Structured radiological reporting system

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Abstract. Design and implementation of a system that can be used by radiologists to create structured radiological reports. The system uses sets of standardized, frequently used phrases to: describe state of patient's body captured by other medical diagnostics methods, provide set of tools that minimize risk of mistake and increase productivity.

Keywords: structured reporting · informatics ·quality reporting · radiology · templates

1 Introduction

1.1 The Need for Medical Diagnostics

Everyday millions of physicians treat injuries and illnesses of different kids. Before a doctor can plan an individual treatment for a patient, they have to diagnose which organs are in pathological states [1]. This sometimes can be achieved by simply glancing at the body, however, there are many illnesses that require specialized set of tools and methods in order to observe which parts of patient's body are in an unwanted state. Through years of research, many different techniques were established, and a separate specialization emerged – radiology. Radiologists focus mainly on analyzing and interpreting diagnostic imagery and as a result of their work they create a document called radiological report which contains description of what can be observed in the image of patient body. Reports may contain description of state of particular organs, measurements (e.g. radius, volume, concentration of certain substances in the blood), comparison of medical condition of a patient observed at different times and description of overall state of the patient.

1.2 The State of the Art

Currently, the research is focused on finding new ways of diagnosing diseases by the use of more advanced equipment or brilliant algorithms that try to automate image analysis [2]. On the other hand, there exist initiatives that try to improve quality of the radiological reports themselves. There are groups consisting of both computer scientists and physicians that try to standardize reports, prepare checklists that require doctors to describe patients' state in particular order and create a set of phrases that will be

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understood in the same way by all physicians [3]. A lot of work has been done to provide both common medical nomenclature for medical conditions and theoretical framework to describe relations between causes and effects of patients' condition. As there are more and more methods used to diagnose, the amount of information captured increases, so the reporting methodology has to be kept up to date with the state of art. This is why a very specific field – Structural Reporting (SR) emerged. The basic idea is to provide a way to create radiological reports that conveys as much semantics as possible in a way that is easy to understand. One can find great ideas implemented in such standards as SNOMED SR [4] and also HL7 version 3 Clinical Document Architecture (HL7 V3 CDA). By using these standards, one can encode relations between organs and diseases (causality) in a very regular format. After encoding structure in the report, one can use algorithms to e.g. highlight what changed since last visit, look for diseases that were diagnosed in the specified time range etc. This is very difficult to achieve when reports are stored in plain text. Structural reporting focuses mainly on encoding meaning–the visual representation of resulting reports is a separate matter that is treated as an implementation detail [4]. In spite of the existence of these standards, it is almost impossible to find software that implements structural reporting techniques. One of the most important reasons is the fact that in order to understand benefits of SR, one has to acquire certain level of understanding of the typical work-flow of a radiologist. As there is huge demand for software that is much easier to understand (e.g. RIS and HIS software), most of the effort is made to implement simpler concepts.

1.3 Typical Work-Flow of a Radiologist in Poland

In order to find places where optimization of productivity could be applied, one has to get to know how a radiologist works and what are activities that waste significant amounts of time. In a medium-sized clinic, medical imagery is captured by a radiologic technologist who then uploads the data to the Picture Archiving and Communication System (PACS) and attaches identification information to the images. Next to the PACS system in most cases exists Radiology Information System (RIS) that is used by radiological staff to keep track of patients treated in the clinic. These systems are used to distribute imagery to the team of radiologists.
Imagery can be distributed in one of the following manners:

- Particular patient is always serviced by the same radiologist.
- RIS system acts as an accumulator of service requests and radiologist decides which patient they should focus on now.
- Certain types of medical examinations are always assigned to a radiologist that is specialized in describing them.

1.4 The Bad Parts of the Work-Flow

Focus on Text Rather than Semantics. It is expected that the radiologist will produce a consistent, ordered report by means of text editors. Some RIS systems provide basic text formatting functionality like italicization, underlining, but they are limited to the textual presentation of the report. There are no dedicated tools to encode relations in this representation.

Each Radiologist Has Their Own Style of Writing. Usually there are no structural expectations about the resulting report. Each radiologist can have their own style of writing, order of organs observation, text formatting. This leads to the waste of time as people who read the report have to make some effort to infer the meaning from plaintext.

Selective Description. It is very frequent that radiologists include in the report only things that they consider bad for the patient. This makes the report more goal-oriented, but it means that it is useless to get to know the overall state of patient body.

Copy-Paste. Radiologists try to solve the problem of typing on their own by creating templates that contain certain pathologies listed and what they do is execution of the commonly called ’copy-paste’ method to create report content. Sometimes they do not notice parts of copied text that are different from the actual state of the body, so the reports may contain observations that are false.

