

Exemplary Design of a DICOM Structured Report Template for CBIR Integration into Radiological Routine

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ABSTRACT

The large and continuously growing amount of medical image data demands access methods with regards to content rather than simple text-based queries. The potential benefits of content-based image retrieval (CBIR) systems for computer-aided diagnosis (CAD) are evident and have been approved. Still, CBIR is not a well-established part of daily routine of radiologists. We have already presented a concept of CBIR integration for the radiology workflow in accordance with the Integrating the Healthcare Enterprise (IHE) framework. The retrieval result is composed as a Digital Imaging and Communication in Medicine (DICOM) Structured Reporting (SR) document. The use of DICOM SR provides interchange with PACS archive and image viewer. It offers the possibility of further data mining and automatic interpretation of CBIR results. However, existing standard templates do not address the domain of CBIR. We present a design of a SR template customized for CBIR. Our approach is based on the DICOM standard templates and makes use of the mammography and chest CAD SR templates. Reuse of approved SR sub-trees promises a reliable design which is further adopted to the CBIR domain. We analyze the special CBIR requirements and integrate the new concept of similar images into our template. Our approach also includes the new concept of a set of selected images for defining the processed images for CBIR. A commonly accepted pre-defined template for the presentation and exchange of results in a standardized format promotes the widespread application of CBIR in radiological routine.

Keywords: Content-based image retrieval (CBIR), Computer-aided diagnosis (CAD), DICOM Structured Reporting, Picture archiving and communication system (PACS), Integrating the Healthcare Enterprise (IHE)

1. INTRODUCTION

The benefits of content-based image retrieval (CBIR) [1, 2] for computer-aided diagnosis (CAD) have been approved and are widely accepted [3, 4]. CBIR provides the radiologist with a second opinion by supplying similar examination images linked to their corresponding report, thereby improving the diagnostic assessment. Picture archiving and communication system (PACS) integrated CBIR can be helpful to any radiologist seeking for differential diagnosis in rare disease or seldom seen patterns. But still CBIR is not an integral and established part in radiological routine.

Usually CBIR is done off-line and CBIR systems hardly supply a possibility to share CBIR results with PACS and involved physicians [5]. The way results are available and how components like PACS and associated viewers process the data is essential for the application of CBIR. One major factor for any application area integrated into radiological routine is a standardized encoding and a concerted composition of the result data. This ensures that any software processing the data has all necessary information in order to interpret the data appropriately, and this facilitates that all persons involved in the workflow have access to the data in a suitable manner.

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The use of standards like Digital Imaging and Communications in Medicine (DICOM) allows convenient and reliable interchange of information in the medical context. DICOM Structured Reporting (SR) [6] is a concept for encoding reports in a standardized format. This offers the possibility of further data mining and automatic interpretation [7]. Because of the many advantages [8, 9], the Integrating the Healthcare Enterprise (IHE) employs DICOM SR in several integration profiles [10]. DICOM SR has become a standard format for exchanging CAD results in clinical environments, e.g., for mammography, which can be stored to PACS [11, 12].

But DICOM SR does not ensure full compatibility with components storing and representing a DICOM SR. The reason is the high flexibility of SR documents. As a consequence, the interoperability of SR documents is restricted to those document structures that are known to the processing components. This is achieved by DICOM SR templates that set up allowed patterns of content and define constraints.

DICOM SR standard templates are designed for different application areas. Working group 15 concentrates on computer-aided detection templates and developed among others templates for mammography and chest CAD [13]. Other working groups established templates for procedure reports, radiation dose, general purposes etc. DICOM SR standard templates have been iterated, checked and revised several times by many people of different professional background. However, the DICOM SR standard templates do not address the CBIR domain. Our design of an SR template customized for CBIR is a proposal for filling this gap.

2. METHODS

We first analyze the CBIR process and derive the requirements of a CBIR results report. The analysis of the CBIR workflow determines the components depending on the CBIR template. Then we give a short introduction to the definition of SR templates as far as it is relevant to our application. Thereafter, based on the identified requirements and supplied with the needed tools, we establish a design appropriate for a CBIR results report.

