Defining an Ontology for the Radiograph Images Segmentation

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***Abstract*—The quantity of thoracic radiographies in the medical field is ever growing. An automated system for segmenting the images would help doctors enormously. Some approaches are knowledge-based; therefore we propose here an ontology for this purpose. Thus it is machine oriented, rather than human-oriented. That is all the structures visible on a thoracic image are described from a technical point of view.**

***Index Terms*— normalization, onotologies, radiographs**

I. INTRODUCTION

A large amount of literature in the medical image analysis research community is devoted to the topic of segmentation. Many methods have been developed and tested on a wide range of applications. The most common lung fields segmentations in radiographs are rule-based or pixel classification based. For the former one, the algorithm is supposed to be trained using some domain specific rules and the best way of representing them is ontology-based.

Ontology is a formal conceptualization of a particular knowledge about the world, through the explicit representation of basic concepts, relations, and inference rules about themselves. Domain ontologies can be used to provide knowledge support in underlying cognitive processes and inter-relations, and a methodology for connecting databases and facilitating professional communication, by supplying added-value information about structural and logical properties of the modeled conceptual network.

II. RELATED WORK

Segmentation of lung fields in postero-anterior (PA) chest radiographs has received considerable attention in the literature.

Rule-based schemes have been proposed by Li et al. [10], Armato et al. [3], Xu et al. [19], [20], Duryea and Boone [6], Pietka [14], and Brown et al. [4].

Lung segmentation by pixel classification using neural networks has been investigated by McNitt-Gray et al. [12], and Tsujii et al. [17]. Vittitoe et al. [18] developed a pixel classifier for the identification of lung regions using Markov random field modeling. An iterative pixel-based 4 classification method related to Markov random fields was presented in [11].

Van Ginneken and Ter Haar Romeny proposed a hybrid method that combines a rule-based scheme with a pixel classifier [7]. ASM has been used for lung field segmentation in [8].

Segmentation of the outline of the heart has been studied by several researchers, usually with the aim of detecting cardiomegaly (enlarged heart size). For this purpose, only parts of the heart border need to be known. Published methods typically use rule-based schemes, using edge detection and a geometrical model of the heart shape [13].

In medicine large-scale ontology domains have been implemented, besides UMLS: GALEN [2], NCI [1] and Medical Entities Dictionary [5]. Though containing huge amounts of useful domain knowledge, most available medical ontologies have been designed under different design principles than those required for Semantic Web applications and therefore can not be directly integrated in such applications. On one hand most of the available ontologies are not formalized in an appropriate representation language to be shared and reused. On the other hand they have been realized for very concrete tasks and their content is modeled in an ambiguous way. One of these ontologies is the Digital Anatomist Foundational Model of Anatomy (Foundational Model or FMA, for short) [15], [16]. The FMA symbolically represents the structural organization of the human body from the macromolecular to macroscopic levels.

The ontology proposed by us is meant for formalizing the knowledge used by an application for radiological images segmentation. In this case, certain biological features are discarded (such as the characteristics of the tissues etc.) and theirs are enhanced, such as the characteristics visible of a radiograph.

Unlike all the other medical ontologies, which are built as a single hierarchy, the one proposed by us consists of several hierarchies, especially meant for image segmentation:

- Radiograph entity
- Features
- landmarks

The ontology is not centered on anatomical structures, as in the case of a general-use ontology, but rather on radiography entities because a segmentation application makes use of entities which can be determined in a radiograph.

III. THE STRUCTURE OF THE ONTOLOGY

As mentioned in section II, we structured the ontology a little different than usually. All the medical ontologies are constructed as unique trees (with one root). We built our ontology as 3 trees, refining: the radiographic entities, their features and the anatomical landmarks.

We have chosen this approach for several reasons:

1. the three classes are disjunctive, thus it appropriate to build
2. this way the ontology is modular. That is different persons can work on different classes and yet is a structured and well defined manner.

Further, the three main notions are described.

A. Radiography entities

The hierarchy with `radiography entity` is further divided into 3 other specific sub-hierarchies based on the categories in which radiological structure may be classified:

- Anatomical structure
- Pulmonary abnormality
- Non-anatomical structure

The non-anatomical structures appear in radiographs more often than one would expect. They vary from catheters to jewels.

