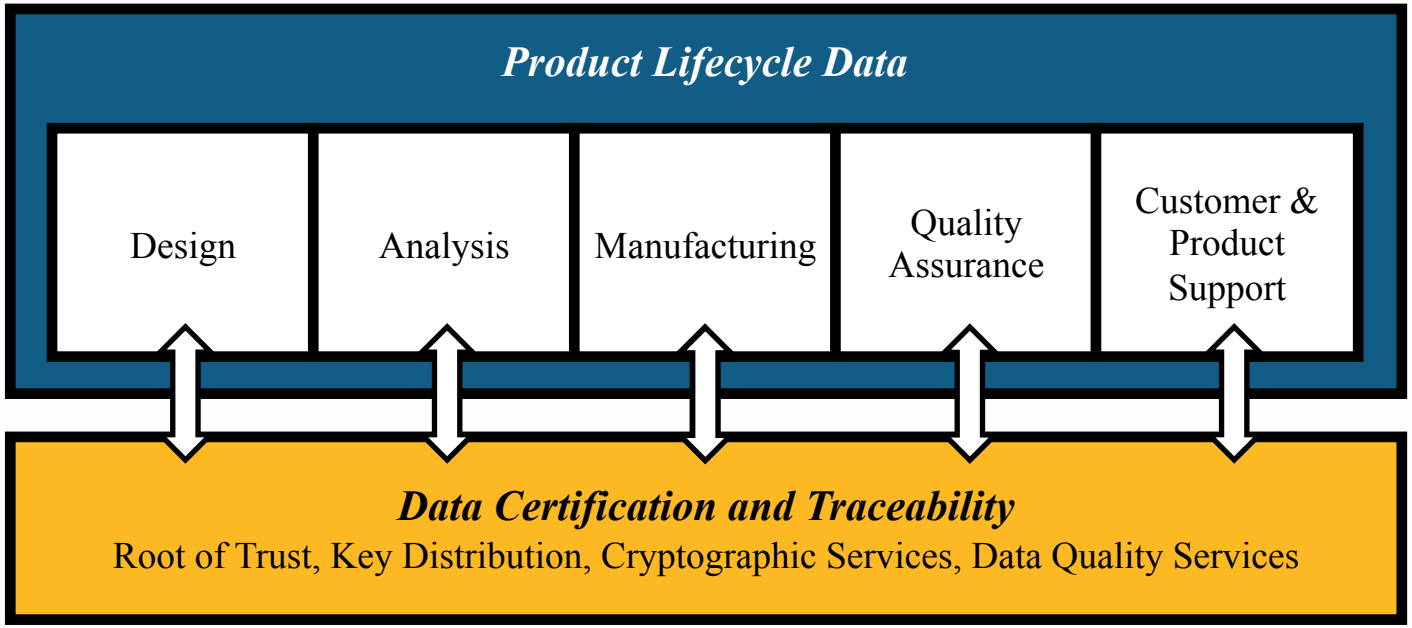
# Lifecycle Information Framework and Technology




*…TO LINKED DATA…*

Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

# Lifecycle Information Framework and Technology

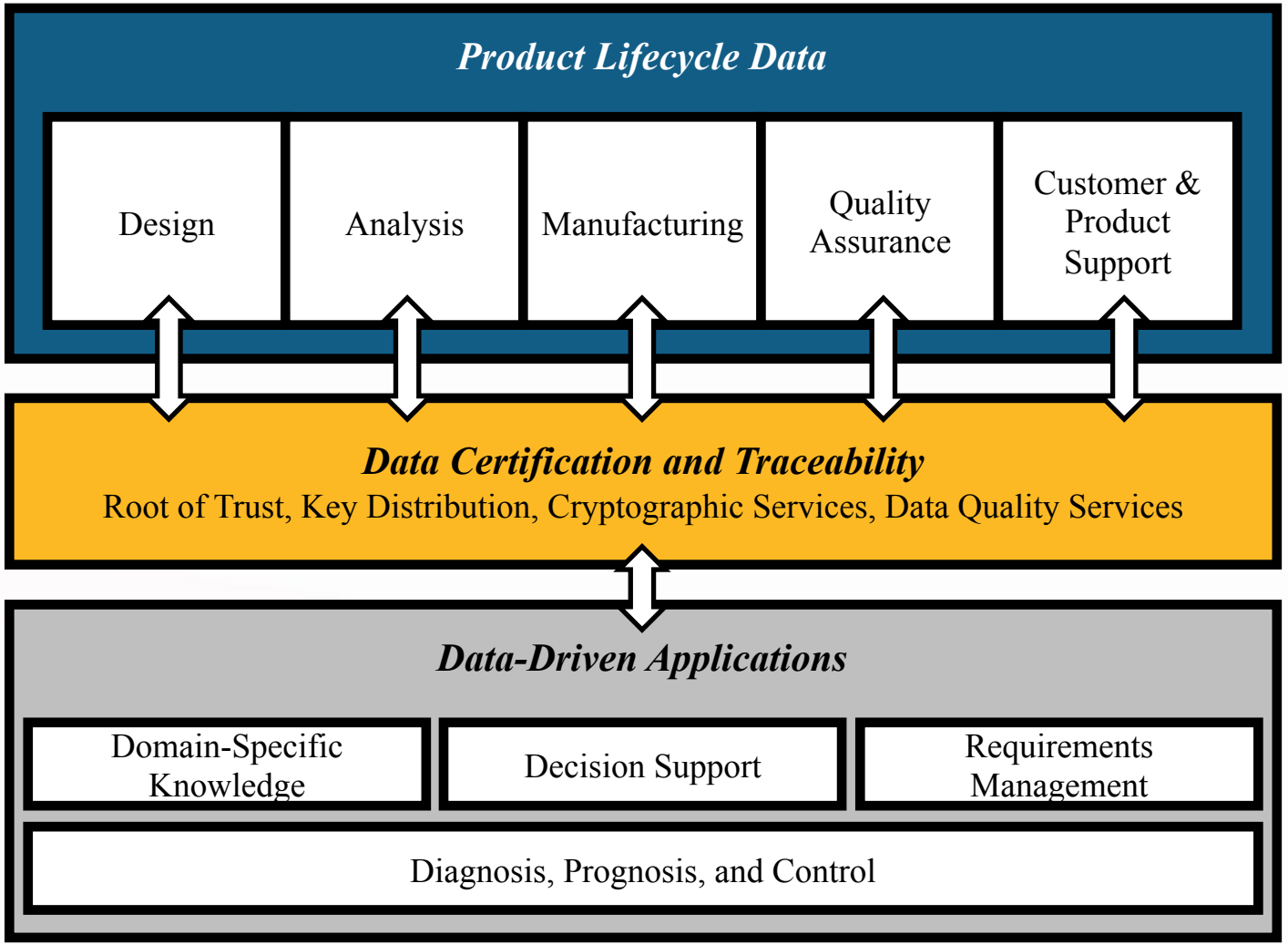



*…WITH BUILT IN TRUST AND TRACEABILITY…*

Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

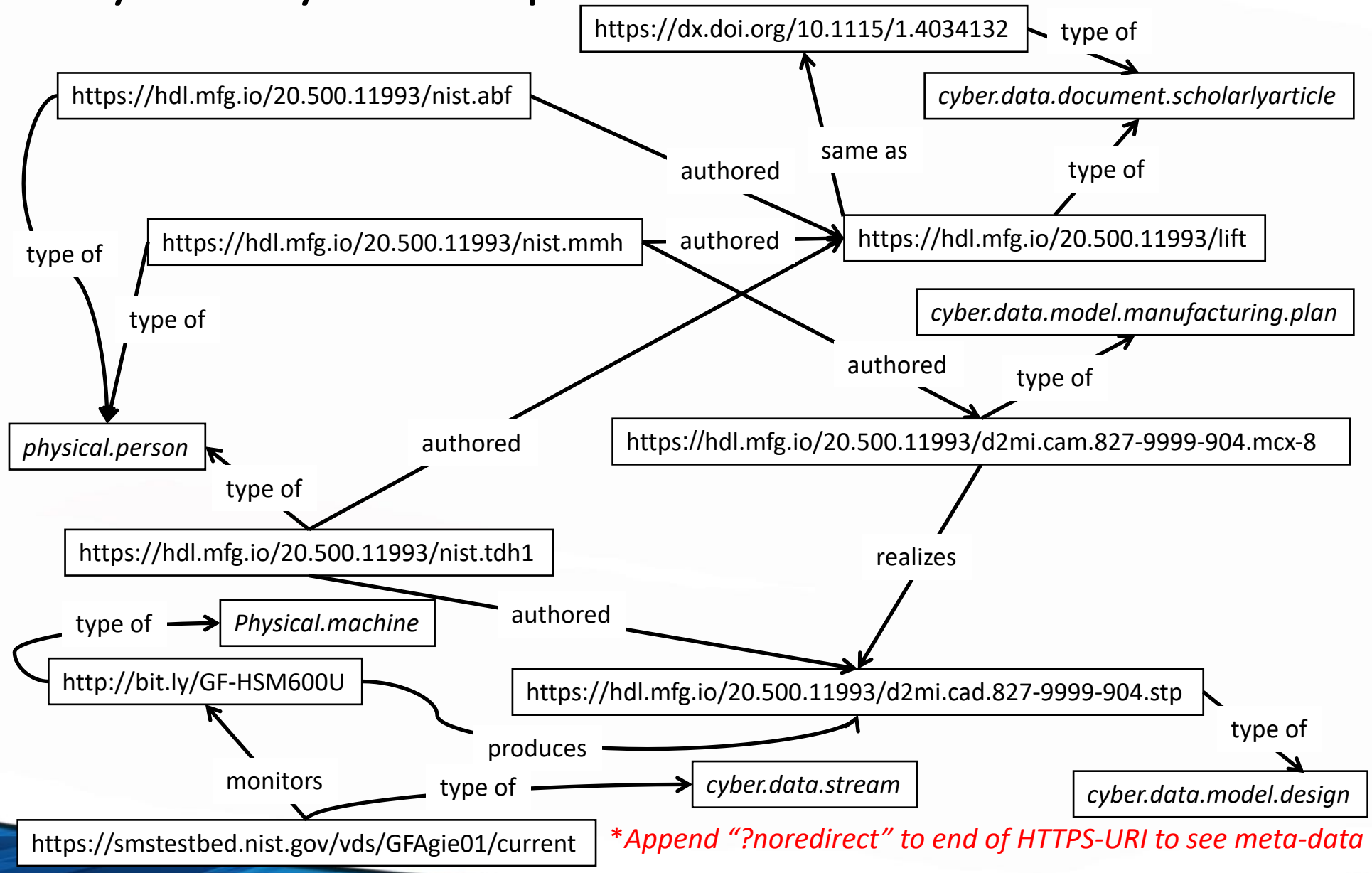
# Lifecycle Information Framework and Technology

## *…FOR DRIVING APPLICATION WITH DATA!*



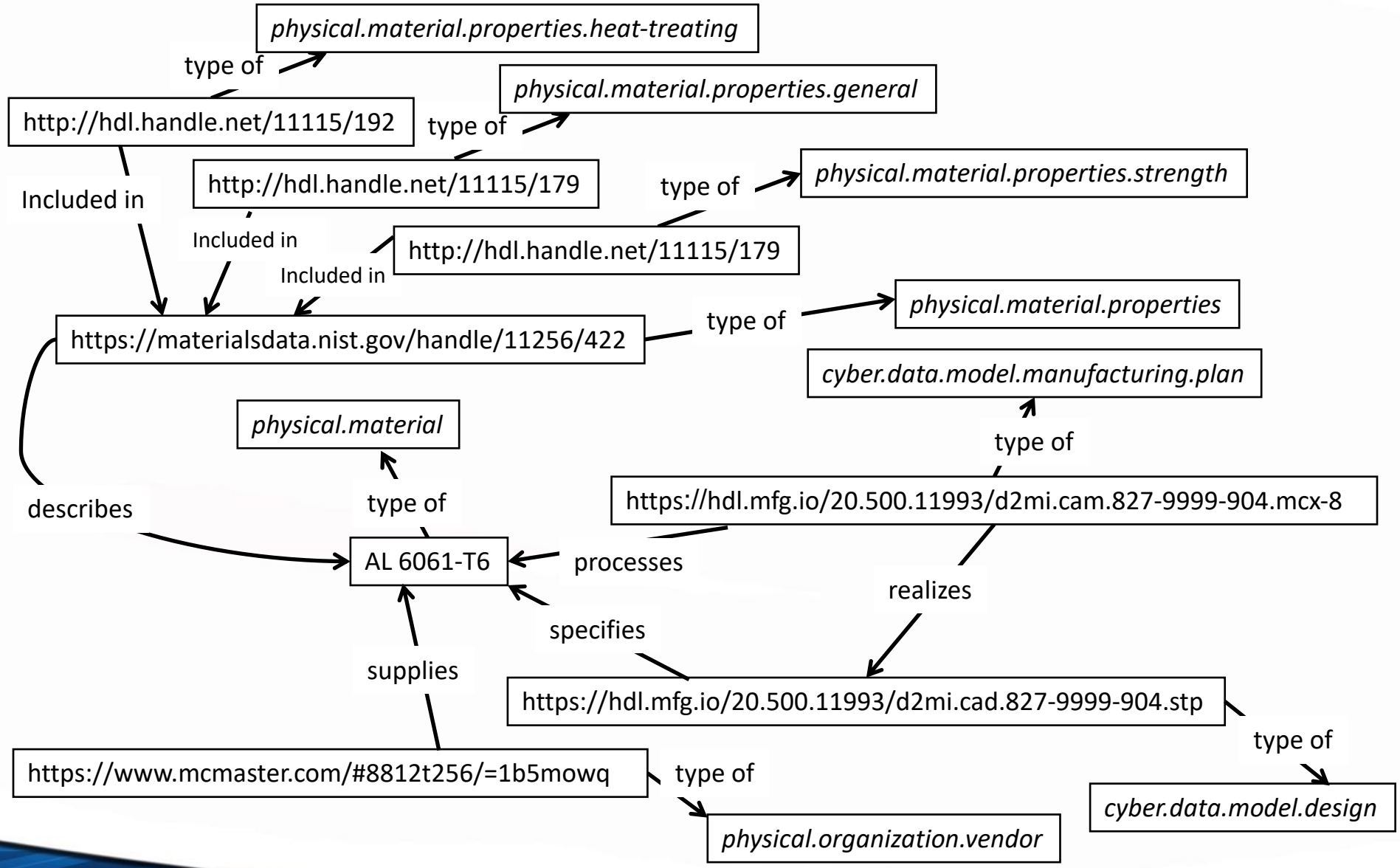

Hedberg Jr, T., Barnard Feeney, A., Helu, M., & Camelio, J. A. (2017). Towards a Lifecycle Information Framework and Technology in Manufacturing. *Journal of Computing and Information Science in Engineering, 17*(2), 021010-021010-021013. doi:10.1115/1.4034132

