A Framework for Radiological Assistant Systems

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Abstract

The market for health care systems supporting physicians and improving their daily routine is dynamically growing. The development of these systems makes great demands on the handling of medical knowledge like anatomical and process knowledge. In this paper a special approach for the radiological domain will be presented. Our framework includes mechanisms to store medical knowledge in different knowledge containers, whose importance is varying from application to application, and to support the execution of the processes. Three applications are introduced exemplary. We analyzed the application scenarios to find the knowledge intensive tasks, that can be supported by an assistant system. The implemented solutions are integrated in daily work of our radiological partner hospitals.

1. Introduction

In the last decades the costs of health care increased dramatically, among other reasons founded by the rising demand of the population for better health services. Moreover, health care organizations and especially hospitals are changing to profit organizations. Thus the market for health care systems supporting the physicians and improving their daily routine is dynamically growing.

In this paper a special approach for the radiological domain will be presented. Radiology is a typical medical domain with diagnostic problems, but also one very specialized part, namely the analysis of medical images. This task can be supported by computer systems in a manifold manner, but for their development one has to be aware of the following problems and limitations: information technology can easily capture, transform, and distribute large amounts of highly structured medical knowledge, but for tacit, hard to formalize knowledge like digital radiological images that must be interpreted in a broader context and combined with other types of information, humans are the recommended tool. If the effort for formalizing knowledge is too high, it should be left informal and be processed by humans.

Medical information systems can increase the quality of decision-making and problem-solving by providing relevant informal knowledge in the current work context. An intelligent assistant system should cooperate with the radiologist during problem-solving by performing image processing routines, solving sub-problems, and verifying users solutions. A good strategy to solve important problems is to let the computer do
what might be done and let the medical staff decide. Thus, workload versus decision competence and responsibility has to be distinguished.

The main problem is to integrate the human agents and the software agents and divide and organize the labor between them. A simple guideline is to give the formalized routine parts on large data sets to the software agents and let the creative parts and difficult decisions for the human agents. In the international Cyclops project we build up an assistant system that incorporates process-oriented guidelines with image processing routines and Case-Based Reasoning (CBR) techniques for treating explicit and tacit knowledge.

2. Objectives

In our partner hospitals we always start with an analysis of the processes in daily routine and the identification of candidates for computer support. A suitable candidate in two applications (FM-Ultranet, see 4.1 and POKMAT, see 4.2) was the generation of the final examination report, which has to be created based on the findings in the images. Report generation is a complex task were a real knowledge support by knowledge management techniques is needed. Nowadays, the reporting style is mostly depending on the performing radiologist and the lack of standardization is bad for a real quality control or the creation of organizational reference case bases.

Possible diagnoses should be verified by the performed images and this image analysis task is another critical step, which can be supported by computer systems. Traditionally, a radiologist has to check huge amounts of data in form of printouts, which is often a time consuming and error-prone task. "Technical" steps like the comparison of pixel values in the same area in different images, the appliance of filter, or the interpolation of pixel values can be carried out by a computer. Of course, the interpretation of the outcomes of these steps has to be done always by a human being.

Recapitulating, our main objective is to identify the knowledge intensive tasks in the daily routine of our medical partners. To analyze these tasks and to find an optimal distribution of work between the computerized agents of the assistant system and the human agent (physician) is the greatest challenge.

3. Methods

An assistant system has to provide useful formal knowledge (medical guidelines) and informal knowledge (reference cases) during the reporting step in a usual DICOM based radiological workstation. In addition to this medical knowledge types, image analysis and processing knowledge is used to support the diagnostic processes. This provided knowledge and image processing routines help the practitioner to perform the image analysis and by using checklists he or she creates a standardized report that can act as the base of a best practice experience base.

The system uses several knowledge containers: formal knowledge structures that are based on enhanced semantic nets for anatomical knowledge, diagnostic knowledge and image analysis knowledge. The informal (tacit) knowledge is stored in reference case bases. These knowledge sources are used by a medical workflow system, based on a goal oriented configuration system [1], that invokes e.g. image analysis sequences and special image processing routines, generates queries for the reference case base or interactively asks for decisions from the human agent (physician).

The presented framework includes powerful knowledge acquisition tools to create process-oriented guidelines, image analysis process models and case representations. It uses standard interfaces like DICOM, so that it is very easy to integrate it in real environments.
4. Applications

We have developed several medical applications by using the methods and tools described in 3.3 and now describe three of them in detail. In the first application called **FM-Ultranet** the dominant knowledge container is a formal knowledge structure for anatomical knowledge. The **POKMAT System** is an example how diagnostic knowledge can be used to model a process-oriented guideline for MR knee examinations. Image analysis knowledge plays a decisive role in the last application, dealing with early detection of breast cancer called **Mammalyzer**.

4.1. FM-Ultranet

This first application shows an example how a not well-formalized field of radiology can be supported by an assistant system. The idea is to use the well-known parts of the domain especially the anatomy to describe a case and then try to find similar cases from reference cases that have been collected by a group of specialists. So the tacit knowledge of the experts is stored in the case base.