1.5 Other Ways to Create Radiological Reports

In many English-speaking countries the work-flow of a radiologist differs in the way the radiological report is generated. A radiologist may record their voice while describing the imagery vocally. The recordings are then transcribed using either speech recognition algorithms or manually by technologists. Having a good skill of typing by a radiologist is not required, only knowledge to interpret imagery is used. This approach, however, has some architectural disadvantages. More personnel are needed – technologists, who transcribe the recorded voice [9]. Also, it is difficult to make changes to what has been said. In some cases, a mistake can be made while transcribing the text [10].

1.6 Incentives for the Paper

After analyzing bad parts of the presented work-flow and general situation on the market – demand for radiological services increases but the number of radiologists appears to be constant, the author decided to design and implement a system that would be used by radiologists to encode semantics of diagnostic imagery in a form that can be easily transformed to the human readable form, analyzed by algorithms.

A primary goal is to find a solution to the problem of not satisfactory productivity of radiologists by implementing a program used to create structured radiological reports. The system should apply sets of standardized, frequently used phrases to: describe state of patient's body captured by other medical diagnostics methods and should also provide set of tools that minimize risk of mistake and allows radiologists to create reports faster.

2 Description of the proposed solution

2.1 Contextual Suggestions

The author has analyzed several hundreds of anonymized radiological reports and observed that a lot of time could be saved, if a radiologist would at any time select text fragments from a predefined set of possibilities that are appropriate to the current context. This approach can be similar to the way Integrated Development Environment (IDE) for statically typed languages (e.g. Visual Studio supporting C#) are suggesting what the programmer can write based on the namespace, class, scope they currently edit. In the case of programming languages, the problem is defined in a stricter way as languages are formally defined using grammars [11]. Radiological reports, however, are written using natural language, so there always exist some exceptions. Ideally, a radiologist would always use phrases that are well-defined in the standards, but the act of scanning long list of possibilities by a radiologist could take a lot of time making it less appealing to the practitioners.

2.2 Assumptions

After observation of actions taken by radiologists while working in environments like hospital, medium-sized clinic, independent teleradiological practice the following assumptions are suggested:

- Radiologists prefer using mouse to keyboard.
- The user interface of the program should be simple.
- Reports must be rendered in a way that allows for copying contents using clipboard as radiologists developed custom ways to save drafts of reports.
- The system should allow for exporting reports into formatted text and pdf.

2.3 Goals

- Minimize the time radiologist uses keyboard.
- Split report into structural parts that allow to express description of patient's state.
- Any fragment of template text should be editable.
- Maximize number of reports that can be generated by a radiologist in a unit of time.
- At any time allow to include custom phrases that are not defined in the template.

2.4 Proposed Reporting Ontology Based on Ideas from DICOM SR and HL7 CDA

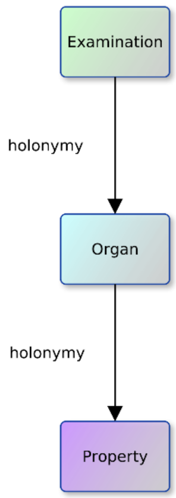

Fig. 1. Simple ontology representing entities and relationships between them encoded in reports generated using the proposed system

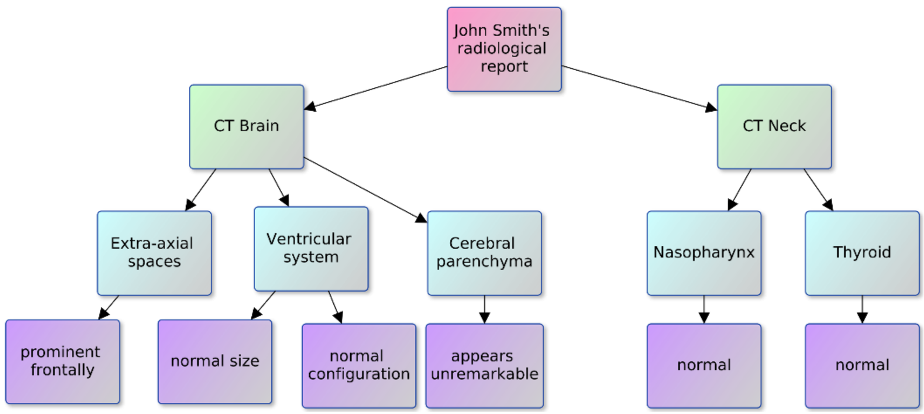

Fig. 2. Typical structure of a radiological report created using the proposed system

In order to provide context for the radiologist at any given moment, it is proposed to split report into the following nested structures:

- Examinations
- Organs
- Properties

Figure 1 shows how report structures are related by semantic relations. By using this ontology, a radiologist can create a report that is similar in structure to a tree (as it is presented in figure 2). At any given moment, the doctor modifies the tree at a single level, which allows for suggesting what are the items that can be included. The idea was taken from statically typed languages which, thanks to their strictness, allow for coding with smaller number of mistakes at the lexical level [13].