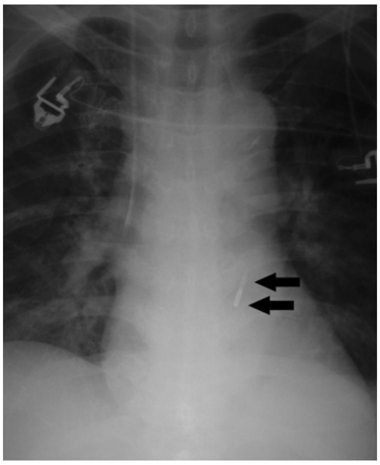

Figure 1. An example of non-anatomical objects.

It is important to make a clear distinction between these non-anatomical objects and the other opacities visible on a radiographs. The table I makes a comparison of the features of anatomical and non-anatomical structures in a radiography.

TABLE I. THE DIFFERENCE BETWEEN ANATOMICAL AND NON-ANATOMICAL OPACITIES

Non-anatomical opacity	Anatomical opacity
High intensity	Lower intensity
String edges	Softer edges
Usually straight edges	Indefinite edges
Constant texture	Variable texture

The anatomical structures are split into

- whole thoracic structures, such as heart, lung, rib etc.,
- parts of anatomical structures, such as parts of the ribs, of the heart etc. and
- composed structures, such as thorax, rib cage and hilum.

The composed entities are necessary because some anatomical structures simply make no sense alone and are always more together, making up a distinct structure. It is the case of the ribs composing the rib cage and of the bronchi composing the hili. It helps in distinguishing between normal and abnormal radiological structures.

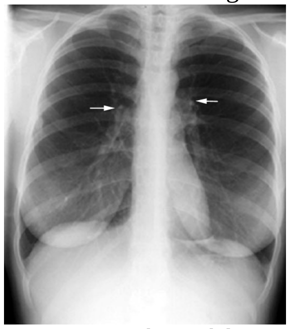

Figure 2. The two hili.

The parts of the anatomical structures are very useful for refining the segmentation. For instance, the left side of the diaphragm is a few centimeters lower than the right one because of the liver located right below the diaphragm.

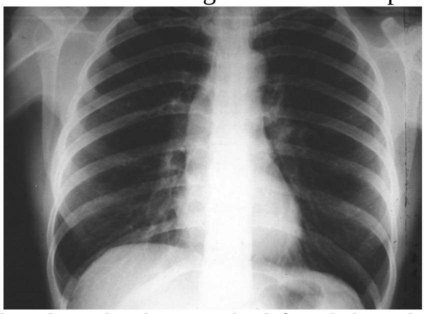

Figure 3. The relationship between the left and the right side of the diaphragm.

B. Features

To make a clear distinction between the type of each opacity, certain features have to be defined, which have been split into:

- Radiography features
- Patient features

The radiography features are the ones used directly for image segmentation and concern the opacities. The patient features may be missing and must be provided to the segmentation application by a physician. They may help the application in making a clear distinction between certain abnormalities. An opacity on the radiography of a non-smoking person younger than 35 years of age, the most probably represents a benign tumor. If a similar opacity is on the radiography of a smoker older than 35 years, there is a suspicion of a malignant tumor.

C. Anatomical landmarks

The landmarks are of great importance for image segmentation algorithms. Based on them, all the thoracic structures can be determined.

Key thoracic landmarks include the suprasternal notch just above the junction of the clavicles and sub-xiphoid region. The bony sternum overlies the spine on the frontal film and is therefore not clearly identified in that projection. The junction of the ribs with the sternum is usually composed of calcified cartilage and are shown as a segmental change as the rib approaches the sternum. Note the small spaces between the ribs at the sternum which is the only allowable soft tissue window for ultrasound imaging of the heart. The nipples are soft tissue and sometimes appear on chest x-rays as suspicious symmetric nodules in the lower lung fields.