2.1 Requirements analysis for CBIR reports

The CBIR system operates on a database of images with known features describing the images' contents. Features from an unknown image are extracted and compared to features in the database and their differences are computed. These values are sorted in ascending order. The image with the lowest difference or highest similarity value is the result image evaluated to be most similar to the input image. In the following, we consider the items that should be listed in a results report for CBIR:

Input of query. Most CBIR systems use the query by example (QBE) paradigm [3, 14]. The example image may also be a region of interest (ROI), e.g., marking a finding that should be further investigated. Sketched drafts, additional text, as well as query refinement and relevance feedback [15] need user interaction and a graphical user interface (GUI). CBIR results are displayed directly to the physician during this process. However, the CBIR task will terminate and DICOM SR may be used for the permanent representation of the final results. In diagnostic workflows, only the current examination image or the defined ROI are taken into account for CBIR input. The physician examines for example a patient's radiograph or sonogram and passes the whole image or a specified region as input to the CBIR system in order to receive similar examination cases.

Reference database. The reference database is constituted by a set of images known to the CBIR system. The images are represented by features [2] which are compared to the given input in order to find similar ones. The similarity search may be limited to a selection of images. For example, a mammogram usually is only compared to other mammograms. In this case, the reference database is limited to images from mammography.

- We suggest documenting of the reference images from which the result images have been taken. Search restrictions for the CBIR's reference database may be defined by concrete image instances or by search criteria, e.g. modality, time period. Criteria may be any information that is represented in the PACS archive, i.e. any item from the DICOM query/retrieve information model [16] which defines valid keys in DICOM C-FIND/C-MOVE. This method corresponds to the kind of selection criteria that are usually applied when a physician works with a PACS client. CBIR systems may also have other options of selection, so that search restrictions for the reference database may also be given as free text.
- In order to guarantee reproducibility the specification of the criteria has to be sufficient enough to rebuild the database. One has to consider that the reference database usually is a dynamic database that is growing with

every newly acquired examination image. Then, reproducibility is ensured by supplying the exact creation date and time when the CBIR processing started, i.e. when the actual reference set has been assembled.

CBIR results. CBIR results may be manifold when you also include the derived features describing the kind of similarity. This affiliates color histograms, textures, edge histogram descriptors etc. [2]. The features of images from the reference database are compared with the features from the query image using an appropriate distance function. The determined value of distance quantifies how similar the retrieved image to the query image is, regarding the applied feature types. Besides the result images only this evaluated similarity score that assesses the relevance of similar medical images is relevant to the physician while reading the exam.

CBIR system. The identified similar images depend on the applied CBIR algorithm. The different CBIR systems use different methods of pre-processing images, extract different features types, apply different distance functions etc. The range of the determined similarity scores also depends on the particular CBIR algorithm. There is no general normalization between the different CBIR algorithms, i.e. the computed values of different CBIR systems are not comparable. The details of the CBIR process are generally not of any interest to the radiologist. But the information about which CBIR system has been queried classifies the similarity scores into groups that can be handled appropriately.

Altogether, the following requirements are identified for a CBIR SR template:

- (R1) input image of query or ROI of query,
- (R2) set of reference images or search criteria applied to the general reference database,
- (R3) date and time of start of CBIR processing,
- (R4) result images of similarity,
- (R5) result similarity scores,
- (R6) specification of CBIR system.

2.2 Analysis of entities in workflow

The analysis of the CBIR workflow identifies the involved components and determines at which point during the processing and how the SR template will be applied. This checks the usage of the SR template from the point of the dependant systems. Figure 1 shows an overview of the entities involved in the CBIR workflow in clinical environments:

- (1) Diagnostic workstation: The physician examines medical images and data from the current patient's context is transferred to the CBIR system in order to make a CAD request.
- (2) CBIR system: The Image Retrieval in Medical Applications (IRMA) framework [17], our CBIR system of choice, processes the query input and generates a SR document from the CBIR results which is stored at PACS.
- (3) PACS: The DICOM archive holds all SR documents and delivers the requested CBIR report to the diagnostic station and the physician, who is awaiting the CBIR support for his diagnosis.

