journal homepage: www.intl.elsevierhealth.com/journals/cmpb

Generic integration of content-based image retrieval in computer-aided diagnosis

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ARTICLE INFO

Article history:
Received 22 November 2010
Received in revised form 4 July 2011
Accepted 29 August 2011

Keywords:
Content-based image retrieval (CBIR)
Computer-assisted diagnosis
Computer-aided diagnosis
Systems integration
Picture archiving and communication system (PACS (Radiology))
Digital Imaging and Communications in Medicine (DICOM)
Health Level 7 (HL7)

ABSTRACT

Content-based image retrieval (CBIR) offers approved benefits for computer-aided diagnosis (CAD), but is still not well established in radiological routine yet. An essential factor is the integration gap between CBIR systems and clinical information systems. The international initiative Integrating the Healthcare Enterprise (IHE) aims at improving interoperability of medical computer systems. We took into account deficiencies in IHE compliance of current picture archiving and communication systems (PACS), and developed an intermediate integration scheme based on the IHE post-processing workflow integration profile (PWF) adapted to CBIR in CAD. The Image Retrieval in Medical Applications (IRMA) framework was used to apply our integration scheme exemplarily, resulting in the application called IRMAcon. The novel IRMAcon scheme provides a generic, convenient and reliable integration of CBIR systems into clinical systems and workflows. Based on the IHE PWF and designed to grow at a pace with the IHE compliance of the particular PACS, it provides sustainability and fosters CBIR in CAD.

1. Introduction

In diagnostic decision making, a radiologist typically applies conclusions from closed medical cases. A large and ever-growing number of digital images demands efficient and convenient access methods for identifying relevant patient cases. Picture archiving and communication systems (PACS) commonly used in hospitals access the Digital Imaging and Communications in Medicine (DICOM) [1,2] archive solely textually. This often yields incomplete retrieval due to ambiguous or missing descriptions in the headers of the examination files [3]. Furthermore, natural language of diagnostic reports does not reflect exact appearance of a pathological phenomenon or the relationship between relevant structures, etc. [4,5].

Content-based image retrieval (CBIR) detects images in a large database using automatically extracted features that specify the images' visual content [6,7]. Taking benefit from the visual information contained in the images, CBIR identifies similar past examinations thereby providing the physician with a second opinion in the context of computer-aided diagnosis (CAD). Quality and efficiency of clinical care are improved by CBIR [8], and CAD gains from the accredited high benefits of CBIR [9–11]. There are promising CBIR-based CAD

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doi:10.1016/j.cmpb.2011.08.010

Abbreviations

AET	Application Entity Title
API	Application Programming Interface
CAD	Computer-Aided Diagnosis/Detection
CADx	Computer-Aided Diagnosis
CADe	Computer-Aided Detection
CBIR	Content-Based Image Retrieval
CSS	Cascading Style Sheets
DICOM	Digital Imaging and Communications in Medicine
EC	Evidence Creator Actor (IHE)
GPWL	General Purpose Work List
HIS	Hospital Information System
HL7	Health Level 7
HTML	Hypertext Markup Language
ID	Image Display Actor (IHE)
IHE	Integrating the Healthcare Enterprise
IM/IA	Image Manager/Image Archive Actor (IHE)
IRMA	Image Retrieval in Medical Applications
PACS	Picture Archiving and Communication System
PPM	Post-Processing Manager Actor (IHE)
PWF	Post-processing Workflow Integration Profile
RIS	Radiology Information System
WSDL	Web Services Definition Language
XML	Extended Markup Language
XSL	Extensible Stylesheet Language
XSLT	Extensible Stylesheet Language Transformation

systems, mostly specialized on a particular application, e.g., lung cancer [12], mammography [13], chest computed tomography (CT) [14], or bone age assessment [15]. However, CBIR is not established in clinical practice, yet.

The diversity of installed hospital information systems (HIS), radiology information systems (RIS) and PACS impairs information exchange and interoperability [16], due to varying application programming interfaces (API) and different implementations of standards. For instance, DICOM as well as Health Level 7 (HL7) [17] provide technical interoperability but leave many options for implementation. Hence, CAD vendors prefer stand-alone applications, which are independent from existing clinical information systems [18]. As a result, CBIR systems usually operate off-line and neither share results with PACS nor other physicians involved in the diagnostic pathway [19]. However, becoming part of the IT landscape in radiology will help to establish CBIR in clinical practice [8]. This paper presents a generic scheme that aims at filling this integration gap.

2. Background

Existing approaches of CBIR integration into clinical environments are twofold:

(i) **Vendor-specific embedding into PACS**: COBRA [20] embeds CBIR extensions into PACS components such as the database retrieval engine and the query interface. In cbPACS [21], images are supported as a native data type, seamlessly integrating syntactical constructions to express similarity predicates to the existing SQL syntax. The similarity retrieval engine (SIREN) is based on this concept [22]. However, such approaches engage in the internal structure of the particular PACS and, therefore, impede general integration of CBIR and PACS for arbitrary systems.