# Cyber-Physical Graph: Fabrication Context




*Append "?noredirect" to end of HTTPS-URI to see meta-data

# Cyber-Physical Graph: Materials Context



# Contents

# System Lifecycle Handler (SLH) – Use Cases

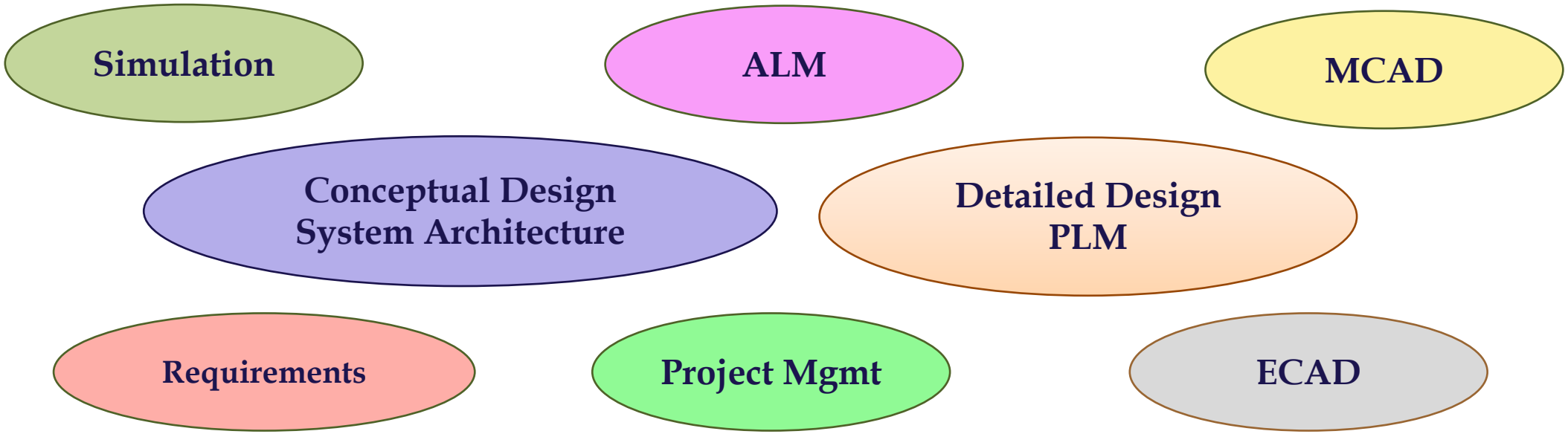


- ***Build*** digital thread for systems
  - ***Connect*** to data across the enterprise (Systems, PLM, CAD, ALM, Project management, Manufacturing, Operations) and spin a digital thread
  - ***Generate*** models as information moves across disciplines
- ***Query*** *and* ***search*** the digital thread
- ***Manage*** the digital thread
  - ***Track changes*** in versioned models connected in the digital thread
  - ***Compare, synchronize, repair*** connections and models
- ***Visualize*** the digital thread

# Silos of models and data



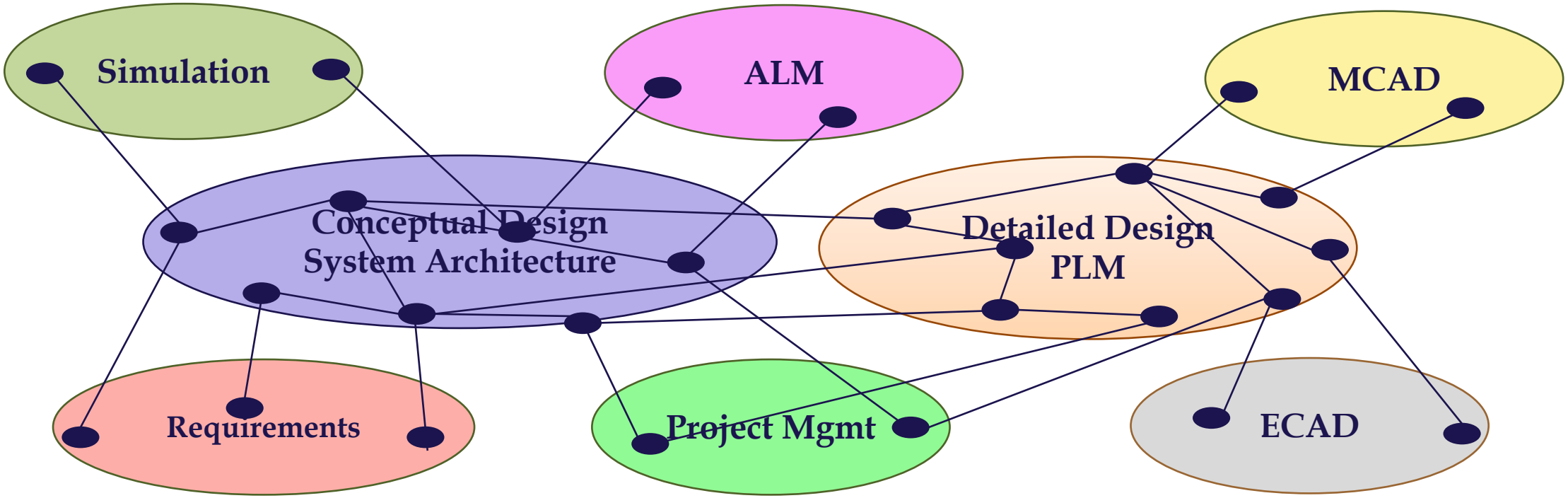
- Organizations deal with a diverse, multi-vendor engineering toolset.
- They create and store product/system data in a variety of tools, models and repositories: PLM, ALM, CAD, spreadsheets, databases, SysML models…



# Digital Thread – Connecting the domains for true MBE



- Federating data and models across disciplines
- Connecting model elements and data at different levels of abstractions

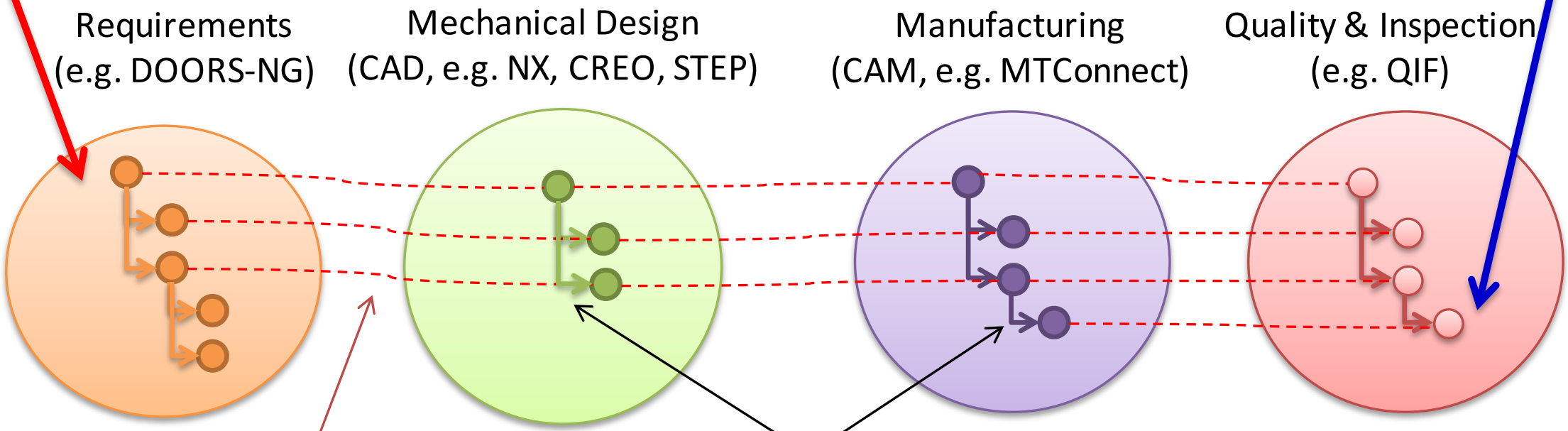


# Digital Thread – Example showing artifacts and connections



*If I change this requirement, what is the downstream impact, e.g. to CAD and CAM models?*

*Trace the CAD and CAM models for this part and compare attributes against test results*



# Connections / Links in the Digital Thread

- What is the purpose of model-based connections?

Reference Connections

Track/compare/sync versions of connected elements

Data Map Connections

+ Track/compare/sync element attributes

Function Wrap Connections

+ Track/execute connection elements

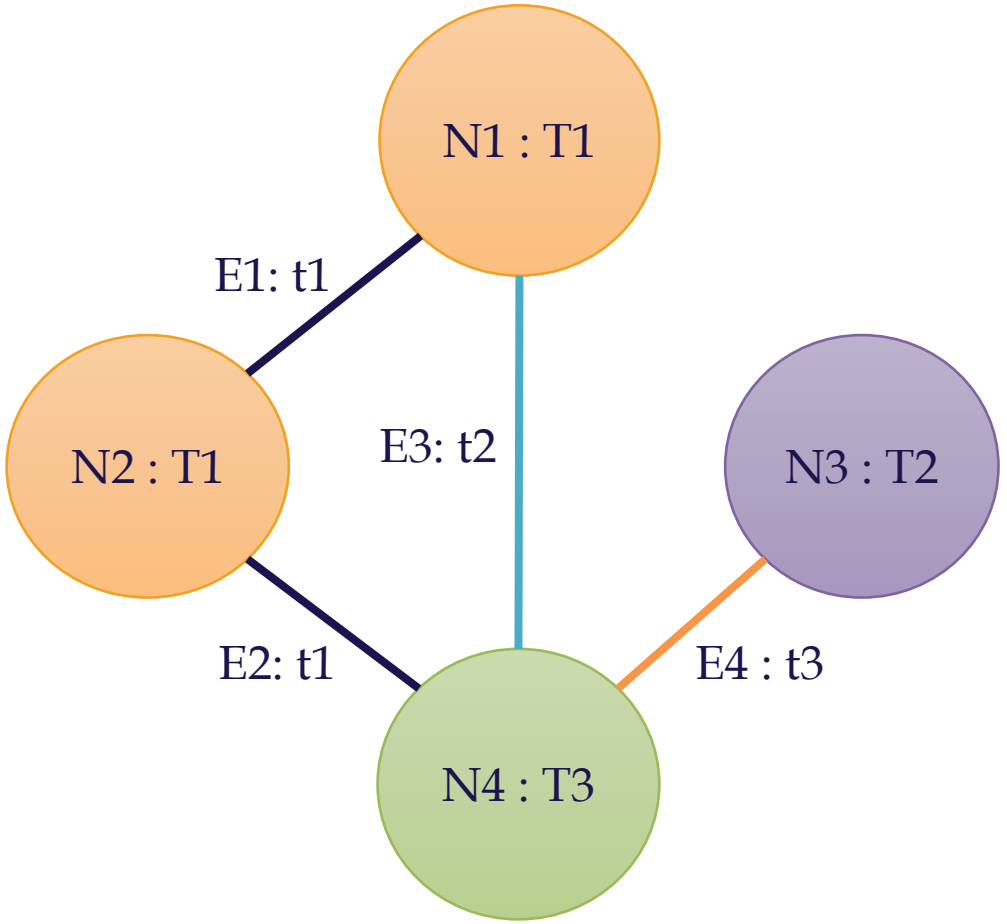
Model Transform Connections

+ Track/compare/sync element structure (multi-level)

