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Radiology interpretation process modeling

Rita Noumeir *

École de Technologie Supérieure, 1100 Notre-Dame West, Montreal, Que., Canada H3C 1K3

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Abstract

Information and communication technology in healthcare promises optimized patient care while ensuring efficiency and cost-effectiveness. However, the promised results are not yet achieved; the healthcare process requires analysis and radical redesign to achieve improvements in care quality and productivity. Healthcare process reengineering is thus necessary and involves modeling its workflow. Even though the healthcare process is very large and not very well modeled yet, its sub-processes can be modeled individually, providing fundamental pieces of the whole model. In this paper, we are interested in modeling the radiology interpretation process that results in generating a diagnostic radiology report. This radiology report is an important clinical element of the patient healthcare record and assists in healthcare decisions. We present the radiology interpretation process by identifying its boundaries and by positioning it on the large healthcare process map. Moreover, we discuss an information data model and identify roles, tasks and several information flows. Furthermore, we describe standard frameworks to enable radiology interpretation workflow implementations between heterogeneous systems.

Keywords: Radiology; Interpretation; Diagnostic report; Process modeling; Workflow modeling; Workflow management systems; Process reengineering; Business process redesign; Integrating the healthcare enterprise; Digital imaging and communications in medicine

1. Introduction

Information and communication technology (ICT) is deeply shaping every organization in our society. Healthcare organizations are being profoundly transformed with the introduction of ICT. However, despite ICT promise of delivering quality of care while ensuring efficiency and cost-effectiveness, the results achieved so far in heath care are far from expectations [1]. In fact, technology by itself will not bring the predicted changes without any process reengineering [2]. Healthcare process reengineering is ever more unavoidable since healthcare organizations are increasingly pressured to deliver optimized patient care for an aging population with limited resources.

Process reengineering or business process redesign (BPR) has retained great attention in the last decade [3,4]. Its methodology, success and failure conditions have been extensively studied and documented [5]. BPR has been defined as the critical analysis and radical redesign of existing business processes to achieve breakthrough improvements in performance measures [3]. ICT, the most powerful tool for reducing the costs of coordination [3], is the key enabler of BPR [6]. In the last decade, BPR tremendously transformed the manufacturing industry and the retail sale process.

To perform BPR, guidelines have been proposed and documented [3]. Analysis of an existing business process is essential to its redesign. Analysis is achieved by identifying the process, by modeling its workflow and by monitoring its execution to collect performance measurements [7].

In healthcare, process modeling has been identified as fundamental to provide suitable solutions to the

* Fax: +1 514 396 8684.
E-mail address: noumeir@ele.etsmtl.ca.

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problems of designing and building innovative healthcare information systems [2]. In radiology, for example, in order to achieve cost reduction and improvement in productivity with picture archiving and communication systems (PACS), it has been demonstrated that workflow redesign was much more important than filmless operation [8–14]. The Baltimore Veterans Affairs Medical Center case study revealed that the introduction of PACS did not achieve improvements in productivity and cost savings until the diagnostic imaging process had been reengineered. The reengineering efforts resulted in much fewer workflow steps, fewer member staff, and dramatically increased efficiencies [8].

Even though in many cases in the literature, 'workflow' and 'business process' are used interchangeably, a subtle difference exists between them. A business process is a structured, measured set of activities designed to produce a specified output for a particular customer or market [3]. Therefore, a process has boundaries, a customer, and a specified output. Furthermore, a process produces the output by means of interrelated activities, the workflow. Consequently, process modeling implies identifying the process by depicting its boundary, customer and output; it also implies modeling its workflow by describing who does what, when [15].

Since a process coordinates people, resources, systems, and work, an information system that manages a process workflow controls the work of individuals and may introduce delays or constraints on how and when tasks are performed. Consequently, analyzing and optimizing a process consists in analyzing and optimizing each task involved in its workflow as well as each hand off of work between tasks [15]. But, a complex task may be performed according to its own sub-process. So, analyzing and optimizing a large process can be achieved by analyzing and optimizing its sub-processes, recursively. Therefore, even if the healthcare process is a large, not very well-modeled process, its sub-processes can be modeled individually and their respective models are important pieces of the whole model.

In this paper, we propose a model for the radiology interpretation process. Radiology interpretation is a sub-process of radiology, which is itself a sub-process of the healthcare process [16]. Its goal is to generate a diagnostic radiology report that is made available for clinicians outside the radiology department. The generated report captures the radiologist's interpretations and impressions. The radiology report is an element of the patient healthcare record and contains important clinical information to assist in healthcare decisions [17].

An accurate interpretation model is needed to design and implement information systems that efficiently manage the interpretation process workflow. The interpretation workflow model is necessary for designing and implementing digital signature [18] and authorization control [19,20]. The workflow model has major consequences. An inaccurate model introduces inefficiencies, frustrations and may result in a useless information system.

