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# Ontology-Driven Generation of Radiation Protection Procedures

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***Abstract*****—**In this article, we present the principle and suitable methodology for the design of a medical ontology that highlights the radiological and dosimetric knowledge, applied in diagnostic radiology and radiation-therapy. Our ontology, which we named «Onto.Rap», is the subject of radiation protection in medical and radiology centers by providing a standardized regulatory oversight. Thanks to its added values of knowledge-sharing, reuse and the ease of maintenance, this ontology tends to solve many problems. Of which we name the confusion between radiological procedures a practitioner might face while performing a patient radiological exam. Adding to it, the difficulties they might have in interpreting applicable patient radioprotection standards. Here, the ontology, thanks to its concepts simplification and expressiveness capabilities, can ensure an efficient classification of radiological procedures. It also provides an explicit representation of the relations between the different components of the studied concept. In fact, an ontology based-radioprotection expert system, when used in radiological center, could implement systematic radioprotection best practices during patient exam and a regulatory compliance service auditing afterwards.

***Keywords*****—**Ontology, radiology, medicine, knowledge, radiation protection, audit.

## I. Introduction

OVER the past years, there has been a significant evolution in the technologies and techniques deployed within the diagnostic and therapeutic radiation environment. This highlighted a range of potential benefits to the field of radiology. Most of these newly emerging techniques are being used nowadays as a first-line method for diagnosis and treatments. Consequently, ionizing radiation effects and risks on patients are getting more and more important, presenting a controversial subject in medical healthcare. In fact radiology modalities could present many ionization risks to patients' health. In particular if they are not managed within a well informed environment governed by strict procedures and with regards to very clear radiation protection standards. In this context, it is worth mentioning that unfortunately, many existing works dealing with adverse effects of ionizing radiation (IR) are only theoretical studies and could not always be applied in practice. This is due to the lack of efficient radiation protection solutions. Thus, a rise of non-compliant practices in radiology has been noticed in the last few years.

A study by the Institute for Radiological Protection and Nuclear Safety indicates that more than 600 nuclear accidents have been spotted in the world between 1945 and 2007 resulting in 180 rapid deaths caused by acute radiation syndrome [1]. The majority of these cases have developed leukemia and cancer [2]. The poor application of radiation protection and the lack of knowledge about the radiation risks to human beings have caused the death of eight people from 28 irradiated civilians in Panama 2001 [3]. In addition, the enormous diversity of radiological procedures (both for diagnosis or therapeutic purposes), requires a big amount of context information and knowledge generation. This makes it difficult for a human practitioner alone to deduce the right radioprotection practices for each patient case. A good example of this is what happened at Plymouth hospital in England in 1961. The radiotherapist used a 50 kV voltage instead of 10 kV, while subjecting 11 patients to doses that are 60 times higher than the required standard. This has caused erythema and ulcers, three days after exposure [4].

The development of our ontology Onto.Rap ensures first the control and the measurement of the exposure dose. Second, it specifies and evaluates the appropriate guidelines for ensuring a satisfactory level of patient protection. Thus, our ontology, as a way of reasoning and decision-making, could largely bring the knowledge together to reform some cases if tests are used in subsequent audits, to grasp facts and write some checking rules related to radiation protection. The guidelines and appropriate knowledge in our ontology are inspired and based on international standards of radiation protection recommended by the scientific committees, experts, and other regulatory agencies. Furthermore, our ontology serves for intelligence on radiological manipulations and as an experimental method for inquiring into communication.

Through this ontology, we seek to detect any risk that can occur and inform the patient for his/her immediate care. Besides this, it aims to determine the source of medical malpractice and helps with the decision to maintain the situation.

In fact, the digitization of radiology allowed us to achieve effective monitoring for the different exposure procedures to IR. On the other hand, the development of computer tools ensures, moreover, the implementation of such functions and such tasks. It is also known that the radiopharmaceuticals and IR doses can be measured or calculated using some knowledge related to the manner in which they are administered. The information is usually contained in the text of the radiological reports, but it should also be stored in the object of the appropriate radiological examination in a Picture Archiving and Communication System (PACS) [5]. Note that the complexity of interferences between knowledge and data (dosimetric or technical) from radiological manipulations can

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disrupt the auditor's reasoning who will be called for monitoring or verifying the supplied doses and its relative techniques. To solve this problem, we had recourse to artificial intelligence facilitating the reasoning task while helping on decision making in auditing [6]. So as part of the development of our bioinformatic solution (the audit expert system of radiation dosimetry in radiology RAP.Expert), we had to develop a medical ontology of radiological area specifically for the acts and knowledge in diagnosis and in radiotherapy, as part of the integration of artificial intelligence in the medical organization. This ontology is the subject of radiation protection that tends to ensure radiology.