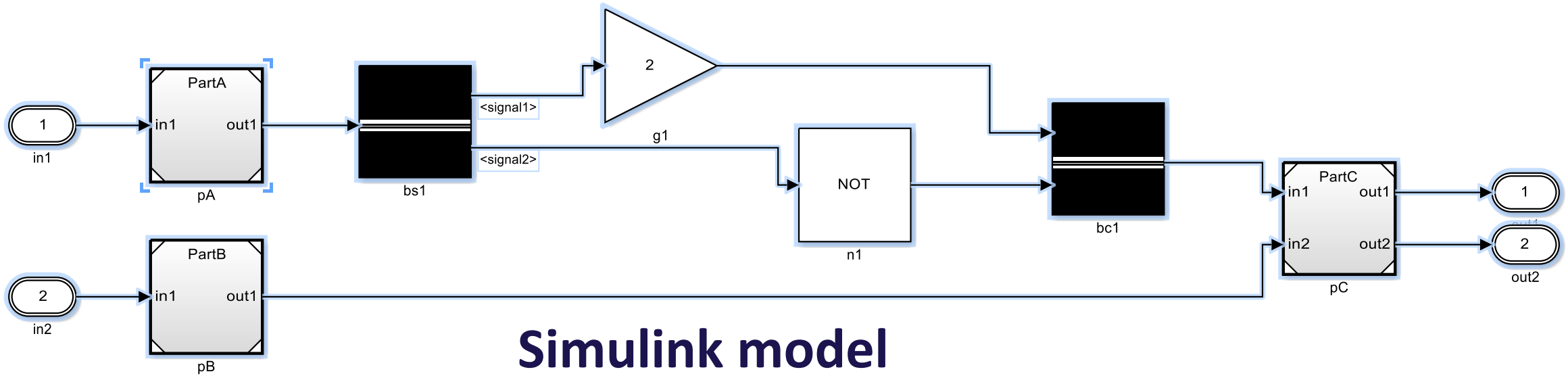
# Digital Thread is a *Graph*



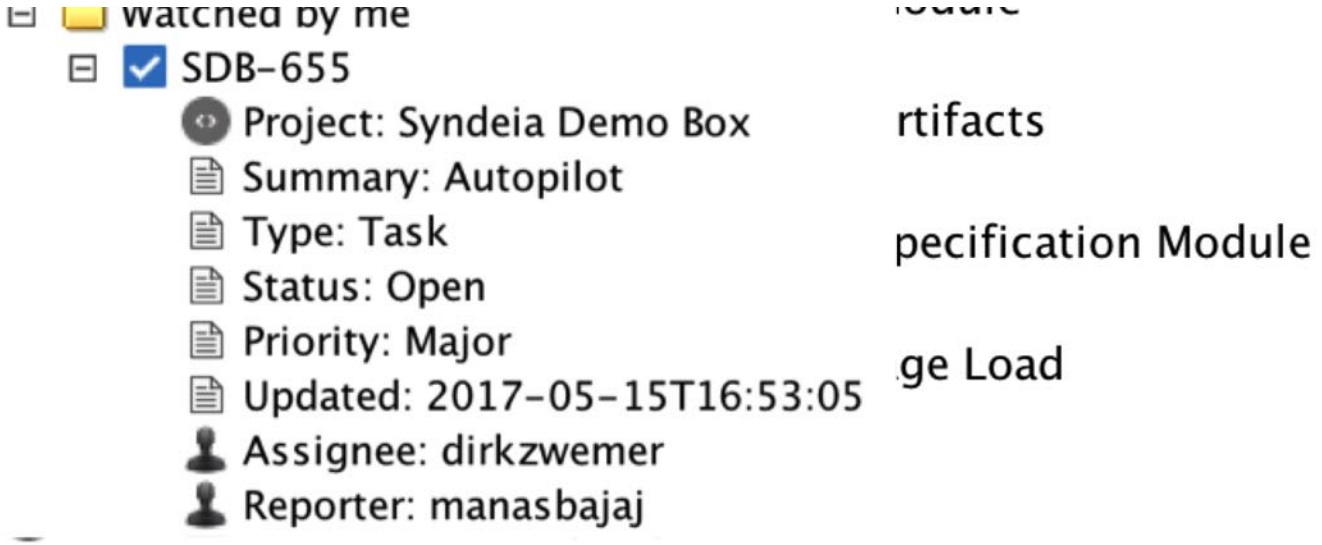
- Graph – Nodes and Edges
- Nodes and Edges may have
  - Name
  - Type (Typed Graph)
  - Properties (Property Graph)
- Edges may have
  - Direction (Directed vs. Undirected Graph)
- Graphs can be
  - Stored
  - Queried (Pattern matching)
  - Traversed (e.g. Breadth-first, Depth-first)
  - Generated and Transformed
  - Analyzed

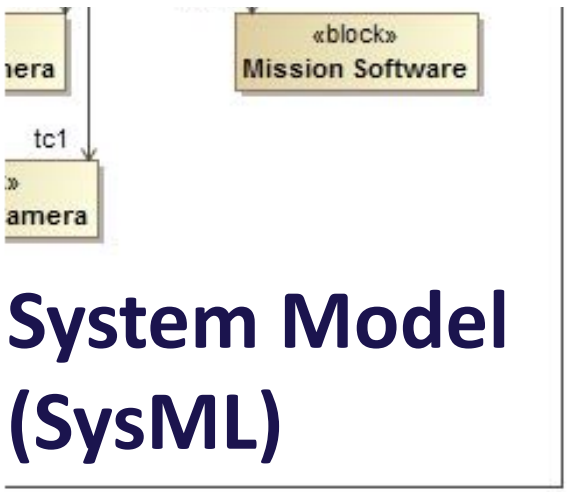


# Information models can be abstracted as graphs




**Simulink model**



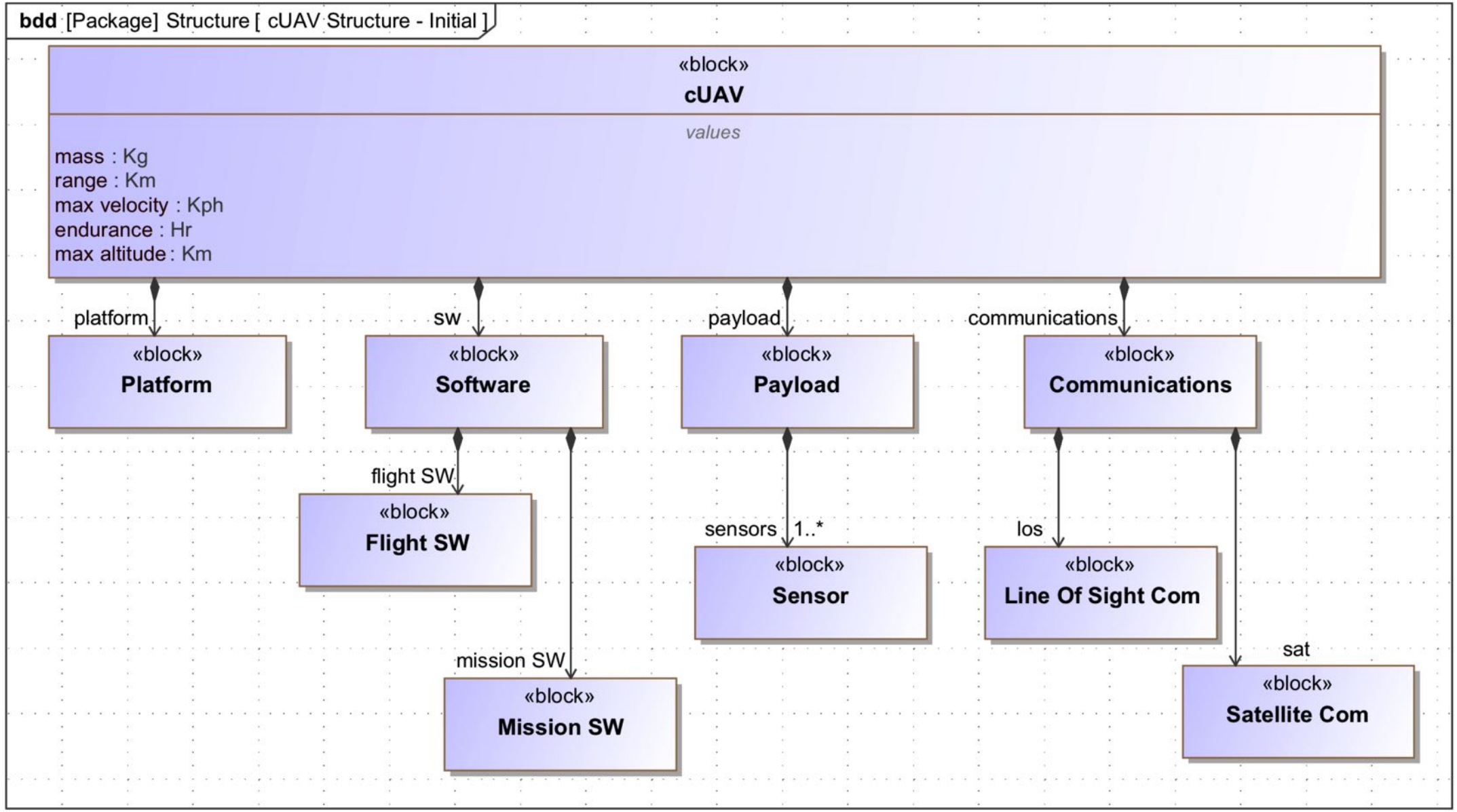

**System Model (SysML)**

# Contents

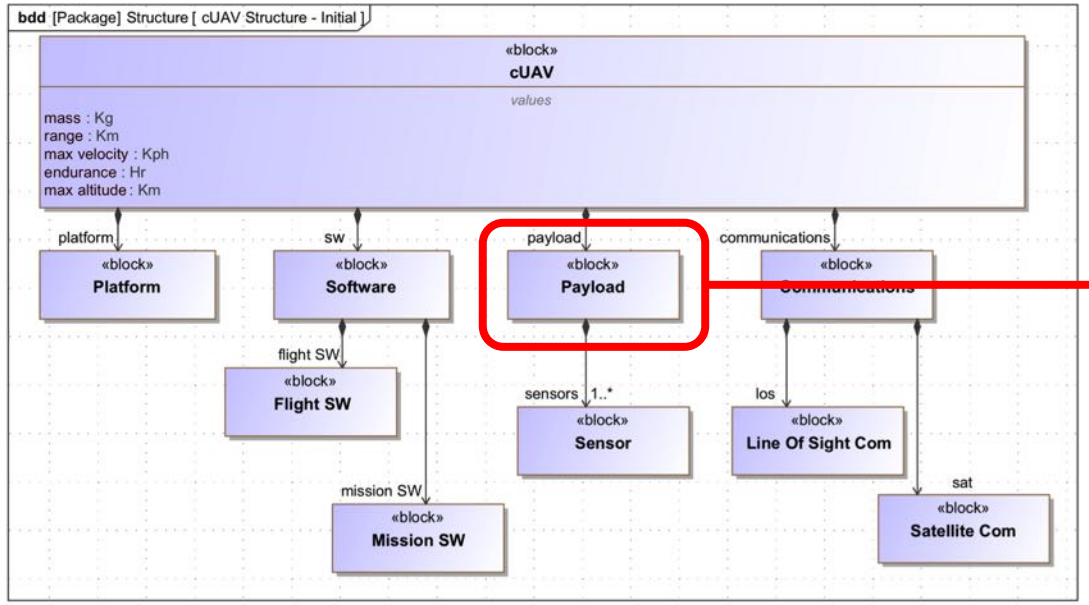


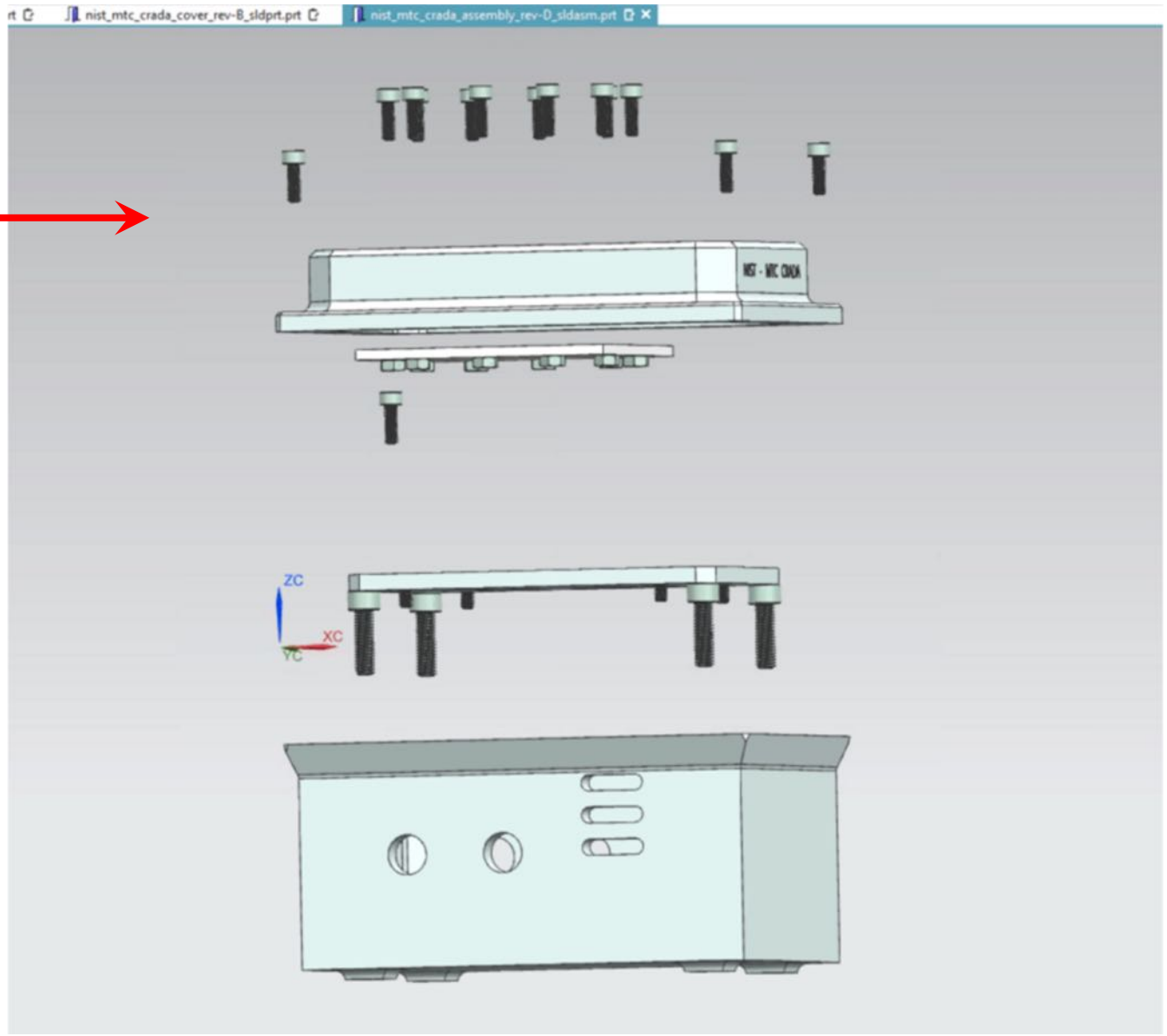
- Digital Thread for Smart Manufacturing
- System Lifecycle Handler - Foundations
  - Project goals
  - Use Cases
  - Graph foundations
- **System Lifecycle Handler – Proof-of-concept demonstrations**
  - **Querying the digital thread**
  - **Building the digital thread**
  - **Maintaining the digital thread**
  - **API for the digital thread**
  - **Tools, APIs, and open standards used in the PoC**
- Next steps
- Questions and Comments

