A clinical workflow integrated LCMS for cardiological imaging

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Abstract. Given the continuous need of medical education and the wide diffusion of reference case repositories, Web-based e-learning technologies promise to improve the availability of e-learning tools and content, especially in the evolving area of diagnostic imaging. In this paper, we present the design and implementation of a Learning Content Management Systems (LCMS) in the area of cardiac imaging that allows collecting heterogeneous clinical information in a guided simply way, integrated with the everyday clinical workflow. The system has been developed in a clinical environment and integrates specific authoring tools for distributing case-studies in cardiac imaging area for allowing improved interactivity and the concrete possibility to define multiple-phase learning sessions.

1 Introduction and background

New opportunities for medical education and training are based on the adoption of modern information and communication technologies (ICT). Concerning continuous medical education of physicians, the wide diffusion of reference case repositories and more and more advanced Web-based e-learning technologies promise to augment availability of teaching and training tools especially in the area of diagnostic imaging. In this evolving area, medical images are extensively used and case-based teaching files (i.e., commented set of images concerning a specific case) are adopted to illustrate teaching points. Furthermore the introduction of new imaging modalities, such as cardiovascular CT angiography (CCTA), requires an extensive training to ensure quality outcomes and an enhanced cooperation between different competencies to provide a better understanding of the clinical implications of an exam. Moreover, training complexity necessarily increases because of the need to integrate several data and various specialized knowledge. Simple teaching files may not be adequate anymore for an effective learning. Therefore purposeful Learning Content Management System (LCMS) has to be designed in order to manage data collection and organization based on suitably articulated learning objects (LOs) providing interactive step-by-step educational sessions and tests. The purpose of a LCMS is therefore both the provision of an effective learning experience and the facilitation of the population of case-study (CS) repositories.

The cooperation of Radiologists, Cardiologist and Nuclear Medicine physicians is a crucial aspect to build databases of CS derived from real patients that illustrate a particular teaching point, diagnostic pitfall or unexpected outcome in the area of cardiovascular imaging. Rich and complete LOs permit to describe a CS according to different perspectives and therefore should contain a complete set of information, anamnestic data, clinical examination, laboratory findings and the results of imaging modalities. These heterogeneous data must be stored, organized and available for easy access to generate LOs. In fact, a main requirement in a medical LCMS is to minimize the time spent for information search [2] and for the arrangement and organization of the selected data towards the creation of significant and sufficiently articulated case-studies. The idea is that the creation of CS related LOs should be integrated in the everyday clinical workflow with the minimal overhead for the medical specialist [3, 5]. Actually, the complexity and heterogeneity of data sets (e.g., structured-unstructured text, signals, images, metadata) and data sources (i.e., different
information systems) make difficult or even impossible a direct editing of new cases by the physician because of task complexity and time/effort required.

Therefore, easy to use and effective developing of LOs by expert physicians is a key factor for the sustainability of the whole system and for its successful adoption. In particular, to support the integration process in a easy way we rely on the use of a data aggregator, i.e., an enhanced PACS/RIS, which would allow a single point of access to all clinical data and images. The workflow of creating LoS, starting from the data/exams generation till the exploitation of the system by final users, is then relevantly shortened. This aspect is especially valuable in the cardio-vascular domain because of the various data sources and kinds of exams to be collected, analyzed and selected [8].

In this paper, we present the design and implementation of a LCMS prototype in the area of cardiac imaging that allows collecting heterogeneous clinical information (e.g., SPECT-CT, CTA images obtained by their fusion from PACS; clinical data from RIS) in a guided simply way, integrated with the everyday clinical workflow. This LCMS permits to produce, store and make available LoS representing case studies selected for their didactical relevance. Specifically, the system is composed of: (i) a domain data aggregator capable to collect basic data units from different systems and repositories based on a single patient CS, (ii) a guided data importing tool to define the basic learning units which are relevant to the CS, (iii) an editing module to authorize LoS from the above imported content, (iv) a presentation module to implement test and evaluation Web sessions based on the created LoS. In the following of the paper, without loosing generality, we will use preferably the term case-study/CS also to denote a LO, because more meaningful in the considered domain. The paper is organized as follows. After presenting related work and positioning our contribution in Section 1.1, we motivate and describe the specific requirements for the proposed LCMS in Section 2. The data importing and case study creation processes are detailed in Section 3. Some implementation choices and details are given in Section 4. Finally, a conclusive discussion and future work are given in Section 5.

