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# Capitalizing Data, Information and Knowledge on mechanical experiments through ontologies

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**Abstract** Experiments in a laboratory or a company, either physical or virtual, generate a large amount of data and information (raw data, consolidated results, experimental conditions, etc.) that has to be managed in order to preserve and enhance the knowledge and the expertise of the organization, especially when turnover happens. If simulation data management has been especially explored and standardized (STEP AP 209 for instance), experimental data did not create the same interests and only standard data management tools are proposed. In this paper, we propose an ontology to capitalize such information and knowledge, with an efficient reuse objective. This ontology, for which specific taxonomies have been defined according to the relevant literature of the domain, is illustrated on a set of data on previous experimental campaigns, corresponding to two kinds of mechanical experiments: tribology tests and material characterization tests.

**Keywords** Ontology, experimental data and information, knowledge management

## 1. Introduction

In the current context of digitalization of the product design process and the reduction of physical mock-up usage, having knowledge on properties and behaviors of material components and systems is of prior interest for companies. Even if material science is a well-established one with a large community, material innovation and new usages imply an important turn-over of knowledge and so specific needs in competency and knowledge capitalization. Moreover, the design process is faster if accurate and reliable materials data are made quickly available. Paper reports on such material data and experiments, although tidy and available, are not so efficient if compared with modern data storage techniques, in particular because the data classification is not standardized from one report to the other and these data

tend to be considered as “dead” because it is difficult to reuse raw data for new analyses.

If management of digital simulation data and knowledge has been largely explored (Kibamba *et al.*, 2009) (Buda *et al.*, 2011) and standardized (STEP AP 209 for instance), experimental data did not create the same interests and only standard tools are proposed, like Granta MI<sup>1</sup> for material information management or classical content management software tool for experimental data. To overcome this research gap, ontology is a promising approach, allowing both the capitalization of data and information and the capture of certain domain knowledge.

The paper is structured as follows. Section 2 analyzes the domain of material experiments in laboratory, and in particular what has been proposed to structure data and information in this domain. Section 3 focuses on data and information modeling, especially by ontology. Section 4 describes the proposed approaches and how the demonstrator has been tested. Section 5 discusses the results of the experimentation.

## 2. Modeling a mechanical experiment

An experiment can be generically defined as a campaign of tests realized on several machines by different operators and with different experimental protocols, in order to validate a certain objective and deliver a set of deliverables.

Several types of mechanical experiments exist, like tensile, torsional or flexural testing, metal fatigue, creep etc. (Lemaitre *et al.*, 2009). To illustrate our approach, we selected the field of tribology, involving all contact, friction, wear and lubrication phenomena for its multi-physic, multi-domain characteristics, and complexity of situations and experimental data (Fig. 1). This choice is motivated by our laboratory, which is dedicated to engineering of complex systems with teams working on nearly all the fields involved in design and production of complex systems. More than fifty years of parallel development of experimental apparatus and models have enlightened the need to structure experimental data and basic lines to do it. In this context and due to the accumulated experience in the considered laboratory (Pieuchot *et al.*, 1969), (Gras & Courtel, 1973) (Lemaire-Caron *et al.*, 2009), several aspects have to be detailed.

First of all, tribology implies a set of operational variables: local geometry of the contact, external loading, kinematics of the contact, surfaces roughness and environment (including lubrication). On each of our test machines, some of them have been settled, the others varying in a more or less wide range. In this field, experimental scattering is a main feature observed which guided us toward some statistic models (fatigue or roughness influenced evolutions).

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<sup>1</sup> <http://www.grantadesign.com/products/mi/>



**Fig. 1.** Pin-on-disc under thermo-regulated lubrication test machine with some examples of results.

Design of each of the test machines was guided by the contact mode and range of loading, kinematics and environment encountered in the industrial applications which retained our interest; according to the natural scattering of results, having the best knowledge of what happens during the test is a mandatory need: this implies to use single contact, with a precise measurement of load, displacements and possibly temperatures and accelerations.

### 3. Ontology for Data, Information and Knowledge modeling

In order to model DIK (Data, Information and Knowledge), ontologies are currently recognised to be a powerful instrument. An ontology can be defined as a formal specification of a shared conceptualization of a domain (Gruber, 1993). Born from artificial intelligence community, ontologies are used in the semantic web to model knowledge objects of a certain domain, by associating to them a structure of semantic network plus an inference engine. Currently, it is possible to find them in the design community, when databases are too restricted to model linked information, especially in the “PLM 2.0” perspective. Ontologies are used to capture information, to assist on-line collaboration by proposing a common understanding, dais of communication and knowledge exchanges between different collaborators of a product development process (Giménez *et al.*, 2008), (Matsokis & Kiritsis, 2011).

