AN ONTOLOGY SUPPORTING THE DAILY PRACTICE REQUIREMENTS OF RADIOLOGISTS-SENOLOGISTS WITH THE STANDARD BI-RADS

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Abstract: This paper presents concepts and relationships allowing the development of an ontology that supports the daily practice requirements of radiologists-senologists with the standard BI-RADS (Breast Imaging Reporting and Data System). This ontology aims at describing the radiologic-senologic knowledge shared by the community of technicians, practitioners, gynecologists, radiologists, surgeons and anatomo-pathologists. It represents a unifying scope for reducing and eliminating ambiguities as well as conceptual and terminological disarrays. It also ensures the understanding of the concerned community. It allows communication and dialogue between members of the scientific community even though they are working in different fields having different requirements and viewpoints. This ontology allowed us to obtain a conceptual model of the domain. Details concerning the development of the ontology and the generalization of the conceptual scheme that leads to the design of the conceptual model are described.

1 INTRODUCTION

Current methods are unable to capitalize and to reuse knowledge acquired from experience. Re-use is employed with an *ad hoc* manner. It is a traditional technique based on experience acquired during developments of different systems in a specific domain. The *ad hoc* manner is inadequate because it does not allow to share accumulated experience, contrarily to what medical experts wish to obtain. In order to achieve investigations on a vast number of cases, experts only use their own experience, even though this is a vast amount of experience. It would be advisable to gather the experience of the numerous experts for a shared utilization. Besides the obvious advantages that could result from this shared knowledge, it would allow to homogenize the knowledge on the same topics by standardizing the vocabulary and definitions. Identical notions should be labelled using the same terminology so as to compare them. It is a well-know fact that in medicine, the development of specialized ontologies is a mandatory step for elaboration and maintenance of increasing a thesaurus and not an ambiguous one, for the sake of communication between terminologists (Rector, 1999).

As Gruber (Gruber, 1993) wrote, an ontology is defined as follows: '*an ontology is a formal, explicit, specification of a shared conceptualisation*'. It defines concepts used to describe knowledge, their relationships and their constraints of use.

We have built an ontology based on the standard BI-RADS (Breast Imaging Reporting and Data System) (Chabriais and al, 1998), on the scientific reports of the EBM (Evidence-based on medicine) and on the reports and experience of radiologists-senologists of the Necker Hospital in Paris (France) in view of representation of radiologic-senologic knowledge and associated clinical reports (Demigha and al, 2001).

This ontology is fitted to the description of the senologic knowledge shared by the scientific community of technicians, practitioners, gynecologists, radiologists, surgeons and anatomo-pathologists. It represents a unifying scope for reducing and eliminating ambiguities as well as conceptual and terminological confusions. It also

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ensures that the concerned scientific community shares a mutual understanding. It allows communication and dialogue between members of this scientific community even if though they are working in different fields that have different requirements and viewpoints. This ontology allowed us to obtain the conceptual model of the domain in radiology-senology, which is structured as cases using the case-based reasoning approach.

We have analyzed requirements of radiologists-senologists with the Department of Radiology of the Necker Hospital in Paris using the Crews-l'Ecritoire approach (Cooperative Requirements Engineering With Scenarios) (Ben Achour 1999). Radiologic-senologic knowledge is made of both text and images. We have only considered textual knowledge; images are just associated to patients' reports for the sake of information. Analysis performing has allowed to structure the radiologic-senologic knowledge according to stringent rules. It is an original approach to solve the issue consisting in considering the ontology definition as an engineering issue requirement.

The paper is organized as follows:

- Section 2 positions our work with respect to existing ontologies.
- Section 3 presents the acquisition of radiologic-senologic knowledge using the Crews-l'Ecritoire approach.
- Section 4 presents in details the steps that allowed us to construct the ontology in the radiology-senology domain.
- Section 5 provides the conclusion.

2 STATE OF THE ART

The engineering of ontologies (or ontological engineering) arose from the will to diversify the applications of the Knowledge-Based-Systems (KBS). It allows for a representation of knowledge that does not depend on these various applications, so as to ensure its portability from an application to another (Furst, 2004).