1.1 Related Work

MIRC [2] is an initiative and an open-source software tool by the RSNA (Radiological Society of North America) for defining standard practices for creating, storing, searching and visualization of teaching files. This initiative maintains a public portal with hundred of teaching files provided by educational institutions. The IHE initiative (www.ihe.net) proposes the TCE profile to define the requirements for a generic process of teaching files creation from images/series PACS. The profile defines involved actors and activities of the process: selection of relevant data, adding clinical information and interpretation, storage of teaching files. However, as observed also in [4], the most of the PACS do not support and implement the IHE TCE profile. Moreover, the exportation and storing functionalities are implemented also by the MIRC platform, so in [4] the Authors propose a software tool based on DICOM services for adding an exportation function toward MIRC to PACS platforms. This solution allows for generating teaching files to be stored and processed in MIRC in a semi-automated way. AuntMinnie.com is a Web portal aiming for providing a huge amount of radiological images. The e-learning functionality is only a part of the Web portal. Radiology case studies are accessible after registration. A case study is presented as a sequence of blocks, each of them composed of images and a short description. For each block, there is a related question (true/false or multiple choices). At the end of the presentation of a case the system asks for a diagnosis and presents a final short discussion. A similar, well known e-learning portal is RadiologyTeacher.com. The strong point of both these portals is the remarkable number of cases collected by the open community of the users. However, the interaction level of these portals permit is limited to the answer selection and image magnifying.

Contribution. With respect to the cited works, our system collects images and clinical data from PACS, RIS and other information systems through the mediation of an aggregator, allowing the user for: (i) a suitable and well structured data access, (ii) composing case studies and related LoS from large heterogeneous sets of data in a guided and simple way. Our system implements the case study creation phases described in
the IHE-TCE profile. Moreover, the system integrates specific authoring tools for distribution of Web-bases study cases in cardiac imaging area and, specifically, allows improved interactivity and the concrete possibility to define an articulated multiple-step LO for a meaningful and complete e-learning experience, also comprising the auto-evaluation tools.

![Activity diagram for the Creation of a Case Study](image)

**Fig. 1.** Activity diagram for the Creation of a Case Study

## 2 LCMS requirements and implementation

The learning system has been designed following a user-centric approach [6], considering the point of view of both case editors and learners. This means involving users in each phase of the project with the target of implementing a system that minimizes the efforts for learning and use.

Specific requirements have been therefore set by a panel of physicians involved in the LMCS project because of their long term experience in teaching diagnostic procedures about cardiovascular pathologies.

Moreover, we assumed that the case study editor role is played by one or more specialists with knowledge about the patient’s medical history on which the case study is based. The physicians involved in the requirements definition phase made experience with the e-learning portals cited in Section 1.1 and set, on the basis of this experience, some initial high level requirements:

- **operational clearness**, in the importation phase of the data, exams, clinical images.
- **simplicity** in accessing data, both in the phase of case authoring and in case usage.
- **interactivity** with the learners, obtained by: (i) allowing interactions (like pointing/selecting a relevant part) with the images of a case; (ii) allowing to build cases articulated in phases to introduce incrementally the learner to the case complexity.
- specialization on the cardiovascular domain, with the target to implement a meaningful case database in this domain.

As a consequence, the case study presentation has been organized so that the learners is involved in a multiple-step evaluation/decision procedure [7] where at every step she/he is asked to provide an answer or to take actions like identifying interactively a relevant item inside an image. The presentation is built to guide the user gradually toward a correct diagnosis and bring her/him back on the correct track if an intermediate incorrect answer/action is given. When this happens, proper corrections and explanations associated with each decision step are presented at the learner.

As we told, to implement this structured presentation model, the clinical cases have to be based on teaching files including a pretty large amount of information concerning the patient. An aggregation of the patient clinical data from the different clinical information systems is then crucial to obtain simplified data access when, as in our case, we have to deal with heterogeneity of data. In our scenario, the aggregator system has not been introduced on purpose for the LCMS, but it is part of the pre-existing infrastructure and allows for exporting data into the LCMS with a high degree of automation. Specifically, we have used the aggregator developed by GE Healthcare: Centricity CARDDAS [1]. CARDDAS is a set of tools serving as the collection point for patient data and exam administration in a cardiology department, including streamlined workflow, tracking inventory stock, creating clinical reports, and running clinical and administrative queries on department data. The system can be either used as stand-alone PACS or permits the connectivity with existing image storage system in hospitals.