After a large increase of works in this domain the last years, several papers propose a state-of-art in this domain (Liu & Lim, 2010), (Fortineau *et al.*, 2011), each proving a large diversity of ontology usage in design, like knowledge management systems specialized for a particular point of view (Xie & Shen, 2006) to interoperability of information systems (Ishak, 2010).

Moreover, ontology development is known to be a dynamic process and a literature exists to ensure a consistent ontology evolution (Sure & Tempich, 2004).

This property is especially interesting here, since the mechanical experiment domain is still evolving.

More than the ontology by itself, the methodology to obtain such shared understanding of the domain is of prior interest for the different actors implied in the process. As a matter of fact, providing an effective methodology for creating ontological models is a crucial issue, especially since there is a lack of a general methodology for creating ontologies (Nanda *et al.*, 2006). In various domains, some methodologies for creating ontologies have been developed, like METHONTOLOGY for chemistry applications (Fernandez-Lopez *et al.*, 1999), Toronto Virtual Enterprise (TOVE) with a scenario-based methodology (Gruninger & Fox, 1995) or the On-To-Knowledge methodology (Staab *et al.*, 2001). In software engineering, (De Nicola *et al.*, 2009) proposes the UPON methodology, as an adaptation of the Unified Software Development Process or Unified Process (UP) for ONtology building.

According to our context and knowledge, we chose the On-To-Knowledge methodology, which includes the identification of goals that should be achieved by knowledge management tools and is based on an analysis of usage scenarios (Staab *et al.*, 2001). As a consequence, an ontology developed with such methodology does not provide an exhaustive conceptualization, but ensures the consistency between the needs of the domain expert and the ontological model. The steps proposed by the methodology are:

- *kick-off*, where ontology requirements are captured and specified, Competency Questions (CQs) are identified, potentially reusable ontologies are studied and a first draft version of the ontology is built;
- *refinement*, where a mature and application-oriented ontology is produced;
- *evaluation*, where the requirements and competency questions are checked, and the ontology is tested in the application environment;
- and *ontology maintenance*.

In order to model the ontology, we use the Protégé software<sup>2</sup> and the OWL-DL language.

## 4. DIK modeling of an experiment

The objectives of the ontology are first to model the crucial data and information related to each experimental projects and secondly to make explicit the specific knowledge of the laboratory on the experiments. A part of such knowledge is used to define the crucial data and information, but the other part allows to model specific restrictions or axioms inside the ontology.

For the kick-off phase, we integrate both experts from the domain, i.e. professors of our laboratory scientifically known for the experience in the tribology do-

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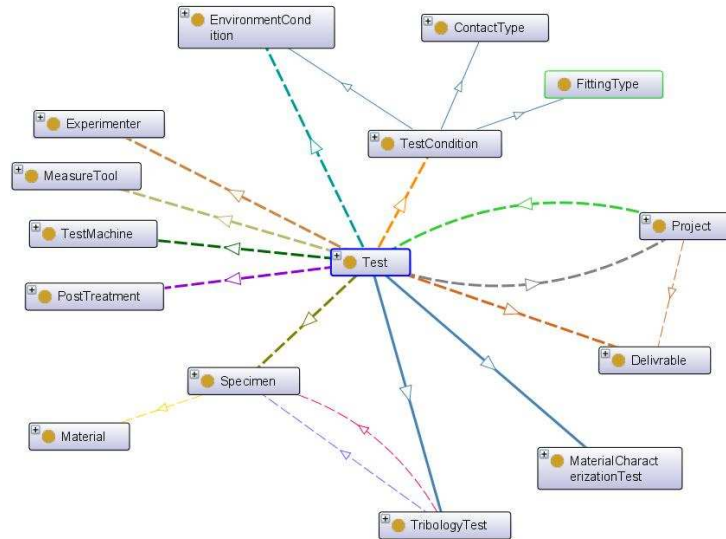
<sup>2</sup> Version 4.1, available at <http://protege.stanford.edu/>

main, and some “naïve” people that should use such ontology, i.e. young PhD students of the tribology research group. From such phase, we define a set of CQs that lead us to the definition of the ontology in the refinement phase.

#### 4.1 Ontology model

The ontology is decomposed in two different facets. We model the generic and common concepts of the domain in the core ontology and we add all specific instances of projects and tests in the instance ontology.