Modeling the interpretation workflow consists in describing who does what, when or in other words, describing the roles, tasks, and sequences of tasks [21]. The radiology interpretation process implies different information flows. Although information flows may vary between institutions, there are simple common workflows such as the one that involves dictation, transcription, and verification steps; there are also other more complicated and exceptional workflows, but yet very common, such as the one that involves resident performers or delays. An exceptional workflow is a deviation from an ideal care delivery workflow. Exceptions can arise from changes in resources availability or tasks priorities for example. Even though exceptions are infrequent, they can be expected. Moreover, the same exception can be expected regardless of the institution. Since exceptions can occur in any process implementation, modeling specific exceptional workflow enables systems to handle them consistently and effectively.

We propose a model for the radiology interpretation process by following a formal approach. In Section 2, we identify the interpretation process boundaries by specifying the event that triggers it, the result achieved, and the customers that receive the result. We also position the interpretation process on a larger process map with respect to the radiology process, which is by itself a sub-process of the large healthcare process. In Section 3, we propose and discuss a data model for the information involved. In Section 4, we propose a workflow model by identifying roles, tasks and information flows. Several common interpretation workflows are discussed and presented by using the unified modeling language (UML) swimlane notation [22,23]. Moreover, since interpretation may involve heterogeneous systems, we describe, in Section 5, how to implement the proposed model using transactions defined by the digital imaging and communications in medicine (DICOM) standard. We also discuss the integrating the healthcare enterprise [24] (IHE) reporting profile that specifies a general framework to allow various workflow implementations between different systems. Finally, as process improvement requires collecting performance measurements, we present, in Section 6, general process measurements and how they translate into specific measurements that are relevant for the radiology process.

2. Radiology interpretation process boundaries

The only reason a business process exists is to deliver a specific result to a customer who is the recipient or beneficiary of the result. The process is initiated by an event that is a specific request for the process result.

Identifying the process boundaries requires the specification of the result, the customer and the trigger. It also requires positioning the process on an overall process map. In fact, the interpretation process is related to other processes. It is a sub-process of radiology, which is itself a sub-process of a bigger healthcare process. Besides being fundamental for understanding a process, boundaries are also important for achieving integration, efficiency, and optimization of the larger process.

The radiology process is initiated by a request for a radiology procedure for a specific patient. This is usually part of a radiology order that may request multiple procedures. However, each requested procedure generates a different result instance. So, the radiology process trigger is a radiology order. This trigger source is usually outside the radiology department. For each requested procedure there is a radiology process instance.

The radiology process result is a radiology report that is a document whose content holds the interpretation and the impressions of the radiologist.

The radiology process customer is the recipient of the radiology report. The customer is a healthcare specialist, outside of the radiology department, involved in the patient care. The radiology process is shown in Fig. 1 with its trigger and result. The trigger is an order that is composed of one or multiple radiology procedures. Each radiology procedure results in an external diagnostic report. The radiology customer may be notified at the end of the process about the result availability.

The interpretation process is initiated by the existence of images or other radiology evidences to be interpreted. Interpretation is one of the radiology processes. Its inputs, images and evidences, are the results of other radiology processes such as image acquisition, image processing, or other evidence creation processes. The image acquisition process includes scheduling the acquisition steps and acquiring the images. The image processing process includes the creation of additional images derived from the acquired ones such as three-dimensional reconstruction. The evidence creation includes performing measurements or computer aided diagnosis on the images. These sub-processes are shown in Fig. 2. The interconnections between the image processing and the evidence creation processes are not discussed since this does not affect reporting. Both processes are represented as one post-processing process.

The interpretation process usually starts after the post-processing ends. The post-processing usually starts after the acquisition ends. In practice, this ideal sequencing is difficult to implement primarily because there is not a definitive end to the acquisition or post-processing. A technologist can append images for the same procedure at any time. Furthermore, variations in the sub-processes sequencing exist. Some procedures do not require post-processing; others can be urgent in which case the interpretation could start as soon as images are available even if the acquisition has not yet ended.