At the present time, there is a relative consensus on the role of ontologies. This consensus is built around the Gruber formula. "An ontology, is a formal, explicit, specification of a shared conceptualisation ". The construction of an ontology is a conceptualization work. It consists in identifying, within a corpus, the knowledge specific to the field of knowledge to be represented, and consensually acknowledged as pertaining to this field. Guarino proposes a four level-classification of ontologies according to the link between the ontology and the application (Guarino, 1997). High-level ontologies describe general concepts while low-level ones describe concepts that depend on a domain.

The Crews l'Ecritoire approach is based on the ‘‘Requirement Engineering’’ concept and helps understanding users needs using a semi-automatic analysis of textual scenarios, i.e. scenarios written in natural language. Moreover, Crews permits strong control and verification of the extraction process.

Starting from a high-level problem statement, it guides the discovery of a complete hierarchy of goals illustrated by scenarios in a top-down manner. The approach is based on a set of guidelines to guide linguistic analysis and verification of scenarios written in natural language. Use of natural language allows radiologists to understand scenario meaning without having expertise in Crews approach and use.

Section 3 presents the acquisition of radiologic-senologic knowledge using the Crews-l'Ecritoire approach.

3 ACQUISITION OF SENOLOGIC KNOWLEDGE

Crews-l'Ecritoire associates concepts of *goals* and *scenarios* to support the requirement elicitation (Rolland and al, 1999). A *goal* is defined as something that some shareholder hopes to achieve in the future, it is expressed as a verb with eight optional parameters, each parameter playing a different role with respect to the verb, and a *scenario* is a possible behavior limited to a set of purposeful interaction taking place among several agents. A couple <*goal, scenario*> is a requirement chunk (RC).

When a goal is discovered, the approach proposes to author a scenario (coupling in the forward direction). Then, the approach analyzes every scenario to yield new goals (coupling in the backward direction). Starting from a high-level problem statement, the Crews-l'Ecritoire approach guides the discovery of a complete hierarchy of goals illustrated by scenarios to help writing scenarios in a top-down manner. The approach is based on a set of guidelines. These guidelines consist (1) of automated rules to guide goal discovery and (2) of guidelines to guide linguistic analysis and verification of scenarios.

Crews introduces three abstraction levels in RCs specifications: behavior, functional and physical.

- The behavioral level identifies services to be provided (Behavioral level::= <Design Goal, Service Scenario>).
- The functional level focuses between the system and users to complete the services (Functional level : := <Service Goal, System Interaction Scenario>).
- The physical level deals with the actual performance of the previous level (Physical level ::= <System Goal, System Internal Scenario>).

Crews allows to organize RCs according to three strategies in order to construct the RC model, namely: refinement using the (‘‘Refined by’’ connector), complementary (‘‘AND’’ connector) and alternative (‘‘OR’’ connector). This organization is performed thanks to guidelines and rules which allow to map RC defined at a given abstraction level into RCs defined at a lower abstraction level.
Section 4 presents in details the ontology in radiology-senology domain.

4 CONSTRUCTION OF THE ONTOLOGY IN SENOLOGY

This section presents detailed steps that allowed us to construct the ontology in the domain of radiology-senology.

4.1 Concepts Underlying the Ontology

This section presents the concepts elicited during our analysis and explains how to translate actions defined at the behavioral level into actions defined at the functional level, then into actions defined at the physical level. This translation mainly uses the refinement rule ‘‘Refined by’’ and it results in a structured network of RCs (see Figure 1). An example about the use of the model is used to illustrate the three previously mentioned strategy of RC organization and to explain how to face with exceptional conditions.

4.1.1 The Behavioral Level

The behavioral level lists services required at the highest level in order to achieve a goal. A behavioral RC couples a ‘‘Design Goal’’ to a ‘‘Service Scenario’’.

