

Integration of CBIR in Radiological Routine in Accordance with IHE

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ABSTRACT

Increasing use of digital imaging processing leads to an enormous amount of imaging data. The access to picture archiving and communication systems (PACS), however, is solely textually, leading to sparse retrieval results because of ambiguous or missing image descriptions. Content-based image retrieval (CBIR) systems can improve the clinical diagnostic outcome significantly. However, current CBIR systems are not able to integrate their results with clinical workflow and PACS. Existing communication standards like DICOM and HL7 leave many options for implementation and do not ensure full interoperability. We present a concept of the standardized integration of a CBIR system for the radiology workflow in accordance with the Integrating the Healthcare Enterprise (IHE) framework. This is based on the IHE integration profile 'Post-Processing Workflow' (PPW) defining responsibilities as well as standardized communication and utilizing the DICOM Structured Report (DICOM SR). Because nowadays most of PACS and RIS systems are not yet fully IHE compliant to PPW, we also suggest an intermediate approach with the concepts of the CAD-PACS Toolkit. The integration is independent of the particular PACS and RIS system. Therefore, it supports the widespread application of CBIR in radiological routine. As a result, the approach is exemplarily applied to the Image Retrieval in Medical Applications (IRMA) framework.

Keywords: CBIR, IHE, PACS, RIS, Post-Processing Workflow Integration Profile, DICOM Structured Report

1. INTRODUCTION

Content-based image retrieval (CBIR) has a high potential of improving the quality and efficiency of clinical care processes, especially when used in combination with text-based methods [1]. Many CBIR prototypes and testbeds have proven the manifold benefits of CBIR to medical systems processing image data [2, 3], as for example supporting the decision making process by supplying the radiologist with a second opinion. CBIR will gain even more acceptance when clinical CBIR applications become part of the everyday routine in radiology [1]. But the integration of CBIR systems into environments made up of a hospital information system (HIS) with a radiology information system (RIS) and a picture archiving and communication system (PACS) as typically given in hospitals is still hampered today [4]. One reason is the large degree of variability in how the existing components may be combined and communication chains are performed, and the consequential need of adaptation to each individual hospital setting. The differing implementations of standards in the vendor systems require the laborious and costly process of understanding and reconciling them. Another problem is the complexity of coupling the CBIR system to the application programming interfaces of the various HIS/RIS/PACS manufacturers. There is no automatic mechanism to plug in and apply a CBIR component to arbitrary clinical environments.

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Le, Mai, Liu and Huang [5, 6] designed a concept for the integration of standalone computer-aided diagnosis/detection (CAD) workstations with PACS in the context of the Integrating the Healthcare Enterprise (IHE) [7]. They also developed DICOM-CAD-IHE based on their CAD-PACS Toolkit, a migration concept for the integration into PACS environments that does not require IHE compliant PACS and RIS. Yet their concept does not address CBIR systems.

Last year we presented an integration scheme focusing on the technical interfaces and standard protocols [8]. It described one possible coupling of a CBIR system with HIS/RIS/PACS, using the example of the Image Retrieval in Medical Applications (IRMA) framework [9]. The concept is based on the application of Digital Imaging and Communication in Medicine (DICOM), Health Level 7 (HL7) and Hypertext Transfer Protocol Secure (HTTPS). Usually, workflows are hardly coordinated as to when the single post-processing steps are to be performed. Our concept solved this problem by giving a sound procedure of interaction. The necessary steps for the CBIR application were weaved into the particular workflows not disturbing the standard procedure.

In this paper we broaden this solution to an independent and general integration paradigm by IHE compliance. IHE is a global initiative by healthcare professionals addressing interoperability challenges. IHE does not define new standards but provides an aligned and balanced framework by which existing standards are to be used. One major aim is to share information transparently and conveniently between the various components and thereby to optimize the clinical workflow. Its process model includes profiles defining a complete workflow in an exactly described context. These profiles establish a suitable, specific and predictive way for all participating components how to interact using standards in order to circumvent room for conflicting interpretation. Profiles are defined by actors and transactions. Actors are compact functional entities represented by a software or hardware product. A transaction is the definition of the communication between the actors using existing communication standards such as DICOM and HL7.