Therefore, the interpretation trigger is not a tangible signal. As a minimum, images are needed to start the interpretation process. Whether to trigger interpretation as soon as some data are available will depend on the

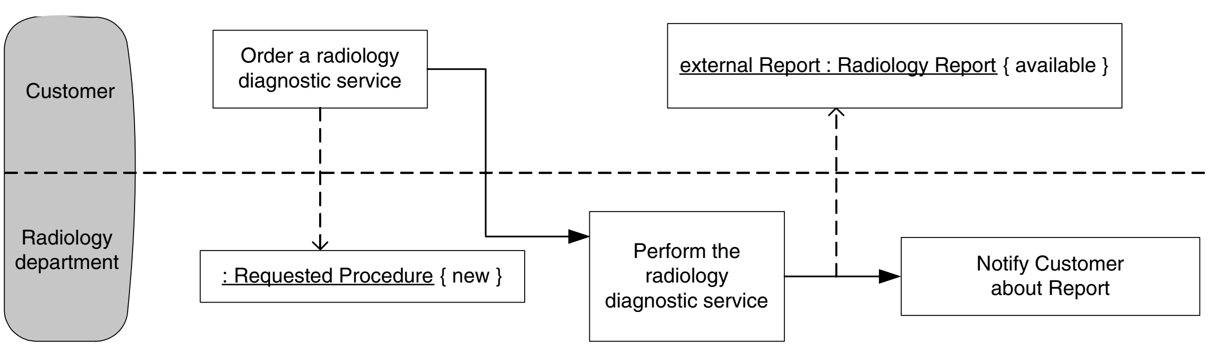

Fig. 1. The radiology process.

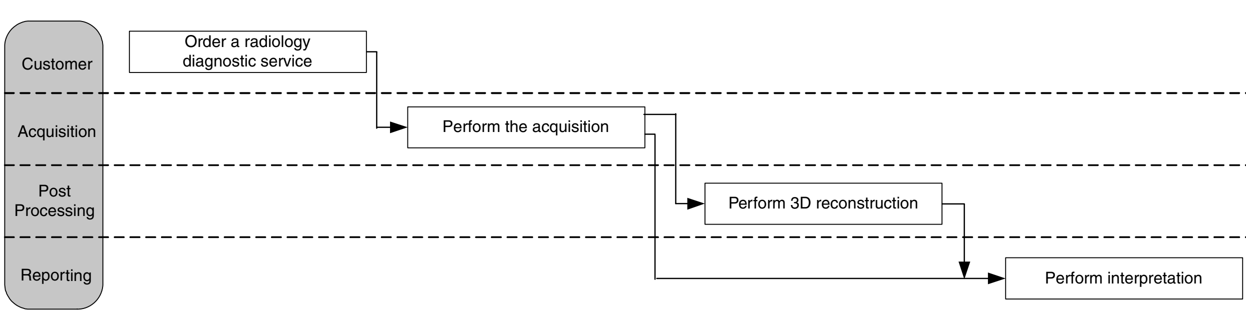

Fig. 2. The radiology sub-processes.

procedure emergency and institution policies. Commonly, interpretation is triggered when all expected data are available. The expected data are derived from prior knowledge about the overall procedure protocol that describes the procedure's usual acquisition, post-processing and results steps.

3. Interpretation data model

The data entities relevant to the interpretation process are the requested procedure and the report. A requested procedure instance results in exactly one report instance that is available outside the radiology department (Fig. 3). A referring physician that has requested a radiology procedure is interested in receiving the radiology report. There is always one radiology report that is accessible from outside the radiology department for each performed procedure, even though within the radiology department, one procedure may result in more than one report. When a report is revised and modified, only the amended report is accessible by clinicians, while the non-modified and the modified instances are archived and associated with the same procedure, within the radiology department. Furthermore, the amended report replaces any document that was previously made available outside the radiology department. The mapping between the procedure and the report is one-to-one as seen from outside the radiology department (Fig. 3). But the relationship between the procedure and the report instances is not one-to-one as seen from within the radiology department. Report amendment involves an association between one procedure and more than one report (Fig. 4).

On the other hand, multiple procedures may result in one report instance. Three procedures, CT chest, CT abdomen, and CT pelvis may be requested at the same time, for example. Although three different reports, one for each procedure, may be generated, one report instance that fulfills the three procedures is more practical and clinically appropriate. This depicts an association between multiple procedures and one report (Fig. 4).

Moreover, if a radiology process is not completed, a procedure may result in no report at all. Examples include cases where the patient cancels the visit or the acquisition is discontinued because the patient died. This illustrates an association of one procedure with zero report (Fig. 4).

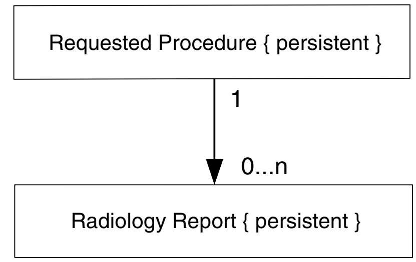

Fig. 4. Interpretation data model.

4. Interpretation workflow modeling

Modeling a process requires the description of tasks, roles, and routes [21]. Tasks are the individual piece of work executed by a performer. Roles are the performers who participate in the process. Routes are the workflows and decisions that connect the tasks together. Therefore, they define the path an individual work item takes through the process.