Specifically, the used aggregator connected to other clinical information systems (HIS, RIS, LIS, PACS) can import and organize data related to the patient’s medical history, allergies, risk factors, current therapies, laboratory tests, reported infections, and other patient exams (CT, SPECT, CCTA, CABG, ECG, ECHO, EMO), with related reports and associated images.

![Fig. 2. Creation of a case-study in the LCMS authoring tool](image)
This information is then exported by the aggregator and imported selectively in the LCMS according to the physician choice. The exportation of the alphanumeric data is performed by running a group of queries to produce an output as simple text (like CSV) files. Moreover, after the selection of key images the exportation procedure is totally automatic and creates a patient folder which contains a predetermined set of structured text files, corresponding to the concepts relevant for a case, and a subdirectory containing the selected images in a high quality compressed JPEG format. It is remarkable that any system that can export a text file appropriately structured can interoperate with our system with small changes.

The LCMS content can be searched by keywords, for example regarding: previous pathologies, symptoms and risk factors. The result of a search is a list of matching case studies, each one summarized by a code, date of creation and a set of associate keywords. Finally, we remark that the LCMS has been implemented as Web-based application and adopting open-source technologies to be easily distributed on many kinds of software platforms and systems with the purpose of improving usability and portability.

3 Authoring tool implementation

In this section, we provide details about the actual steps that have to be followed in the LCMS to import clinical data, authoring a case study and making interactive an image.

3.1 Data upload and import

A central component of our LMCS is the data importing tool. After the exported files have been loaded by the tool, a replica of the data is created and organized according to the original directory tree. (e.g., the image folder is still present). The tool loads these data in a database conforming to a schema designed to provide data structured in a suitable way for the successive case-study authoring. In particular, we use a relational database located on the LCMS application server. In this phase, the original patient ID is remapped to an anonymized ID to the purpose of removing reference to the original patient record.

The data are finally presented according to different categories and organized in tables (in our case we have one to one correspondence with the tables exported by the CARDDAS, that is, generic patient information, risk factors, etc.). If there are texts and images associated with an exam, these are displayed as explicitly linked to show their relationship. Each block of data (e.g., laboratory tests, drugs, etc.) can be easily skipped during the importation by deselecting corresponding checkboxes. At the end of this phase the database will contain all and only the selected data. With these data, the case-editor can build a case study and select the critical points on the images, as described in the following.

3.2 Creation of the case study

The study case creation must be performed with a limited effort (with “a few mouse clicks”). In particular, in Fig. 1, the required activities are shown using the standard UML notation. The authoring tool therefore minimizes the number of information to be manually entered and allows a good level of structuring (the case is organized according to different phases). Each clinical case can be created composing established blocks: a) the set of descriptive elements, b) the assigned closed answers, c) the explanation of the correct answer, and d) a list of items in support of the explanation. The system allows assigning a purpose to every previously imported data. This purpose can be "description" if one want the item to appear in the descriptive phase of a level, “explanation” if the item must appear in support of the textual explanation inserted by the editor, or "both" if the item must to appear in both phases (this can be useful to highlight the false positives, making a reference to an image in the description). For the items, selected as “description”, is also possible to give a display order (numeric field checked by the presentation engine). In addition, for the various exams, the editor can select to display only the related textual and/or tabular data, only the associated key images, or both. This specification is also necessary to enable the tests based on the selection of critical points on the images (see below). More levels can be created to guide step-by-step the learners.
towards a right interpretation of clinical data. At the end, the case study editor has to introduce a textual conclusion and assign keywords for retrieval of clinical case using the search engine (as explained in Section 2). In Fig. 2 is shown a screenshot of the authoring tool; after presenting the editor all the imported data and images about the patient and the exams, it is possible for the editor to insert the question/answer/evaluation parts of the LO. The authoring tool here shows the data in a way similar to the one used for presenting the case to the learner.