# Testbed model for proof-of-concept – Configurable UAV



# Testbed model for proof-of-concept – Configurable UAV




Enclosure Box for an Avionics assembly used in the Configurable UAV

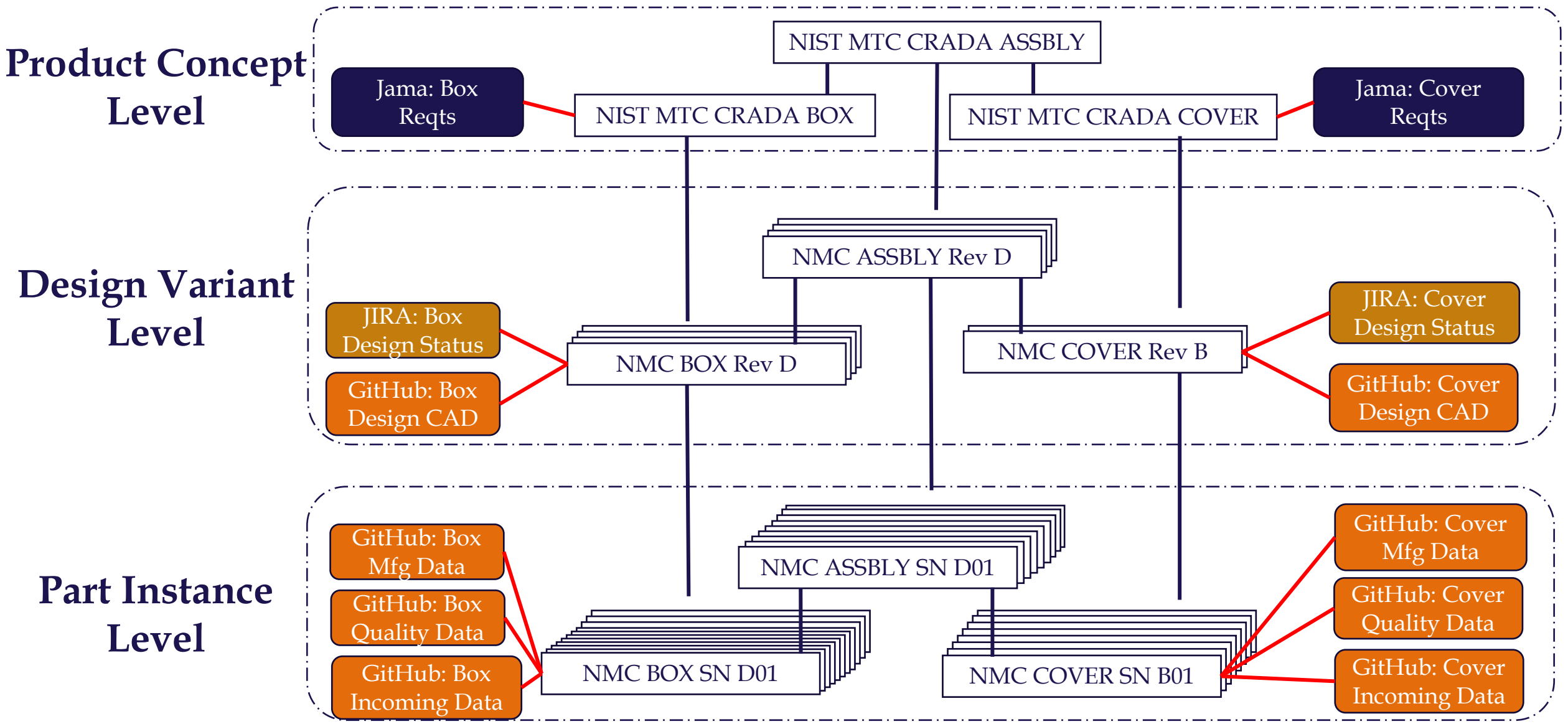
# Available data and models for the Enclosure Box



- **SysML** model of the UAV and the payload
- CAD models for multiple variants and revisions of the Box (**SolidWorks files on GitHub**)
- Design flow management in **JIRA**
- 20 instances of each part are manufactured. For each instance:
  - Machine sensor data streams for each part instance (**MTConnect 1.3 XML on GitHub**)
  - NC code data - ISO 6983 **(G-code files on GitHub)**
  - First article inspection reports (**QIF 2.1 XML on GitHub**)
  - Receiving inspection reports (**QIF 2.1 XML on GitHub**)

# Approach for organizing the digital thread





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# Demo video #1 – Querying the digital thread for the simple avionics box assembly

See video **DigitalThreadQuery.mp4**

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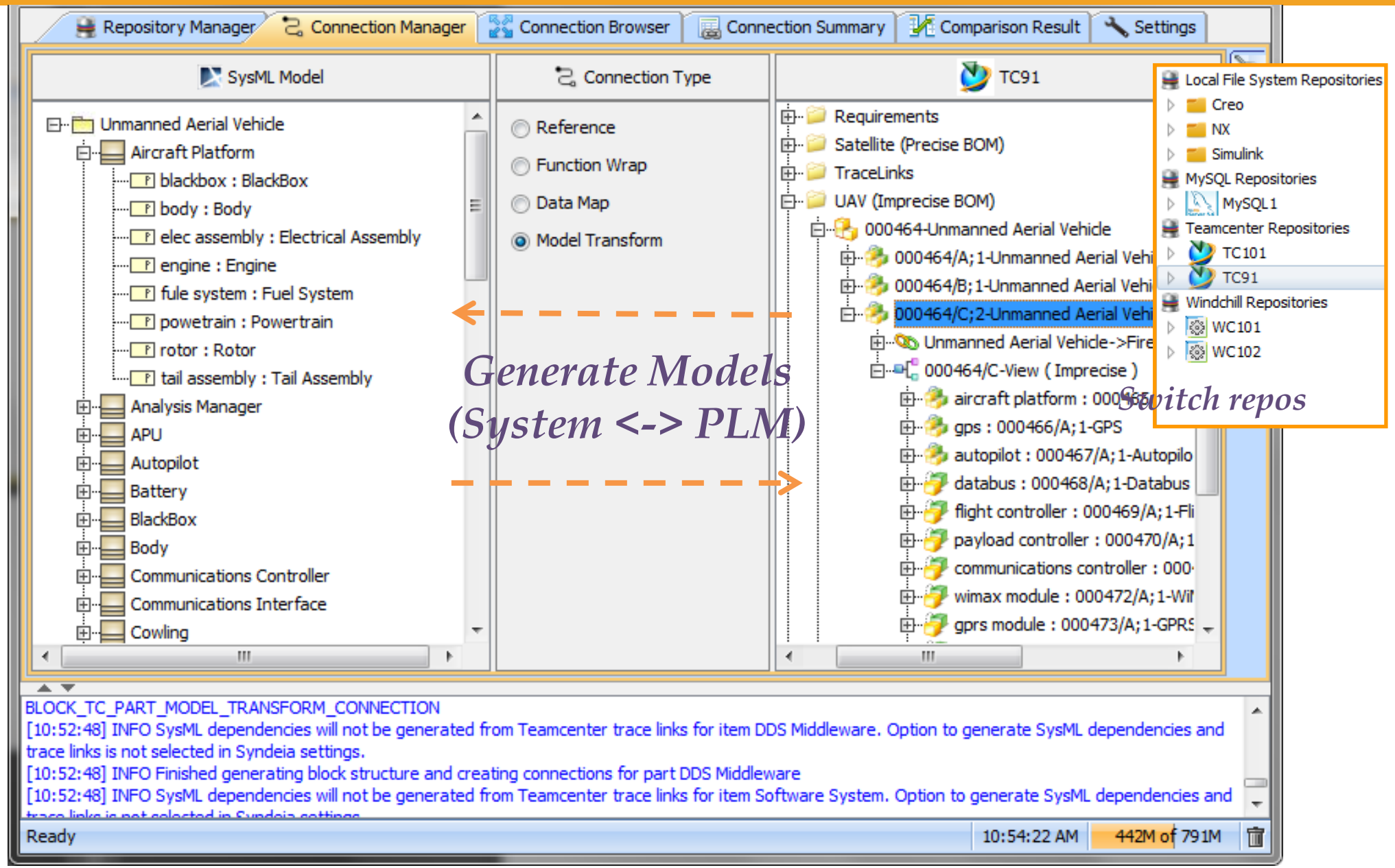
# Demo video #2 - Building the digital thread for the simple avionics box assembly

See video **DigitalThreadBuildManage.mp4**

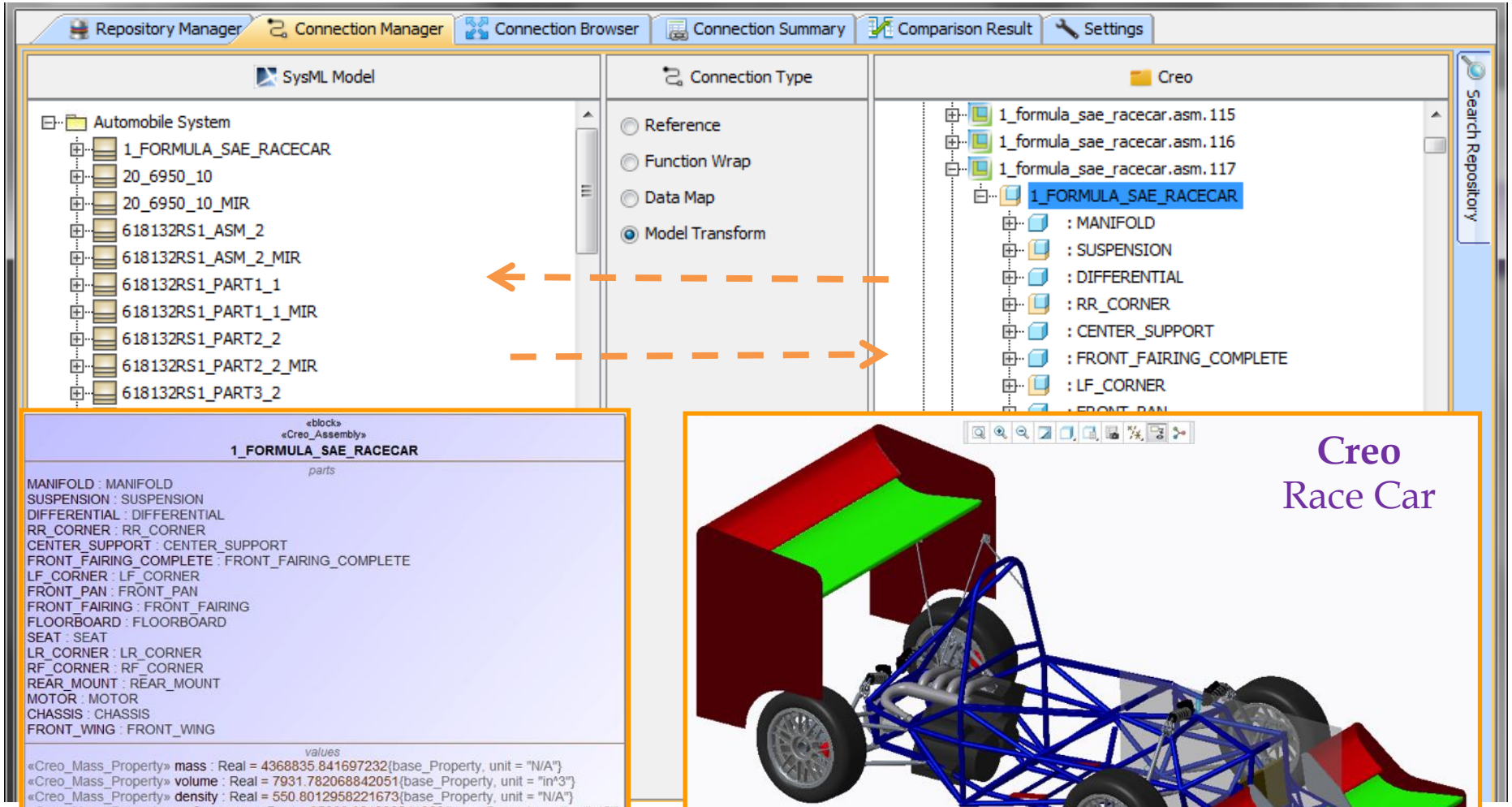
# Model Transformations – Automatically spinning the digital thread



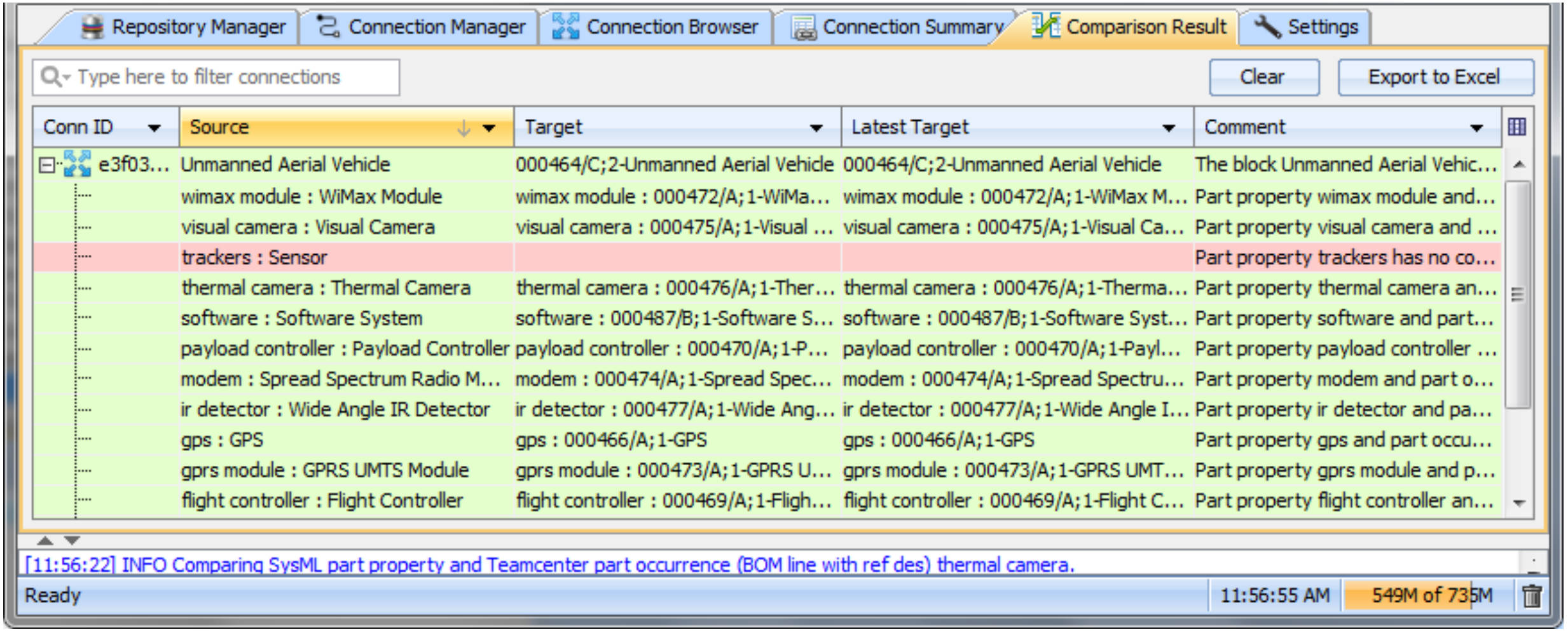
# Digital Thread as a conduit for information flow