Many of these anatomical features serve as nodes of a qualitative coordinate system in the body utilized for the physical exam and various diagnostic and invasive procedures, as well as for the measurement of body parts, organs, organ parts and the spaces associated with them. This coordinate system is augmented by arbitrary planes, lines and points (sagittal plane, mid-clavicular line, McBurney's point). We have grouped together these concepts in the subclass Anatomical Landmark, which we define as a body location that is an organ part or anatomical feature, visible or palpable on an exterior or interior surface of the body, or a line or plane that may be defined with reference to such visible or palpable organ parts or anatomical features.

D. *Anatomical junctions*

In this subclass we have grouped together the various kinds of continuities and junctions through which the physical integrity of the body as a structured object is assured. Anatomical Junction is an anatomical spatial entity of zero to three dimensions where two or more anatomical structures, body spaces, surfaces or lines meet and establish physical continuity with one another or with the body's exterior, or intermingle their organ components. Junctions of body spaces like orifices (ostium of left coronary artery, external cervical os), branching points of nerves, blood vessels and ducts, and junctions of anatomical structures, like plexuses of nerves (e.g., brachial plexus) and vessels, all satisfy the constraints of this definition.

IV. Knowledge Modeling Environment

Software tools are available to accomplish most aspects of ontology development. While ontology editors are useful during each step outlined above, other types of ontology building tools are also needed along the way.

Development projects often involve solutions using numerous ontologies from external sources as well as existing and newly developed in-house ontologies. Ontologies from any source may progress through a series of versions. In the end, careful management of this collection of heterogeneous ontologies becomes necessary to keep track of them. Tools also help to map and link between them, compare them, reconcile and validate them, merge them, and convert them into other forms. Ontologies may be derived from or transformed into forms such as W3C XML Schemas, database schemas, and UML to achieve integration with associated enterprise applications.

Still other tools can help acquire, organize, and visualize the domain knowledge before and during the building of a formal ontology.

When starting out on an ontology project, the first and reasonable reaction is to find a suitable ontology software editor. It's hoped this broad summary of available editors will give prospective ontology developers a head start.

Despite the immaturity of the field, or perhaps because of it, we were able to identify a surprising number of ontology editors - more than 50 overall.

Among the most relevant criteria for choosing an ontology editor are the degree to which the editor abstracts from the actual ontology representation language used for persistence and the visual navigation possibilities within the knowledge model. Next come built-in inference engines and information extraction facilities, and the support of upper ontologies such as OWL-S, Dublin Core, etc. Another important feature is the ability to import and export foreign knowledge representation languages for ontology matching.

For all these reasons we decided to use Protégé, a Java-based tool, from Stanford University

A. *Classes, slots, slot values, and facets*

Anatomical concepts are represented as frames in Protégé. A frame is a data structure that contains all the information in the ontology about a given concept. This information includes the properties of the entity to which that concept refers and also the relationships of that entity to other entities. A frame is a named anatomical entity, such as `thorax`. With each frame is associated a defined set of attributes; each of these attributes has a value. Thus each frame consists of a concept and a set of attribute/value pairings. Figure 4 depicts a part of the tree structure of our ontology.

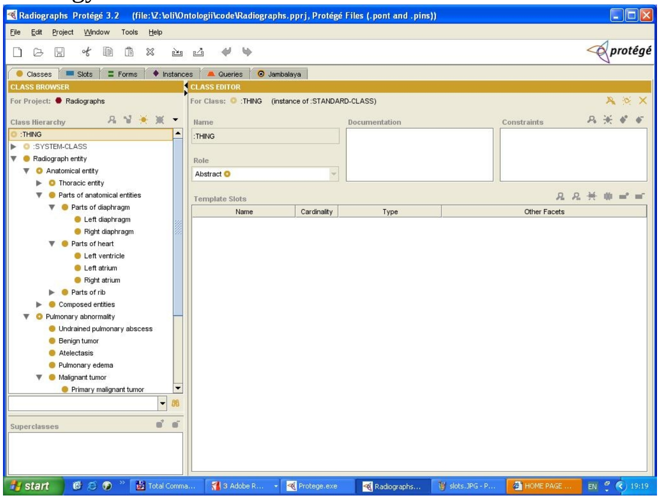

Figure 4. A part of the class hierarchy.

Attributes (properties) and relationships of the entity associated with the concept are expressed as slots of the class. Slots correspond to such non-structural attributes as preferred name, synonyms, and numerical identifiers (UWDA-ID), as well as such structural attributes or relationships as `consists of`, `is part of`, `has size` etc.