At this point, we introduced a simplification. Even nowadays not all PACS are already capable of handling SR documents comprehensively. Intermediate solutions have been proposed [18, 19], using for example a separate DICOM entity holding the SR documents and a trigger for retrieving the SR document by DICOM C-FIND command from the DICOM entity to the diagnostic workstation. Important to our analysis are the requirements for the SR document and its processing units. The components are expected to have knowledge about the structure of the SR document in the following manner, in order of their contribution to the workflow:

- CBIR system: IRMA stores its CBIR results according to the specification given by the SR template into a newly created SR document instance.
- PACS: No internal knowledge about the SR template is needed. The SR document is archived as any other SR document. The use of a standard DICOM object offers the possibility of sharing the already existing DICOM infrastructure for transfer, archival storage, etc.
- Diagnostic workstation: The SR viewer generates a suitable representation with an appropriate layout according to the SR template.

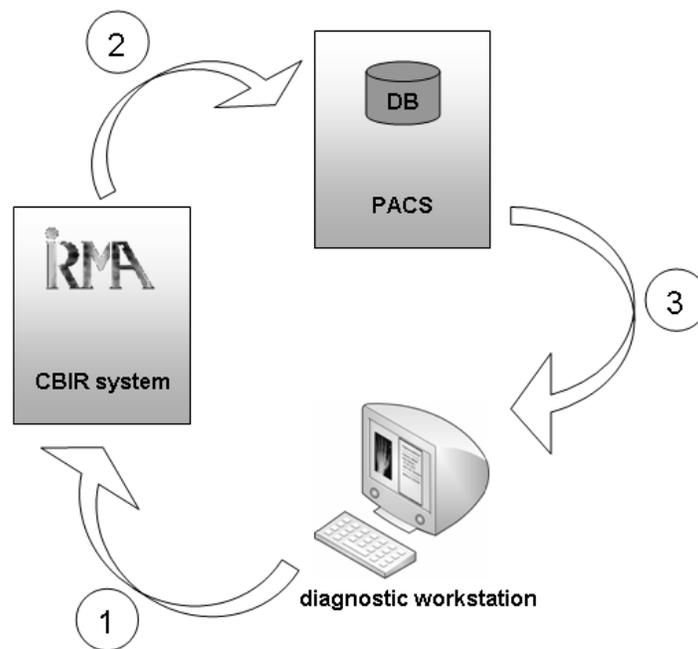


Figure 1. Overview of CBIR workflow and involved entities in clinical environments

The CBIR system and the SR viewer are those components which need to agree on the same SR template. Every CBIR system applying the same SR template ensures that its results are represented to the physician in a familiar way by the same SR viewer. This improves the workflow of a radiologist because there is no need to adapt to a new viewer with every CBIR system.

2.3 SR template specification

A DICOM SR document contains header information as known from DICOM images, augmented by a document tree that embodies the content and structure of the actual report [7]. SR templates relate to the document tree and are specified by a table [6]. Each template is assigned a unique template identifier (TID) and a name. Templates are specified in a table where each line defines a tree node and stands for a content item or indicates another template to be included. The columns have the following meaning:

- The first column is a consecutive row number.
- The 'Nesting Level' (NL) specifies indenting, by a ">", for defining sub-structures.
- 'Relationship with Source Content Item' (Rel with Parent) defines the relationship of nodes, always directing from the superior to the inferior node. If missing, then the template including this one has to specify it. DICOM SR also allows to point to an arbitrary node in the tree, called "by reference" relation in contrast to the regular "by value" relation. By reference relations are used when information is needed at different positions in the document, thereby avoiding redundancies. Listed are types of relationships defined by the standard that are used in our template:
 - HAS CONCEPT MODE: The parent node has a modification of concept,
 - CONTAINS: contains content items aggregated as a sub-structure,
 - SELECTED FROM: references an item.
- The kind of a node's information is specified by a 'Value Type' (VT), incorporating besides TEXT for arbitrary textual information for example:
 - NUM: numerical value with unit,

- IMAGE: reference to a SOP-instance of an image,
- SCOORD: list of spatial coordinates and their graphic type (circle, ellipse, point, etc.),
- CONTAINER: aggregation of content items,
- INCLUDE: another template has to be inserted.
- Every node is assigned a ‘Concept Name’ specifying the purpose of the information item. The concept name has to be uniquely declared by a code. ‘Enumerated Value’ (EV) specifies that the given code value is the only valid one, whereas “DT” (Defined Term) also allows other values.
- ‘Value Multiplicity’ (VM) defines the frequency of a content item.
- ‘Requirement Type’ (RT) specifies if an entry is mandatory (“M”), optional (“U” for user option) or depending on certain conditions (“MC”, “UC”).
- The column ‘Condition’ contains conditions for frequency or value type and is given in pseudo-formal notation.