*Requirements (SE -> ME)*

*Mass properties (ME -> SE)*

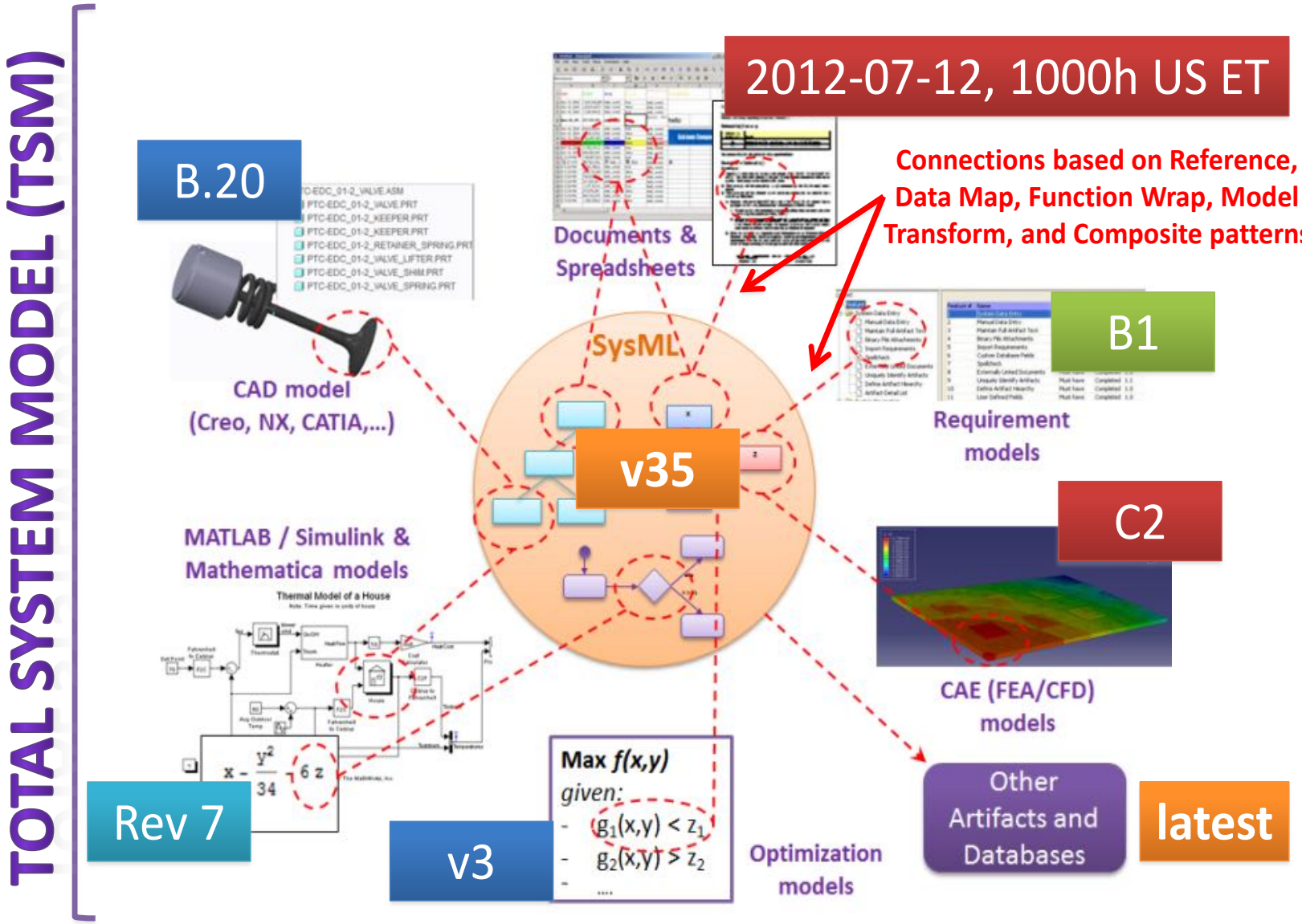


# Tracking changes in connected models in the digital thread




| Conn ID | Source | Target | Latest Target | Comment |
|---|---|---|---|---|
| e3f03... | Unmanned Aerial Vehicle | 000464/C;2-Unmanned Aerial Vehicle | 000464/C;2-Unmanned Aerial Vehicle | The block Unmanned Aerial Vehic... |
| | wimax module : WiMax Module | wimax module : 000472/A;1-WiMa... | wimax module : 000472/A;1-WiMax M... | Part property wimax module and... |
| | visual camera : Visual Camera | visual camera : 000475/A;1-Visual ... | visual camera : 000475/A;1-Visual Ca... | Part property visual camera and ... |
| | trackers : Sensor | | | Part property trackers has no co... |
| | thermal camera : Thermal Camera | thermal camera : 000476/A;1-Ther... | thermal camera : 000476/A;1-Therma... | Part property thermal camera an... |
| | software : Software System | software : 000487/B;1-Software S... | software : 000487/B;1-Software Syst... | Part property software and part... |
| | payload controller : Payload Controller | payload controller : 000470/A;1-P... | payload controller : 000470/A;1-Payl... | Part property payload controller ... |
| | modem : Spread Spectrum Radio M... | modem : 000474/A;1-Spread Spec... | modem : 000474/A;1-Spread Spectru... | Part property modem and part o... |
| | ir detector : Wide Angle IR Detector | ir detector : 000477/A;1-Wide Ang... | ir detector : 000477/A;1-Wide Angle I... | Part property ir detector and pa... |
| | gps : GPS | gps : 000466/A;1-GPS | gps : 000466/A;1-GPS | Part property gps and part occu... |
| | gprs module : GPRS UMTS Module | gprs module : 000473/A;1-GPRS U... | gprs module : 000473/A;1-GPRS UMT... | Part property gprs module and p... |
| | flight controller : Flight Controller | flight controller : 000469/A;1-Fligh... | flight controller : 000469/A;1-Flight C... | Part property flight controller an... |

# Total System Model – A snapshot of the digital thread



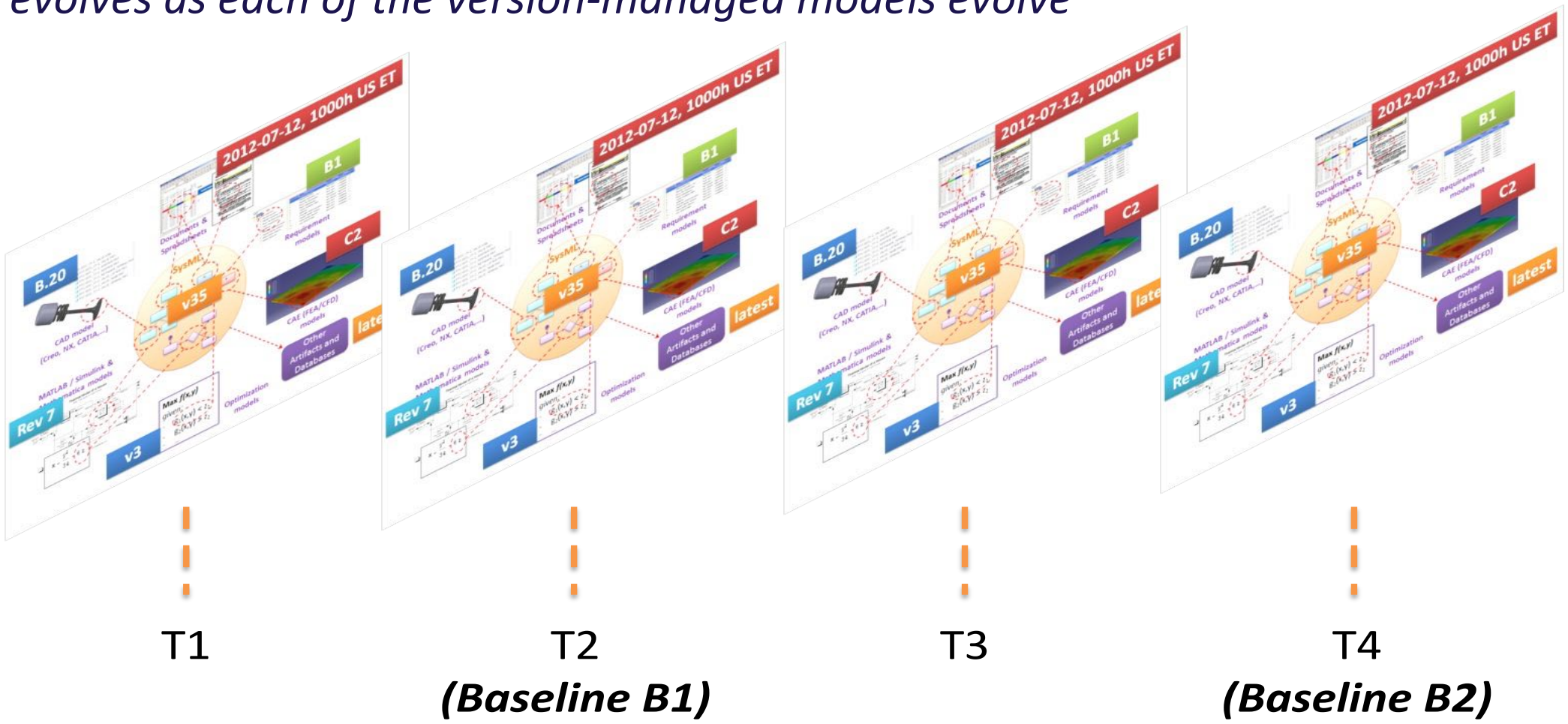

Connect architecture model (SysML) with domain-specific models

Total System Model (TSM) as a digital blueprint of the system connecting models across disciplines, tools, and version-management systems

Goal: Seamless traceability between disciplines across the system lifecycle

# Total System Model maturing though the lifecycle

*TSM evolves as each of the version-managed models evolve*



# Handler System – A registry for all participants in the digital thread

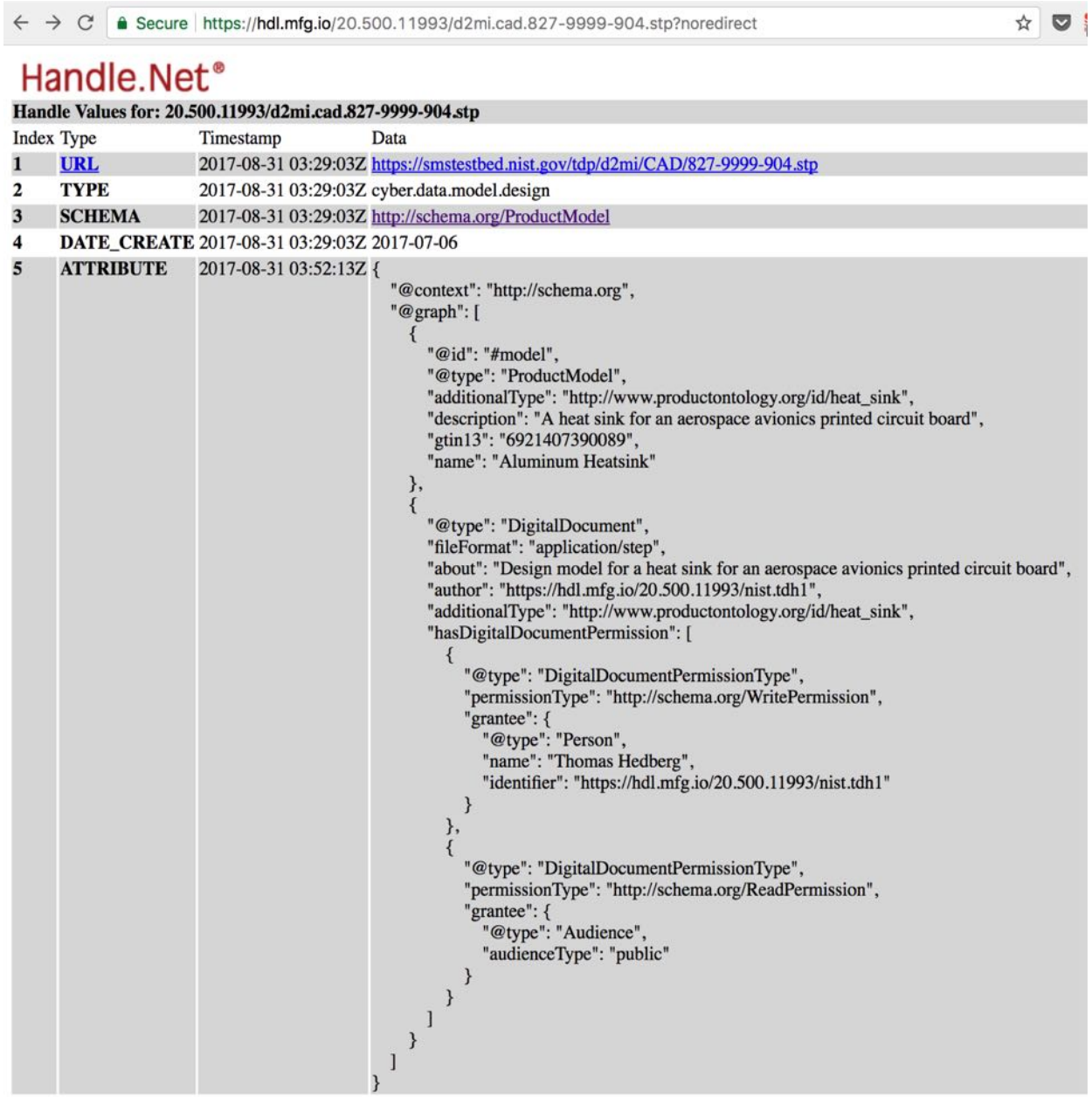
- Provides a unique registry for all artifacts in the digital thread (similar to DOI)
- Global ID system to identify artifacts (part, sensor, data, machines, …)
  - chain of addesses {A1, A2, A3, ...} similar to postal address. Addesses may be URIs.
- Basic meta-data for each artifact (full artifact data in native repository – PLM, ALM,...)
- Uses Handle.Net system