(ii) **System-specific embedding into workflow**: Mostly, a single procedure step is defined on a lower level of information processing calling a particular CBIR system and specifying the data exchange of the specific CBIR system. Elter et al. [23] have suggested a fixed sequence of DICOM and HL7 commands integrating CBIR with radiological workflow. However, a convenient transfer between CBIR and PACS with different interfaces is not supported.

The *Integrating the Healthcare Enterprise* (IHE) [24] is a global consortium of healthcare professionals from industry and research that has been founded to improve interoperability between medical IT-components. While not defining new standards, this initiative provides an aligned and balanced Technical Framework using existing standards like DICOM and HL7. The IHE framework accumulates requirements in use cases and defines guidelines, in IHE terminology called 'integration profiles', which represent scenarios and prescribe how standards shall be applied [25].

Noteworthy is the concept of CAD-PACS [26], which aims at generic integrating of CAD into clinical practice aligned to IHE integration profiles. Based on the CAD-PACS toolkit, Le et al. have developed DICOM-CAD-IHE 2nd Edition, a migration concept that implements those parts related to the CAD side of the IHE 'Post-Processing Workflow' integration profile (PWF). DICOM-CAD-IHE 3rd Edition addresses the IHE compliance of current PACS [27]. Inter alia, it eliminates workflow management functionalities of the PWF. Furthermore, their concept does not address CBIR systems.

We consider scheduling and workflow management as necessary and reasonable for the application of CBIR systems in clinical practice, which seamlessly integrate in the radiological workflow. Commonly, scheduling is used with imaging modalities to acquire examination data. It simplifies and regulates the workflow and yields improved processes. Therefore, we plead for a CBIR integration scheme including scheduling of CBIR tasks.

In this paper, we present a generic concept of integrating CBIR systems used for CAD in accordance with the accredited IHE framework. It is based on the IHE PWF that defines responsibilities as well as standardized communication and utilizes DICOM Structured Reporting (DICOM SR) [28] for persistently preparing CBIR results. Because of the aforementioned insufficient IHE compliance of current PACS, RIS and HIS, we suggest an intermediate scheme enabling gradual transition until fully compliant systems are available and operated routinely. In contrast to existing integration schemes [20–24], we aim at supporting all functionalities contained in the PWF.

3. Methods

3.1. *IHE 'Post-Processing Workflow' integration profile*

IHE profiles are defined by actors and transactions. Actors represent components or modules that occur in medical

Table 1 – Overview of the actors used in the PWF adapted to CBIR.

Actor	Description
Evidence Creator (EC)	The EC actor creates evidence objects (images, documents, etc.) intended to serve diagnostic interpretation. It stands for the particular post-processing or CBIR system.
Post-Processing Manager (PPM)	Central role in the PWF profile has the work list holding work items, e.g. requests to a CBIR system. The list is maintained by the PPM actor, who schedules work list items, provides items to clients and updates their status. The PPM typically resides on PACS where it provides central scheduling.
Image Manager/Image Archive (IM/IA)	The IM/IA actor is responsible for managing PACS' data including provision of information and long-term storage. Because of its crucial role in PACS operation, the IM/IA is usually located on PACS.
Image Display (ID)	The ID actor's task is to provide the presentation of images and evidence objects. The ID actor is mostly situated on the PACS client, where it generates the requested output. Depending on the implementation, parts of the ID may also be installed on the PACS server.

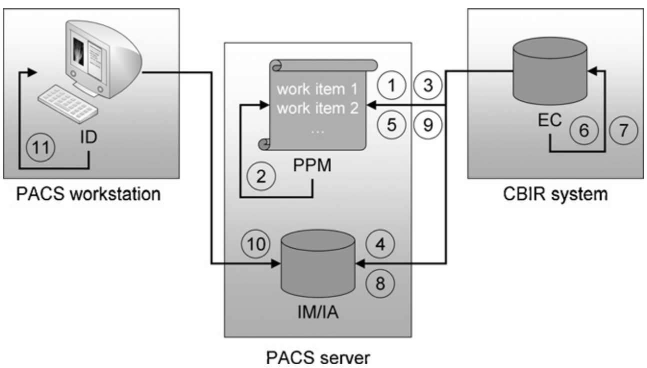

Fig. 1 – IHE compliant workflow of the PWF for CAD by a CBIR system. The numbers refer to actions described in Table 2; the arrows indicate direction of actions and communication between the IHE actors.

Table 2 – Steps in the PWF adapted to CBIR.

