Using models for improving the efficiency of ESA mission operations

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Outline

- Introduction of the activities to be presented
- Overview of use cases
- Detailed use case presentation
- Conclusion and next steps

Activities introduction

- Combined presentation of the output of 2 study activities
  - Both activities had a **similar goal**
    - integrate **engineering models** for enhancing operations at the European Space Operations Centre (ESOC) and **improve the efficiency of routine operations** for our space missions
  - **Enabling continuity: from design to operations**
    - focused on capturing and modelling information about the space system to improve mission operations in mission planning, operational procedures, and machine learning (ML)
  - **MBSE and Space to Ground ICD**
    - focused on modelling information from the Space to Ground Interface Control Documents (SGICD) to automatically generate manually created documents and improve the efficiency of the initial configuration of next-generation mission control systems based on European Ground Systems Common Core (EGS-CC)
  - Both activities proposed in the context of **OSIP** (Open Space Innovation Platform) Platform via Visionspace Technologies

Modelling and operations

While models and **MBSE** are often used for the implementation of space systems, often these are **not fully utilized** throughout the **entire lifetime** of the system.

Mission operations typically analyse the provided information (encoded models usually written down in text-based design documents, user manuals, and operational procedures) to configure all the needed systems (planning, data distribution, mission control, among others) and to build all the supporting knowledge and procedures required by the Mission Operations Centre (MOC) to operate the space system.

Furthermore, different operational teams within the MOC typically must produce other documents or databases to include, maintain and internally share all the previously collected information needed to configure each system.

Both presented activities aimed at **improving this situation** by defining and using system **models** to **increase the efficiency and quality of various tasks now done manually**, demonstrating the value of utilizing models also in the operations phase.

Use cases identification

Both activities implemented **proof of concept applications**.

The **selection of use cases** for **mission preparations** and **routine operations** was done after conducting several **interviews** covering different aspects of mission operations (e.g., Mission Planning and Procedure Preparation, Execution and FDIR, others) and considering what could be most positively impacted. The following use cases were investigated :

- Generate planning domain model: configuration of a mission planning system
- Verify Mission Planning System (MPS) models: verify mission planning system domain models
- Generate/update procedure: generate operational procedures in the Operations Preparation ENvironment (OPEN)

Moreover, the use case of modelling the SGICD was pre-selected and we explored the usage of models for supporting the development and deployment of Machine Learning (ML).

Use cases presentation

The detailed use cases will be presented according to the following categories

- the configuration of systems (EGOS-CC) and document generation
- the definition of operational procedures and plan
- the validation of operational artifacts
- aiding the development and deployment of machine learning

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EGOS-CC configuration and doc generation

For the **EGOS-CC configuration**, the main information sources were typical **SGICD** documents.

- Those documents are the central part for **monitoring and control**, **data processing** and **distribution** of monitoring and control data received from the satellite. This information includes **Ground Station Link Geometry**, **Uplink**, **Downlink**, **Virtual Channel, MAP ID**, **S/C ID**, etc.
- To a degree, the effort to set up the ground segment from these documents has already been mitigated by having the satellite provider deliver the onboard S/C database (e.g., **Mission Information Base**), which contains the telemetry and telecommand packet definitions.
    - However **there is still plenty of information that is not modelled** which can be used to generate documents and configure the control system.

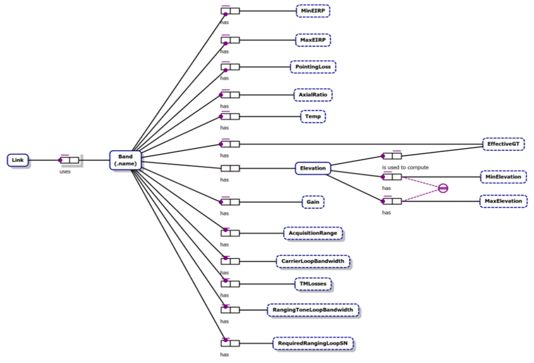
Analysis if existing SGICD documents resulted in **mapping** the information of what is available in the document to **configuration variables of the mission control system**.

