# Ontologies for Experimental Mechanics

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**Abstract.** This paper deals with the development of ontologies for data integration in the large-scale mechanical testing facilities required by the aircraft industry. Ontologies can help unify models from various data sources by formalising a consensus knowledge base of measurement techniques, regardless of the specific characteristics of sensors, testbeds, or software systems. The authors developed a network of ontologies to support the exchange of measurement data produced by mechanical testing experiments.

## Introduction

Aircraft mechanical testing facilities produce large amounts of measurement data from different kinds of sources using different data formats. This heterogeneity poses challenges to human and machine data consumers, not only for the exchange of experimental results but also with respect to their interpretability. Comparing results from different measurement techniques or collating results from different test specimens requires engineers to understand heterogeneous data models, potentially using ambiguous terminology (different definitions of the same term) and/or inconsistent taxonomy (different interrelationships between concepts). For example, *grinding* is an abrasive process for generating fine finishes or making tiny incisions but can also denote a material processing method to decrease particle size. If not used within the context of its specific process, this ambiguity could cause large issues.

In collaboration with domain engineers at Airbus, NPL ontology developers have built point-based measurement (PBM) ontologies that unify the terms used in multiple point-based measurement techniques, including strain measurement. Elementary Multiperspective Material Ontology (EMMO) is also a network of ontology fragments, with varying levels of abstraction, from fundamental to applied. However, EMMO's Domain Mechanical Testing extension [7] and the PBM ontologies differ by their intended usage. The Domain Mechanical Testing ontology is designed for the description of physical models (e.g., simulation), whereas the PBM ontologies focus on data integration in experiments. As a result, they cover different concepts of mechanical testing. EMMO's Domain Mechanical Testing ontology, on its own, would be limited for the application targeted in this research.

The next section of this paper describes the methodology adopted to design the ontologies. The following section gives an overview of the PBM ontologies. Finally, a discussion on the current development progress and higher-level comments on the outcome of this research conclude the paper.

## Methodology for capturing and formalising domain knowledge.

The main technologies used to implement this research are the Web Ontology Language (OWL) [1], a formal language to specify ontologies and the SPARQL Protocol and Resource Definition Framework Query Language (SPARQL) [2]. OWL and SPARQL being only implementation tools, the authors defined an ontology engineering methodology by applying principles from the Simplified Agile Methodology for Ontology Development (SAMOD) [3] and the Networked Ontologies (NeOn) methodology [4].

**Iterative and collaborative ontology engineering.** The methodology iterates over the following steps:

1. specify some overall user requirements, for example, in the form of a mind map,
2. write natural language questions that the ontology will support, with typical exemplar answers,
3. identify the meaningful concepts present in the questions,
4. derive concepts, relationships, and typical data from the outcome of the previous steps,
5. implement the OWL ontology following the new specifications and any previous version,
6. and check the fitness for purpose of the OWL ontology using SPARQL queries.

**Reusing upper-level ontologies.** The NeOn methodology encourages and systematises the re-use of ontological resources. Step 5 of the above ontology development process can benefit from existing resources both internal, for example enterprise glossaries, and external such as publicly available ontologies. The ontologies developed in this research rely on two public ontologies: (a) the Semantic Sensor Network ontology (SSN) [5] is reused as an abstract model of sensors, observations, sampling, systems and procedures involved in the measurement techniques, and (b) the Ontology of units of Measure (OM 2.0) [6] is reused as a model of physical dimensions, quantities and units of measure.

## A network of point-based measurement ontologies

A network of ontologies has been developed, the PBM ontologies, which depend on each other as depicted in Fig. 1, where dashed arrows point from a dependent ontology to an ontology that provides reusable entities. A PBM core ontology that relies on SSN and OM 2.0 was designed to group the general concepts that are common to all point-based measurement techniques. It defines generic concepts that are intended to be specialised in dependent ontologies, such as *measurement technique* (a top-level concept that describes the measurement set up), *test specimen* (object that will be mechanically tested). The core ontology also contains concrete definitions to avoid redundancies in dependent ontologies: entities such as *3D vector* (3-coordinate geometric object) or *data acquisition system* (interface between sensor and computer), as well as relationships, such as *is connected to* (relation between a sensor and a data acquisition channel). The PBM ontologies that depend on the PBM core ontology have been designed to semantically characterise the experimental data flows of specific measurement techniques. The approach is both neutral to vendor-specific terminology and tailored to the domain experts' knowledge and jargon.

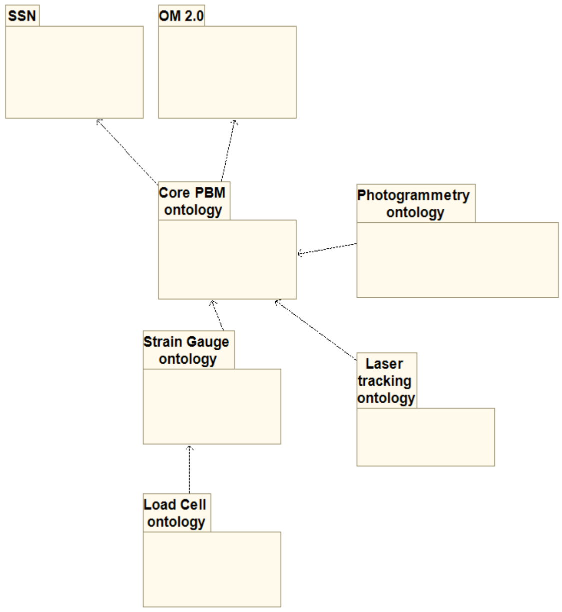


**Figure 1 : Dependencies between PBM ontologies**

## Discussion and Conclusion

NPL and Airbus have been collaboratively developing a network of ontologies for data integration in experimental mechanics, the Point-Based Measurement (PBM) ontologies. They follow a methodology that borrows from agile development methodologies and systematic ontology engineering. PBM ontologies reuse some concepts from more abstract public ontologies to describe the testing hardware and software environments as well as physical quantities and units of measure. The structure of the PBM network is based on a hierarchical dependence between ontologies with, for example, the load cell ontology depending on the strain gauge ontology. Since PBM ontologies are designed to support data exchange and interpretability of real testing facilities, it could theoretically complement the publicly available Elementary Multiperspective Material Ontology (EMMO), that focusses on the description of physical models. Lessons learned from the collaborative development process include that during validation of the latest iteration (step 6 of the methodology), using realistic exemplar data is key not only to align ontological concepts with the understanding of the domain experts, but also to detect related concepts that may have been overlooked at the requirement specification step. Future work will include further iterative validation and enrichment of the ontologies, as well as evaluating the role of the PBM ontologies as an interface to facilitate the elaboration of digital twins for virtual testing.

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