Step	Action
1	EC regularly checks for new CBIR work items at the PPM.
2	PPM adds a CBIR work item to the work list as soon as a new image is available.
3	EC claims the new work item the next time of checking.
4	EC retrieves images referred to in the work item from the IM/IA.
5	EC informs the PPM that the claimed work item is now 'in progress'.
6	EC performs the CBIR processing.
7	EC creates a DICOM SR document containing the CBIR results and the reference to the original examination image.
8	EC stores it in the archive of the IM/IA.
9	EC informs the PPM about the completion of its work item.
10	ID retrieves the DICOM SR document containing the CBIR results.
11	ID presents the CBIR results to the radiologist.

information systems and hold a predefined role. Transactions define communication and information exchange between actors.

Scheduled post-processing is addressed by the IHE PWF offering the following advantages:

(i) scheduling, distribution, and tracking of tasks using standardized mechanisms;
(ii) linkage of post-processing results with corresponding images and order;
(iii) management of subsequent workflow steps, e.g. reporting, billing.

In particular, we modeled the Evidence Creator (EC), the Post-Processing Manager (PPM), the Image Manager/Image Archive (IM/IA), and the Image Display (ID) (Table 1). The workflow defined by the PWF is adapted to CBIR systems. It is initiated by EC checking the work list for new CBIR items, and ends with IDs presenting the CBIR results to the radiologists (Fig. 1 and Table 2).

Due to the aforementioned limited IHE compliance of current PACS, the original PWF cannot be established. Therefore, the integration of CBIR is proposed using an intermediate stage.

3.2. *CBIR intermediate integration scheme*

At the intermediate stage, tasks concerning IHE actors and communication expected on the PACS side are substituted by components implemented independently from PACS, as software modules residing on a different workstation. Since various PACS differ in PWF implementation, a modular design is developed that allows convenient exchange of single actor modules by PACS actors when available. The intermediate integration scheme differs from the original PWF in the following aspects:

(i) **PPM module**: The CBIR scheduling is realized by a PPM component that is independent from PACS and resides on the CBIR system.
(ii) **SR archival**: Our concept rolls out the management of the DICOM SR documents as part of the responsibility of the IM/IA to a dedicated DICOM SR-IM/IA actor on the CBIR system.
(iii) **ID module**: Management and interpretation of the CBIR results contained in DICOM SR documents is performed by a special ID component on the CBIR system. The web browser on the PACS workstation is used avoiding any extra installation.

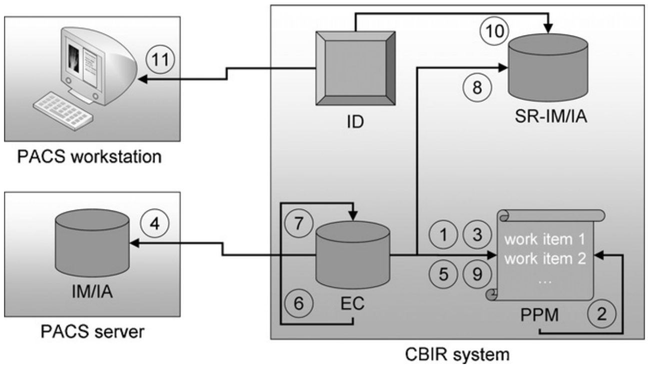

Fig. 2 – CBIR workflow at the intermediate stage; Sequence of steps remains unchanged (Table 2), IHE components under PACS responsibility are transferred to the CBIR system; Arrows illustrate direction of actions and communication between actors.

By shifting critical PACS actor modules to the CBIR system, the intermediate stage facilitates that the workflow does not deviate from the original PWF (Fig. 2).

3.3. *Scheduling of CBIR tasks*

CBIR systems can be integrated into the radiological workflow by means of scheduling or by calling the CBIR application directly from the diagnostic workstation. The unscheduled solution may be sufficient in settings of only a few systems and persons. Problems arise, for example, when the CBIR system has to manage several calls at the same time. Concurrently running tasks usually cause a decrease in performance. To manage incoming tasks in a queue requires an extension to each single CBIR system. Thus, the proposed CBIR integration scheme applies central scheduling [29].

With the general purpose work list (GPWL) [30], DICOM offers a standardized mean for implementing the post-processing work list. Queries of work items are performed by DICOM C-FIND commands. The PWF profile provides three kinds of queries:

(i) **Patient-oriented**: The information on the patient of the processed examination image is entered into the work item and can be used for retrieval. Because CBIR-based CAD is usually performed irrespective of the particular patient, we do not further consider this type of query.
(ii) **Class-oriented**: In order to balance the work load, the CBIR system can be installed independently on several machines. Work items can be dedicated to a whole class or group of machines, and any EC from this class is allowed to query and claim such a work item.
(iii) **Station-oriented**: The station-oriented query allows the retrieval of work items that are registered for a particular machine. In cases where different single CAD systems have been installed, the station-oriented query allows distinguishing particular EC actors.