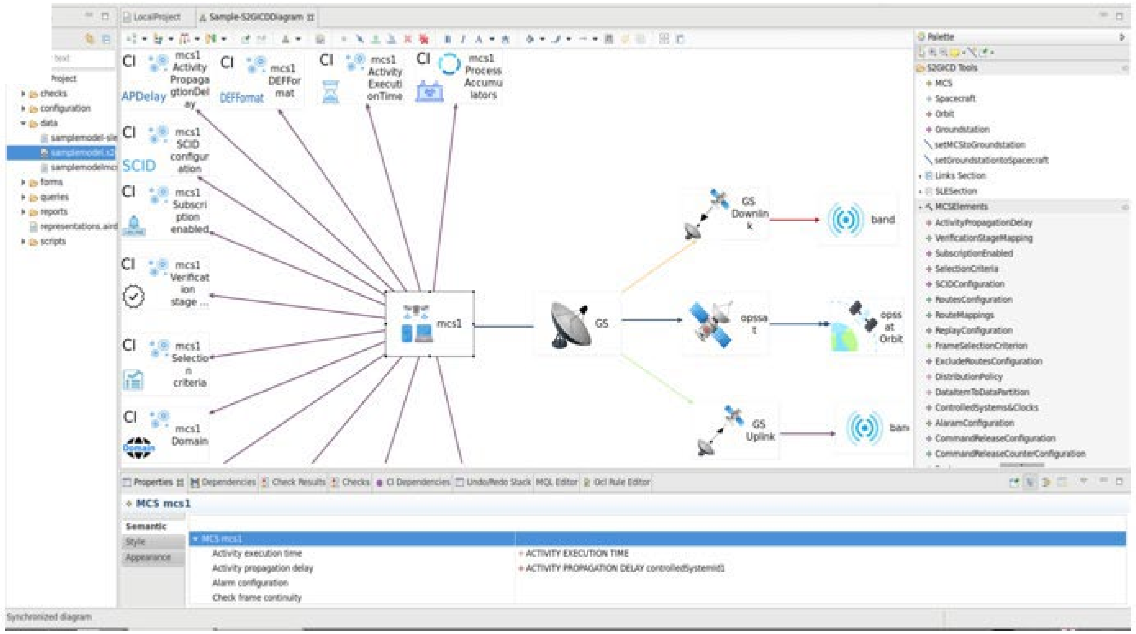
From the information in the SGICD document, we can also automatically generate documentation (**Ground Segment Requirements Document**) which is currently manually created.

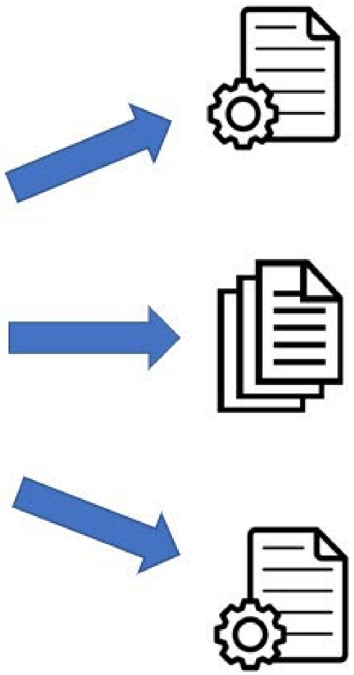
EGOS-CC Configuration and doc generation – proof of concept

The SGICD information has been formally described in ORM then manually converted to Ecore

The proof of concept application is an EMF application, integrated in to OPEN.