Our aim is to propose an IHE compliant paradigm for the integration of CBIR into clinical environments consisting of HIS/RIS/PACS. This offers the opportunity of a convenient and accurate integration of CBIR systems in new settings with a high interoperability. We aim at delivering the basis of an extensive and modular integration and at becoming independent of particular system components to support the widespread application of CBIR in radiological routine. We cope with the problem that today's PACS and RIS are not fully IHE compliant. The DICOM-CAD-IHE [6] concept proposes a solution that eliminates the necessity for adapting existing PACS server, that we transfer to CBIR systems and apply to the IRMA framework. Future systems will have to be compliant to a common agreement of interaction because of the drawbacks mentioned earlier. Since IHE is becoming the de-facto standard it is substantial for systems at this stage to already fulfill as many of the IHE specifications as possible. This helps to clear the way for a commonly agreed framework, IHE, and to minimize future efforts of transition.

2. METHODS

Post-processing nowadays is often done on dedicated workstations restraining the exchange and cooperation of the involved responsible persons in clinical environments. IHE covers this specific demand by the Post-Processing Workflow (PPW) integration profile, which provides the critical links between the components. Our integration scheme is based on the PPW integration profile. Most PACS and RIS do not support the presumed PPW integration profile yet [10]. Our scheme therefore grants a stepwise integration of CBIR into exemplary applications.

2.1. Integration using IHE Post-Processing Workflow integration profile

The PPW facilitates the seamless enclosure of post-processing steps such as CAD, image processing and CBIR into the standard workflow. It ensures scheduling, distribution and tracking of post-processing tasks using standardized mechanisms. This includes the management of work lists consisting of the particular post-processing steps, tracking their status, performing and notifying the single post-processing tasks.

The following actors are required for the PPW integration profile:

- **Post-Processing Manager:** handles the post-processing work list by scheduling work list items, providing items to clients and updating status.
- **Evidence Creator:** creates additional evidence objects (images, documents, etc.). In our scenario this will be our CBIR system, IRMA.

- **Department System Scheduler/Order Filler:** manages orders of a medical department, e.g. the radiology department.
- **Image Display:** displays imaging evidence objects.
- **Image Manager/Archive:** handles image data including a provision of information and long-term storage.

The post-processing work list is realized by the DICOM General Purpose Work list [11] Service Object Pair (SOP) Class, supporting to query and retrieve the list by standard DICOM commands. The work list item status is updated by General Purpose Performed Procedure Management. The evidence results produced by CBIR systems are created as DICOM Structured Reports (DICOM SR) [12], ensuring access by standard commands and possible storage in DICOM SR compliant PACS. DICOM SR is a mean of encoding structured information, it does not define how to present these contents. As such it is comparable to eXtensible Markup Language (XML) containing tags with meaning in opposition to HyperText Markup Language (HTML) with explicit directives for presentation [13]. It is reasonable to set up constraints for the composition and valid items in a DICOM SR, similar to what XML DTD and XML Schema accomplish. SR information object definitions [14] serve as a basis for atomic units and how they are combined. As a further constraint and therefore a prerequisite for a comprehensive data exchange, DICOM SR templates have been defined to specify structure and the allowed items [15]. We propose to use the template TID 350, “REFERENCES TO SUPPORTING EVIDENCE” [15]. This template offers the option to reference supporting evidences such as images with similarity to the current examination image based on their content.

2.2. Stepwise Integration of CBIR

The migration is proposed in two steps. The steps are presented starting from a top to bottom approach to disclose all compromises due to the limitations of today’s PACS and RIS. CAD manufacturers prefer the possibility to install necessary IHE components and to integrate their results with the clinical workflow independently from existing PACS [16].