3.4. *CBIR workflow initialization*

According to the PWF profile, the PPM has some internal logic to check for newly available images at PACS (IM/IA), and creates a work item if post-processing is appropriate. The internal logic might be a set of adapted rules. For instance, in CBIR-based bone age assessment, it automatically creates a CBIR post-processing work item for each newly acquired hand radiograph. CBIR results are generated before the radiologist starts with decision making. Thus, the radiologist is supported appropriately in frequent and time-consuming tasks. The automatic post-processing is also advantageous if response times of the CBIR system are inacceptable. If the radiologist uses the CBIR's results only in rare cases, an obligatory CBIR post-processing would unnecessarily allocate too many resources, e.g., memory, storage, or computing time. Thus, we suggest two alternative initializations of the CBIR workflow:

(i) **Automatic initialization**: Compliant with the PWF profile, the PPM automatically applies predefined rules, which determine the creation of work items. This is appropriate for classes of images that are processed unconditionally by the CBIR system. An example application is bone age assessment from hand radiographs, where CBIR identifies reference images with known bone age similar to the current examination [15].
(ii) **Manual initialization**: The CBIR work item is created on demand. This is favored if CBIR is requested only in selected cases. The workflow is triggered by the PACS user, e.g. using a special plug-in on the PACS client. The generation of a work item ensures scheduling and maintains the regular workflow.

3.5. *Standardized exchange of CBIR results*

The use of standards like DICOM allows convenient and reliable data interchange in clinical practice. DICOM SR [31] is a standardized method and means of encoding structured information. Because of numerous advantages [32,33], DICOM SR has been employed in several IHE integration profiles [34] and is commonly used for encoding CAD results in clinical applications, e.g., mammography [35,36].

The processing components have to agree on the composition of a DICOM SR document in order to assure full compatibility when creating, interpreting, and representing the SR document. This is achieved by DICOM SR templates setting up allowed patterns of content and defining constraints. Templates facilitate an automated processing and interpretation of SR documents [37]. SR templates enable convenient exchange of data during the workflow. However, existing DICOM standard templates do not address the domain of CBIR. To overcome these drawbacks, DICOM SR templates have been customized for CBIR [38]. This approach is based on approved parts of the DICOM standard templates for mammography and chest CAD. Special CBIR requirements such as the concept of similar images have been incorporated into the CBIR SR template.

3.6. Representation of CBIR results for CAD

Content and layout of the radiology report substantially impact the radiologist's efficiency [39–41]. On this background, we determined the following requirements for a viewer of CBIR-CAD encoded as a SR document:

(i) **Integration of related diagnostic findings**
Diagnostic findings related to medical examinations deliver essential information to the radiologist. Typically, these findings are generated at different departments, e.g. pathology, radiology, or laboratory. In further support of the radiologist's diagnosis, our integration scheme presents CBIR results together with associated diagnostic findings.
Depending on the particular HIS/RIS configuration, findings are usually archived in a central data repository or are managed centrally by a so-called 'mediator' collecting requested data from clinical repositories [41]. In both settings, data access is managed and provided regularly by HIS, and communication is based on HL7. Accessing diagnostic findings related to a DICOM image requires a mapping of unique identifiers between DICOM and HL7 domains. Because of a missing standard, we have defined a mapping based on generally applied guidelines [34,42] (Table 3). HL7 messages are constructed by mandatory and optional segments and fields, and vary depending on the particular message type. Each message begins with a header segment, introduced by the keyword "MSH". A HL7 query message is further composed of a query definition ("QRD") and a query filter ("QRF"). Diagnostic findings are requested by message type QRYˆR02, "Query For Results Of Observation", which are returned by message type ORFˆR04.

(ii) **Combined viewer**
Common SR viewers do not support direct access to diagnostic findings, and diagnostic viewers do not support the representation of related SR documents, at least they normally do not provide a presentation showing their interrelation and their common context. In order to close these gaps, a combined viewer for CBIR DICOM SR and associated diagnostic findings was developed [43].
The DICOM SR format encodes semantics but no layout directives. Existing SR viewers, e.g. [44,45], convert the SR document into HTML and produce a predominantly textual output containing DICOM image references. Information is arranged according to the internal SR structure but disregarding their meaning. The layout is generic and therefore not adjusted to the special needs of CBIR for CAD. In order to define a suitable layout, SR documents converted into HTML or XML format may be applied to *Cascading Style Sheets* (CSS) or *Extensible Stylesheet Language* (XSL), respectively [33].
Converting DICOM SR directly into a format suitable for representation complicates the integration of diagnostic findings. Thus, we convert the SR document into XML format to extract the content and to generate an output in HTML format, which includes examination images and links to diagnostic findings. This method offers flexible composition and layout of information.

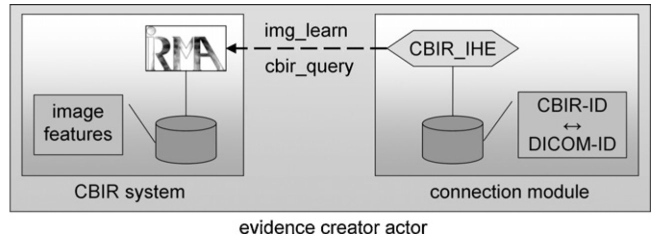

Fig. 3 – Splitting of the EC actor into CBIR system (IRMA) and general connection module (CBIR_IHE) using a SOAP interface ("img_learn", "cbir_query") for communication and a matching database for mapping image IDs of DICOM and IRMA.