2.5 Work-flow of a radiologist who uses the proposed system

In figure 3 a typical work-flow of a radiologist is represented in the form of a flowchart.

Connotation. Besides having text, each property can have a semantical attribute called connotation. Connotation is used to highlight the impact of this property on the result of the organ and examination. This attribute can have one of three values: positive, negative and neutral.

Meta-Data. Report may also contain some meta-data which can be used to identify the patient whose body is described in it. Shape of these pieces of information strongly depends on the RIS system used in a clinic. Text segments present in meta-data have no special influence on the semantics of report, so it has no detailed description in this work. Names for ontological structures shown in Figure 1 were chosen so it is easier for radiologists to imagine what they describe, however, they can be used not strictly (e.g. in a CT scan it is possible that a radiologist adds an organ that contains details about intracranial hemorrhage which is a kind of bleeding within the skull [12] but not an organ in its very meaning). This is one of the known weak-points of the proposed ontology.

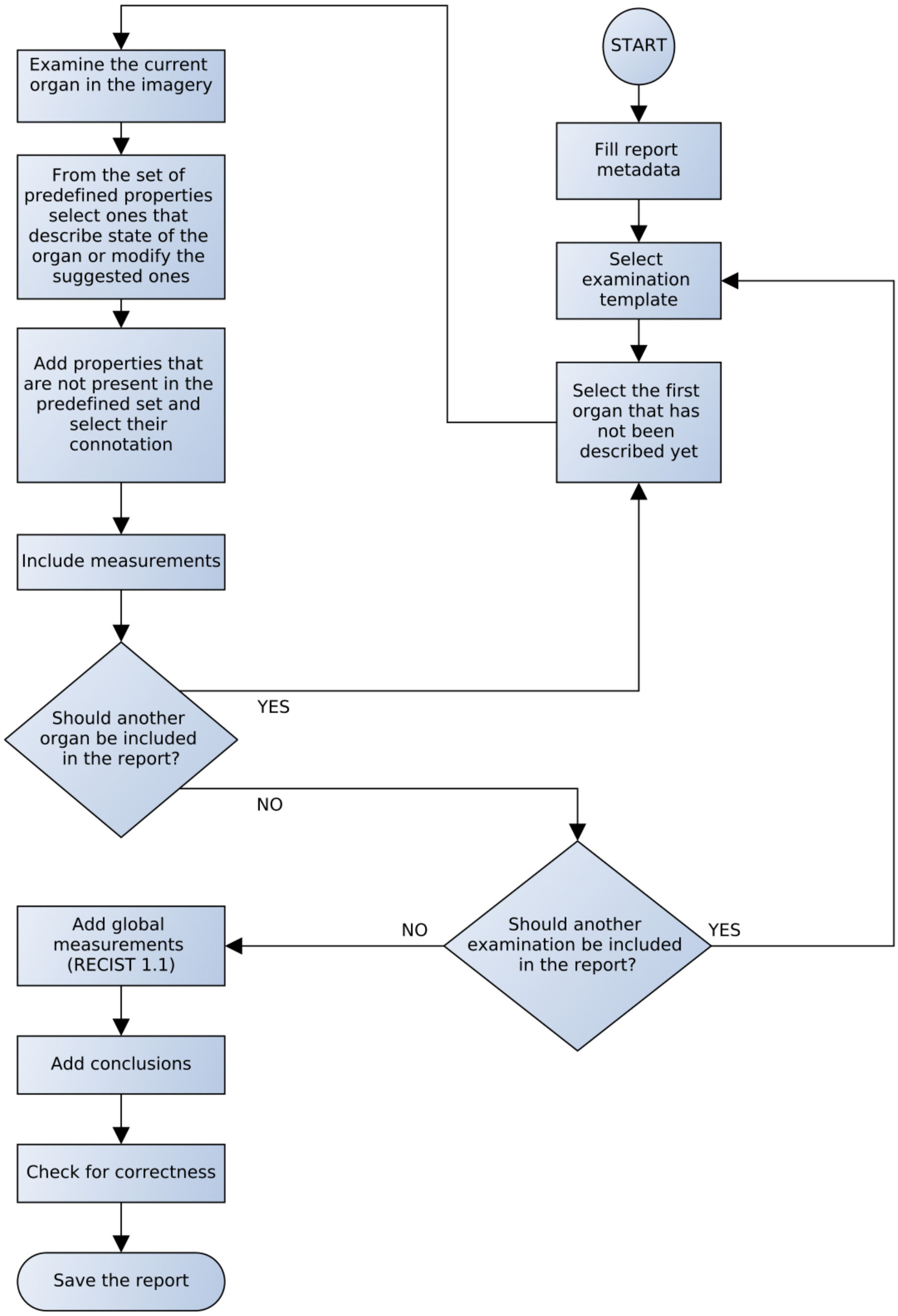

Fig. 3. Work-flow of a radiologist who uses the proposed system to create contents of a radiological report

2.6 Reporting improvements

Standardized nomenclature. There exist several attempts to standardize the language doctors use to describe precisely medical imagery. Templates created for the proposed structured reporting system can be created with the help of terminologists who specialize in systematized nomenclatures like SNOMED and LOINC to create reports what can lead to improved reporting quality as a radiologist does not have to explore huge volumes of precise textual definitions of terms used.

Reports have Ordered List of Elements. Reports created using the proposed system can be represented as trees, nested lists of items, so it is easy to spot relationships between properties and organs and differences between two reports describing one patient

Highlighting the most Important Pieces of Information. The most important pieces of information can be highlighted using proper value of connotation. When one of properties of an organ should be interpreted as a main cause of health problems it is marked as a pathology. When the report is then rendered as a document, this property can have e.g. different font color, some text-decoration element or different background color.

3 Implementation

3.1 Back-end – ASP.NET, C# and Microsoft SQL Server

The ASP.NET application is created using MVC pattern (Model-View-Controller) that is widely known for helping to create applications that consists of loosely coupled, pluggable components. Some interactions with user interface result in HTTP requests that are then mapped by the server to routes that are forwarded to Controllers. Controllers are used to react to user action, instantiate proper classes which implement application logic (they are part of the Model), feed them with sanitized and validated user input and invoke proper methods. When the results of execution are present, Controller finds a View that is expected to be used to present results to the user. View can be treated as a template for the data that is returned from Controller. It can be an ordinary HTML file with placeholders for certain pieces of information (it can also include formatting) or even JSON or XML documents that are only concerned with shape of the data, not the visual representation (e.g. formatting).