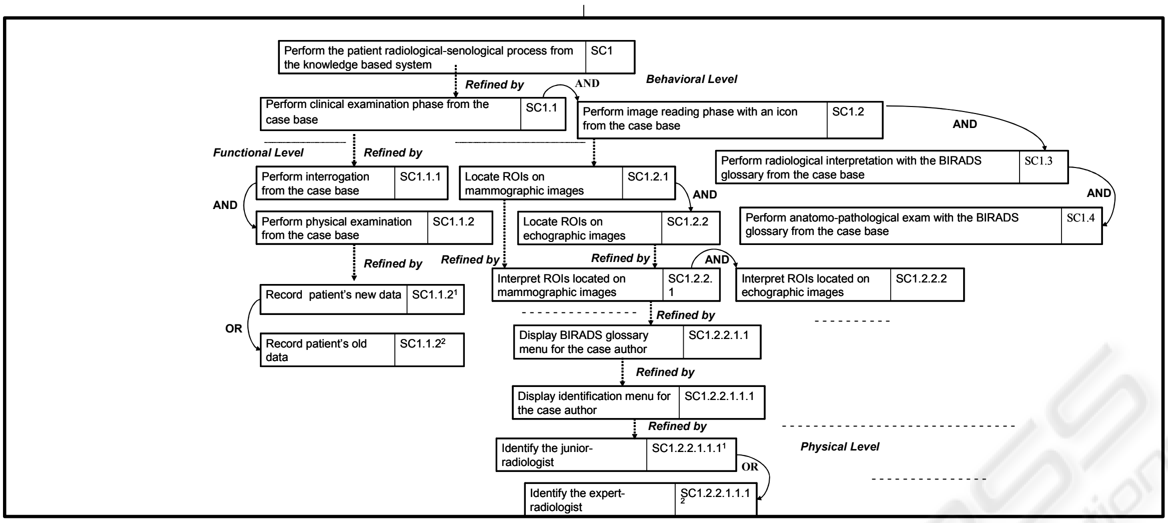
Let us consider the ‘‘Design Goal’’ associated with the RC ‘‘*Performing the patient radiological-senological process from the case base*’’ (see Figure 1). This goal means that the case base must provide radiologists with a mean to support their mammography-related activity. In the RC, this goal is coupled with a ‘‘Service Scenario’’ which contains four basic steps: (1) Performing clinical examination phase from the case base, (2) Performing image reading phase with an icon from the case base, (3) Performing radiological interpretation with the BI-RADS glossary from the case base, (4) Performing anatomo-pathological examination with the BI-RADS glossary from the case base. These steps are services requested by radiologists in the course of the daily practice and are complementary. They are linked through an “AND'” connector. In the Crews approach, these four steps refine the initial RC. As they also define services, the refinement takes place at the contextual level. This is allowed by Crews when refined scenarios have the same semantics as the initial scenario.

4.1.2 The Functional Level

The functional level refines services defined at the behavioral level when the refinement can be expressed in terms of user-oriented tasks. They lead to ‘‘Service Goals’’ and ‘‘Interaction Scenarios’’.

Let us consider the first refined ‘‘Design Goal’’: “Performing clinical examination phase from the case base” (see Figure 1). It generates two actions that correspond to two ‘‘Services Goals’’: (1) Performing patient’s interrogation from the case base and (2) Performing patient’s physical examination from the case base. These actions are complementing each other and thus are linked through an ‘‘AND’’ connector. These actions are complementing each other and thus are linked through an ‘‘AND’’ connector.

As for the behavioral level, Crews allows to refine RC belonging to the functional level into new RCs defined at the same level. For instance, the second step: ‘‘Performing patient’s physical examination from the case base’’ can be refined in two steps: (1) to record old data into the case base, (2) to record current data into the case base.



SC1 is a sub-goal of the Information System (IS) building. SC1.X... indicates the scenario number.

Figure 1: Part of the Requirements Chunks Hierarchy.

