IEDM: An Ontology for Irradiation Experiments Data Management

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Abstract. Irradiation experiments (IE) are an essential step in the development of High-Energy Physics (HEP) particle accelerators and detectors. They are used to assess the radiation hardness of experimental devices by simulating, in a short time, the common long-term degradation effects due to energy loss in matter. Usually carried out with ionizing radiation, these complex processes require highly specialized infrastructures called “irradiation facilities”. Aiming to promote knowledge sharing and digital management of IEs, we introduce IEDM, a new Irradiation Experiments Data Management ontology. This work presents an overview of the development of the key concepts and structure of IEDM while discussing possible applications.

Keywords: Ontology, OWL, Irradiation Experiment, Data Management.

1 Introduction

In an irradiation experiment (IE), a piece of material (e.g., electronic chip, silicon detector, etc.) is purposefully exposed to radiation (of electromagnetic or corpuscular nature). IEs are often necessary, for instance, when designing and building High-Energy Physics (HEP) experiments. In HEP, the purpose of performing an IE is typically the qualification of detectors or electronic components in a radiation environment equivalent to the one these devices will encounter in actual HEP experiments, thus simulating, in a short time, long-term radiation-induced degradation effects [1]. Worldwide, IEs also find applications in other scientific and technical fields. For example, in space technology and avionics, the materials composing aircraft or spaceships are affected by radiation damage during their flights. Therefore, engineers need also to test components during their development projects. Other examples of IEs can be found in industry, where they are used for various purposes such as food sterilization or seed treatment. IEs are also performed on patients as part of radiotherapy treatments or for medical imaging in hospital environments. Even though these IEs are performed for a wide range of fields and in different infrastructures (e.g., hospitals, factories, and scientific institutes), they can all be assimilated, in an abstract manner, to what is called an "irradiation facility".

An earlier thorough survey about existing HEP irradiation facilities and their practices shows that at least hundreds of them are operational around the world [2]. Considering all the other IE-related fields of applications mentioned above, we estimate that these represent only a small subset of the facilities currently operating worldwide. Although these facilities use and produce knowledge of high scientific value, our survey shows that they often follow informal procedures for their overall data handling, storing data in spreadsheets or even only on paper. This practice makes irradiation facilities more prone to the risk of data errors and loss, hence the obvious need for a standardized approach in the data management of IEs.

Ontologies facilitate knowledge sharing and formalization of specific domains [3]. Thus, the main goal of this work is the formalization of the knowledge linked to the management of data associated to IEs by introducing a new ontology, called the Irradiation Experiments Data Management (IEDM) ontology[1]. IEDM has been built by investigating and analyzing the common elements and practices used in irradiation facilities around the world, building thus upon the knowledge of domain experts.

2 Related Work

In the literature, several ontologies attempt to formalize scientific knowledge. One example is the Knowledge Graph for Science, where the authors work on axiomatizing the knowledge present in the scientific literature [4]. However, this work describes mainly scientific documents rather than actual experimental information. Another example is the Web Physics Ontology [5], presenting physics equations and relationships among physical quantities; it is though limited to the domain of electromagnetism and mechanics. Another approach is the ontology design pattern proposed for particle physics analysis [6]. Although this work includes concepts that are typical in HEP experiments, it focuses mainly on the analysis of HEP data and not on the representation of experiments. Thus, to the best of our knowledge, an ontology dedicated to the formalization of the principles of irradiation experiments does not exist yet.

3 Methodology

Ontology Reuse. Following best practices in developing IEDM, we reuse existing ontologies that could partially describe IEs [7]. Specifically, we reused classes from the Ontology of Scientific Experiments (EXPO), the Units of Measure ontology (OM) and the Friend-of-a-Friend ontology (FOAF). EXPO is a general ontology for the formalization of scientific experiments. It introduces concepts specifically linked to the notions of experimental design, scientific methods, and other core principles of experiments [8]. In IEDM, EXPO is reused for describing abstract and physical concepts linked to the features of IEs. To ensure compatibility with the potential future enhancements of EXPO and other ontologies, one important design choice was to never copy, override

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[1] https://gitlab.cern.ch/bgkotse/iedm

or modify them. Instead, when more information was needed, we introduced IEDM-specific variants of existing classes, using the iedm namespace to avoid ambiguities.