# Example entry in the Handle System for a Heat Sink part



Handler system
https://hdl.mfg.io

Entry for he Heat Sink part
https://hdl.mfg.io/20.500.11993/d2mi.cad.827-9999-904.stp?noredirect



# API for the digital thread



**Request URL**

```
http://localhost:9000/api/v1/repositories
```

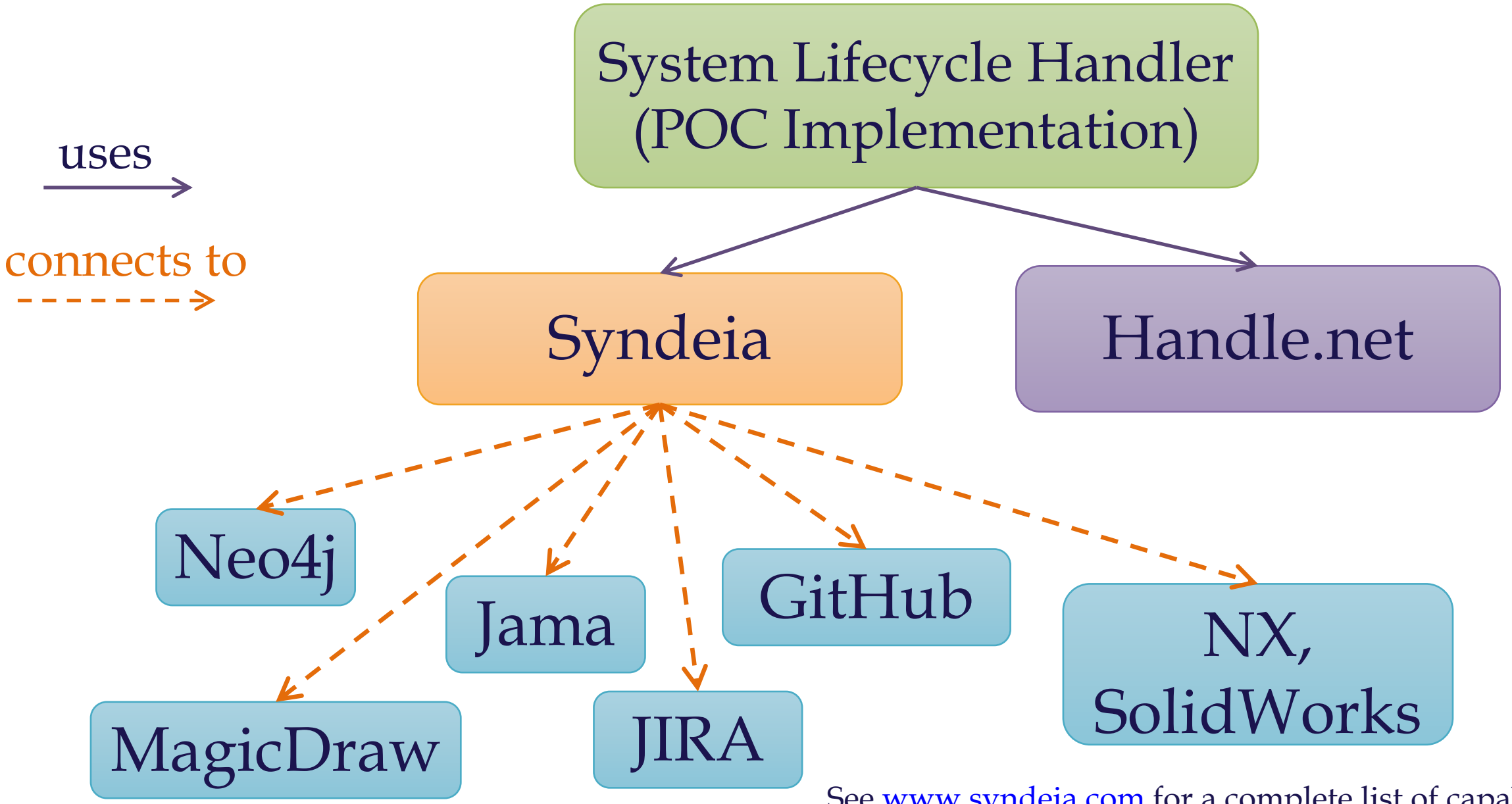
**Server response**

| Code | Details |
|---|---|
| 200 | **Response body** |


```
{
  "statusCode": 200,
  "headers": {},
  "pageInfo": {
    "startIndex": 0,
    "resultCount": 38,
    "totalResults": 0
  },
  "resources": [
    {
      "id": "63bd28f1-2fd9-11e8-9021-336807f93a57",
      "createdBy": "af860442-f78b-11e7-b394-c9ef258a9419",
      "createdDate": "2018-03-24 23:05:36.252-0400",
      "modifiedBy": "af860442-f78b-11e7-b394-c9ef258a9419",
      "modifiedDate": "2018-03-24 23:05:36.252-0400",
      "key": "JAMA-30",
      "gid": "eXd1cVIVVLa8__Q9kW6ELozkLqCIHitQ",
      "name": "Jama 3 @ Intercax",
      "description": "",
      "attributes": {
        "RESTFUL_REQUESTS": "[]"
      },
      "type": {
        "id": "63bd28f3-2fd9-11e8-9021-336807f93a57",
        "name": "Jama repository"
      },
      "host": "https://intercax.jamacloud.com",
      "authentication": {}
    },
    {
```


- REST/HTTP API to access data in the digital thread, such as:
  - Repositories, projects, model elements, and connections
  - Query capabilities to search for connections given type, source, target, etc. (basic graph navigation)
- Foundation for new apps that can be built to access, analyze, enhance the digital thread

# Tools used in this proof-of-concept (POC)




See www.syndeia.com for a complete list of capabilities

# Open Standards and APIs used in this POC



- SysML
- MTConnect
- QIF
- JSON
- REST/HTTP
- OSLC
- OAuth
- JDBC
- Other relevant open standards – STEP, FMI
- Native APIs, and Multiple open source Apache and Google libraries

# Next Steps

- Common schema(s) for the artifacts and relationships in the digital thread
- Library of queries (FAQs) for the digital thread
- Tracking active lifecycle states – design, make, ops, service
- Explore multi-level change management scenarios, e.g. replay cascading changes that may happen if one artifact changes
- Test suites for V&V of the digital thread, automated testing and release builds (Technical Data Packages) of the digital thread

# Questions and Comments

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Thomas Hedberg -- thomas.hedberg@nist.gov

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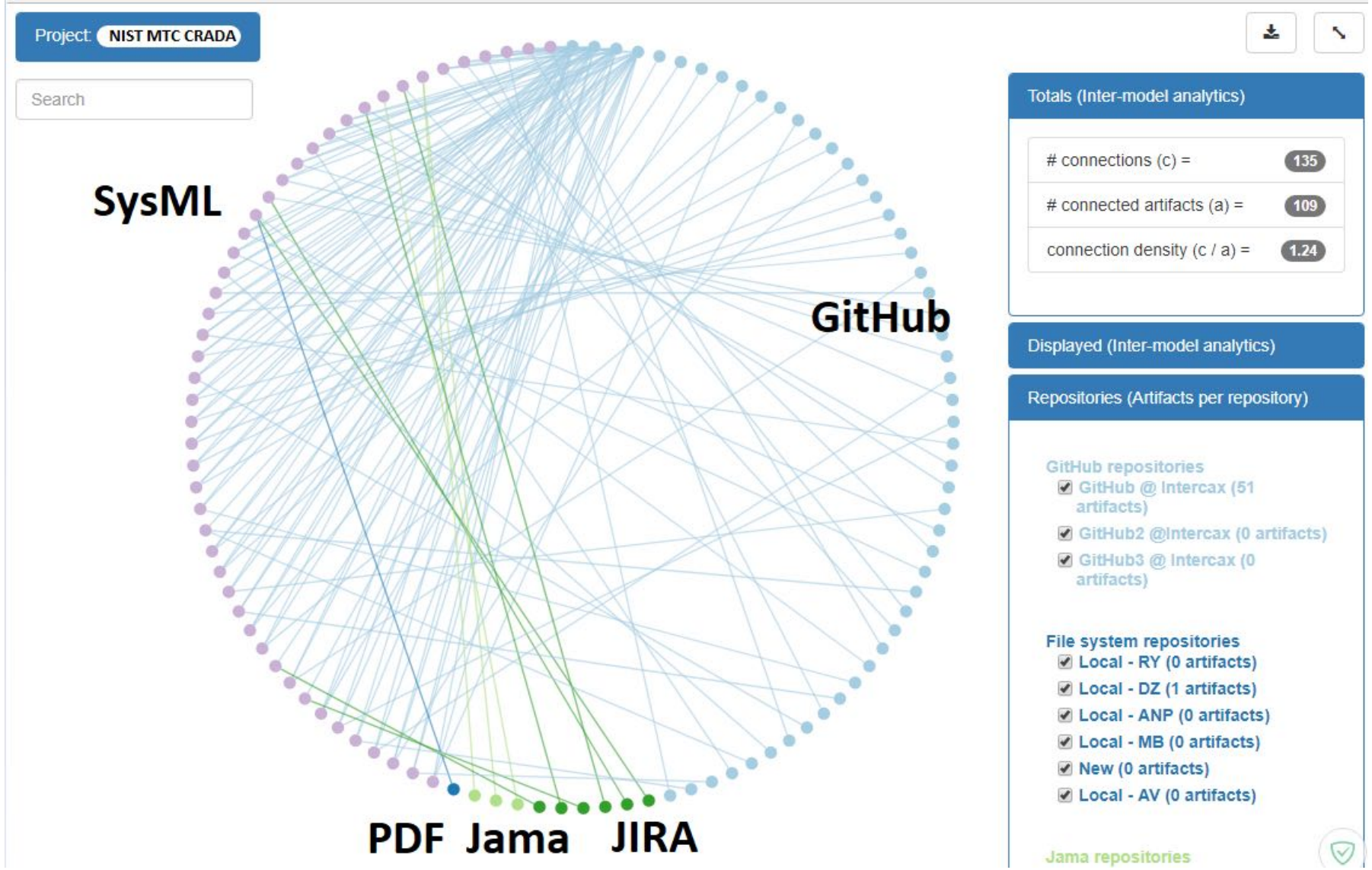
# Screenshots of the key visualizations shown in the demonstration videos