4. Results

A prototypal system has been implemented to prove the presented IHE intermediate integration scheme for CBIR. It has been applied to the Image Retrieval in Medical Applications (IRMA) framework [46,47], resulting in the integration system 'IRMAcon'. The IRMA project aims at developing and implementing CBIR methods for medical applications on a radiological image archive, which currently contains more than 250,000 images. Furthermore, we opted for iSite PACS from Philips Healthcare [48] as it is employed at the University Hospital Aachen with a test server granting access for research.

4.1. Management of work list (PPM actor)

Our system makes use of the IHE PPM component included in the dcm4chee PACS [49], which are adapted for CBIR-CAD [29]. DICOM objects in dcm4chee are represented internally in XML format. Information extracted from the examination object is transformed into the corresponding work item using XSLT. The work item's configuration used in the IRMA scenario defines the initial status and priority of a newly created work item as "SCHEDULED" and "MEDIUM". The unique DICOM identifier of the examination image is copied into the 'Input Information Sequence' of the work item for later referral. The context is defined in the 'Scheduled Workitem Code Sequence' as "Computer Aided Diagnosis". In dcm4chee, the creation of new work items is triggered by a rule-based work list maintainer. Rules may be adjusted individually for each imaging modality. The dcm4chee PPM is configured to generate work items as soon as new images have been acquired.

4.2. Management of CBIR system (EC actor)

We separated IRMA from a general adapter module named "CBIR_IHE" that connects CBIR to clinical systems according to the IHE intermediate integration stage (Fig. 3). This extends the design of the original PWF where the CAD post-processing system forms the EC actor. In IRMAcon, the EC actor is comprised of CBIR_IHE and IRMA. The CBIR_IHE adapter is aligned

Table 3 – Mapping of DICOM and HL7 identifiers in the combined CBIR viewer.

Identifier	DICOM	HL7
Order	(0008,0050) Accession Number	OBR-3 Filler Order Number
Patient	(0010,0020) Patient ID	PID-3 Patient ID

to the corresponding design pattern in software engineering for wrapping of interfaces [50]. According to the design pattern, the algorithm is separated from its embedding into PACS. Then, an arbitrary CBIR system is connected simply by modifying the CBIR_IHE module.

The interaction of IRMA and CBIR_IHE uses a Simple Object Access Protocol (SOAP) interface with the following functionalities (Fig. 3):

(i) **img_learn**: IRMA is told to learn a transferred image, i.e. extracting, storing, and indexing features enabling CBIR queries. Beforehand, CBIR_IHE converts the DICOM image file into a graphic format that is appropriate for IRMA, e.g. PNG. IRMA returns the unique identifier (CBIR-ID) assigned to the image.

(ii) **cbir_query**: IRMA is given the CBIR-ID of a query image and returns a list containing CBIR-IDs of identified similar images from IRMAs feature database.

The CBIR_IHE encodes CBIR results as DICOM SR documents, taking benefit from the already existing DICOM infrastructure of a PACS environment for storage and retrieval. CBIR_IHE is responsible for creating and storing the SR document at the IM/IA actor. A matching database is used to map DICOM- and CBIR-IDs. Thus, CBIR_IHE provides all DICOM connectivity needed for integrating IRMA with clinical information systems.

CBIR_IHE, as part of the EC, is implemented as a standalone application that periodically checks for new work items at the PPM. It provides a configuration file specifying the DICOM logical addresses or Application Entity Titles (AET) of the used DICOM services and the time period between successive queries, etc.

4.3. *Management of results' representation (ID actor)*

CBIR-CAD results encoded as DICOM SR are displayed by the IRMAcon viewer [42], a system adjusting the layout of CBIR SR documents for CAD. The IRMAcon viewer additionally provides insight into diagnostic findings of identified similar examinations from HIS.

The graphical user interface (GUIs) of the IRMAcon viewer uses web-based IRMA modules [51] adapted to CAD. The IRMAcon viewer is constituted of three components (Fig. 4):

(i) **HL7 program**: Diagnostic findings are queried from HIS and reports are answered by HL7 QRY^R02 and ORF^R04 messages, respectively. Referenced reports may be in plain text or binary format, e.g., Portable Document Format (PDF) or Microsoft Word, usually encoded as Base64 [52].

(ii) **Web server**: This PHP application converts the CBIR SR document into XML format, interprets its content, and creates a HTML formatted output. Furthermore, it retrieves referenced DICOM objects from PACS and converts images to PNG format for HTML inclusion. The output also links to diagnostic findings, which have been delivered by HL7 communication. Configurable smarty templates [53] are applied to define the layout of the HTML output [51].