2.4 Design of CBIR SR template

The standard templates have been approved what motivated us to reuse them as much as possible. We concentrated on the mammography CAD SR (TID 4000) and chest CAD SR (TID 4100) [6] because of their close relation to CBIR applied for CAD. Our proposal of CBIR SR template differs mainly in the following items:

- The Image Library as defined by the included TID 4020 identifies each image referenced in either the algorithm summaries or CAD results. CBIR may operate on the whole PACS image archive and the list of references will explode. We propose a new template <CBIR_11> that will alternatively hold criteria that unambiguously define the CBIR reference database (R2).
- The integrated templates TID 4015 and TID 4016 sum up the different performed algorithms. The typical application of CBIR for CAD does not include results of different CBIR systems, so this does not apply.
- TID 4017 and 4018 identify the images and/or ROI on which the detection and analysis have been performed. References to the Image Library are allowed. The specification of a result set containing the identified similar images is not provided. For the context of CBIR we suggest for our new template named <CBIR_12> to collect all result images that the CBIR system has evaluated to be similar to the query image (R4).
- Findings are summarized separately from the description of the performed CAD algorithm. <CBIR_12> holds all evaluated similar images. We favor to also include CBIR further results right away with each single image. Typically CBIR systems evaluate the similarity score of a found similar image (R5).

There are also other standard templates that we have considered:

- The “Basic Diagnostic Imaging Report” with TID 2000 must not be included nor extended. It delivers no description of the CBIR algorithm. The only data structure capable of holding the query image, the result set and the similarity scores is “Diagnostic Imaging Report Elements”. But its semantic meaning is not clear for our use of CBIR.
- TID 4014 describes the CAD image quality. Meant is the quality of the image itself, like image noise for example. A quality in terms of similarity to the query image can not be expressed.

3. RESULTS

3.1 CBIR SR template

We name our CBIR SR template TID CBIR_10 (Table 1), not to confuse it with the DICOM standard templates but just for simplification. The main template CBIR_10 includes besides language information the query image (row 3) or the query ROI (row 4) respectively. The query image is of value type “IMAGE” and the ROI of value type “SCOORD”. The image from which the ROI is taken has to be specified in row 5. CBIR_10 further includes the templates CBIR_11 and CBIR_12 specifying the reference database (row 6) and the CBIR execution (row 7). The template CBIR_11 (Table 2) specifies in row 2 the date and time of start of processing. In the standard DICOM header, there is an entry for the

creation time of the SR document. We decided to include an extra item because of the time difference between the assembling of the reference database and the writing of the SR document. In row (3), CBIR_11 alternatively holds any number of images used for image retrieval or the search criteria that made up the image database (row 4). Search criteria are given as DICOM attribute tags, divided into group (row 5) and element number (row 6). Because of leading zeroes in the attribute tags the value type is TEXT. Their corresponding search key value is given in row 7. The semantic is analog to C-FIND, interpreting each pair of tag and value as an equality and combining pairs in a Boolean AND expression. Alternatively, a free text specified search string may be given (row 8). CBIR_12 (Table 3) includes the description of the performed algorithm (row 2). The standard template TID 4019 "Algorithm Identification" describes the performed CBIR algorithm and is included. The CBIR results are given as a set (row 3) containing identified similar images (row 4) or ROI (row 5). If a ROI has been specified, the image from which it is taken from has to be listed in row 6. Row 7 contains their similarity scores.