Protégé allows different binary relationships for slots. Some slots, like `name`, have a binary relationship with atomic values like string; for slots that describe binary relationships between frames, the values are derived from established classes. For example, `radiography entity` is the domain for the slot `has edge`, whereas the class `edge` is the co-domain of it. Such a relation states that a radiography structure (thus all its subclasses) has a specific edge (eventually derived from the class `edge`).

B. *Classes and instances*

In Protégé a frame may represent a class or an instance. However (and as explained below) all the nodes of the hierarchy may be regarded as classes.

A class in the hierarchy is a collection of anatomical entities or collections of collections. For example, the class `radiography entity` represents such a collection of collections. It subsumes different collections of `anatomical structures` (which are in turn, `thoracic structures`, `parts of anatomical structures` and `composed structures`), `pulmonary abnormalities` and `non-anatomical entities` (see Figure 4). Moreover, the members of each of these collections are likewise further grouped into more specialized collections. This is true even of the leaves of the thoracic organs tree, which have no further subclasses.

Although the above explanation suggests that all concepts of anatomical structures in the ontology are classes, in fact, we had to assign the role of instance as well to the frames of these concepts. In the frame-based system of Protégé, this was the technical solution for enabling the selective inheritance of attributes, discussed in the next section. This solution required the establishment of a meta-class hierarchy and assigning the frames of the ontology classes as instances of the corresponding meta-classes (see below). Thus, except for its root, all concepts in the ontology are subclasses of a superclass and also an instance of a meta-class. These dual assignments integrate the ontology and the meta-class hierarchy. Class-to-class relationships and hierarchies are encoded in Protégé as direct superclass and direct subclass links, whereas the inverse relationship between a class and its instances in the meta-class hierarchy is direct type and direct instance.

C. Selective inheritance of attributes

The purpose of the hierarchy is to assure the propagation or inheritance of attributes. It is necessary, however, to distinguish between the attributes that should and should not be propagated. As intimated above, the desired selective inheritance is achieved operationally, in a seemingly contradictory way, by assigning a dual role to each frame: in Protégé each frame is modeled both as a class and as an instance. Its role as a class allows it to propagate its set of attributes to its subclasses, but in its role as an instance it is prevented from doing so.

The insertion of new slots at appropriate levels of the ontology provides for introducing definitional and other attributes that should be inherited by descendants of a class. Such a class has been designated as a property introduction class [9], whereas in Protégé new attributes (slots) are introduced in meta-classes. Meta-classes function as templates, and serve to define new classes. Newly created classes are assigned as instances of corresponding meta-classes. Thus a class is a subclass of its ancestor classes and its frame is an instance of its meta-class.

This arrangement allows for discriminating between slots that should and should not be propagated. The definitional attributes are propagated to descendants of the class as template slots; they specify which slots each member of the class shall have and what the restrictions (facets) on the values of these slots shall be. Instances of the class, on the other hand, inherit such template slots as own slots and assign specific values to them (own slot values). Own slots are not propagated. For example, `parts of anatomical structures` has a template slot `is part of` with the co-domain a `anatomical structures`. The slot `is part of` of the the subclasses of `parts of the anatomical structures` have different codomain; So, `parts of diaphragm` are parts of `diaphragm`, `parts of the heart` are parts of the class `heart` and `parts of rib` are parts of the class `rib`.

D. Properties of the relations

The relations between the thoracic entities are mainly spatial. That is because the entities may be determined based on the spatial relationships between them.

The spatial relations may be classified in 2D and 3D. The 2D relations are:

- `above / below`
- `to the left / to the right`
- `inside / outside`

The 3D relations are: `in front / behind`.

All these relations are asymmetric and transitive. For instance, if $(a,b) \in left$ then $(a,b) \notin left$. They are also transitive: if $(a,b) \in left$ and $(b,c) \in left$ then $(a,c) \in left$.

V. Our practice

The basic steps in building an ontology are straightforward. Various methodologies exist to guide the theoretical approach taken, and numerous ontology building tools are available. The problem is that these procedures have not coalesced into popular development styles or protocols, and the tools have not yet matured to the degree one expects in other software practices. Further, full support for the latest ontology languages is lacking.