EGOS-CC Configuration files

Documentation

SLE configuration files

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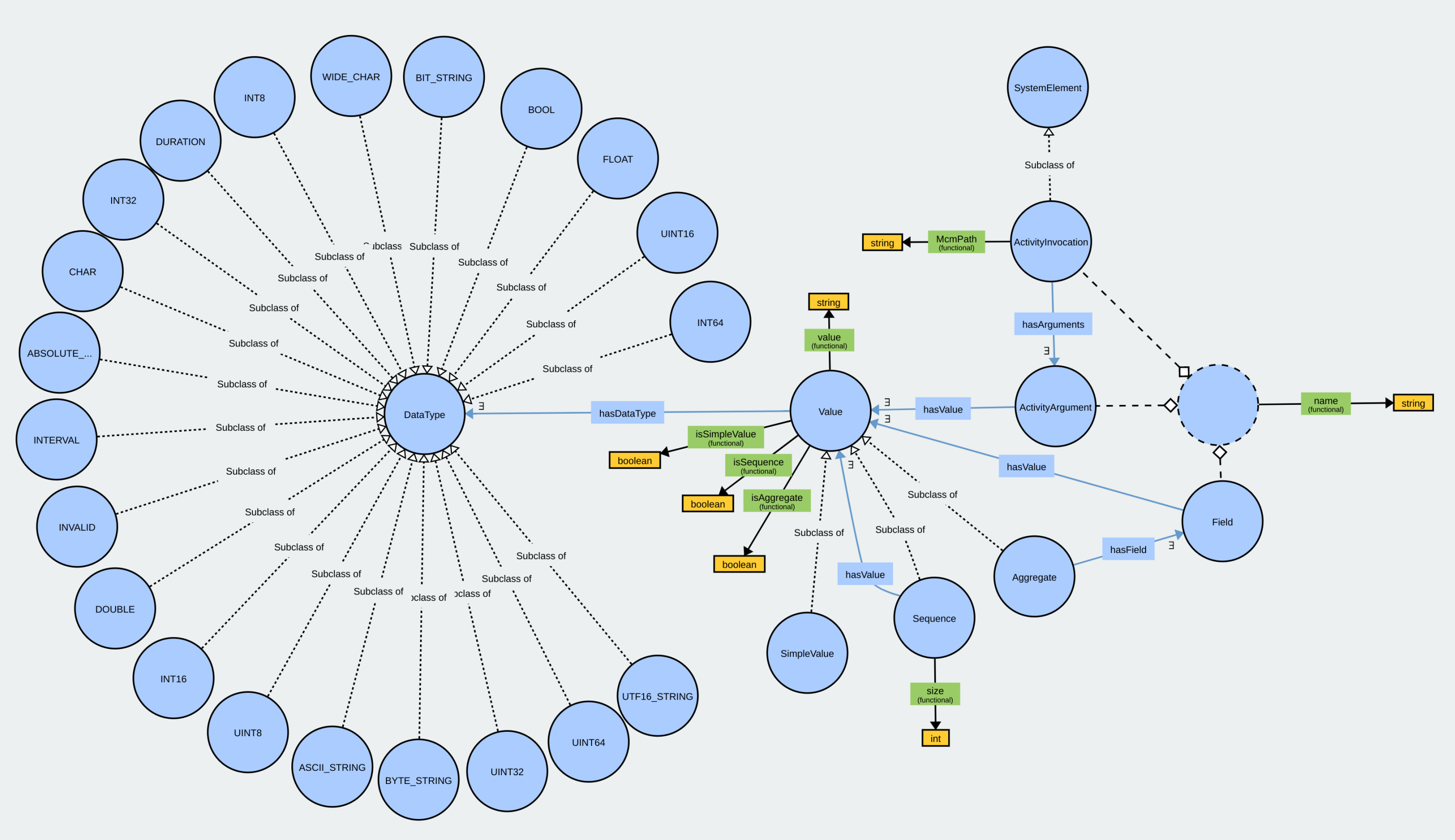
Activity invocation