3.2 Front-end – JavaScript, AngularJS

Not all interactions with the application result in HTTP requests sent to the server, many of them are about shaping data that has already been received from the server. In order to make use of this fact main part of the application – tabs: New Report and Templates were developed as a Single Page Applications (SPA) in order to minimize the time that user has to wait between actions they take. Technologies used in these parts are JavaScript and AngularJS framework

4 Validation

4.1 Teleradiologists

Structured reporting system is used by several independent teleradiologists in Poland as their main text editing tool. They receive reporting requests with images they are asked to describe. They use several RIS systems from different vendors to store reports they generate. Most of them simply copy and paste reports from the Structured Reporting System to the RIS systems they use. As majority of the teleradiologists who have used this software are paid on the per-report basis and the average time to create a report using this program is on average three times smaller, most of the users observed significant increases in their salaries.

4.2 Hospital

Proposed system was used in hospital in Wieliszew by a group of radiologists who specialize in oncological reporting. They provided precious feedback and many of their suggestions were included in the system.

4.3 Large network of clinics

Structured reporting system is used by a large network of private clinics in Łódź. Integration with their RIS system is being developed, so the systems will cooperate with existing systems to optimize the work-flow of radiologists.

5 Conclusion

Ideas implemented in this structured reporting system are very simple from the theoretical point of view. In fact, template-based text generation existed for years and can be found in most of the programs developed hitherto. However, even such simple methods, supported with well-thought user experience design can give satisfying results. In the future, one could think about a way to generalize the reporting ontology or implement a mechanism to create custom ontologies to provide tools that would allow to encode a hierarchy of an arbitrary depth. After obtaining a well-formed tree representing relations between causes and effects, one could experiment with applying recurrent neural networks (RNNs) to automatically generate report's text from structured data source [19]. Another direction for improvement would be a natural language processing mechanism that would learn typical co-occurrences of report items and would ask the radiologist whether an unusual report content is caused by a mistake made while creating the report or a truly unusual pathology.

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