4.1. Interpretation tasks

The business process is a collection of steps, or tasks. They are an identifiable piece of work, done at a certain point in time, by a single actor, or multiple cooperating actors.

The interpretation process traces a single work item, a requested procedure that needs interpretation, from trigger event through to result. The work item is transformed along the way. Any activity that changes the report, moves it along or introduces a delay is a step that needs to be identified and described [25]. To identify the interpretation steps, we consider the ones that result in: (1) work being performed on the report, (2) a state change in the direction of the completion or in the opposite direction, and (3) a delay without changing the report state nor moving it along, but in stopping some subsequent step to proceed.

Among steps that result in work being performed on the report, we have identified interpretation, dictation, and transcription. The interpretation is a step performed by a radiologist who examines the acquired images and evidences to generate the report content. The dictation consists in recording a discussion of findings, impressions, and diagnosis into an audio file. The transcription consists in transforming the audio data into a document.

Among steps that result in a state change, we consider the verification and the review. The verification consists

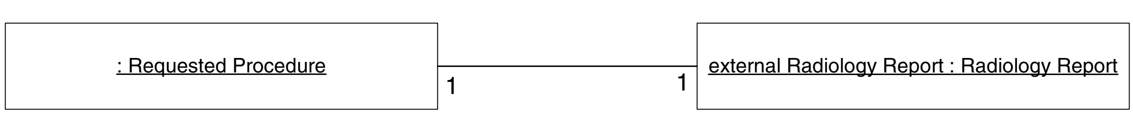

Fig. 3. Relationship between a requested procedure instance and its external radiology report instance.

of verifying the correctness of the transcribed report content. The verifying radiologist is accountable for the report content. The review consists of reviewing a verified report content followed by a decision to agree or to disagree with its content. Therefore, reviewing a report implicitly includes an interpretation task.

We have also identified delay steps when interpretation or verification cannot proceed awaiting an external input such as a new acquisition or an old report.

On the other hand, an amendment task consists of adding a section to a verified report to correct or append its content. To keep the model intelligible, we have considered it as a single task where in fact it is a process that may involve multiple steps such interpretation, dictation, transcription, and verification. The amendment process is similar to the interpretation process.

4.2. Interpretation roles

An actor is any identifiable person or group that handles the work between the process trigger and the achievement of the process result. An actor can be an information system or an automated device. It is important to identify all actors that handle the work even if their contribution has no value added. By handling the work, an actor is preventing subsequent tasks to take place and thus affecting the workflow. Since we consider no difference between an actor and a role, we use these terms interchangeably.

Different individuals are involved in performing reporting tasks: a radiologist who is responsible for interpreting the images as well as verifying the report content; a transcriptionist (or a speech recognition system) who is responsible for transcribing audio data into an electronic document; a radiology resident who is being trained to become a radiologist. Since the resident is a trainee, he usually needs feedback from a radiologist. The resident responsibilities vary according to his or her experience. A senior resident may be able to generate a report that is made available outside the department while a junior resident may not.

4.3. Swimlane notation

The steps in the process interrelate through sequence and flow; the completion of one step leads to the initiation of the next one. To depict the workflow, swimlane diagrams are used [22,23]. A swimlane diagram is a UML diagram that is used to illustrate activity flows. It shows what is done, by whom and in what sequence by tracing the path of a report item as it flows through the process. It shows the actors involved, the steps they accomplish, and the flow of work between them. The actors are listed down the left side of the diagram. Each actor in the process gets its own-labeled swimlane, delineated by dotted lines. A box represents a task; it is placed in the swimlane of the actor that performs it.

Arrows indicate the sequence of tasks: the flow of work from one step to the next.

Arrows entering a step box show the preceding steps necessary for that step to begin. Two different lines going into a step means both preceding steps must occur for that step to begin, while two lines joining and then going into the step box show that one or the other preceding steps must occur before that step can begin (Fig. 5).

Arrows leaving a step box show the following steps. When the workflow is directed to mutually exclusive alternative flows according to a decision or a condition, only one branch leaves the step box and forks into multiple branches. Multiple branches leaving the step box indicate a situation in which multiple simultaneous flows are initiated (Fig. 5).

4.4. Interpretation information flows

We present models for common flows that involve dictation, transcription, and verification. Models for flows that involve senior or junior resident performers are also presented. Report amendment and delaying steps are modeled as well.

The most common interpretation workflow is also the most traditional one. It is very simple and consists of the sequence of interpretation, dictation, transcription, and verification tasks (Fig. 6). The radiologist performs interpretation, dictation, and verification while a typist or a speech recognition system usually performs the transcription task (Fig. 7). Variations from this sequential flow exist. While verifying the transcribed report, the radiologist may correct it by dictating the correction and handing the report back to transcription.