Activity invocation

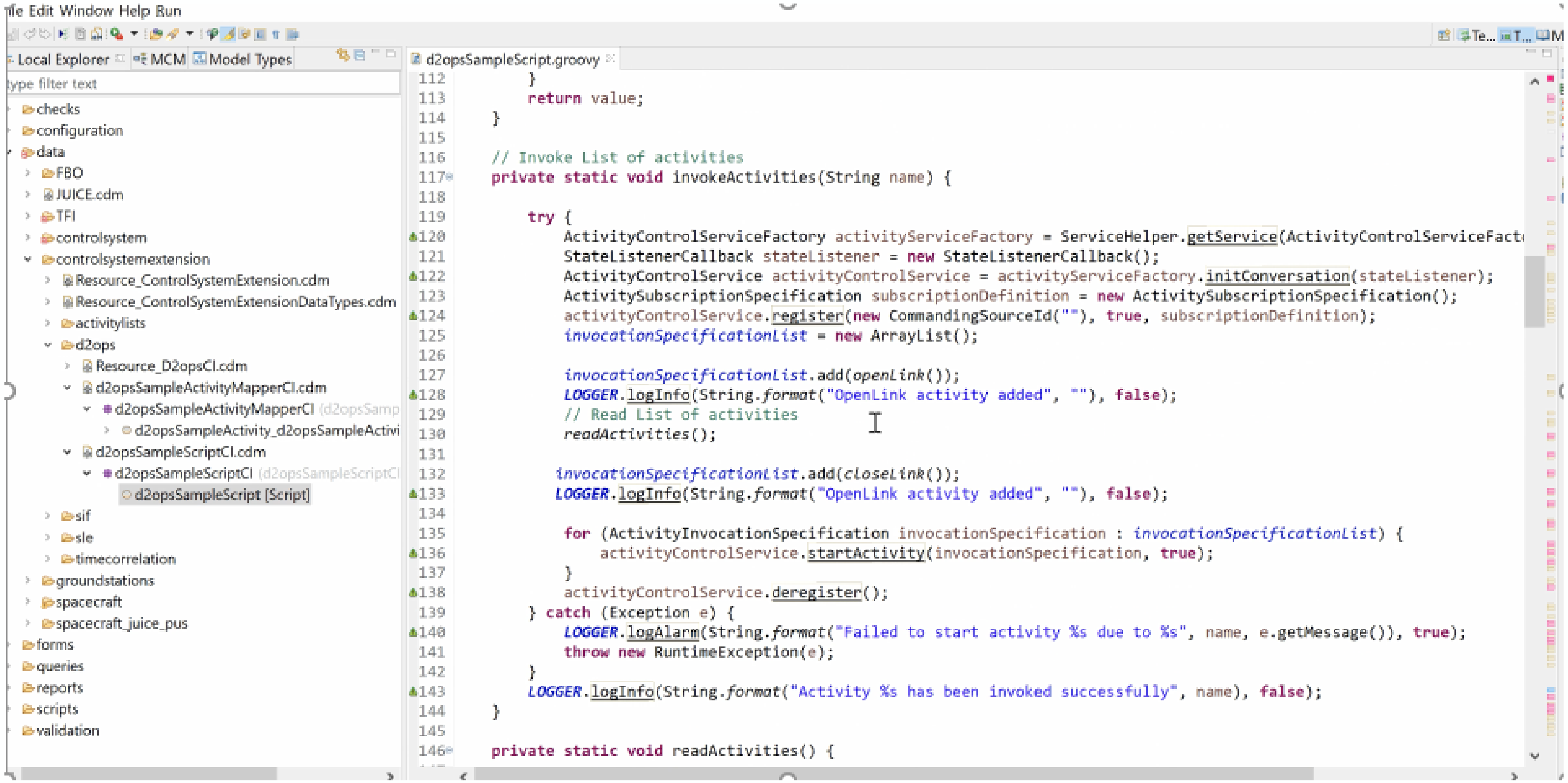
- Model of an activity (activities invocation)
- Generation of activity script (Groovy)
- Get McmPath and activities/commands to send
- Get activities names and arguments



➔Generates the new activity (groovy script) and the mapping to run the script when we invoke the new activity

Activity invocation – proof of concept

Implemented as a plugin in OPEN



Further control logic implemented as a proof of concept (invoke a set of activities and act according to the output)

Plan generation

APSI: Advanced Planning & Scheduling Initiative (link)

APSI Domain Definition Language (DDL)

Application Scenario: OPS-SAT Onboard Autonomy experiment

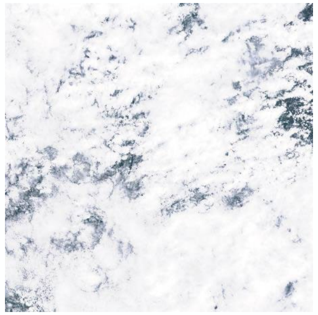
Goal:

Generate plan to take a picture at given latitude and longitude;