![Data Editing State](image)

**Fig. 3.** Circular and rectangular selections of relevant image parts are allowed in RI editor.

### 3.3 Selection of the relevant points in an image

A specific tool, the reactive image (RI) editor, developed as a part of the LCMS case editor implements the interactivity requirements on images. The editor is a Java application and permits to highlight critical points on cardiac images. The RI editor is invoked by the system and acts on an image without changing its original information content. In fact, a text file containing an array of points (or rectangles) is assigned and can be edited/invoked as a graphical layer overlapped on the original image. The applet can be used with any type of image and has been implemented with some specific features which are suitable for images in the field of cardiovascular imaging. The RI editor allows the selection of the image and a point or a region of interest, as shown in Fig. 3, in a few mouse clicks. The selection can be associated with a tolerance region in order to allow the system to accept some imprecise mouse pointing selection by the learner within a predefined margin. The application permits to save the image with the selectable areas on the LCMS server. After this step, each case that will be associated with the image is automatically proposed with the graphic test as active. The test requires the student to select relevant keypoint/keyregion on the reference images and her/his response is evaluated as right or wrong, highlighting mistakes and correct answers.

### 4 LCMS implementation details

The system has been developed with suitable and well known open source technologies: the adopted DBMS is MySQL, and the pages have been written entirely with the scripting language PHP. The main controls on user input and the visual effects were handled using the JQuery JavaScript library [9] version
1.4.2, which allowed to maintain the greatest possible interoperability between the most diffused web-browsers. Additional libraries have been used, such as the PclZip [10] to allow the loading and unpacking of the zip archives in a single operation. In particular, the PHP function imagettftext has been used to dynamically generate the 17 segments diagram (visible in Fig. 2). This diagram is a standardized map to describe the left ventricle of the heart used in SPECT and ECO where predefined fields are filled with numeric values associated to normal or abnormal function. Generated maps are stored and selected as additional images.

As a general consideration, the system has been designed with emphasis on the maintenance and extensibility through modularity and carefully commented source code. PHP allows for system function reuse, while JavaScript and JQuery give a contribution in visualization and graphic object handling without affecting the operation execution speed. In addition, JavaScript in the interactive pages has been preferred to Adobe Flash to further improve portability.

5 Conclusions and future work

In the past decade, the field of diagnostic medical imaging has experienced rapid growth and change through both the introduction of new imaging modalities and enhancement in capabilities of the existing techniques. Due to the complexity of new technique, such as CCTA, the integration of different images modalities with all other anamnestic information and laboratory findings is crucial to perform a correct diagnosis and facilitates the acquisition of invaluable knowledge and skills for better patient care. The availability of peer reviewed teaching files is a fundamental aid for the education and training of physicians.

This paper demonstrated a preliminary result on the construction of a LCMS in the area of cardiac imaging that permits to integrate ultrasound, computed tomography, radionuclide imaging, coronarography results as well as anamnestic data and laboratory findings. Specific efforts have been devoted to simplify the creation of case studies and to integrate the whole information needed. This task is crucial if different competencies are necessary. The developed system can be adapted to support LOs also for other medical imaging subspecialties by adapting the importing mechanism for the specific exam files. The phases of creation and use of a case study can be reused without changes. Only some specific parts of the case study presentation have to be adapted. As an example, the 17 segments diagram is specific of the cardiac domain.

The system has been preliminarily tested by a panel of physicians specialized in radiology, nuclear medicine and cardiology. The experience has been conducted at the San Raffaele Scientific Institute in Milan (Italy). At this writing, 30 cases have been introduced expected to grow to about 100. The complexity and the exhaustivity of selected clinical cases justify the relative low number. All the specialists participating to the creation of teaching files phase, found our system optimally designed with easy and intuitive user interface. At the moment the application is accessible in a department solution, the next step is to open the access to the Web in order to collect more feedback on it.

Future work includes defining mechanisms for the case study search by defining suitable LOs metadata. For example, we will decide whether to adopt keywords based on controlled taxonomy vs. folksonomy. After the introduction of a relevant number of cases we will have more information to decide effective ways for searching a case based on keywords that are familiar to the physicians.

In conclusion, the tests till now performed have proven that the system has a user-friendly interface for authoring realistic and interactive cases, that can be utilized in a number of teaching aspects and can be easily integrated into existing electronic environment as RIS/PACS.

6 References

1. GE Healthcare Centricity™ CARDDAS.