(i) Aim: Full IHE compliant integration

At this stage the PPW is implemented to its full extent providing comprehensive access to all necessary actors. All components are IHE compliant and may fully participate in the PPW integration profile. The integration of the CBIR system is accomplished without any extra efforts.

(ii) Intermediate stage: Facing PACS and RIS limitations

Tasks concerning IHE actors and communication expected on PACS or RIS side are substituted by components implemented independently from PACS and RIS. We adopted the DICOM-CAD-IHE concept based on the CAD-PACS Toolkit [6] for the integration of CBIR. The concept rolls the management of the DICOM SR out to the CAD SR server. To stay in our domain of IHE, this would be part of the responsibility of the Image Manager/Image Archive (IM/IA). The DICOM-CAD-IHE workflow designs a component Display-SR for viewing the DICOM SR. In our IHE compliant scheme this belongs to the actor Image Display.

2.3. Exemplary application to IRMA

The IRMA project aims at developing and implementing high-level methods for CBIR with prototypical application to medico-diagnostic tasks on a radiological image archive [17]. There are currently more than 20,000 diagnostic images in the IRMA database, which are used for image retrieval [3, 18]. We want to perform semantic and formalized queries on the medical image database, which includes intra- and inter-individual variance and diseases. Example task is the retrieval of images with similar diagnostic findings in large electronic archives. Methods of pattern recognition and structural analysis are used to describe the image content in a feature based, formal and generalized way. The formalized and normalized description of the images is then used as a mean of comparison with images in the archive, which allows a fast and reliable retrieval. IRMA results by means of DICOM SR data can be converted and used for arbitrary purposes, for example:

(i) Support of pre-fetching

Pre-fetching means the task of retrieving all images of past examinations relevant to the current examination. These images may reside on archive and therefore usually have to be queried from archive manually. PACS systems carry out pre-fetching in general by textual criteria like examination code. CBIR of similar and therefore relevant images improves the pre-fetching in cases where textual descriptions are ambiguous or missing.

(ii) Support of hanging

Hanging means the positioning of examination images ordered by relevance and date on the diagnostic screens. CBIR reduces the radiologist's work by suggesting a suitable hanging automatically which takes into account the image content. Only those examination images are proposed for hanging which are meaningful for the diagnosis of the current case.

2.4. General principles of system integration

Successful system integration considers some rules that are substantial for an efficient and seamless interaction of the participating components. These are [19]:

- Data integration: data does not need to be entered more than once;
- Functional integration: services provided by a module can be used where they are needed;
- Presentation integration: data is presented in a unified way independently of module and manufacturer;
- Context integration: settings made up of for example a certain patient or an examination are transparently passed to another module when the user switches to it.

We aim at the best integration according to all the above criteria:

- Data integration: data is shared between the participating components transparently and seamless to the user. Patient and examination information, images and reports are requested and transferred by DICOM commands for the CBIR system, the Post-Processing Manager and Image Display actor.
- Functional integration: the use of web-based applications and standard protocols such as HTTPS offers the possibility to start the CBIR application and the Image Display from any workstation connected to the inter- or intranet. When the radiologist adjudges an examination he is not forced to another computer.
- Presentation integration: The chosen CBIR system IRMA is designed according to well-known standards of usability and with commonly accepted ergonomic features. IRMA has a powerful user interface for an extended query refinement including for example mechanisms for combining queries by Boolean operators and for restoring previous session states [20].
- Context integration: The transmission of the patient's id and the relevant examination data is guaranteed by the use of the work list. Each work list item contains all relevant information that the CBIR system needs to set up the same context as the user has established.

3. RESULTS

3.1. Implementation requirements for the stepwise integration of CBIR

(i) Aim: Full IHE compliant integration

The IHE technical framework allows the Post-Processing Manager to be grouped with either the Department System Scheduler or Image Manager [21]. Depending on this design, the Post-Processing Manager receives the information that an image has become available on the Image Archive from the Scheduler or from the Image Manager. Status about the progress of a work list item is given to the other actor in succession.