Fig. 2 presents a partial model of the crucial data and information generated and used during an experiment, with the main classes and object properties between classes. In this figure, the plain arrows represent the *isA* property with the adequate direction (i.e. a *tribologyTest* is a certain type of *Test*) whereas the dot arrows represent the other type of semantic object properties (e.g. a *Test* *isRealisedOn* a *TestMachine*).



**Fig. 2.** Core ontology model of the experiment, with main classes and object properties represented.

The **Test** class is the central element of the ontology. So an experiment is a project constituted of several tests. Each test is realized on a specific context: machine, experimenter, measurement tools, post-treatment chain, that are each modeled as instances in consistency classes. It is realized on one specimen for material characterization test or two specimens for tribology test, with adequate conditions, either in terms of environment (for example: ambient temperature or cryo-test, atmosphere or under neutral gas) or in terms of load (nature and intensity of force

for instance). These conditions are defined by specific values of data properties when being digitally differentiable (like the sliding speed for a tribology test) or by instances when being chosen between a list of predefined concept (like the contact type).

Specific taxonomies have also been defined for the classes *Test*, *Material*, *TestMachine*, *MeasureTool* and *PostTreatment*, based on the literature in the domain (Gras 2008), (Ashby 2010).

Several object properties are more detailed, always with the idea of fasten and simplify the queries of the ontology:

- the relations between the two classes *Project* and *Test* are defined as inverse ones: in the CQs defined, one can ask the ontology either for a project that contains tests with specific conditions or for tests that have been performed for a specific project, without a too complex syntax,
- the relations between the classes *Test* and *Specimen* are defined as a taxonomy, with adapted semantics (fig. 3): *isPerformedOn*, generally linking a *Test* instance to a *Specimen* one, is specialized through functional two sub-properties, linking a *TribologyTest* instance to a *Specimen* one. Such modeling allows to define that if a test is generally performed on one or several specimens, there are exactly 2 specimens in the case of a tribology test, one considered as the large surface, the other one as the small surface.

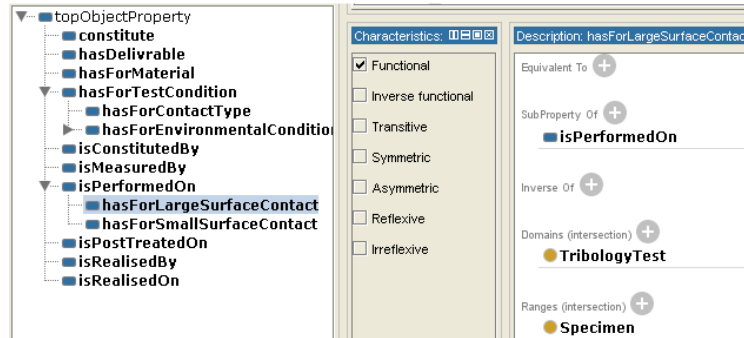
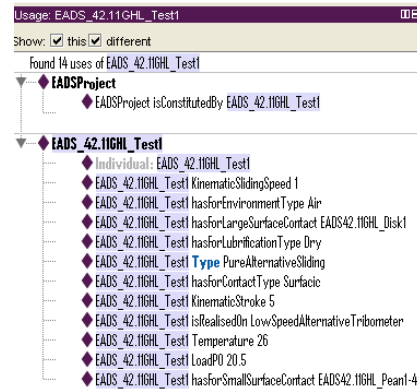


Fig. 3. Taxonomy of object property *isPerformedOn*

Fig.4 illustrates an example of *Test* instance with its connection either with core instances (like the name of the considered *TestMachine* instance *LowSpeedAlternativeTribometer*) and specific instances (like the *Specimen* instance *EADS42.11GHL\_Disk1*).

## 4.2 Experiments of the model

Once the ontology created and the instances added, two types of experiments have been performed. The first one validates the consistency of the ontology, either at the class level or at the instance one.



**Fig. 4.** Example of instance insertion inside the ontology

The second validation considered the match of the ontology to the CQs defined in the On-To-Knowledge process. The ontology is questioned through the DL Query widget of Protégé by using the Manchester OWL syntax<sup>3</sup>. In the example (Fig. 5), two queries have been defined:

1. on the left, which are the projects with at least one test that has been realized on a particular machine,
2. on the right, which are the projects with at least one test that has been performed with a load greater than a specific value.

To ease the addition of instances of each tribology project without a complex training on ontology for the experimenters, a specific interface has been developed on Microsoft Excel (Fig. 6). The characteristics of the project is defined and we use the properties of the OWL language (close to XML and interpreted by a parser inside Protégé) to add, at the end of the instance OWL file, the new elements.