As these actions are alternative (i.e. new patient vs. already registered patient), they are connected by an ‘‘OR’’ connector. The scenario SC1.1.2 illustrates this refinement process through the refinement of the scenario SC1.1.2. The scenario SC1.1.2 is defined at the behavioral level as follows:

Initial state:
The case base is online.
The case author is granted access to the case base.
The case author must perform radiological-senological process.

1 Perform patient’s interrogation from the case base.
2. Perform patient’s physical examination from the case base.

Final state:
Data of radiological-senological process are recorded into the case base.
The case base is consistent.

The second step or action is refined at the functional level by:
1. Record patient’s new data.
2. Record patient’s old data.

4.1.3 The Physical Level

The physical level refines interactions defined at the functional level. This refinement can be expressed in system-oriented tasks. They lead to ‘‘System Goals’’ and ‘‘Internal Scenarios’’.

Let us consider the ‘‘Goal Service” ‘‘*display identification menu to the case author”* (see Figure 1). It can be refined in two alternatives (i.e. connected by an ‘‘OR’’ connector) actions: (1) to identify the junior-radiologist and (2) to identify the expert-radiologist. Identification means that the case author is registered as case author by the case base, and known by the case base. Access authorization is then granted by the Database Manager System (DBMS) according access rights as defined by the administrator. These can be refined into new Internal Scenarios. Extensive details for level hierarchy are presented in (Demigha, 2005).

The following scenario illustrates the procedure by the refinement of the scenario SC1.2.2.1.1.1: ‘‘display identification menu to the case author”.
SC1.2.2.1.1.1is defined at the functional level by:
1. Display identification menu to the case author.
- - - - - - - - - - -

It is refined at the physical level as follows:
1. The system asks the case author to login.
2. The case author introduces his login.
3. **If** the code is valid **then**
4. The system continues the login procedure. When ‘‘the code is not valid’’, system denies the author case to access database. This cannot be expressed in a unique scenario as Crews does not allow the use of the ***IF/ELSE/THEN*** structure into a scenario. In order to manage such a structure, Crews offers the concept of exceptional scenario. This scenario is connected to the ‘‘normal scenario’’ with an alternative connector. In our example, the associated connection rule is:

If code is valid ***then*** perform SC1.2.2.1.1.1.1
else perform SC1.2.2.1.1.1.1 [1]

Exceptional scenario SC1.2.2.1.1.1.1managing ''not valid code'' is defined at the physical level as follows:
1. **If** the code is not valid **then**
2. The system denies access.
3. The system is consistent.

4.2 Generalization of the Conceptual Scheme

This section describes the conceptual scheme obtained from expressions of the three abstraction levels and illustrated by examples appropriated to our analysis. We display how we have extracted the different RCs, concepts and relations gathering them. These concepts and relationships constitute the ontology of radiology-senology domain according to the definition of Gruber (Gruber, 1993).

We display how we have built the ontology of the radiology-senology domain via the step-to-step Crews L'Ecritoire approach. It is an approach based on engineering requirements and on formal guidelines and rules. It allows to analyze the user's requirements, needs and specifics, it defines the goals at different levels of abstraction, it defines the scenarios with different levels of abstraction, thus resulting in a structured network of goals and scenarios (see Figure 1).

If we take again the behavioral goal at the highest level illustrated on Figure 1: Performing the patient radiological-senological process from the case base.

This goal is refined according to four complementary actions: (1) Performing clinical examination phase from the case base, (2) Performing image reading phase with an icon from the case base, (3) Performing radiological interpretation with BI-RADS glossary from the case base and (4) Performing anatomo-pathological examination with BI-RADS glossary from the case base.

The four basic actions will be now detailed.

Starting from these actions, we will show how we have extracted the concepts and their relationships and thus, how to construct the ontology.

Let us consider action 1: SC1.1: Performing the clinical examination phase from the case base.

One key-concept can be extracted at once: *clinical examination.*

Key-concept: *clinical examination.*

This action generates itself two actions:

- SC1.1.1. Performing patient's interrogation from the case base.
- SC1.1.2. Performing patient's physical examination from the case base.