Table 1. SR Template *CBIR DOCUMENT ROOT*

TID CBIR_10, CBIR DOCUMENT ROOT, Type: Non-Extensible

	NL	Rel with Parent	VT	Concept Name	VM	RT	Condition
1			CONTAINER	EV(, , "CBIR Report")	1	M	
2	>	HAS CONCEPT MOD	INCLUDE	DTID(1204) "Language of Content Item and Descendant"	1	M	
3	>	CONTAINS	IMAGE		1	MC	XOR rows 3, 4
4	>	CONTAINS	SCoord	EV(111030, DCM, "Image Region")	1	MC	
5	>>	SELECTED FROM	IMAGE		1	M	
6	>	CONTAINS	INCLUDE	DTID(CBIR_11) "CBIR Database"	1	M	
7	>	CONTAINS	INCLUDE	DTID(CBIR_12) "CBIR Execution"	1	M	

Table 2. SR Template *CBIR DATABASE*

TID CBIR_11, CBIR DATABASE, Type: Extensible

	NL	Rel with Parent	VT	Concept Name	VM	RT	Condition
1			CONTAINER	EV(, , "CBIR Database")	1	M	
2		CONTAINS	DATETIME	EV(, , "Time of Setup")	1	M	
3	>	CONTAINS	IMAGE		1-n	MC	XOR rows 2, 3, 7
4	>	CONTAINS	CONTAINER	EV(, , "Search Criteria")	1-n	MC	
5	>>	CONTAINS	TEXT	EV(, , "DICOM Tag Group Number")	1	MC	
6	>>	CONTAINS	TEXT	EV(, , "DICOM Tag Element Number")	1	MC	
7	>>	CONTAINS	TEXT	EV(, , "Key Value")	1	MC	
8	>	CONTAINS	TEXT	EV(, , "Search Clause")	1	MC	

Our SR template design with CBIR_10 as our root template fulfills the identified requirements in the following way:

- (R1) The main template CBIR_10 (Table 1) includes the query image (row 3) or the query ROI (row 4) respectively.
- (R2) CBIR_11 (Table 2) specifies the set of images the CBIR system has processed.
- (R3) CBIR_11 (Table 2) holds an entry for the time and date when the reference database has been assembled.
- (R4) CBIR_12 (Table 3) lists the result images in row 4 and alternatively the result ROI in row 5.
- (R5) CBIR_12 (Table 3) has an entry in row 7 containing the similarity score.
- (R6) The standard template TID 4019 is included in CBIR_12 (Table 3) in row 2 to specify the CBIR system.

Table 3. SR Template *CBIR EXECUTION*

TID CBIR_12, CBIR EXECUTION, Type: Extensible

	NL	Rel with Parent	VT	Concept Name	VM	RT	Condition
1			CONTAINER	EV(, , "CBIR Execution")	1	M	
2	>	CONTAINS	INCLUDE	DTID(4019) "CAD Algorithm Identification"	1	M	
3	>	CONTAINS	CONTAINER	EV(, , "Scored Image")	1-n		
4	>>	CONTAINS	IMAGE	EV(, , "Image")	1	MC	XOR rows 4, 5
5	>>	CONTAINS	SCoord	EV(111030, DCM, "Image Region")	1	MC	
6	>>>	SELECTED FROM	IMAGE		1	M	
7	>>	CONTAINS	NUM	EV(, , "Similarity Score")	1	M	

The templates that comprise our CBIR SR template are aggregated as shown in Figure 2.

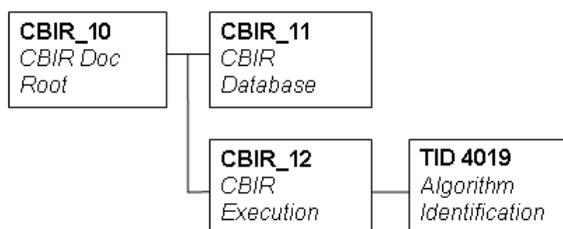


Figure 2: Composition of CBIR SR template CBIR_10

3.2 CBIR SR document representation

We applied the template to the IRMA framework [14] and produced CBIR output according to our SR template. We