The work in this paper will be divided into sections as follows: In Section II, we present a summary of related work; in Section III, we present the concepts, interest, and computer (informatics)-context on which we relied to develop our ontology; in Section IV and V, we describe the adopted methodology which was divided into stages of ontology development; in Section VI, we present the composition of our ontology; finally in Section VII, we present the conclusion and future work.

## II. Related Work

In the literature, many studies about ontologies and semantic web representation were established in medicine, but a very few works gave importance to radiation protection. Among them, we found some general ontologies trying to cover the medical field as a whole namely: SNOMED [7], UMLS [8], [9], and NCIT [10]. These ontologies did not have a special interest in radiation protection, thus it does not permit a reasoning about radiology contexts and their associated radiation risks. However, some of these ontologies were extended with more specialized medical taxonomies, focusing for example on radiology. This is the case of SNOMEDCT [11] and Radlex [12] ontologies. Unfortunately, not all the classes and properties that we require for accomplishing our reasoning task were found in these works [13]. However, our ontology allows the use of restrictions and contains a rule base that simplifies reasoning and helps obtaining concrete results about radiation protection measures in radiology and provides more guarantees for a compliant solution. Moreover, these ontologies did not model the concepts and rules building radiation protection regulations.

## III. Background

Theoretically, there are many definitions of ontology depending on its type and the functionalities, but for our case, it is defined as a form of formal concepts description clearly structured and outlined [14]. In fact, the term ontology comes from the philosophy of knowledge, designating all concepts in a domain. Formally, in computer science, an ontology represents knowledge as a hierarchy of concepts (classes) in a field, using a common vocabulary to describe and identify the types of properties and relationships between these concepts and the component of roles restrictions [15]. Ontologies are used in artificial intelligence, the Semantic Web, systems engineering, software engineering, biomedical informatics, library science and information architecture [16], as a form of world knowledge representation or part of it.

The ontology is devoted to the representation and organization of information about the real world [17] in a form that the computer system can use to accomplish tasks and solve complex problems such as the diagnosis of disease or have a dialogue of natural language.

The development of our ontology is based on the knowledge representation language Web Ontology Language (OWL) [18], for editing ontologies and knowledge bases to describe a field. The language is characterized by formal semantics and is built on the Resource Description Framework (RDF) data model [19]. OWL is approved by the World Wide Web Consortium (W3C) as it drew the academic, medical, and commercial attention [20]. OWL ontology is interpreted or described by an incorporated terminology of concepts and domain properties (instance concepts). An ontology consists of a set of axioms that place constraints on sets of individuals called "classes" and the types of permitted relationships between them. OWL is able to create classes and properties in order to identify bodies and their operations:

a. An instance is an object that corresponds to a logical description (individuals), in which there is detailed knowledge of a class or domain (medical). Domain objects that we want to model (examples: head, spleen, tunis, fracture, etc.).
b. A class is a set of objects or instances (example: the anatomy concept consists of hand, foot, coccyx, etc.). The classes (concepts) are constructed from logical descriptions that constrain the membership conditions. A class can be a subclass of another (concept hierarchy), inheriting the characteristics (properties, and other bodies) of the parent class (super class). This corresponds to the logic subsumption and logic description of the concept inclusion symbolized by ⊆. All classes are subclasses of "owl: thing" (root class). For example, [RadiologyExamination] could be a subclass of class "owl: Thing" while [XrayRadiography] and [RadionuclideImaging] are subclasses of [RadiologyExamination].
c. A property is a binary relation (inst-inst / inst-class / class-class) that specifies the characteristics of a class (Example: [Radiological Examination] (hasPatient) [Patient_1]). It corresponds to a logical role of description. Properties can have logical capacities as transitive, symmetric, inverse and functional. The properties have areas and ranges. The "Datatype-Properties" are relations between instances of classes and RDF literals or 'datatypes' Extensible Markup Language (XML) schema [21]. The "Object-properties" are relations between instances of two classes.

## IV. Ontology Design Methodology

Practically, there are different ways of development and engineering of the ontology which differ according to its needs and type [22]. For our case, a particular methodology has been adapted to achieve the solution. But first, we had to focus on some essential guidelines of our tasks such as: the definition of ontology classes in our radiology field, the hierarchical classification (in classes and subclasses) [23], defining and setting properties (relations) and specifying their fields and their application range, finally we reach the agreement of the instances describing the classes of our Onto.Rap based on description logic [24]. Our major goal is to model the real world radiological domain (both diagnostic and therapeutic) that could be achieved by the design of our ontology while reflecting this reality.