(iii) **Web browser**: Hosted on the radiologist's workstation, the browser displays the resulting HTML output that was generated by the web server application.

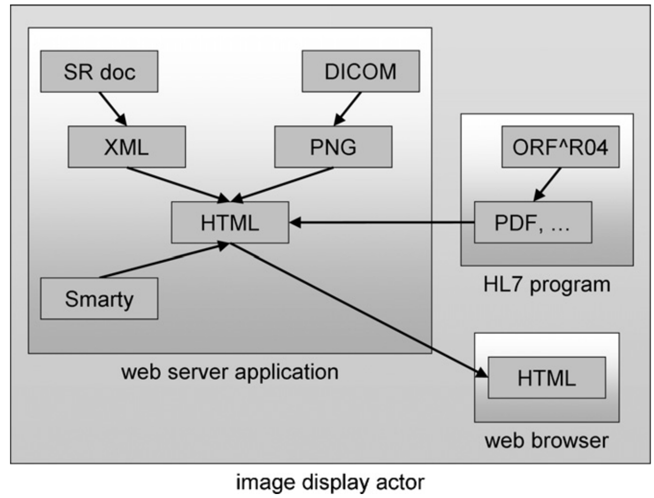

Fig. 4 – Overview of the three components of the image display actor depicting the steps of data processing; Arrows illustrate flow of data.

The DICOM commands used by the IRMAcon viewer are implemented with OFFIS DCMTK [54]. HL7 Application Programming Interface (HAPI) has been used for implementing HL7 messages [55]. DCMTK is also applied for converting SR documents into XML format, which then is parsed by the XML extension of PHP.

The layout of the IRMAcon viewer (Fig. 5) is adapted to CBIR-CAD: The first screen gives an overview of the original examination image and those identified to be similar. Selecting one of these images opens a second browser tab with details on the examination and an according list of diagnostic findings. Interactively, diagnostic reports are shown in an additional window.

4.4. *System architecture*

The CBIR intermediate integration scheme was realized using modular system architecture. This allows a convenient substitution of actor modules by PACS components that are already IHE compliant. Shifting integration functionalities and CBIR to a dedicated machine guarantees a smooth operation of existing clinical systems in case of CBIR-CAD malfunctions. The

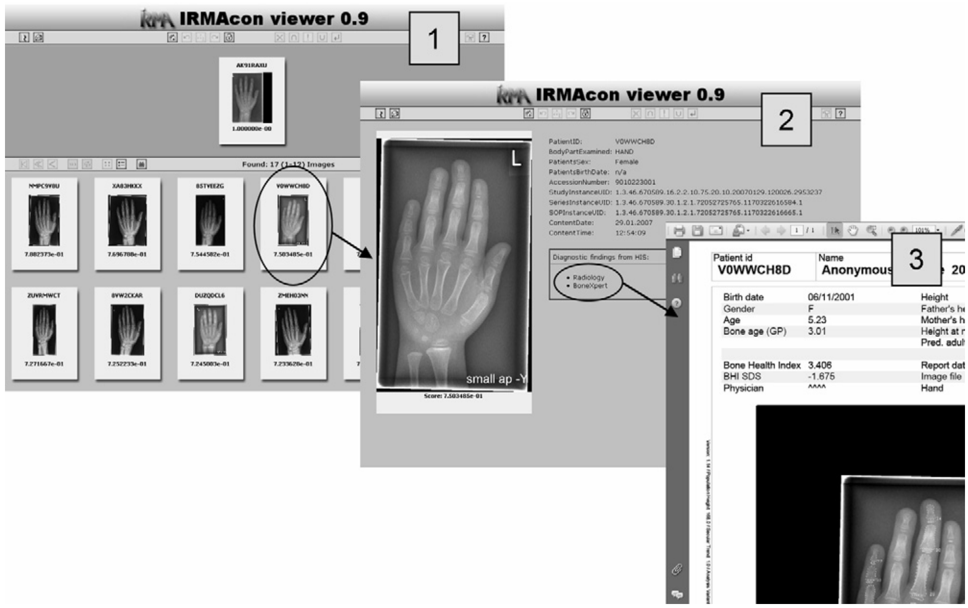

Fig. 5 – Example output of the IRMAcon viewer; window 1 gives an overview of the CBIR results, window 2 presents details on a selected examination image; in window 3 an associated diagnostic report is shown.