1. As soon as an image is available, the Post-Processing Manager adds a CAD work item to the work list.
2. IRMA, the Evidence Creator, queries the Post-Processing Manager for post-processing Scheduled Procedure Steps.
3. IRMA claims the next work item defined for CAD.
4. IRMA queries the new image from the Image Manager and does its CBIR processing. Meanwhile, IRMA reports to be in progress to the Post-Processing Manager.

5. After completion, IRMA stores the created evidence document in form of a DICOM SR to the Image Manager and in relation to the actual examination identification, and notifies the Post-Processing Manager about the completion of its work item.
6. The user may take a look on the DICOM SR containing the IRMA results using Image Display.

(ii) Intermediate stage: Facing PACS and RIS limitations

The main restrictions of topical systems are listed together with our proposed solutions in analogy with the CAD-PACS Integration System [6]:

1. Most PACS or RIS system do not facilitate a Post-Processing and an Image Manager yet. Therefore, these components are implemented as independent software residing on a different workstation. The workflow is triggered by the PACS user who executes a “DICOM Send” command from the PACS workstation to transfer a DICOM image to the Image Manager. The Image Manager informs the Post-Processing Manager about then new examination image.
2. The evidence results in form of DICOM SR created by IRMA are not archived on the PACS server but on a new database residing on a SR server. This means that the part of the Image Manager/Image Archive actor responsible for the DICOM SR is hosted on the SR server. To view the results as a responsibility of the Image Display actor, a web-based component is made available on the PACS workstation that has access to the SR database. Hence, newly created DICOM SR are directly available to the user.

3.2. Exemplary application to IRMA

We present the concept of the full IHE compliant support of hanging by IRMA (Fig. 1) describing the participating actors and their transactions:

1. Evidence Creator (EC) queries next work item from Post-Processing work list from Post-Processing Manager (PPM) regularly and learns about the new work item.
2. EC claims work item at PPM for IRMA.
3. EC notifies work item in progress to PPM.
4. Execute retrieval of those examination images relevant to the current examination and compose a DICOM structured report from IRMA results.
5. EC stores structured report via Image Manager/Archive (IM/IA).
6. EC notifies work item completed to PPM.
7. Image Display (ID) retrieves structured report from IM/IA.
8. Compare and arrange images listed in the structured report for the hanging on the diagnostic screens.

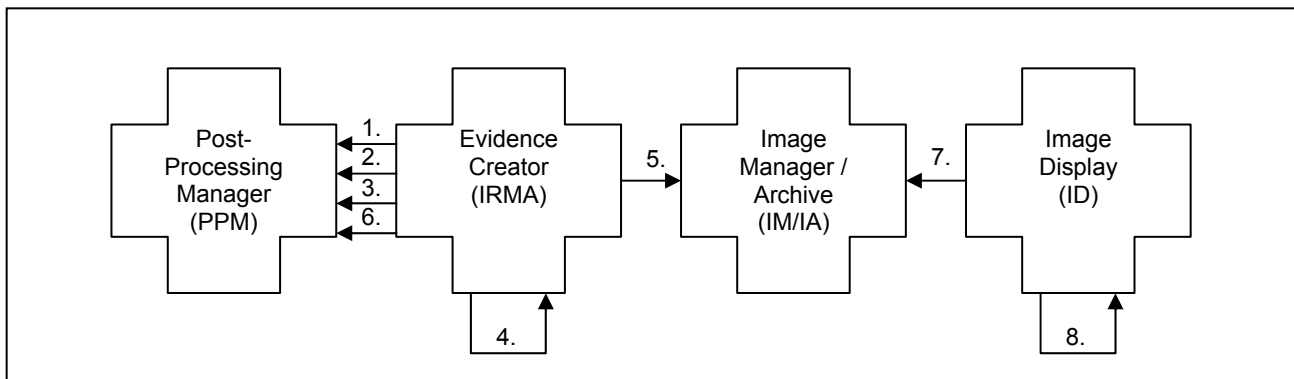


Figure 1: IHE compliant workflow for support of hanging by IRMA. Shown are direction and order of actions/communication (arrows) between the IHE actors (crosses).