<sup>3</sup> [http://www.co-ode.org/resources/reference/manchester\\_syntax/](http://www.co-ode.org/resources/reference/manchester_syntax/)



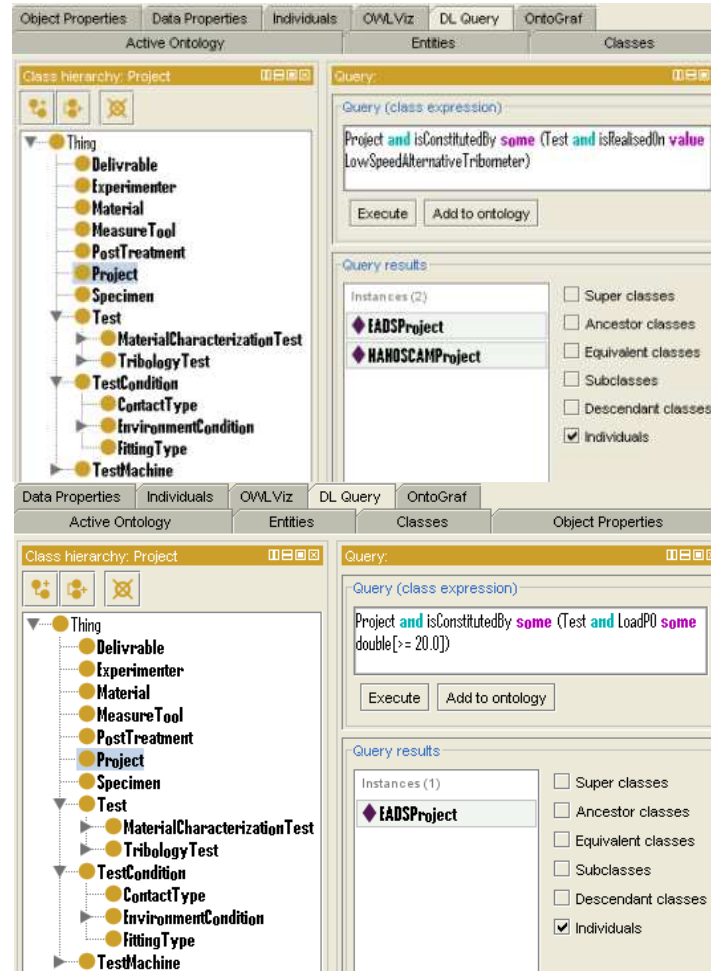


Fig. 5. Queries of the ontology

## 5. Discussion and conclusion

Performing physical and/or digital experiments provide a large amount of data and information that need to be organized, accessible and available for a reuse purpose. In order to capitalize such crucial data and information, and also specific knowledge of the domain, an ontology is developed. Such choice can be explained by the fact that ontologies are able to cope with domains of whose conceptualization is still moving, which is the case of experiments performed in our research laboratory.

Project		Test	
Name	NANOSCAM	Type	PureAlternativeSliding
Nb Test	4	Experimenter	LGH
Reference	ANR-05-RNMP-005-02	Test Machine	LSAT
Partners	EADS	Measure Tool	
	Eurocopter	Post Treatment	
	Marignane	<b>Contact Parameters</b>	
	CEA Grenoble	Contact Type	Surfacic
	PROMES (UPR 8521)	Lubrication	Dry
ACM	Environment	Air	
<b>Delivvable</b>		Temperature (in °C)	26
Name	NANOSCAM_RNMP-005-02	Cycle Length (in s)	
URL	My Folder	Load P0 (in Mpa)	100
Type	pdf	Stroke (in mm)	15
<b>Material</b>		Frequency (in Hz)	2
Nb Material	5	Sliding Speed (in mm/min)	
		<b>Material Parameters</b>	
		Small Surface	32CDV13
		Large Surface	30NCD16

Design of Test sheets

EXPORT

Copy the value of the first test

**Fig. 6.** Excel interface for the experimenter: on the left the project definition interface, on the right the test definition interface

The proposed ontological model is presented in terms of generic core model and domain specific taxonomies and tested on real instances of data from tribology and material characterization tests domains. Using the Protégé software allows us to validate this ontology in terms of both model consistency and expert expectation consistency.

However, query answering in OWL is known to have scalability issue while the number of data increases, whereas relational databases cope well with it. Thus, as a perspective, a relational database should be created, using the work of (Kupfer *et al.*, 2006), in order to make evolve in parallel the ontological model and the implemented corresponding relational database.

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