Pre-defined reports are documents than can be generated automatically. Their content may be assembled from pre-configured text and from patient specific information. They can be associated with the procedure type. They enable efficient workflows. Fig. 7 depicts an interpretation workflow where, after the interpretation, the radiologist may choose a predefined report and verify it without delay, or decide to dictate the report

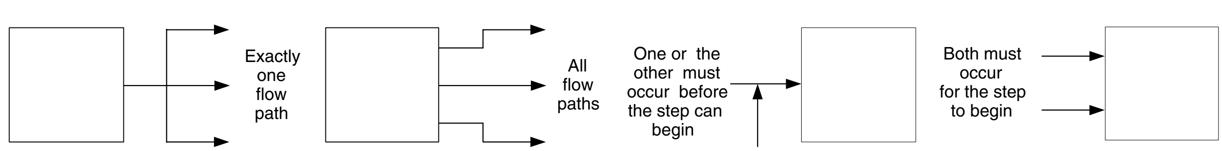

Fig. 5. Task sequencing in swimlane diagrams.

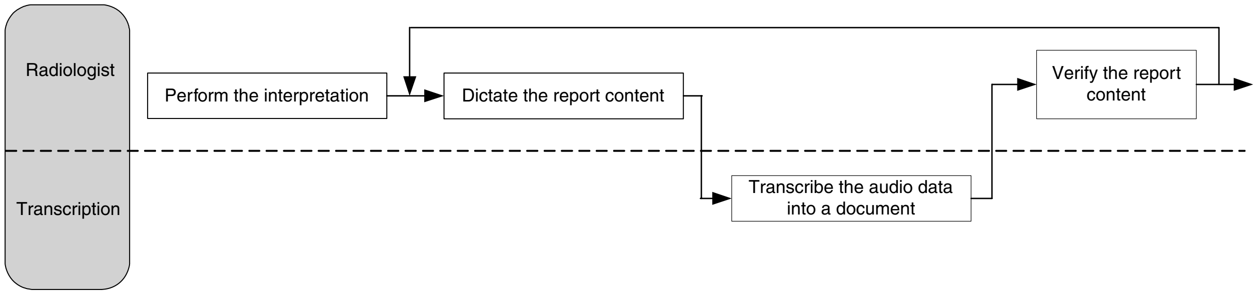

Fig. 6. Common interpretation workflow.

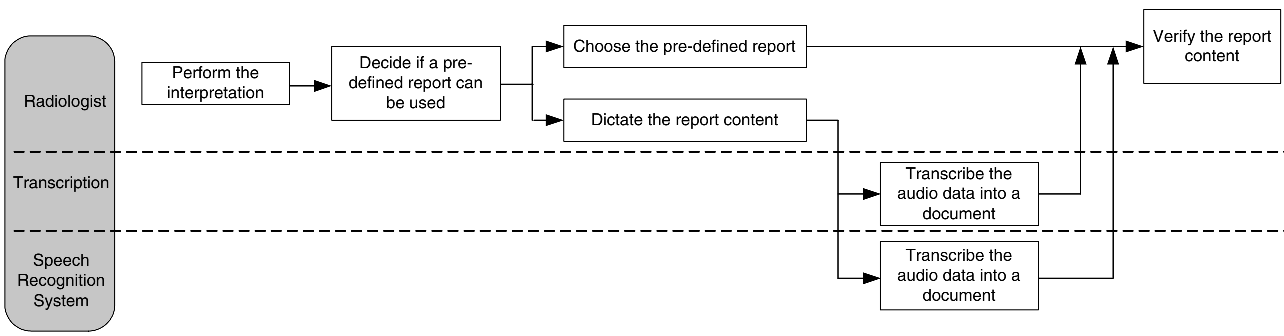

Fig. 7. Workflow involving pre-defined reports.

