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OntoVIP: An ontology for the annotation of object models used for medical image simulation

Bernard Gibaud [a,*], Germain Forestier [b], Hugues Benoit-Cattin [c], Frédéric Cervenansky [c], Patrick Clarysse [c], Denis Friboulet [c], Alban Gaignard [d], Patrick Hugonnard [e], Carole Lartizien [c], Hervé Liebgott [c], Johan Montagnat [d], Joachim Tabary [e], Tristan Glatard [c]

[a] LTSI – Laboratoire Traitement du Signal et de l'Image, INSERM U1099 – Université de Rennes 1, Faculté de médecine, 2 av. Pr Léon Bernard, 35043 Rennes Cedex, France
[b] MIPS – Modélisation, Intelligence, Processus et Systèmes – MIPS EA2332 – Université de Haute-Alsace, 12, Rue des frères Lumière, 68093 Mulhouse, France
[c] CREATIS – Centre de Recherche et d'Applications en Traitement de l'Image et du Signal, CNRS UMR 5220 – Inserm U1044 – INSA-Lyon – Univ. Lyon 1, Bâtiment Blaise Pascal, 7 av. Jean Capelle, 69621 Villeurbanne Cedex, France
[d] I3S – Laboratoire d'Informatique, Signaux et Systèmes de Sophia Antipolis, CNRS UMR 7271/Université Nice Sophia Antipolis, 2000, Route des Lucioles, Les Algorithmes – bât. Algorithm B, 06903 Sophia Antipolis Cedex, France
[e] CEA-LETI-MINATEC, Recherche technologique, 17, Rue des Martyrs, 38054 Grenoble Cedex 09, France

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A B S T R A C T

This paper describes the creation of a comprehensive conceptualization of object models used in medical image simulation, suitable for major imaging modalities and simulators. The goal is to create an application ontology that can be used to annotate the models in a repository integrated in the Virtual Imaging Platform (VIP), to facilitate their sharing and reuse. Annotations make the anatomical, physiological and pathophysiological content of the object models explicit. In such an interdisciplinary context we chose to rely on a common integration framework provided by a foundational ontology, that facilitates the consistent integration of the various modules extracted from several existing ontologies, i.e. FMA, PATO, MPATH, RadLex and ChEBI. Emphasis is put on methodology for achieving this extraction and integration. The most salient aspects of the ontology are presented, especially the organization in model layers, as well as its use to browse and query the model repository.

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1. Introduction

Medical imaging has become a very rich source of information which plays a major role in diagnosis, therapy and patient follow-up. Several imaging modalities, e.g. Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound (US) and Positron Emission Tomography (PET), allow exploring and imaging various facets of the morphology and physiology of a living body, at various spatial and temporal resolutions. The progress of medical imaging will certainly continue and one can foresee that all this imaging data will be used in the future to build some sort of digital patient avatars (i.e. virtual representation) composed of a set of personalized and integrated models representing anatomical, physiological and pathophysiological aspects of the organism. Such avatars could be used to test and compare various therapeutic approaches, to predict their outcome, and thus contribute to decision making. However, prerequisites for this to materialize are: (1) that such models are developed, something that initiatives like the Virtual Physiological Human (VPH) strongly support [1,2] and (2) that appropriate model identification methods are developed, whose function is to estimate the various model parameters from the specific patient multimodal image data.

In this context, an important issue remains: how to validate such models and associated identification methods? Medical image simulation appears as an interesting approach to this problem. It has undergone significant progress in the last ten years, with simulators being developed for many imaging modalities, e.g. SINDBAD [3] in CT, SIMRI [4], BrainWeb [5] in MR, SORTEO [6], GATE [7] in PET and FIELD-II [8] in US. This allows addressing a number of needs related both to the design and optimization of imaging equipment and the validation of image processing software. Indeed, image simulation allows generating realistic images of a virtual object, of which characteristics can be defined arbitrarily (e.g. presence of pathology, arbitrary choice of its size and location), and from which one can derive any kind of simulated image (i.e. by tuning spatial and temporal resolution, nature and

* Corresponding author.
E-mail address: bernard.gibaud@univ-rennes1.fr (B. Gibaud).

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level of noise in images, etc.). The key thing with this approach is that it provides a ground truth regarding image content, which enables quantitative assessment of image processing software. For instance, one can actually compare the result of a segmentation algorithm with the actual definition of the imaged object.

The Virtual Imaging Platform (VIP) (http://vip.creatis.insa-lyon.fr) provides researchers with a platform gathering several image simulators of various modalities [9]. Its major goals are: (1) to offer an easier access to simulators whose installation and use is usually perceived as very complex to potential users, (2) to gather simulators of various modalities, and (3) to deploy them on grid computing resources so that reasonable execution times can be obtained while image simulation usually requires huge computation.