Since EXPO does not elaborate on physical quantities and units, restricting its key constructs to the logical structure of scientific experiments, OM [9] was instead used for their representation. OM describes entities from many physics-related domains, including concepts from particle physics. This ontology is thus necessary for the formalization of the physical quantities related to IEs.

The third imported ontology is the Friend-of-a-Friend ontology (FOAF) [10]. It aims to describe networks of people, their activities, and their relations. IEDM uses FOAF mostly to describe the characteristics of the various individuals involved in IEs. For example, the term "user" has a broad definition and can be a group, an organization, or a person. Therefore, we employed the definition of foaf:Agent, which contains, as subclasses, all these three types of entities.

IEDM Concepts. Since the domain of IEs is larger than those covered by the three foundational ontologies mentioned above, the second phase of the IEDM development required introducing concepts more specific to IEs. In this step, we followed a top-down approach: IE-specific concepts are added as subclasses of the upper ontologies' classes. We also added new relations created via IE-specific object properties. For example, the constraint iedm:hasFieldOfStudy some iedm:DomainOfExperiment is a superclass of the class iedm:IrradiationExperiment. A simplified illustration of some core classes is presented in Fig.1. In total, IEDM consists of 115 classes and 941 annotations. Relations among the classes are represented with 24 object properties and 16 data properties.

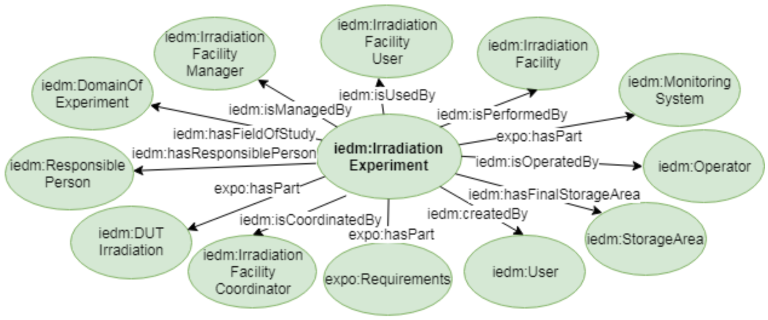

Fig. 1. Graph representation of some core IEDM entities and properties.

During the integration of IEDM with the upper ontologies, we came across several issues. One of them was that a concept could appear in more than one of the three upper ontologies (e.g., expo:Quantity and om:Quantity). In that case, we used the concept whose definition better fits the model. We also noticed cases where two concepts were in fact complementary to each other (e.g., expo:Agent and foaf:Agent), and hence we decided to create another IEDM class (iedm:User) that would be the subclass of both, taking advantage of Web Ontology Language (OWL) multiple inheritance. Finally, given the importance of documentation in ontology development and usage, dedicated annotations are used as internal elements providing information for each new IEDM entity, while external documentation is provided online[2].

IEDM Example. To assess the coherence of IEDM, the data of an actual IE were represented in IEDM. The IE taken as an example (*FCC-RadMon*) is testing a new technology of particle fluence monitors, performed at the CERN proton irradiation facility (IRRAD). For this specific experiment example, 43 instances of IEDM classes were inserted. Moreover, the ontology was also tested with the Pellet reasoner [11] in order to ensure its consistency.

4 Conclusion and Future Work

In this paper, we presented IEDM, a new ontology describing the data management of irradiation experiments. Concepts from EXPO, OM and FOAF are adopted and extended with new ones relevant to IEs. Furthermore, an actual experiment is represented with IEDM as a proof-of-concept test, providing evidence of the ontology's validity.

Beyond its use as a knowledge formalization effort for the whole HEP community, our vision for IEDM is to use it as a model for web application generation. Another application of IEDM could be to annotate the HEP data available in the Irradiation Facilities online database [2].

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