To get in position, we started by identifying the core domain of Onto.Rap, its potential users and stakeholders, the purpose behind using it, the way our ontology will be used. This helped us clarifying our requirements and development approach (objectives, constraints and the thematic framework of our ontology).

As a second step, we moved to building a conceptual model which will constitute the base for ontology reasoning afterward. We initiated the design phase by gathering information about radiology collected from medical documentation, scientific articles and publications. We have focused mainly on the standard recommendation on radiological dose administration. This step was followed and validated by the use of a certain taxonomy consisting of the classified nomenclatures. This helped us representing radiology and radiation protection knowledge in the form of abstracted concepts, relationships, and individuals (instances). Thanks to the expressiveness capability of OWL, the Onto.Rap concepts were represented in a syntax that is the closest possible to natural language. Hence, the semantics is preserved through the proposed formalism [25]. Our approach ensures the modeling of relationships between different concepts as OWL properties (e.g: Nephrotic syndrome [isa] inflammation [localizedin] the glomeruli). In this example, we established the relationship between three concepts (pathology: nephrotic syndrome, symptom: inflammation, anatomy: glomeruli) through the use of two OWL object properties: [isa] and [localizedin].

The creation of the properties is accompanied by a specification of fields and ranges of these relationships between concepts and instances [26]. We provide below, examples of formal specification of some classes and properties in our ontology:

Example 1:

- Mamography ⊆ SpecificRadiographyExamination Π hasAnatomy Э Breast

In this example we describe a Mammorphy concept as a subclass of SpecificRadiographyExamination applicable on a specific Anatomy concept which is the Breast.

Example 2:

- MelanomaCurativeTherapy ⊆ CurativeTherapy Π hasTechRadiTh ∀ (Proton therapy ᴜ Hadron therapy ᴜ Contactotherapy ᴜ TotalCutaneousRadiotherapy).

In this example, we present MelanomaCurativeTherapy as a subclass of the CurativeTherapy concept and has a radiation therapy technology Proton therapy or Hadron therapy or Contactotherapy or TotalCutaneousRadiotherapy.

As a third step and in order to specify ontology concept in more details, we can use owl restrictions. Thanks to its description logic syntax, more complex relationship between concepts could be better described and specified. For example, the following owl restrictions were useful for specifying the required patient dose limits in some radiological procedures (greaterThan, lessThan).

As a fourth step, we have designed semantic rules base constituting of SWRL and SQWRL rules for specifying radiation protection guidelines covering radiological procedures in terms of radiation dose administration. In addition, we have also produced another set of rules which will allow us to check the compliance of recorded past events (patient radiological examination) with standard radiation protection guidelines. The validation and the execution of SWRL rules [27], were effectuated by means of the Jess rules engine [28]. As a result of the firing-up of the audit and compliance rules, we get an instant judgment on the results and a selection of specific inadequate cases of patient radiological examination events as shown in the following examples:

- Rule1:Fluoroscopy(?x)ʌhasDose_Gy(?x,?d)ʌswrlb:greaterThan(?d,0.24) →compliance(?x,False)

This means that if an x review of fluoroscopy having a dose and that dose exceeds 0.24 Gy, then we can consider that this case is not compliant. In a compliant case, the value of the compliance property will be set true.

We have also used a SQWRL rules in order to query the ontology for non-compliant cases of patient examination.

The following SQWRL rule is an example of that [29].

- Rule2:Patient(?p)ʌhasExam(?p,?e)ʌcompliance (?e,False) → sqwrl:select(?i,?e)

This serves to identify all cases of non-compliance recorded in our knowledge base. In addition, the expressiveness power of our restrictions would enable a better reasoning afterwards about radiation protection knowledge; for example, when our ontology is linked to a decision support semantic web application for audit and compliance checking.

In particular, the reasoning about radiation protection procedures and compliance could be better achieved through the use of OWL rules and query languages (Semantic Web Rule language (SWRL) and Semantic Query-enhanced Web Rule language (SQWRL)). The focus on these technologies will be the subject of our fourth step explained in the following section.