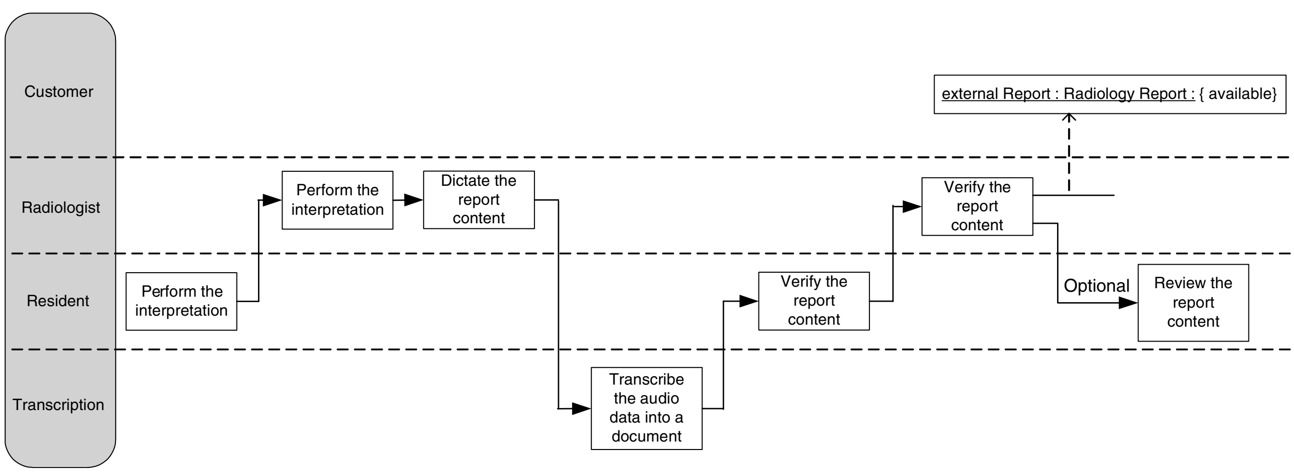

Fig. 8. Workflow involving a resident.

content in which case the subsequent flow follows the one described in Fig. 6. Pre-defined reports permit very expeditious workflows. However, in radiology, structured input configured as pre-defined sections or even sub-section text is more suitable for modeling the interpretation [17]. The radiologist may choose pre-defined text elements to create the report and may dictate free text if needed.

In university-affiliated hospitals, radiology students are involved in reporting. As part of his training, the radiology resident performs the interpretation independently from the radiologist. The resident may verify the report and optionally review the final result for feedback (Fig. 8). The external report is made available only after its verification by the radiologist. However, if the resident is senior, the workflow is substantially different (Fig. 9). A senior resident performs the interpretation, dictation and verification after which the report is made available externally. The radiologist verifies the report and either agrees or disagrees with its content. In the case of an agreement, the radiologist co-verifies the report. In the case of a disagreement, the radiologist corrects the report. Usually, the correction is achieved by adding a section according to the workflow described in Fig. 6. After correction, a new external report is made available to replace the previous incorrect one. The recipient of the result is notified that a new version of the report exists.

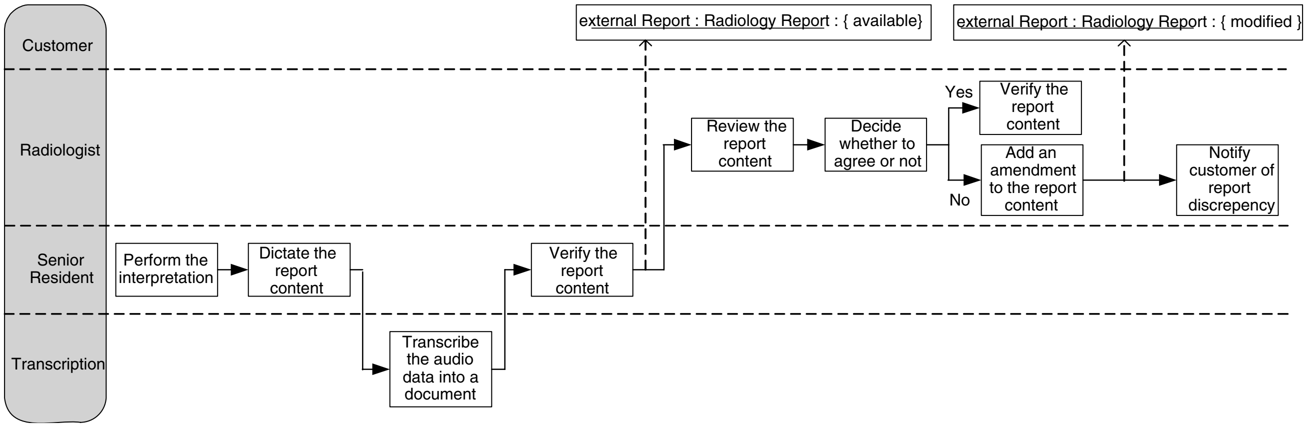

Fig. 9. Workflow involving a senior resident.