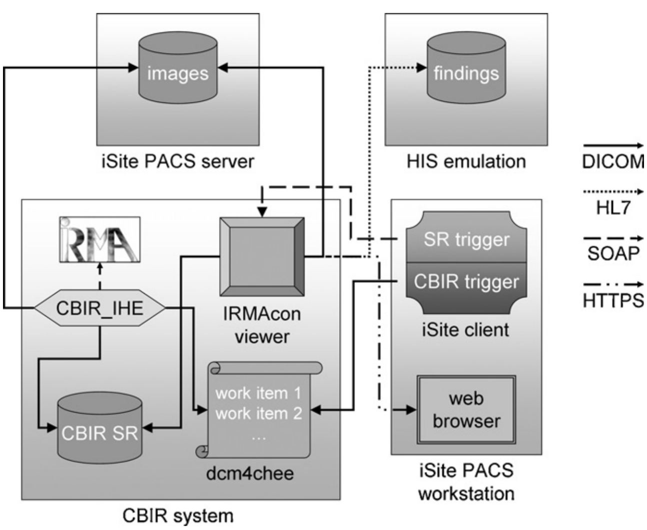

Fig. 6 – System architecture of the CBIR intermediate integration scheme illustrating involved systems and hosted components, arrows depicting initiator of communication.

architecture embraces the following systems and actor modules (Fig. 6):

(i) **CBIR system**: This system hosts the EC, PPM, ID and the SR-IM/IA actors. The EC actor comprises IRMA and CBIR_IHE; the PPM actor is realized using dcm4chee; the ID actor is implemented by the IRMAcon viewer; and the SR-IM/IA actor which is responsible for archiving SR documents is accomplished by providing an appropriate DICOM service.

(ii) **PACS server**: Philips iSite PACS does not support the PWF, but provides an IM/IA actor in the 'Scheduled Workflow' integration profile. Thus, we retrieve examination images directly from iSite PACS.

(iii) **PACS workstation**: The iSite PACS client offers the possibility of embedding plug-ins using a dedicated API. We installed a plug-in that initiates the CBIR workflow ("CBIR trigger"), and another plug-in that activates the IRMAcon viewer ("SR trigger") as soon as the CBIR SR document has been created. A local web browser presents output generated by the IRMAcon viewer.

(iv) **HIS**: In our prototypal setting, HIS is reduced to its relevant function within the intermediate integration scheme. The task of HIS is to return a HL7 message containing diagnostic findings after receiving the according QRY^R02 query message. This is emulated by a simple HL7 application configured with an IP address and port for connection.

The use of standard protocols and the integration with the hospital-wide communication structure are proven prerequisites for reliable and solid clinical system architectures [9]. We utilized DICOM as the prior standard in radiology to implement transactions between the actor modules. Each DICOM service or node is configured with a unique DICOM AET. IRMA and CBIR_IHE, comprising the EC actor, communicate over SOAP, a widespread and reliable communication protocol, assuming an appropriate web server running on the CBIR system. The SR trigger also uses SOAP when transferring information from the SR document to the IRMAcon viewer. The IRMAcon output is displayed in the web browser on the iSite PACS workstation via HTTPS.

5. Discussion

We have presented IRMAcon, a scheme aligned to the IHE PWF integrating CBIR into clinical practice. IRMAcon fulfils principal objectives in health systems [56] and information

Table 4 – Adaptations required to exchange IHE actors in IRMAcon.

Actor	Implications on IRMAcon
PPM	Work items are created automatically by PACS thereby initiating the CBIR workflow. This makes the plug-in "CBIR trigger" dispensable. Scheduling transactions between the CBIR_IHE (as part of the EC) and the PPM have to be reconfigured to address the according DICOM AET of the PACS PPM.
EC	As the EC actor in the PWF stands for the CBIR system, it will not be replaced by PACS functionalities. In case of a connectivity functionality of PACS, our adapter CBIR_IHE has to be modified or replaced accordingly.
ID	A PACS viewer that provides an appropriate representation of CBIR results and related diagnostic findings substitutes the IRMAcon viewer. If the plug-in "SR trigger" is still in use, initiating of the viewer and transmission of necessary SR document information have to be adapted to the PACS viewer.
SR-IM/IA	PACS archives SR documents, and the PACS client lists CBIR results as soon as they are available. Thus, the plug-in "SR trigger" does no longer need to inform the radiologist about incoming CBIR results. For storage and retrieval of SR documents, CBIR_IHE and the IRMAcon viewer have to address the DICOM AET of PACS IM/IA.

management [57] applied to the context of CBIR-based CAD: i.e., to deliver

(i) **the right information** – similar medical examinations as identified by the CBIR system to aid diagnoses,
(ii) **to the right person** – the radiologist at the PACS workstation who is in charge of decision making,
(iii) **in the right format** – encoded as a standardized DICOM SR document and presented in HTML format augmented by additional information,
(iv) **via the right medium** – presented by the IRMAcon viewer along with necessary related diagnostic information,
(v) **at the right time** – scheduled at a well-defined point in the radiological workflow as given in the IHE PWF.

Our concept takes into account the different levels of implemented IHE functionalities in the particular PACS by establishing a modular system architecture, which clearly maps separate IHE functions to individual components. This allows a convenient exchange of single components (Table 4) and a stepwise integration according to the IHE compliance of the employed PACS.