This article focuses on the sharing and reuse of the models used for medical image simulation. A basic assumption of this work is that a major barrier to the wide-scale use of these techniques is the difficulty of creating realistic models that are suited to the researchers' specific needs. VIP aims at setting up a model repository to facilitate their sharing and reuse, based on a comprehensive conceptualization of those models, suitable for all imaging modalities and simulators considered in the VIP project and built according to an ontological approach. The first motivation for a such choice is the need to rely on of a semantically-rich vocabulary to annotate the models; such annotations will enable the VIP platform's users to assess whether an existing model can actually meet their specific needs, or be used as a starting point to derive from it an appropriate model. A second motivation concerns the representation of knowledge about the objects represented in a model involved in an image simulation, such as relating objects and materials to their physical properties; a particular aspect is the ability to use the same model in simulations with simulators of different modalities, which requires that the physical properties of materials and tissues be represented in consistent ways for all modalities. The third concerns the interoperability between biological modeling software and medical image simulation software, which requires that common semantics are given to shared information (regarding anatomical structures, presence of pathology, quantities represented in the models or characterizing the tissues properties).

This paper describes the design methodology and the implementation of an ontology for medical image simulation models, tailored to the needs of integrating the SINDBAD, SIMRI, SORTEO and FIELD-II simulators in the VIP platform, but easily extensible to address the needs of other simulators in the future. This ontology, called OntoVIP is used to semantically annotate the models' files (images, meshes, etc.). It is freely available for consultation, download and reuse, both from the VIP web site,[1] and from the National Center for Biomedical Ontology (NCBO) BioPortal.[2] This paper also demonstrates the added value of this ontology for visualizing the models content and querying the models repository.

This article is organized as follows. Section 2 describes the methodology used to design the ontology, with special attention to the reuse and consistent integration of relevant ontologies. Section 3 (Results) presents the ontology itself and its use in the VIP platform to browse and query the models repository. Section 4 (Discussion) positions our achievements with respect to our initial goals and motivations and provides further details on specific problems we have met and on the solutions proposed to overcome them. The paper concludes in Section 5 with some perspectives opened by this work.

2. Material and methods

2.1. Modularity and integration framework

2.1.1. Modularity

Any ontological modeling has two complementary facets. The first relates to terminology and consists of agreeing on a vocabulary to name the entities of a particular domain. The second consists of associating formal semantics to the elements of this vocabulary, in order to reason about the corresponding classes of objects and their instances. Both facets are important with respect to the goal of capturing, sharing and processing data and knowledge in a particular domain.

The design of an application ontology for medical image simulation is a complex undertaking because of the interdisciplinary nature of this field, which lies at the crossroads of several domains: imaging, physics, biology and medicine. As stressed before, our goal was to define a vocabulary that is likely to gather consensus in this community. Therefore, it is important to rely on existing ontologies (if available and of sufficient quality) rather than developing new ones. Currently, the main challenges in ontology engineering are the reusability, scalability and maintenance of the modeled knowledge. In this respect, modularity is essential. Modularization consists is structuring an application ontology as the combination of independent ontology modules [10]. This approach emerged from the software engineering domain where several techniques exist to design software in such a way it could easily be modified and maintained. However, the field of ontology engineering has not reached this maturity yet, and delineating relatively independent ontological modules remains challenging in practice.

2.1.2. Use of a foundational ontology

In this interdisciplinary context it is also important to ensure that the resulting application ontology will be consistent. Therefore, we chose to rely on a common integration framework provided by a foundational ontology called DOLCE (Descriptive Ontology for Language and Cognitive Engineering) [11]. This choice is based on our important experience of this framework gained in the context of the NeuroLOG project [12,13]. DOLCE was produced during the WonderWeb project (2001–2003). It is an ontology of particulars and defines some 40 basic concepts such as for example *endurant, perdurant, quality, abstract*, and about 50 relations.[3] DOLCE is foundational in the sense that it provides entities and relations that are relevant for many kinds of application domains. It is also an axiomatic theory, and therefore constitutes "formal guidelines for domain modeling" as well as "a tool for making heterogeneous ontologies interoperate or merge" [11]. Of course, other foundational ontologies exist, such as Cyc, or the Basic Formal Ontology (BFO).

Using a foundational ontology provides a basic philosophical foundation but it is insufficient for designing an application ontology dedicated to a specialized domain such as medical image simulation. In particular, one needs to model various actions contributing to the generation of simulated images as well as the roles played by specific software components and by specific data sets in these processes. To address such needs we relied on the experience gained in the NeuroLOG project and especially on our expertise of a number of core ontologies extending the DOLCE basic classes, developed and maintained by the "Modélisation, Information & Systèmes" (MIS) Laboratory in Amiens, and especially an ontology of the domain of information and information bearing

[1] http://www.creatis.insa-lyon.fr/vip/ontologies.html.

[2] http://bioportal.bioontology.org/ontologies/OntoVIP.

[3] Entities of the OntoVIP ontologies are in Courier New font; italics are used to denote entities that were imported from some external ontology.

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