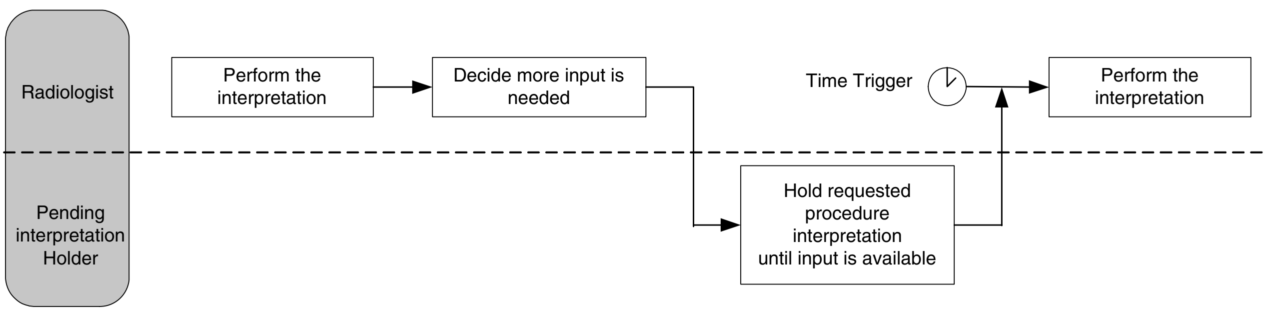

Fig. 10. Workflow involving a delaying step.

Delaying steps are important for workflow modeling. They introduce inefficiencies. A delay step occurs when the interpretation cannot proceed usually because more input is needed. Examples include the case when the old study is not yet available for comparison or when the images need to be processed or re-acquired. A common practice to deal with delaying steps is to use a time trigger that starts the subsequent step after a specific elapsed time interval (Fig. 10). Another delaying step occurs when the typist cannot transcribe the dictated text and must return the work back to the radiologist asking for information.

5. Interpretation workflow implementations

Radiology reporting tasks that are performed by radiologists consist of interpretation of images and evidences, dictation, and final reports verification. While interpreting or dictating, the radiologist visualizes images and evidences, and focuses on them. Images and evidences are thus the input data for the interpretation process. Therefore, image visualization is essential for interpretation. Focusing on images and performing interpretation are executed simultaneously by the same person. In the following subsections, we will present and discuss various implementation environments that integrate interpretation worklists with image visualization.

5.1. Non-integrated environment

Traditionally, image visualization and interpretation worklists are provided by different radiology applications: an image display application and a radiology information system that manages the reporting workflow. Usually, these different applications run on different computers, side by side; they do not share information. In a non-integrated environment, the user has to interact with different applications, to select the interpretation work item on one system and to find and display the associated images on the other. This interaction requires a cognitive effort to achieve a mental mapping between information displayed on different graphical user interfaces. Such non-integrated systems are not efficient at all because the user has to select the interpretation work item twice, on two different systems. The other disadvantage of such non-integrated systems is that the link between the interpretation input data and the reporting work item is done mentally and manually, which may cause occasional errors and delays.

Therefore, such setting is impractical. In small sites where integration between various applications is not achieved, typically because integration cost does not justify the gain in efficiency, the dictation worklist is provided by the visualization workstation and the reporting workflow with its intermediate status may not be tracked.

5.2. Custom-integrated environment

In custom implementations, one application may drive the other by providing a shared identifier that relates to a specific reporting work item. Common identifiers include the accession number or the procedure identifier. This custom integration relieves the user from selecting images or other input data. In fact, by selecting the dictation work item on the application that is managing the reporting workflow, associated images would automatically be visualized on the visualization workstation. This solution still requires the user to interact with different workstations. Moreover, it suffers from problems that come with private integration such as the initial implementation cost, the maintenance cost and the replacement cost that occurs if one of the integrated systems is changed or upgraded.

This customized integration is specific to the applications that are integrated, as specific software development is implemented. When one of the applications is changed, the integration software needs to change. Where as, for an integration that is implemented according to a standard framework, engineering effort to develop the integration software is spent only once.

5.3. Integrated environment with context management

Another integration framework enables independent applications to view data for a single subject on a user's workstation. This framework is based on the health level seven (HL7) context management standard (CCOW) [26]. Context management enables multiple applications to be automatically coordinated and synchronized. The user is able to transition from one application to another without going through the mechanism of selecting the same context object several times. Therefore, selecting a specific item on one application would automatically select the corresponding item on the second application.

This framework is based on an architecture that allows multiple applications to automatically and cooperatively change their state whenever the user sets a new value for one or more clinical subjects of common interest. Such subjects include the user identity, the patient identity, and the DICOM study identity. The CCOW architecture is based on a shared context manager. By sharing the patient context, for example, the context manager is informed when the user selects a patient in one application; it then informs other applications that are participating in the same context about the new patient change, which results in the selected patient data being displayed in all applications.

IHE has defined the patient synchronized applications integration profile (PSA) that enables patient selection synchronization between multiple applications on a workstation desktop. Context sharing could bring a solution for the problem of mapping between images and interpretation work items. However, patient sharing is not sufficient, as a single patient may have multiple radiology procedures to be interpreted. Therefore, to differentiate between multiple procedures for the same patient, sharing of the DICOM study subject is necessary.