In the following, we oppose the full IHE compliant support of hanging to the intermediate stage (Fig. 2). Whilst in the full compliant variant the actors are part of HIS/RIS/PACS, in the intermediate stage these components are implemented independently from HIS/RIS/PACS. We chose an extra server machine, named IHE_int, hosting these actors and providing their functionality. One could also choose to implement them on the CBIR machine. The benefit of our solution is that the components are separated so that other CBIR/CAD systems may integrate easily. The IM/IA actor is split up in two, namely PACS and IHE_int. PACS is in charge for examination images and IHE_int for DICOM SR. We decided to group the PPM actor together with the IM/IA instead of the Department System Scheduler. The PPW integration profile allows both, choosing the already involved Image Manager reduces the efforts to establish the workflow at the intermediate stage.

1. The “DICOM Send” command is executed from the PACS workstation and the DICOM image is transferred to the IM/IA.
2. IM/IA informs PPM about the arrival of a new examination image.
3. PPM creates a new entry in its Post-Processing work list.
4. Evidence Creator (EC) queries next work item from Post-Processing work list from PPM regularly and learns about the new work item.
5. EC claims work item at PPM for IRMA.
6. EC queries the new examination image from IM/IA for IRMA.
7. EC triggers IRMA to start image retrieval task.
8. EC notifies work item in progress to PPM.
9. IRMA executes the retrieval of those examination images relevant to the current examination.
10. IRMA informs EC of the completion of the image retrieval task.
11. EC composes a DICOM structured report from IRMA results.
12. EC stores the structured report via IM/IA.
13. EC notifies work item completed to PPM.
14. The “Display SR” command is executed from the PACS workstation and triggers the Image Display (ID) to create a view on the IRMA results.
15. ID queries the structured report from IM/IA listing the images proposed by IRMA for the hanging on the diagnostic screens.