# Syndeia Chord Plot Visualization

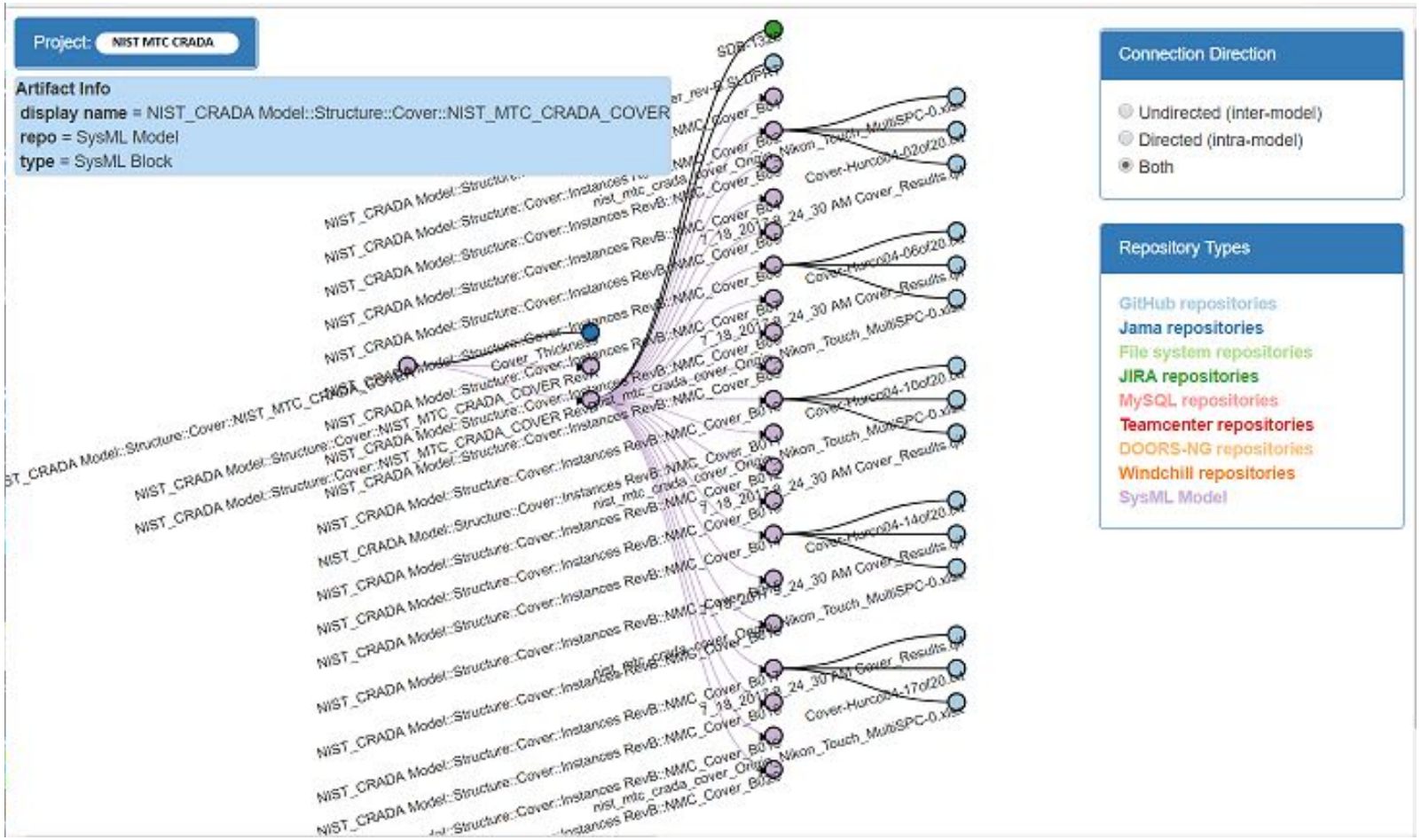





## Chord Plot

## Syndeia Inter-Model Connections

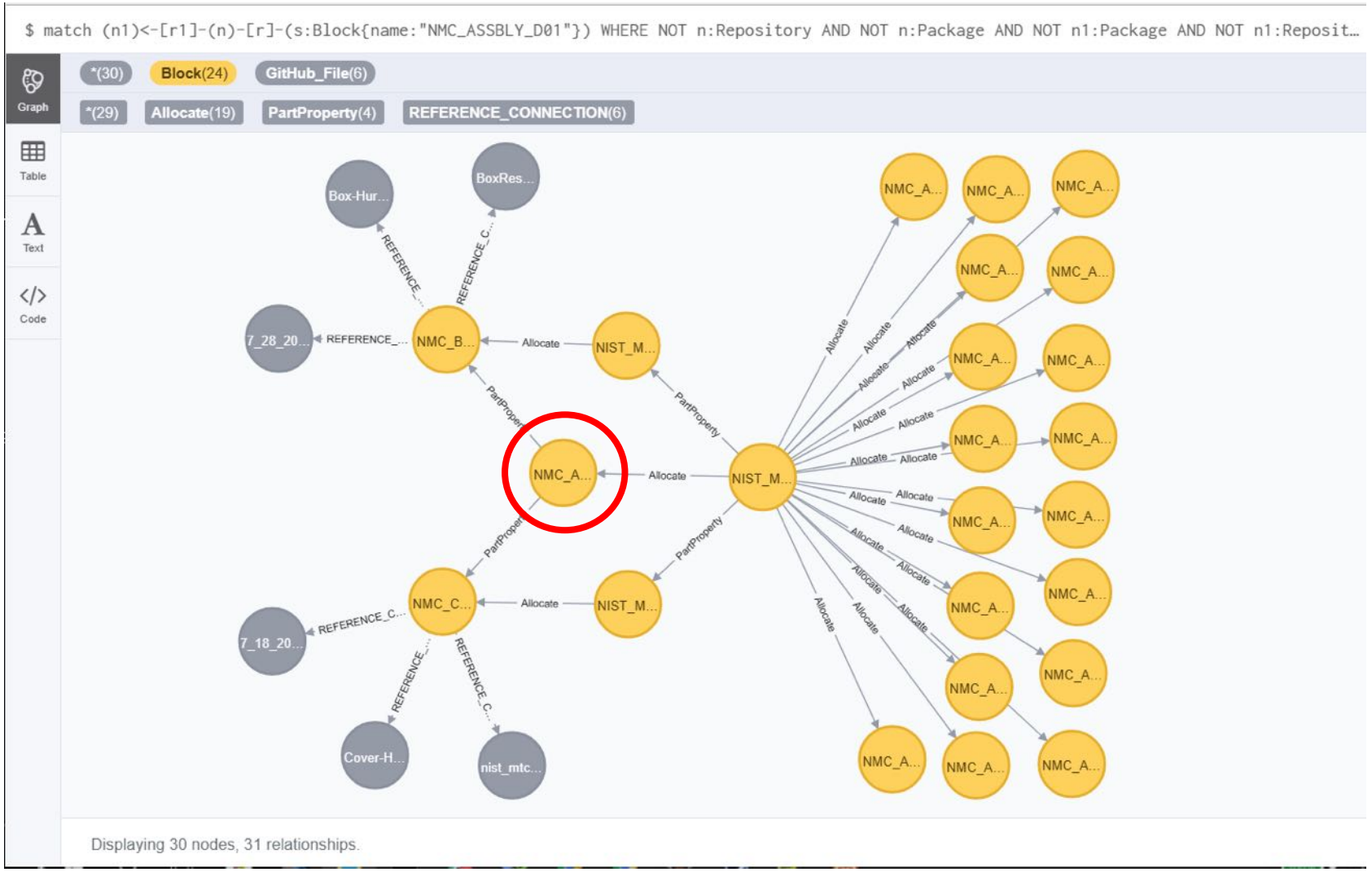
# Syndeia Tree Layout Visualization




Product Concept | Design Variants | Part Instances | Mfg & Quality Data Files

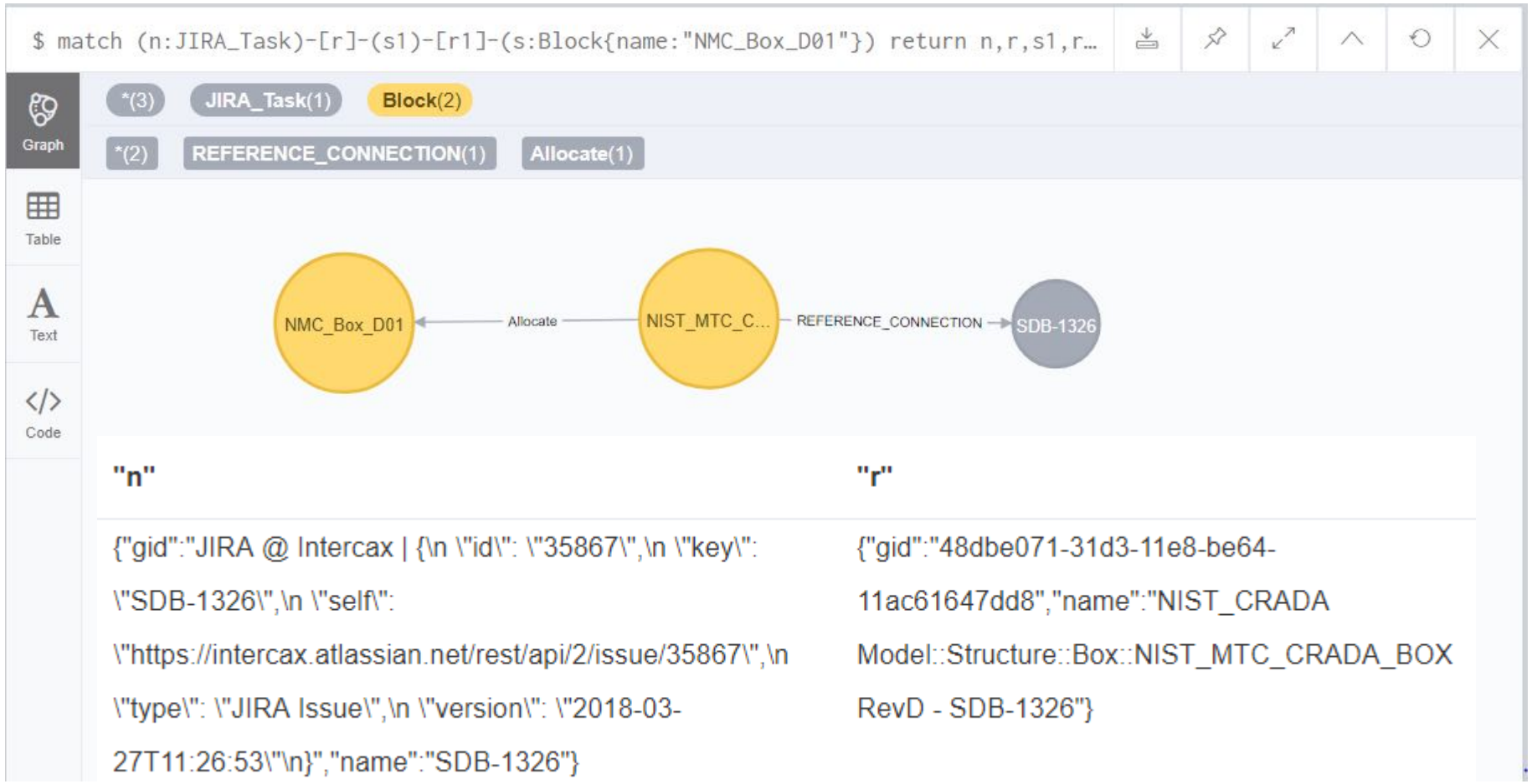
Tree Expansion from Product Concept ‘NIST_MTC _CRADA_Cover’

# Graph Database Queries



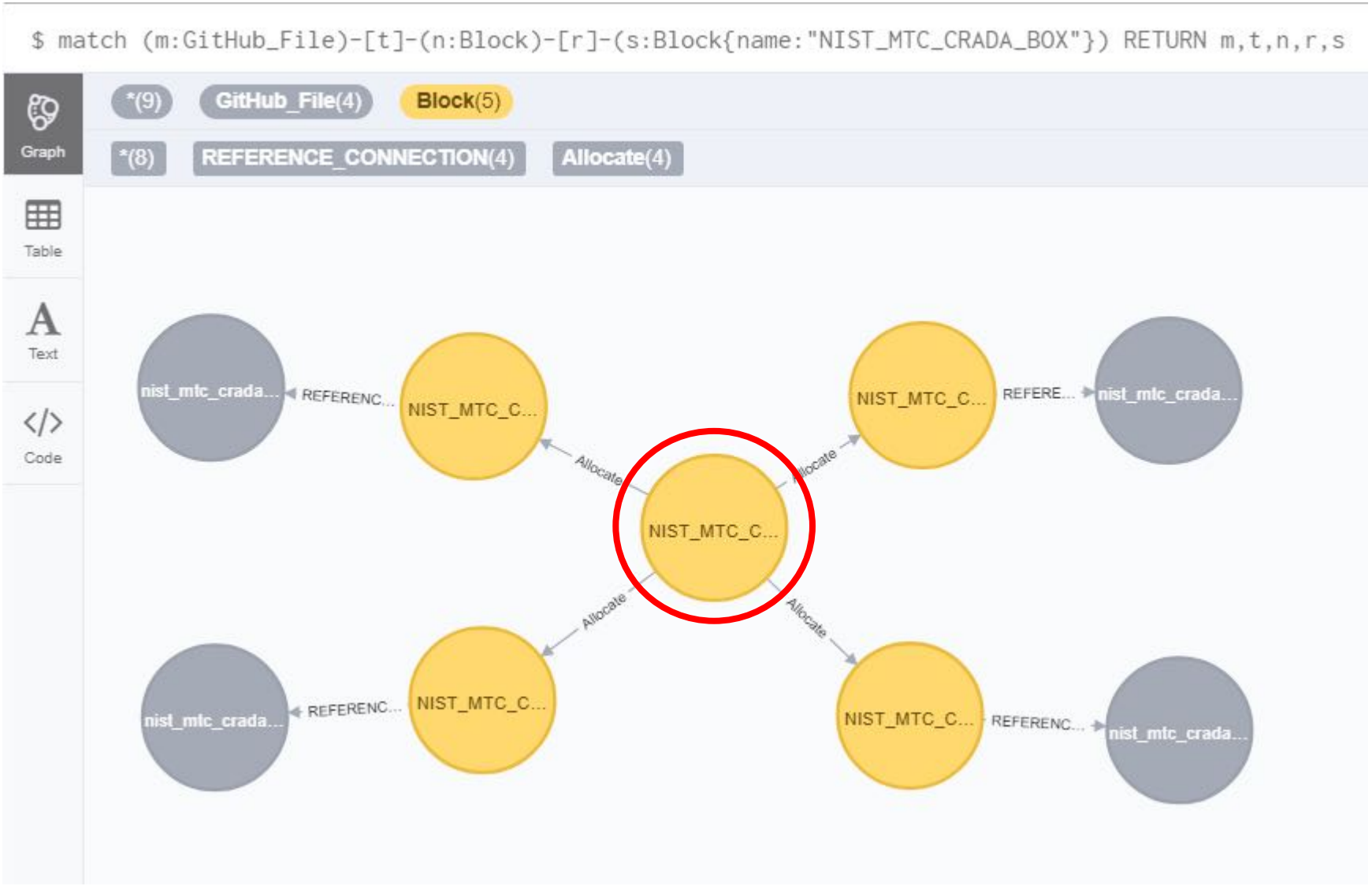

Show all nearest and next-nearest neighbors to Part Instance ‘NMC_ASSBLY_D01’