## V. Onto.Rap Ontology Editing and Implementation

For ontology implementation and editing, we have used the ontology development tool «Protégé3.5» part of the «Integrated Development Environments» [30]. Protégé is a platform of ontology management and a development environment, using tools for modeling the general and specific knowledge depicting different real world domains [31]. It allowed us to create, modify, update, and share knowledge in a single workspace through a customised user interface and in the form of ontology and rule base. It also has provided an advanced help tool for the validation of our ontology and semantic rules base against deferent criteria such as completeness consistency and coherence. Moreover, Protégé have a Java API which will be used in the future to build a semantic web application which will consult the ontology and the rules in order to help the user getting decision support on radiation protection procedures [32].

The manipulation of the contextual parameters describing the cases of judgment, led us to build a conceptual model of rules and reasoning, a conceptual model of knowledge, a model of instances (storage), a formal representation of the knowledge.

Knowledge representation about the dose of IR and the practices of radiation protection, by real semantic modeling in ontology, provided a decision support for a regulatory compliance in dosimetric radiation protection. This presented a comprehensive, generalizable, and effective solution by providing support, audit and decision making.

Fig. 1 presents an example of OWL Onto.Rap code and generated by Protégé. Here we come to model the real world concepts of radiology and radiation protection as classes (owl: Class), relations (owl: DatatypeProperty) and (owl: ObjectProperty) and finally (Owl individuals).