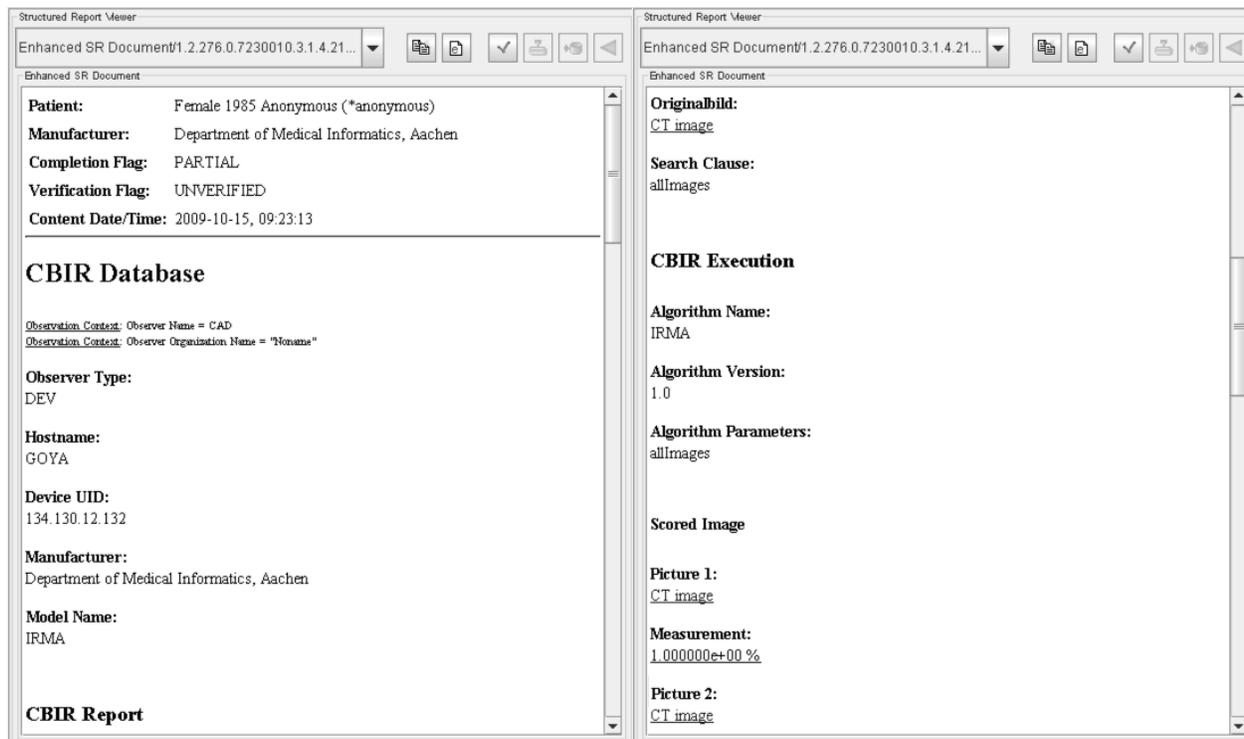


Figure 3. Exemplary CBIR SR document representation in DICOMscope [20]

made use of the DICOM toolkit “DCMTK” [20] for the implementation of DICOM commands. The DCMTK module “dcmshr” offers methods for the access, reading, creation, writing, modification, printing and viewing of SR documents. The CBIR results could be stored to a DICOM archive and be viewed in a DICOM viewer. Our viewer of choice was OFFIS DICOMscope [20]. As most of the SR viewers DICOMscope produces HTML output [21]. The layout is kept generally (Figure 3). A conversion into XML format offers the adapted representation by using XSLT and CSS.

Figure 4 shows preliminary results from our IRMACON viewer. The IRMACON viewer is adapted for representing CBIR results based on our CBIR SR template. The advantage in contrast to DICOMscope or any general SR viewer is that we utilized our knowledge about the workflow and setting in which the CBIR results are used. In the top area the query image is represented. Below, the determined similar images are given in descending order of similarity. Each downscaled image can be increased by double click.