For building this ontology, we followed certain steps used by most researchers in the field:

- acquiring domain knowledge
- organizing the ontology
- fleshing out the ontology
- checking the work
- committing the ontology

A. Acquiring domain knowledge

The domain knowledge was acquired from two different radiologists of the Emergency Hospital in Baia Mare. As expected, most of the knowledge was common in both cases, but some things have been defined differently by the two physicians. This happened with relatively small issues, such as the relative positions of the anatomical entities. In this case, the opinion of a third radiologist was requested or the coalescence of the two divergent opinions was used.

A first challenge was imposed by the difference of background knowledge and language between them and us. So we had to define the specific medical terms.

Another challenge was given by the difference of thinking between the physicians and the engineers who built the ontology. The very origin was the difference of backgrounds. This caused several problems during the project. It was quite difficult for radiologists to understand the meaning of landmarks and their importance in image segmentation. They also faced problems in defining proper landmarks, having the attribute of being fixed and well-determined.

B. Organizing the ontology

The way in which the doctors provided us with the information was driven by their experience. That is radiologists gave the information in the was they analyze a radiography. This differs rather much from how an automated segmentation would work in several aspects:

- humans usually are not aware of common knowledge, thus they omit to verbalize it and transmit it to us;
- the way in which they define the properties of the anatomical entities differ from their mathematical representation.

Eventually we defined 3 major classes:

- `radiography entity`. In turn, it contains the following subclasses:
  - `anatomical structure`
  - `pulmonary abnormality`
  - `non-anatomical entity`
- `features`, which is refined further into:
  - radiography feature
  - patient feature
- `anatomical landmarks`

The ontology is much too large to be presented here, but we hope that we could offer a clue of the way we worked.

C. Fleshing out the ontology

The concepts and relations have been added to the level of detail necessary to satisfy the purpose of the ontology - segmentation of the thoracic images.

General purpose ontologies, such as FMA have a very wide detail range, starting from the body and ending up with tissues, cells and molecules. This is not only useless in our case, but even disturbing. Some entities, such as cells are simply not visible on a radiograph. On the other hand, we focused on thoracic images, so we have been concerned only with the thoracic entities visible on a radiograph.

We have been interested only in the characteristics visible on the radiography, rather than in structural and biological properties of the entities.

D. Checking the work

The process of building up the ontology was a recurrent mixture of a top-down and bottom-up approach. The ontology has been structured on three main classes, which, in turn have been refined more and more. Then, in a bottom-up manner, we structured the similar entities and super-classes based on `is-a` relations. So, one the the `thoracic structures` were `left lung` and `right lung`, which have a common super-class `lung`.

In the same way we defined two classes which are not obvious from the beginning: `parts of the anatomical structures`, respectively `composed structures`. The anatomical structures for which we can refine parts are the heart, the diaphragm and the ribs. The composed structures are the hilum, the rib cage and the thorax. They are not individual structures, but are rather handled as individual ones.

E. Committing the ontology

When the process of building the ontology ended up, it has been checked by the physicians who provided with the domain knowledge. The verification has been carried out in two stages:

- the first stage concerned the correctness of the ontology from a medical point of view: that the medical terms were right, the relations between the structures were the real ones etc.
- the second step aimed the utility of the ontology. It had to be able to provide answers to the various queries of the radiologists. Queries would look like:
  - *What is the anatomical structure behind the aortic arch?*
  - *What anatomical entity is the one with the strong edge and regular shape?*

Further more, two other radiologists, who had not provided us with specific knowledge checked, in turn, the ontology in the same two stages.

We have noticed several discrepancies between the knowledge owned by each physician. They all had the same common sense knowledge, but the experience of each of them made them to have different opinions on specific issues. However, the occurrence of the disputable cases in real life work is less than 2%, which makes us to simply discard them.

VI. CONCLUSIONS AND FURTHER WORK

The ontology proposed by us was specifically meant for segmentation of radiological images. It is processable by computers and therefore provide for machine-based inference, which is a prerequisite for the development of knowledge-based applications.

The field of image segmentation lacks of application capable of determining thoracic structures based on ontologies. The ultimate test of our ontology would be given by such an application.

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