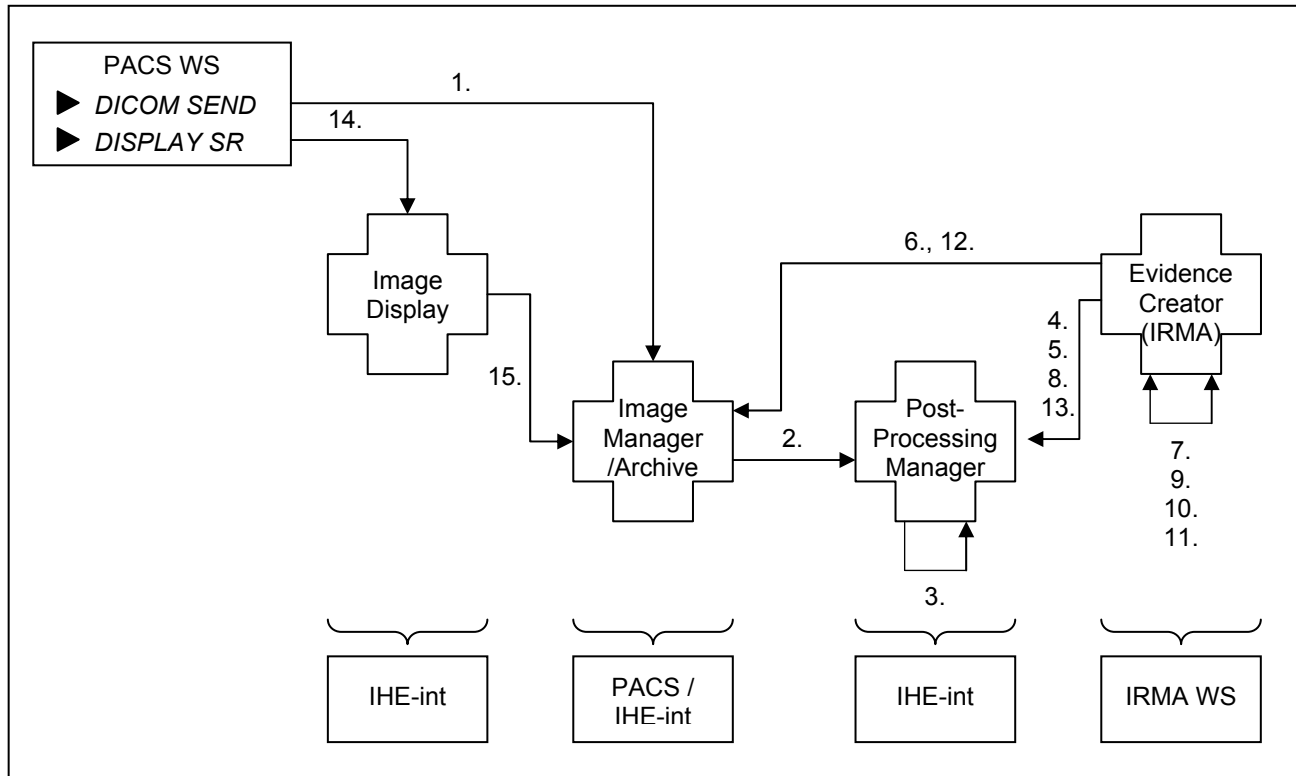


Figure 2: IHE intermediate stage workflow for support of hanging by IRMA. Shown are direction and order of actions/communication (arrows) between the IHE actors (crosses) on the different machines (rectangles).

4. DISCUSSION

We provide a paradigm for the integration of a CBIR system into the healthcare environment that is applicable to any PACS, RIS, and CBIR system. Our proposal is in accordance with the IHE framework and therefore, it is able to establish a standardized procedure in integrating a CBIR system into clinical environment and radiological routine. We propose a stepwise approach which has some impacts. The intermediate step puts a standardized integration into practice right away. It operates with the implementation of IHE components preferably on a different server than the one where HIS, RIS or PACS reside on in order to separate it and to guarantee no influence on the existing systems. As long as HIS/RIS/PACS are not IHE compliant and do not offer the necessary IHE components by themselves the question is who is in charge of implementing them and by which means for the intermediate stage. There are some toolkit supports but as long as the final stage of full IHE compliance is not achieved there is need for an IHE compliant framework independently from HIS/RIS/PACS so the CBIR manufacturers can rely on the existence of the IHE components described in this integration scheme.

5. CONCLUSION

Due to the gap between standards and systems integration, enormous efforts have to be made in each implementation when integrating CBIR systems, often requiring expensive, site-specific interface development. This is the reason for CBIR systems still rarely being used in radiological routine despite their well known and commonly accepted benefits. We have presented a concept for the integration of a CBIR system in the radiological routine based on the IHE Technical Framework, which is becoming the de facto standard of how components in a healthcare enterprise interoperate. Facing the current limitations of PACS and RIS concerning IHE compliance, we also suggest a primary solution which serves as a solid basis for the full IHE compliant integration. It takes into account that the transposition to IHE is still in progress and that many sites do not fully support the necessary IHE profiles yet. In order to avoid future

efforts it is substantial for every component to be prepared in order to make the final conversion to IHE compliance as soon as the requirements are fulfilled as easy as possible. We showed that integration of a CBIR system in radiological routine is possible in a convenient and robust manner. The proposal is demonstrated using the IRMA framework.

ACKNOWLEDGEMENT

This research was supported by the German Research Foundation (DFG), Le 1108/9. We additionally would like to thank IHE Europe and Germany for collaboration and support.

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