In the field of obstetrics, ultrasound imaging of the fetus in the mother's uterus belongs to the standard examinations. It is done mainly to detect abnormalities at a very early stage (e.g. of the head, the heart, abdominal wall, umbilical cord, urinary tract, skeleton, etc.). But the specificity of this exam is far lower than for other areas: in Europe, 60% to 75% of the malformations remain unnoticed before birth [2]. This problem is addressed by our work: Foetal Malformation – Ultrasonography training networking platform. We improve ultrasound scans interpretation and diagnosis through comparison of past existing similar cases stored in a database of reference cases and with guidance of an expert. Hence, FM-Ultranet combines Case-Based Reasoning (CBR) and Expert networking to improve ultrasonography through decision support. After having performed an examination by the help of the tool, an examination report can be created automatically.

**Figure 1. Cutting from the FM-Ultranet hierarchical case model**

Technically, FM-Ultranet is a knowledge-based support system, whose kernel is a CBR system that utilizes an object-oriented case model. The similarity assessment applies specific medical measures that were developed with gynecologists. A case
consists of about 140 attributes, structured in an object-oriented hierarchical model; attributes that represent a set of characteristics in a medical sense are grouped into one class. Most of the attributes store knowledge about the anatomical structure of the fetus, like the urogenital tract and the morphology of head, thorax, or rachis. But to retrieve preferably similar cases to a present case from the reference case base, information about maternal age, medical and obstetrical medical history of the mother, or data of the medical conclusion must also be included in the case representation.

The UML diagram in Figure 1 is a cutting from the complete hierarchical model. The concept urogenital system consists of left and right kidney, adrenal gland and ureter as well as sex, bladder and the information, whether the renal vessel is found or not. The concept kidney and its sub-concepts are shown in detail.

4.2. Use of POKMAT to support Radiological Knee Examinations

The Process Oriented Knowledge Management Tool (POKMAT) is a component to support the modeling and execution of automatic and interactive examination processes. Like in the first example, ontologies (anatomical knowledge, medical terminology) can be modeled, but for the domain of knee examinations a process-oriented guideline about the examination can be used as explicit knowledge source. In our generic model an Examination is a special kind of Process. Besides the attributes Input and Output (inherited by Process), Examination has the attribute ExaminedStructure, containing the anatomical component, which has to be examined. The process Examination consists of four parts, viz Preprocessing, Preliminary Discussion, Interactive Image Analysis, and Generate Report. Further information about POKMAT’s architecture and its abilities to model examinations can be found in [3].

Figure 2. Part of the knee examination model
In cooperation with our radiological partner hospital in Mainz, Germany, we have modeled a radiological knee guideline. The attribute ExaminedStructure is set to the value Knee, and the "abstract process" Interactive Image Analysis is specialized to Activities For Knee Examination. It consists of activities like Check Cruciate Ligaments and Check Medial Meniscus. The pathologies for these anatomical structures are extracted from the anatomical model and are presented automatically, so that the radiologist can choose the appropriate pathology according to what he or she sees at the presented images. Figure 2 shows part of the model for the knee examinations.

4.3. Mammalyzer

In the first two examples the human agent does the image analysis step and the systems only supports him or her by presenting the right pictures at the right time.

In the third example we describe an application where the manual image analysis is a very time consuming and error-prone process, since a complete MR examination of the breast with an up-to-date MR scanner creates up to 160 image slices per examination. An automation greatly reduces the workload and thus errors of medical staff. The system operates on taken images using the method of dynamic contrast-enhanced MRI. Suspicious breast lesions are automatically marked with colors, thus directing the physician's attention towards the critical regions.

The first prototype of MAMMALYZER [4] was structured as a pipeline of different image-processing filters controlled by a graphical user interface. A problem of the first prototype was, that most of the parameters for the image matching and contrast agent marking modules depend on image characteristics such as TE, TR, slice thickness, field of view, and image resolution and also on the extent of motion artifacts.

For this reason, the analysis sequences are modeled with the presented framework that uses AI techniques of configuration and planning to choose optimal image operator sequences and parameter sets for the analysis of given images based on image parameters, coded knowledge and already acquired image analysis results. The aim of modeling the MRM analysis is to automatically use the results of a previous calculation of MRM-inter-volume disparities and knowledge about interrelations between image parameters and module parameters for choosing optimal analysis sequences and module...
parameters. Thus, users do not have to perform the task of choosing between different analysis sequences and lots of parameters, since the sequence is automatically chosen and parameterized. Figure 3 shows the dynamic execution of the analysis process.

After execution of the configured pipeline an expectation-matching module controls the process results and decides whether they have an acceptable quality or pipeline parts must be revised. With the aid of a TMS-structure only the responsible operators, and those operators using their results, must be refined.

5. Results and Discussion

Our framework has been used for the development of several applications, in which the different knowledge containers are more or less dominant. Formal knowledge structures for anatomical knowledge are important in FM-Ultranet to detect malformations of the fetus in ultrasound images as well as in the application to support radiological knee examinations. Diagnostic knowledge is modeled likewise in the knee application. Image analysis knowledge plays an important role in several, very different applications: First of all, in the system to detect early breast cancer in contrast enhanced MR sequences, described in Section 4.3. But it is also momentous in a system to reconstruct and measure aortic aneurysms for the design of personalized endoluminal prostheses [5], and in an application to detect and quantify Neurocysticercosis in CT scans of epileptic patients [6].

Most processes in the medical domain, especially organizational processes like the administrative workflow, are highly flexible and a static and unchangeable definition is inoperative. The next step will be to use the dynamic methods developed for the image analysis processes to represent the medical guidelines and organizational processes. The combination of the two key-technologies "knowledge-based configuration" and "case-based reasoning" will be developed and tailored to handle this type of processes.

6. References