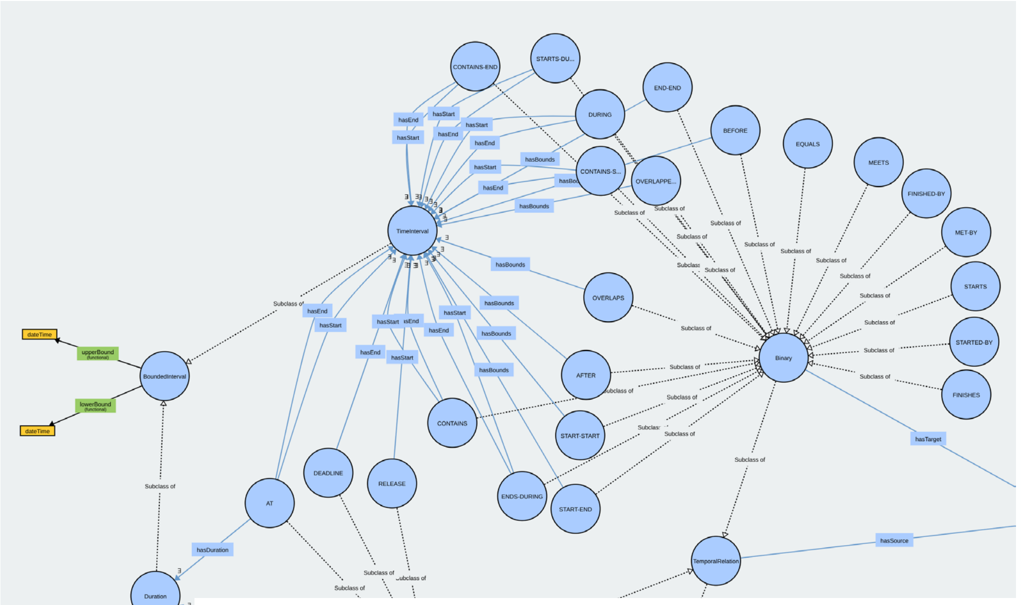
Classify the picture either as cloudy or clear;

Store and dump the picture if clear, discard if cloudy;

Keep re-scheduling the observation until a clear image is taken.



Plan generation




```
SYNCHRONIZE MT.tl {
    VALUE TakePicture(?x_target, ?y_target) {

        op1 CAM.tl.MakePicture(?file_id);
        op2 ADCS.tl.TargetTracking(?x_target, ?y_target);
        op3 GPS.tl.Visible(?x_target, ?y_target);
        op4 CLAS.tl.ClassifyClouds(?file_id, ?class_result);
        op5 CLAS.tl.SavePicture(?file_id);

        CONTAINS [00:00:03,+INF][00:00:03,+INF] op1;
        op2 DURING [00:00:03,+INF][00:00:03,+INF] op3;
        op1 DURING [00:00:03,+INF][00:00:03,+INF] op2;
        op4 BEFORE [00:00:01,+INF] op5;
        op1 BEFORE [00:00:01,+INF] op4;
```

DDL

P	MT tl	GPS tl	ADCS tl	CAM tl	CLASS tl
1	MTIdle()	NotVisible()	Idle()	CamIdle()	ClassIdle()
2	TakePicture(4189,1249,id_0,T,T)				
3		Visible(4189,1249)			
4			TargetTrackingTC(4189,1249)		
5			TargetTracking(4189,1249)		
6				MakePic(id_0)	
7				CamIdle()	
8			Idle()		
9		NotVisible()			
10					ClassifyClouds(id_0,clear)
11					SaveImage(id_0)
12					ClassIdle()
13	MTIdle()				

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Validation of planning config file

Validation of planning configuration files

Given a planning domain model of a S/C subsystem, we can automatically verify compliance with the subsystem model by verifying the configuration of the MPS with the model (e.g., state model, constraints checking, others).

As for the generation of planning files, the PoC application targeted a domain file (DDL) for ESA's APSI planning framework but could also apply to the EGOS-MPS rules file.

The PoC application is a command line tool.