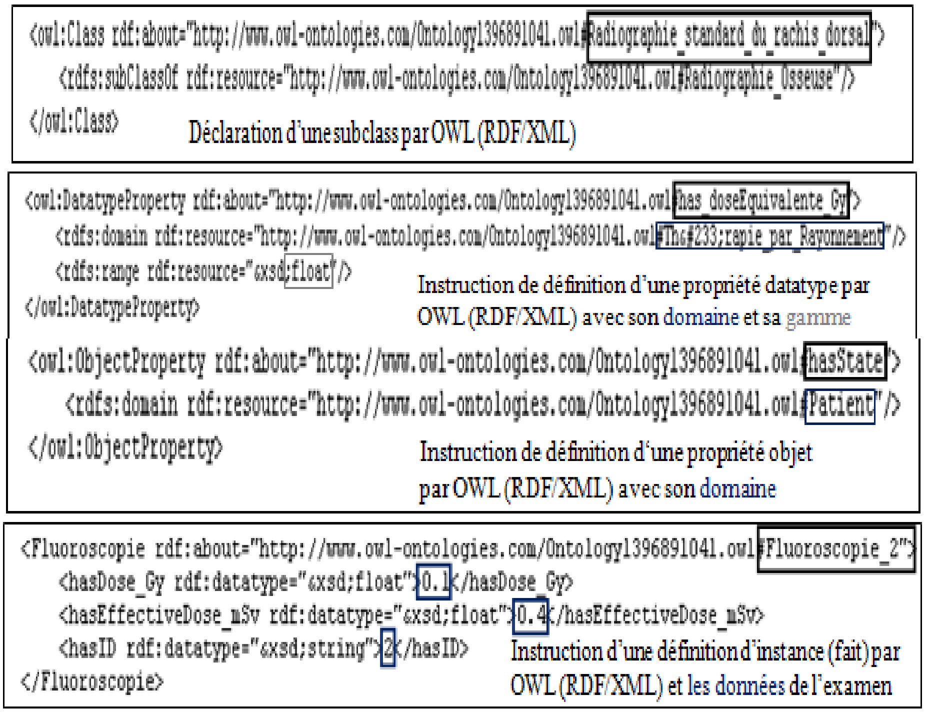


Fig. 1 OWL code extract of Onto.Rap

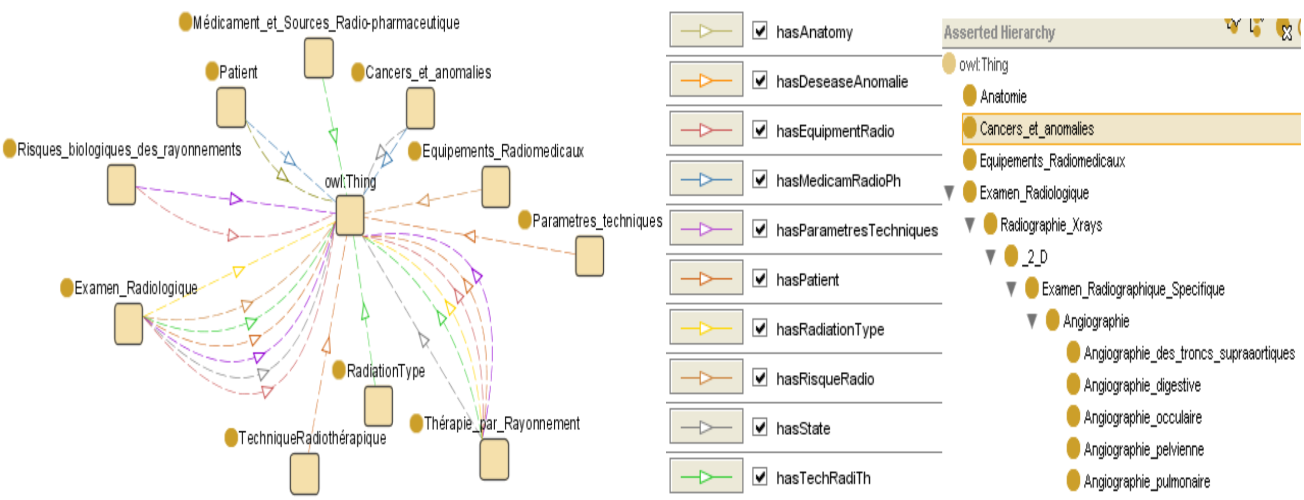


Fig. 2 Diagram of relationships between classes by « Jambalaya

## VI. ONTO.RAP COMPOSITION

In this section, we present the conceptual composition of our Onto.Rap ontology. Our ontology is built with concepts that are classified by types and families of examinations and radiological techniques. It consists of: 12 super-classes including the concepts of radiological examination and radiation therapies. Each one contains many hierarchical sub-classes as presented in Fig. 2. This covers all types of examinations and existing radiology techniques, along with the specific individuals according to the appropriate use case. Some basic concepts of our ontology are shown in Fig. 2. It also contains 10 « object-properties » linking between classes and 45 « data-type-properties» linking between classes and individuals in order to indicate values and parameters that are already related to completed radiology examinations. Examples of «datatype-properties» are presented in Fig. 3.

The Onto.Rap ontology also contains rule base constituting of 339 verification rules written in SWRL syntax which allow us to generate recommendations and guidelines for radiation protection procedures applicable on specified patient radiology examination in a case by case basis. The generated procedures are validated beforehand, against standard regulations on radiation protection through the use of another set of semantic web rules.

Onto.Rap can be linked and adapted easily to other medical ontologies through a specific importation facility; also it is easily extensible when new concept emerges in the future.

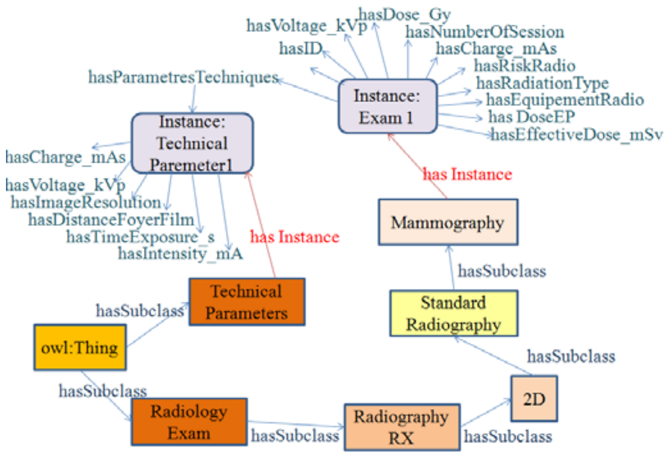


Fig. 3 Diagrams of the relations (in blue) between classes and instances by datatypes

## VII. CONCLUSION AND FUTURE WORK

As part of the decision support system development for the auditing and monitoring of radiation doses, we developed an ontology and knowledge base for patient radiation protection and regulatory compliance knowledge which we named: "Onto.Rap". This unique and exceptional knowledge base is enriched with medical and legal concepts targeting specific radiological services (diagnostic radiology and radiotherapy). When exploited, this ontology is useful for both audit and generating radiation protection best practices. In particular, Onto.Rap allowed us to get rapid detection of non-compliant patient radiation dose administration cases. It also helped us to enforce a strict and disciplinary control of radiological practices.

In the future, our ontology may be extended to act not only as a task ontology but also to be considered as a general core or referential fundamental ontology. We are also continuing the work and we are progressing towards semantic web java decision support system aiming to assist medical end user on choosing compliant radioprotection procedures when administering radiation to patients. Another category of users who might benefit from this system are auditors who could be assisted on checking and verifying compliance of past events of patient radiation by consulting the recorded information on their electronic medical records stored within the hospital radiological information system storage. Our system will also ensure privacy preservation measures when accessing patient data.

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