# Graph Database Queries



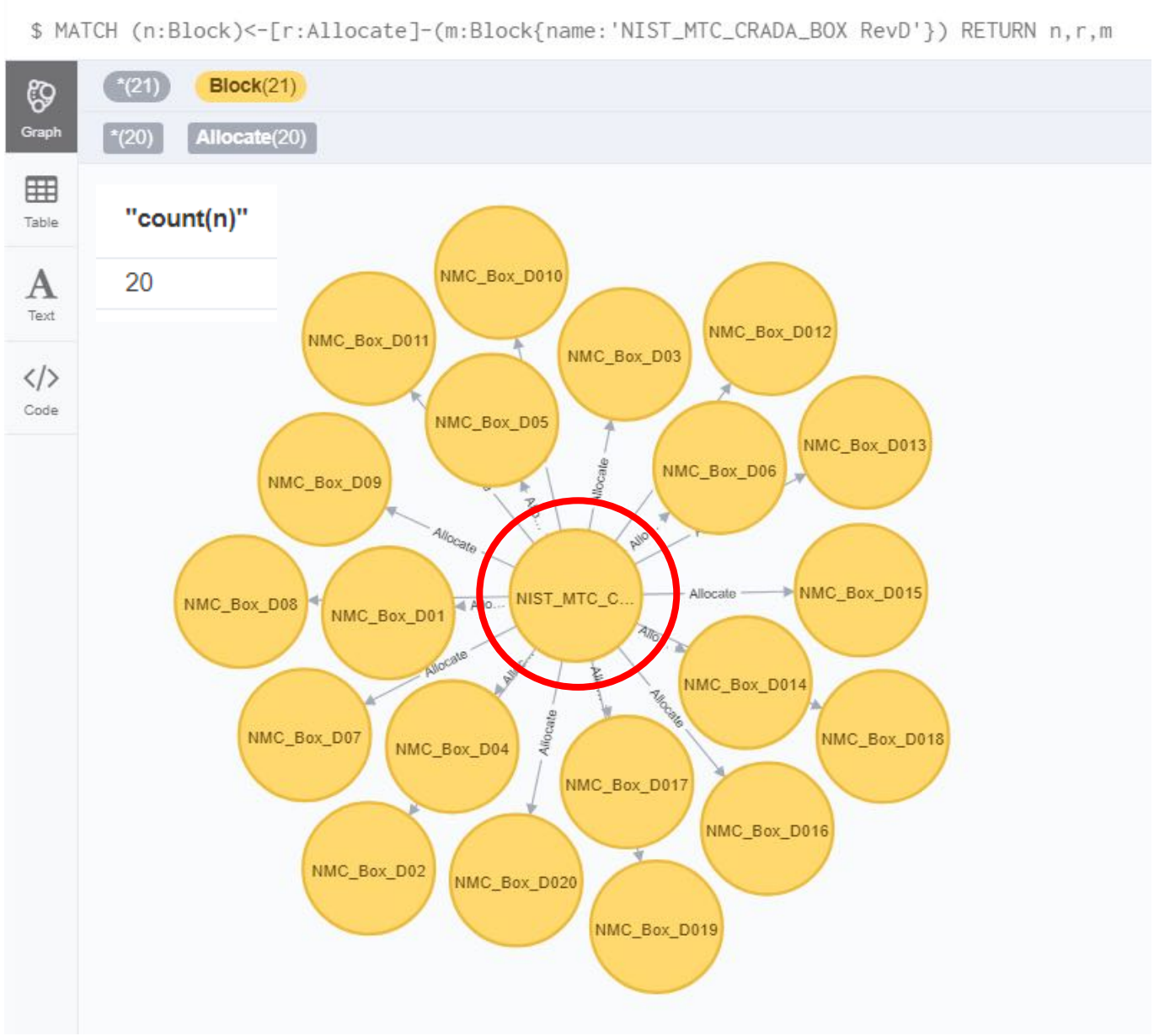

Show all JIRA Tasks connected to Part Instance ‘NMC_Box_D01

# Graph Database Queries



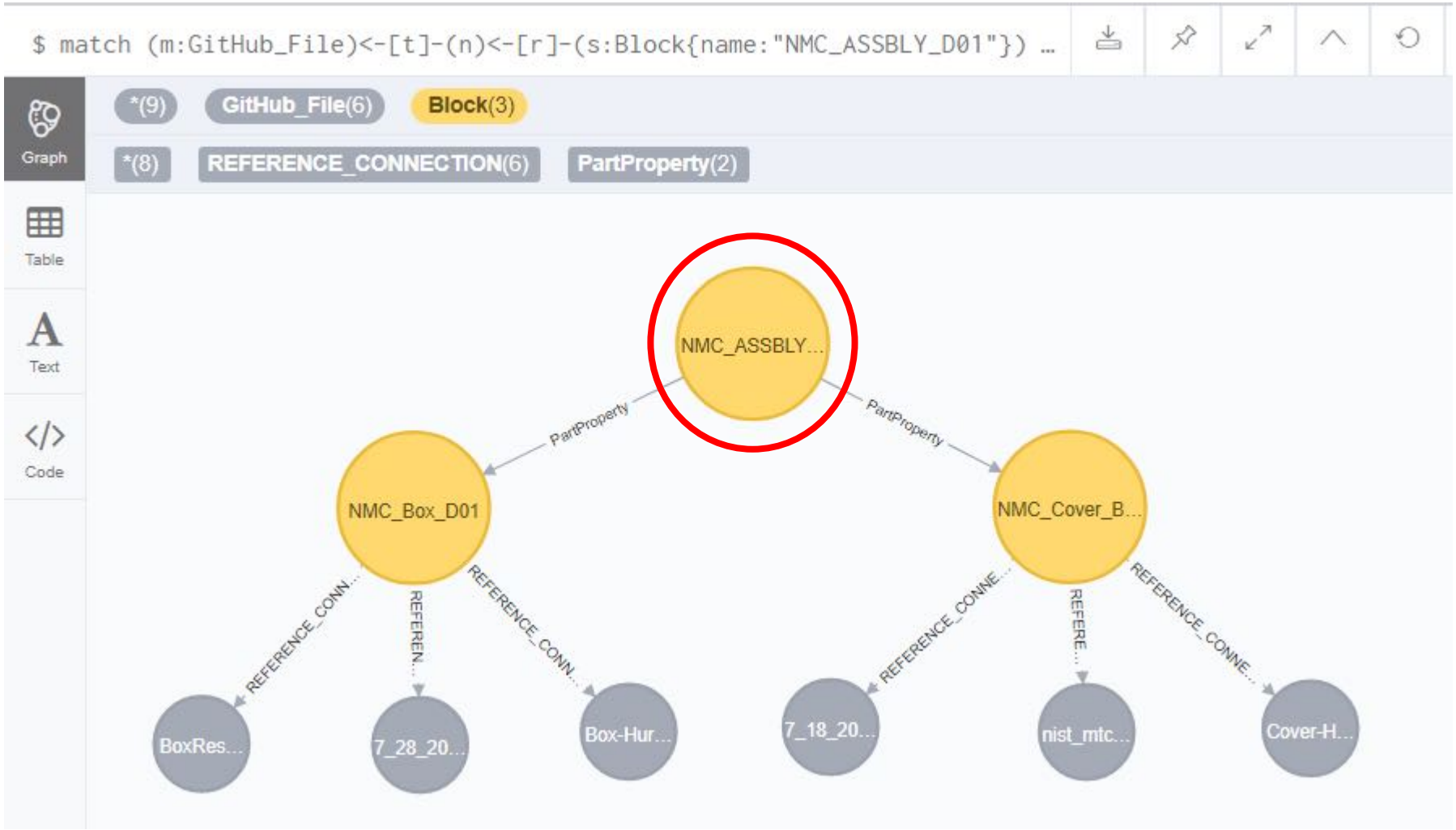

Show all Design Variants of Product Concept ‘NIST_MTC_CRADA_Box’ and associated CAD files

# Graph Database Queries




Show all Part Instances of Design Variant block ‘NIST_MTC_CRADA_Box_RevD

# Graph Database Queries




Show all Mfg and Quality files in GitHub associated with Part Instance ‘NMC_ASSBLY_D01’

# Graph Database Queries



```
$ MATCH (m:Block)-[t:Allocate]-(n:Block)-
```

Table

| "count(m)" |
| --- |
| 20 |

Text

```
$ MATCH (n1:GitHub_File{name:'BoxResults_19_
```

Table

| "count(m)" |
| --- |
| 19 |

```
$ MATCH (n1:GitHub_File{name:'BoxResults_19_samples.QIF'})-[r1:REFERENC
```

Graph

Table

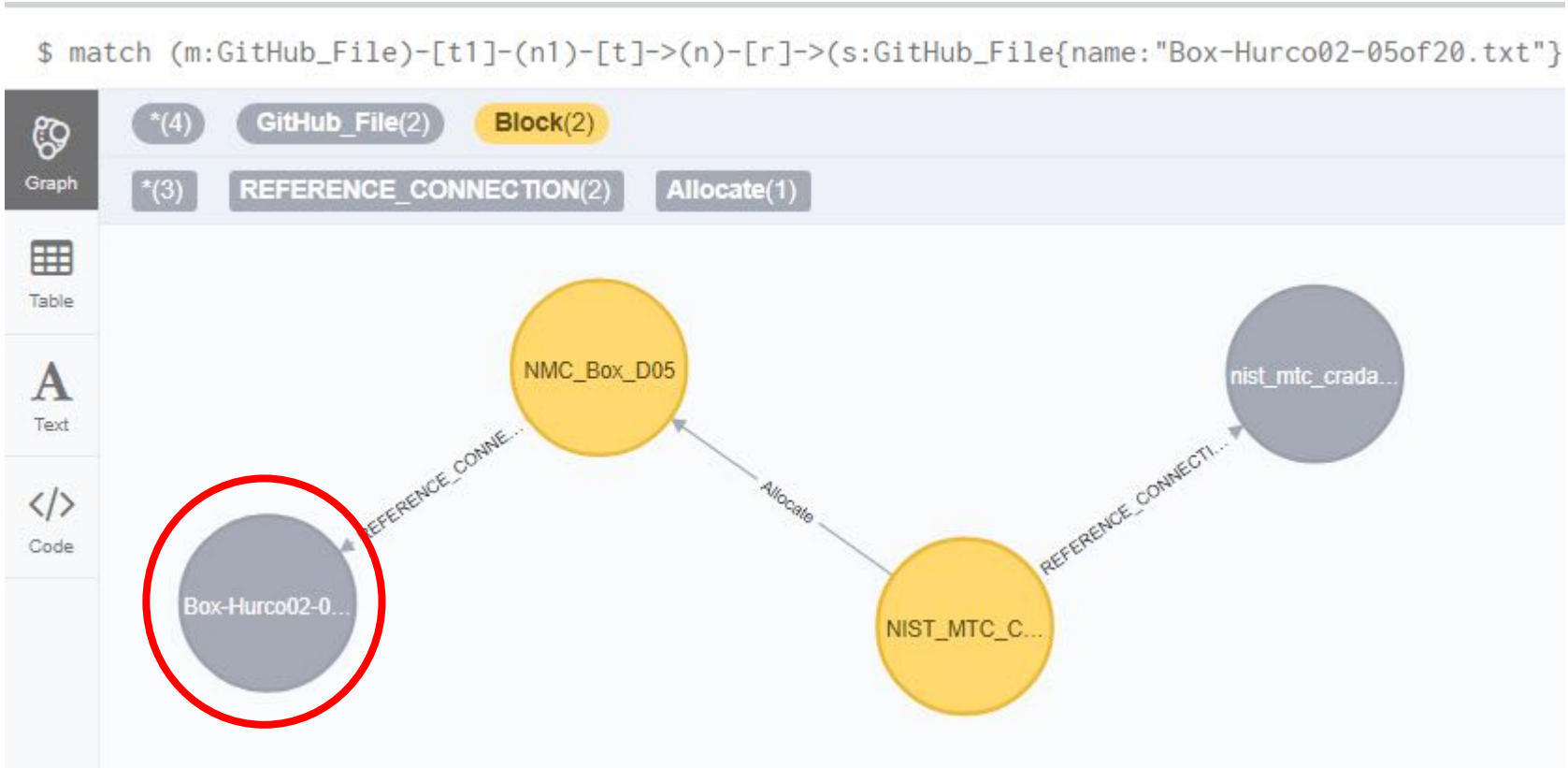
| "m" |
| --- |
| {"gid":"PROJECT-b11f2583-da67-4515-b8d9-1304d22c06a7 \| _18_5_3_63e021c_1521994265350_944094_15411","name":"NMC_Box_D019"} |
| {"gid":"PROJECT-b11f2583-da67-4515-b8d9-1304d22c06a7 \| _18_5_3_63e021c_1521994264434_175058_15408","name":"NMC_Box_D018"} |

How many instances of Box have been manufactured?

How many instances of Box have been through incoming inspection?

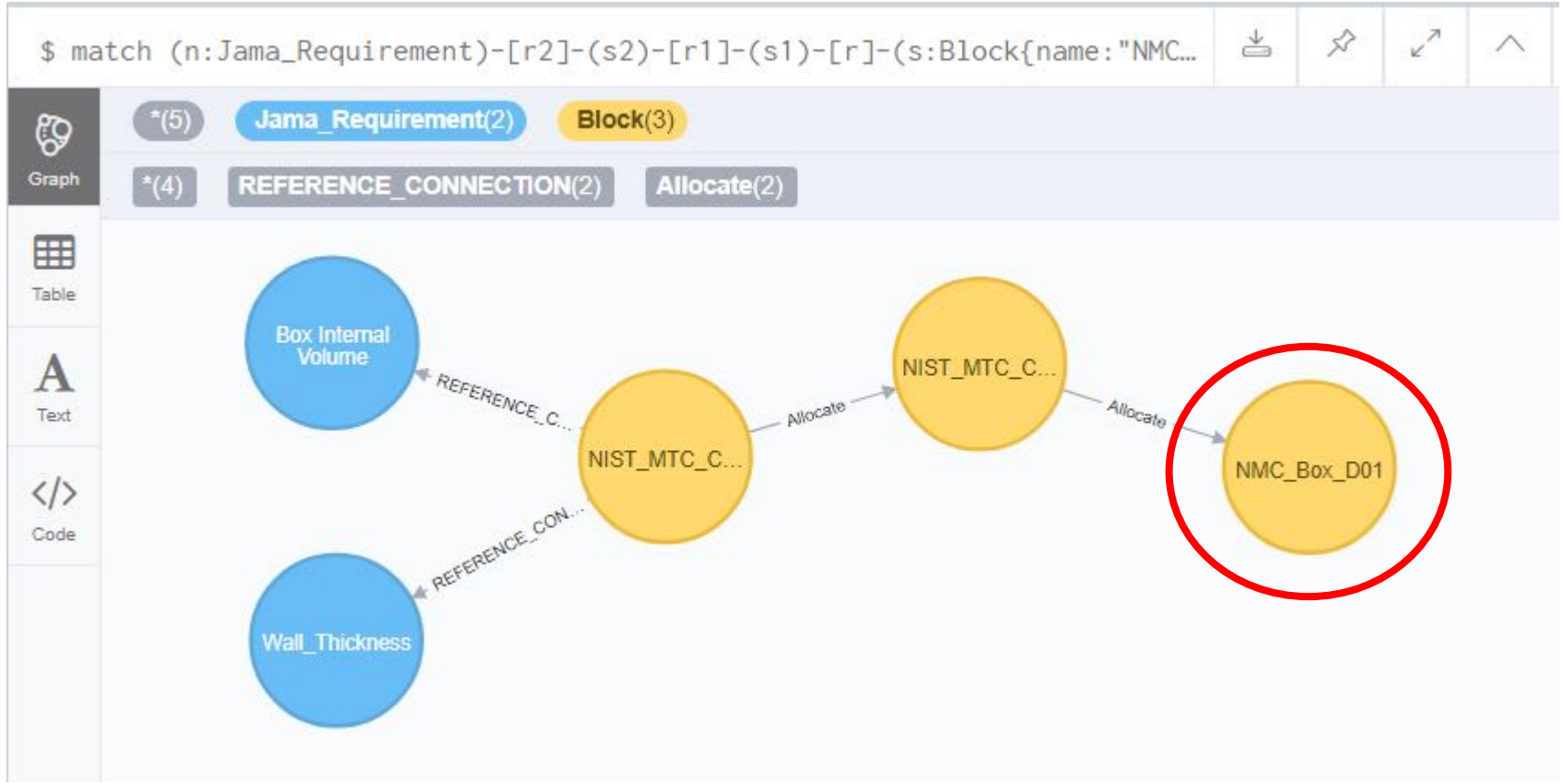
List them

# Graph Database Queries




Show the CAD file in GitHub associated with Mfg Data ‘Box-Hurco02-05of20.txt’

# Graph Database Queries




Show all Jama Requirements connected to Part Instance ‘NMC_Box_D01’