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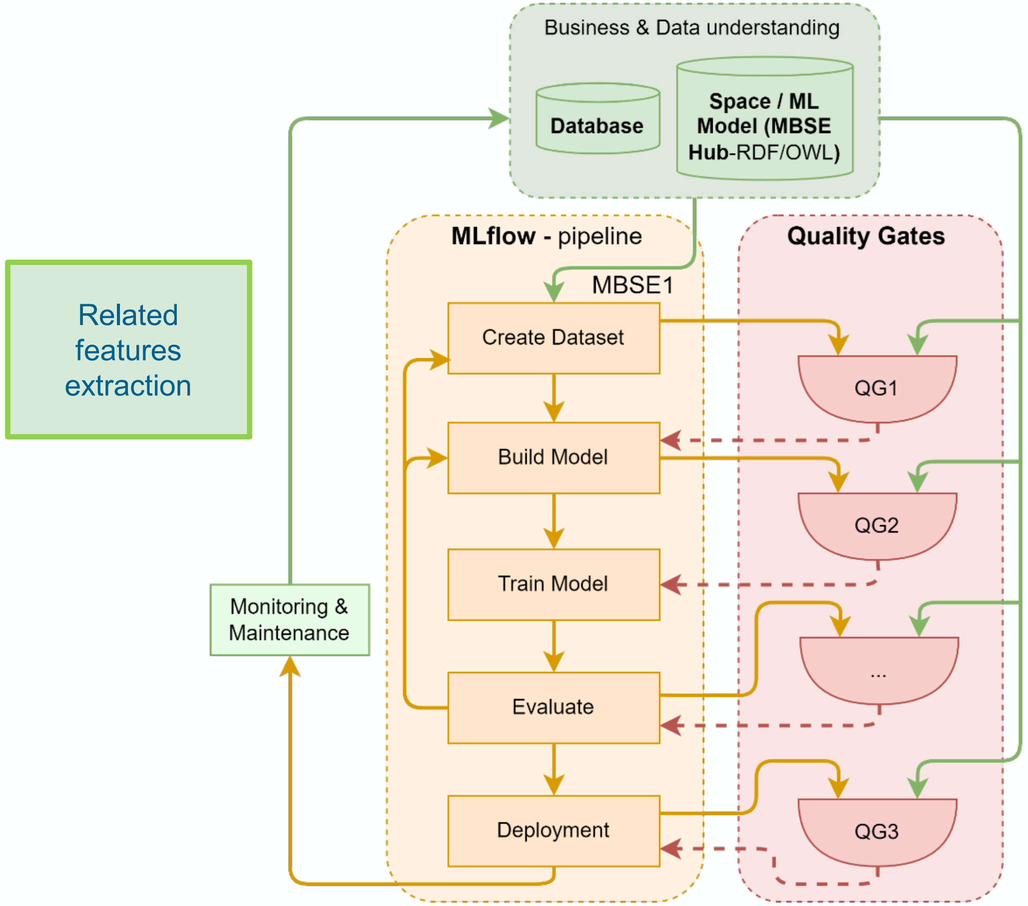
Machine Learning use cases

- Related features extraction
- Data quality checks (range, gaps filling, Great Expectations, expected distribution)
- Algorithm validation considering type of feature
- Output validation (Great Expectations)

Machine Learning use cases

Quality Checks (QCs) for Quality Gates (QGs).



- **QG1**: Representative data
  - QC1: Data range check [min, max]
  - QC2: Data gaps filling (method selection)
  - QC3: Great Expectations
  - QC4: Expected distribution

Data quality checks and representativeness

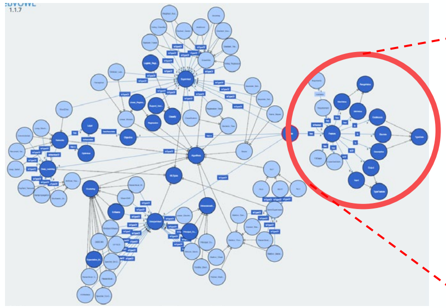
- **QG2:** Appropriate algorithm
  - QC1: Algorithm validation considering type of features