Clinical workflow and context are of vital importance for the success of medical computer systems [58]. These aspects have been addressed in the presented CBIR integration scheme. Founded on workflow and responsibilities defined in the well-engineered IHE PWF, IRMAcon takes into account ongoing IHE developments of PACS vendors. Considering further success factors for CAD [59], IRMAcon does not impose a 'black box' on the radiologist. The listed similar examination images provide understandable results that can be analysed further by the radiologist using the IRMAcon viewer.

IRMAcon implements scheduling by the use of DICOM GPWL, according to the IHE PWF. Besides full provision of work list management, tracking, and notification, GPWL has a DICOM interface. Scheduling might as well be realized using alternative standards, e.g., the Advanced Message Queuing Protocol (AMQP) [60] for messaging middleware. However, convenient integration into arbitrary clinical environments essentially requires a widespread standard that is supported by hospital components (i.e., imaging modalities, PACS server, and workstations).

Concurrency is handled in IRMAcon by two ways of scheduling: (i) The successive processing of entries in the work list handles concurrent CBIR requests and avoids a bottle neck of resources on the CBIR system; (ii) The PPM ensures that work items are only claimed once by the assigned CBIR system.

User feedback is a critical factor for the success of a diagnostic system [59]. In CBIR, feedback typically means refining a query by rating the CBIR response interactively, also referred to as 'relevance feedback'. Relevance feedback improves accuracy [51] and performance [9,61]. The IRMA web interfaces provide appropriate tools for relevance feedback [51] which may be applied to the IRMAcon viewer in the future. This will enable the radiologist to limit queries to a particular pathology or to focus on a certain image region of interest (ROI).

Missing adaptations in the notion of being a good radiologist contribute to the failure of testified systems in clinical routine [62]. In order to establish CBIR-based CAD, the implementation of an integration scheme must also be accompanied by a clarification of professional roles. The application of CAD systems like IRMAcon relieves the radiologist of effort-intensive parts of his work, but not of the diagnostic decision and his responsibility.

Recently, DICOM has been extended by two supplements that might further simplify IRMAcon: (i) The GPWL may be substituted by the *Unified Worklist and Procedure Step* (UWPS) [63] that provides the possibility of pushing a work item to the component responsible for it. Right now, the EC has to regularly check for a new work item not knowing when it will be generated by the PPM. (ii) *Application Hosting* [64] proposes a standardized API to plug-in programs into a medical computing system. The API utilizes DICOM and *Web Services Definition Language* (WSDL) in order to be neutral in programming language, platform, and technology. *Application Hosting* will substitute connectivity functions of CBIR_IHE (as part of the EC actor) in our current design of IRMAcon.

6. Conclusions

The common gap between standards and implementation causes enormous efforts when integrating CBIR into CAD. This is one essential reason why CBIR still is being used rarely in radiological practice despite of its well known and commonly accepted benefits. We have presented IRMAcon, an integration scheme based on the IHE Technical Framework, which is becoming the de facto standard of healthcare components' interoperability. Facing limitations in IHE compliance of current PACS, we have suggested an intermediate solution serving as solid basis for a fully compliant IHE integration. At the intermediate stage, a reliable integration scheme is provided and implemented straight forwardly allowing convenient exchange between individual modules of IHE compliant components. Thus, a final transition to IHE compliance is prepared reducing future integration efforts.

IRMAcon provides sophisticated features: (i) The included scheduling of CBIR tasks takes into account that clinical processes require a solid organization. Scheduled tasks are traced and CBIR results are linked to the corresponding examination data. (ii) The CBIR DICOM SR template enables a reliable and standardized exchange of CBIR results. (iii) The IRMAcon viewer assembles diagnostic evidences sourced from CBIR, PACS, and HIS in a comprehensive and consistent representation integrated into radiologist's routine. (iv) The separation of the CBIR system and CBIR_IHE, the module providing connectivity with the IHE PWF, makes IRMAcon a generic integration scheme for CBIR systems in clinical CAD.

The prototypal implementation of IRMAcon has demonstrated the robust integration of a CBIR-CAD into radiological practice. The proposed approach quits with isolated applications, offers non-ambiguous workflow and responsibilities, and achieves a true embedding of CBIR into the clinical workflow. The IRMAcon integration establishes an essential link between CBIR systems and clinical CAD. As an on-going work, we are adapting IRMAcon for BoneXpert [65], a commercial software for bone age assessment. In the first steps, we evaluate interconnection of BoneXpert and iSite PACS: calling the application from the PACS client and feeding back the CAD result to the PACS archive by CBIR SR documents. Future work will evaluate the performance of our integration scheme in clinical practice and its acceptance by radiologists in daily routine.

Conflict of interest statement

The authors do not have any conflicts of interest, and disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) the presented work.

Acknowledgments

This research was partly funded by the German Research Foundation (DFG), Le 1108/9.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.cmpb.2011.08.010.

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