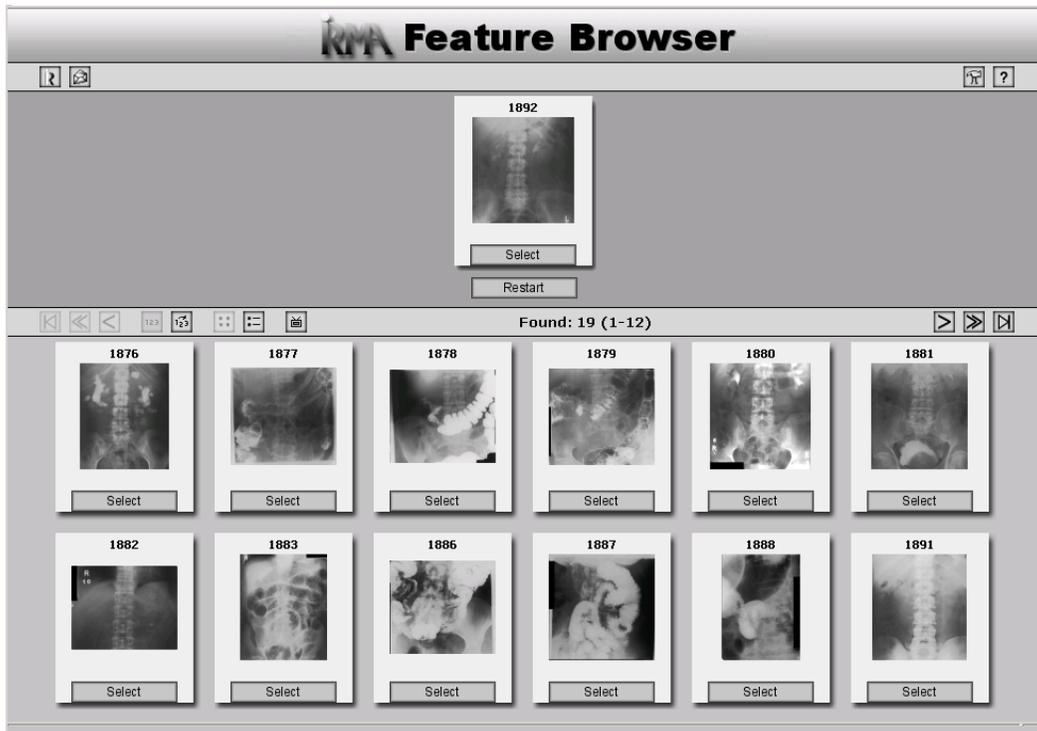


Figure 4. Exemplary output of CBIR results in the IRMACON browser

4. DISCUSSION

We provide a SR template for the usage of CBIR results in clinical environments that covers typical CBIR systems and the requirements determined by the radiological workflow. Results as they are usually generated by CBIR systems together with information needed to interpret CBIR results appropriately are contained in our proposal. The new CBIR SR template makes use of DICOM standard templates which provide a proved and stable basis.

DICOM is a standard format and communication protocol in radiology. Modern medical systems in clinical environments usually support DICOM. Hence, the standard encoding as DICOM SR guarantees that systems in radiology are capable of accessing, transferring and storing the CBIR report.

DICOM SR is a mean of encoding structured information. It does not provide any specification regarding the layout of the representation. DICOM guarantees functional interoperability, but no semantic interoperability. General SR viewers know how to extract the content from a SR document and generate an output human readable. Preconfigured SR viewers, as illustrated exemplarily by our IRMACON viewer, improve the representation by arranging the content items in a suitable way so that the physician obtains a quick and comprehensive perception. This is facilitated by the knowledge about CBIR and its application for CAD on the viewer’s side. Alternative file formats like Portable Document Format

(PDF) already include layout directives. PDF is widely-used and most diagnostic workstations are capable of displaying CBIR reports in PDF format, particularly since DICOM offers encapsulation of PDF documents. However, the drawback is the missing possibility of automatic processing. Because of the structured composition of DICOM SR documents automatic analysis and interpretation are feasible [7]. This is also supported by another standard format in clinical environments, Health Level Seven (HL7) Clinical Document Architecture (CDA) [22]. CDA documents are encoded in XML format. Layout formatting is realized by XSLT for example. Hence, the responsibility of a meaningful representation still lies with the viewer. However, DICOM is the more established standard in radiology and PACS are based on DICOM. Therefore, we conclude that DICOM SR is the preferred encoding for CBIR results.

5. CONCLUSIONS

Using the introduced CBIR DICOM SR template, a reliable and easy exchange of CBIR results is established, thus resulting in a more convenient integration into clinical environments. The CBIR SR template fills a gap in the standard SR templates which do not account for the application of CBIR in CAD.

The CBIR SR template offers a possibility for CBIR being applied in IHE profiles like the 'Post-Processing Workflow' (PPW) [10], further promoting standardized and improved workflows. With the proposal of the CBIR SR template we foster the widespread application of CBIR in daily radiological routine and add to the improvement of medical diagnosis.

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