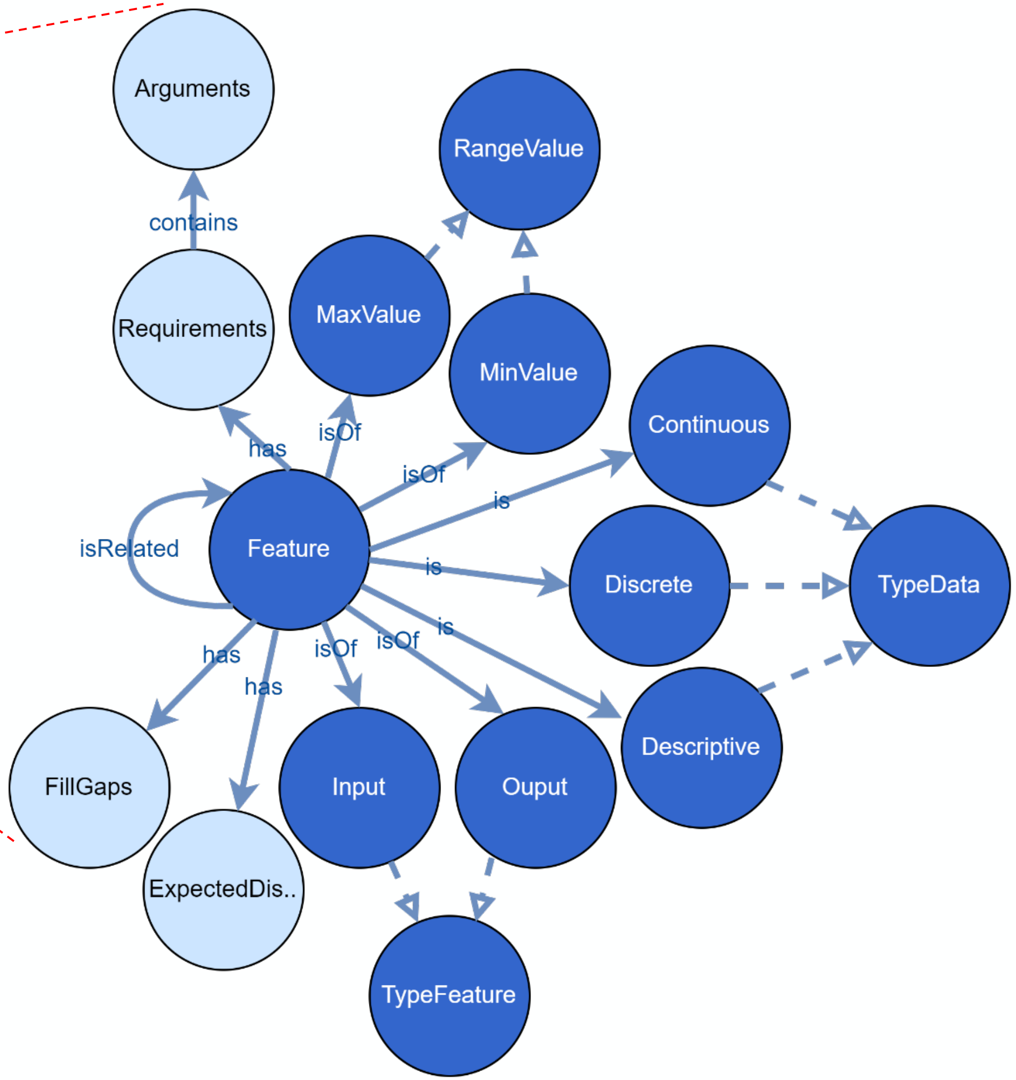
Ensure the selected Algorithm is appropriate to the problem

- **QG3**: Output validation
  - QC1: Select model is appropriate - Great Expectations

Ensure the ML ouput is valid within operational constraints

Machine Learning use cases - Ontology





Conclusion and next steps

At the end of these activities, it is demonstrated that there is a **clear benefit of using model-based approaches in mission operations**. The activities and proof of concept implementations demonstrated that we can use engineering models to

- Improve the efficiency of the configuration of EGS-CC based systems and Mission Planning Systems
- Generate parts of manually generated documents in the context of mission operations
- Validate Mission planning systems configuration
- Generate operational procedures (or at least skeletons of operational procedures)
- Aid the development and deployment of machine learning use cases

As next steps and future work, the work presented in this paper, besides potential enhancements with the tools themselves in order to be more efficiently used in the ESOC operational environment, will aid future tool and infrastructure developments such as the Model Based Engineering Hub and others under the MB4SE advisory group roadmap.