Let us consider the first sub-action SC1.1.1.

SC1.1.1. Performing patient's interrogation from the case base. We can extract two key-concepts: *patient* and *interrogation*.

Key-concepts: *patient* and *interrogation.*

For the second sub-action we can extract two key-concepts: *patient* and *physical examination.*

SC1.1.2. Performing patient's physical examination from the case base. We can extract two key-concepts*:* *patient* and *physical examination.*

Graph of Figure 2 represents the first action of scenario SC1.

From the second sub-action, we also extract two key-concepts: *patient* and *physical examination*.

We have summarized the different extracted key-concepts on a graph where the concepts are represented by labels and linked by relationships symbolized by lines.

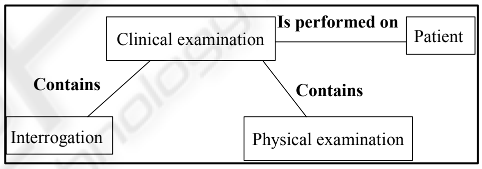


Figure 2: The action 1 of the scenario SC1.

Now, the same operation will be carried out on the second action. We extract two key-concepts: *reading* and *image*.

SC1.2: Performing the image-reading phase with an icon from the case base.

Key-concepts: *reading* and *image.*

This action generates itself two actions:

- SC1.2.1. Locating ROIs on mammograms.
- SC1.2.2. Locating ROIs on echographic images.

The first sub-action contains two key-concepts: *ROI* and *mammograms.*

The second sub-action contains two key-concepts: *ROI* and *echographic image.*

We have summarized the different extracted key-concepts on a graph where the concepts are represented by labels and linked by relationships symbolized by lines.

Let us regroup the concepts extracted from the second action in a graph: like for the first action, we have summarized the different extracted key-concepts on a graph where the concepts are represented by labels and linked by relationships symbolized by lines.

Graph of Figure 3 represents the second action of scenario SC1.

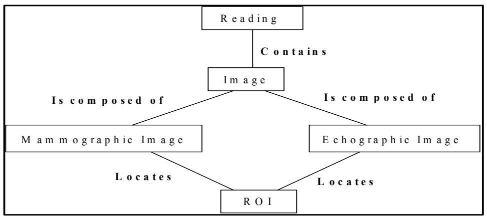


Figure 3: The action 2 of the scenario SC1.

Let us consider action 3 of the scenario:
SC1.3: Performing radiological interpretation with BI-RADS glossary from the case base. We can extract from this action one key-concept: *radiological interpretation*.
Key-concept: *radiological interpretation*.

This action generates itself two actions:
- SC1.3.1. Interpreting ROIs with CMs.
- SC1.3.2. Planning radiological report.

The first sub-action contains two key-concepts: *ROI* and *CM*.
The second sub-action contains one key-concept: *radiological report*.

Let us regroup the concepts extracted from the third action in a graph: like for the first and second actions, we have summarized the different extracted key-concepts on a graph where the concepts are represented by labels and linked by relationships symbolized by lines.

Graph of Figure 4 represents the third action of scenario SC1.

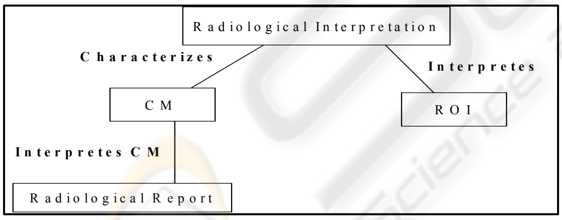


Figure 4: The action 3 of the scenario SC1.

Now, let us consider the last action of the scenario: we extract three key-concepts: *anatomo-pathological examination, patient* and *histological report*. SC1.4. Performing anatomo-pathological examination BI-RADS glossary from the casebase.
We have extracted three key-concepts: *anatomo-pathological examination*, *patient* and *histological report*.
Key-concepts: *anatomo-pathological examination*, *patient* and *histological report*.

Like for other actions, we have summarized the different extracted key-concepts on a graph identical to the previous ones.

Graph of Figure 5 represents the last action of scenario SC1.

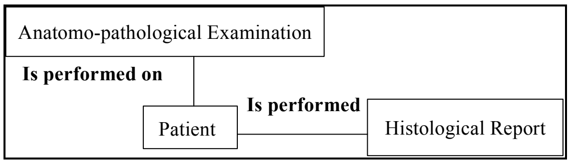


Figure 5: The action 4 of the scenario SC1.

The graph of Figure 6 consists of fusion of the four previous graphs. This scheme represents the overall radiological-senological process. The work illustrated via this scheme was systematically achieved using requirements analysis (RCs); it allowed us to accumulate the knowledge in the particular field of radiology-senology. The defined requirements serve as input of the design modelling of the case base.

The graph of Figure 6 represents the result of this fusion. It translates the course of the radiological-senological process in its totality. The work illustrated here was lead in a systematic manner for the analysis of requirements chunks (RCs) and it allows accumulating knowledge in a particular domain as the radiology-senology. We have elucidated requirements from the hierarchy of RCs produced by the application of Crews-l'Ecritoire approach.

As shown in Figure 6¸ we remark that these objects can possess two common objects or relations that it is necessary to factorize or regroup them in common objects or relations. If we recapture the definition of an ontology given by Gruber: "*an ontology is a formal, explicit, specification of a shared conceptualisation*''. This work: consists of identifying, in a corpus, and specific knowledge-to-knowledge domain to represent and consensually recognized as dependent of this domain. This definition responds
at what we have built.

We have chosen to represent the ontology using an object-oriented approach (and hence the Unified Modelling Language (UML) formalism). An oriented-object approach is acknowledged perfectly powerful to manage complex data (images, sounds, temporal data…) such as the nature of radiological-senological data (text and image).

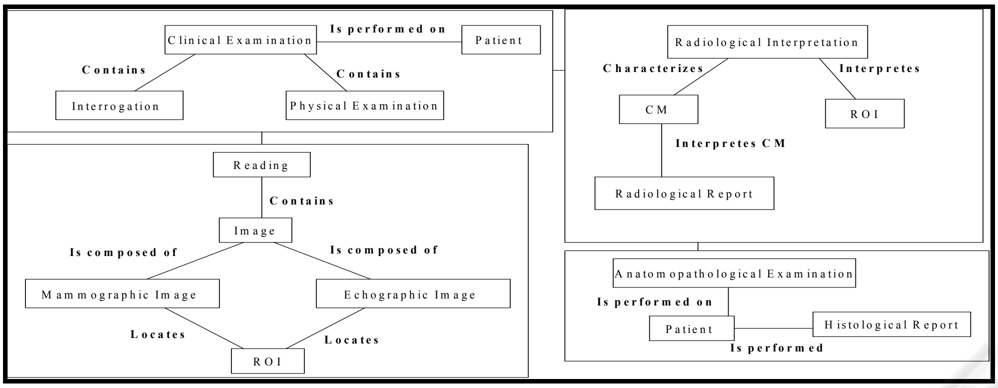


Figure 6: The 4 actions of the scenario SC1.

5 CONCLUSION

The knowledge acquisition process to build our ontology was guided by requirements with the Crews L'Ecritoire approach. It couples notions of goals and scenarios to discover knowledge. With respect to its contribution, this research has produced a step of concept extraction and described their relationships from scenarios. This approach has efficiently guided the construction of the ontology in the radiology-senology domain. The orientation "goal" advocated is relevant since physicians and their requirements are well within the core of the process.

This successful experimentation of the "goal, scenario" approach in order to build the ontology in radiology-senology allows to conclude that this approach can apply to other domains and that it constitutes a systematic approach for ontology engineering.

Systematic approaches for the construction of ontologies are scarce. The association of "goal, scenario" offers, on the one hand, a powerful approach for the localization of knowledge underlying the activities of radiologists and, on the other hand, for generalizing the concepts and their relationships that make the conceptual model of the domain.

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