Even though CCOW framework provides a standard mechanism for integrating multiple applications, it does not allow any workflow management. In fact, the information flows described in the previous section cannot be implemented. Therefore, new developments by the DICOM standard that enable the implementation of the reporting workflow between different systems are discussed hereinafter.

5.4. Integrated environment with DICOM

Radiology interpretation may take place between different systems in different institutions. A common example is when acquisition is scheduled and performed on one site such as an imaging center, interpreted on another site such as a hospital, and transcribed remotely from home. In such situations, the interpretation process workflow may be managed by a system in the imaging center that is completely independent from the system on which the interpretation takes place.

The framework that is enabled by DICOM answers the radiology interpretation integration requirements for workflow management between various systems. Workflow management is addressed independently of persistent information management such as the management of images and reports. A solution for integrating images and reports from different institutions, in the same electronic record, is proposed by the IHE cross-enterprise document sharing for imaging (XDS-I) integration profile [24].

Basically, DICOM provides a network transaction that enables a user to query for reporting tasks that need to be performed. It also provides another network transaction that informs the system that is managing the workflow about the exact tasks that have been performed by the user. These two transactions enable information sharing in two directions between two different systems, one that manages the workflow and one that performs the reporting task. The DICOM general purpose worklist (GP-Worklist) enables a system to query a reporting worklist from a workflow manager using a combination of some query keys; likewise, this transaction requires the worklist provider to answer the query by sending a list of work items that match the query criteria (Fig. 11). The DICOM general purpose performed procedure step (GP-PPS) enables a system performing the reporting task to send feedback about what was really done including the performer identity and the action date and time (Fig. 11).

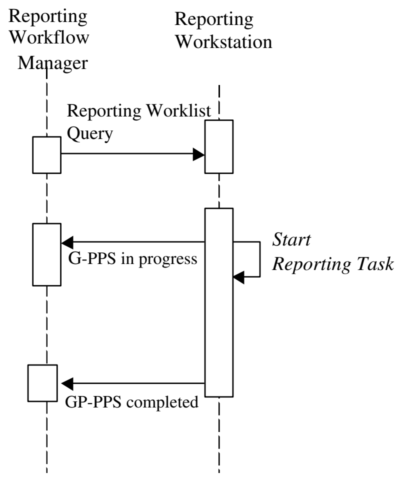

Fig. 11. DICOM transactions that enable integrated workflow.

On the other hand, to enable common understanding of tasks between various systems, DICOM mandates the use of codes. A code value is unique within its coding scheme scope. Codes are used to specify tasks unambiguously. Standard codes have been defined by DICOM for common interpretation tasks such as dictation, transcription, and verification. These standard defined codes can be extended to specify other tasks. Codes are used within the DICOM transactions to describe what is scheduled, what is performed and what are the suggested subsequent steps.

DICOM standard transactions and codes enable an integrated interpretation workflow implementation. However, DICOM did not specify how to use the transactions and the codes to achieve an integrated workflow implementation. The IHE reporting workflow integration profile provides a solution for an integrated workflow implementation based on DICOM transactions. It will be presented and discussed next.

5.5. Integrated environment with IHE

Integrating the healthcare enterprise has defined many integration profiles that specify how to implement integration capabilities between different equipment from different vendors [24,27]. IHE is an initiative sponsored jointly by the radiological society of North America (RSNA) and the healthcare information and management systems society (HIMSS) to stimulate integration of healthcare information resources. The IHE reporting workflow integration profile describes a general framework based on DICOM to implement integrated reporting workflows between different systems.

This framework permits the reporting workflow management by means of worklists for reporting tasks. These worklists are generated by the workflow manager and can be queried by systems performing the tasks using DICOM GP-Worklist. The user selects a workitem, performs the task, and the resulting status is returned from the system performing the work to the system managing the work using DICOM GP-PPS.

IHE defines actors to specify system behavior. An IHE actor, in a specific profile, has well defined, relatively small, responsibilities. Actors can be grouped together to provide an information system available commercially as a single product. Among reporting IHE actors, the report manager provides functions related to reporting workflow management. The report manager functions include scheduling reporting tasks, providing worklists for the various reporting tasks, and tracking reporting workitems status. Additionally, the profile defines the report creator actor that fulfills the work associated with a specific task, such as dictation, transcription, and verification, to advance a specific report in the direction of completion. It retrieves worklist entries for reporting tasks from the report manager and provides notification of task completion, allowing reporting status tracking.

These actors collaborate using DICOM transactions to carry out the interpretation process. Performing a single step involves a data flow that is illustrated in Fig. 12 and network transactions that are illustrated in Fig. 11 and Fig. 13. The report creator uses the DICOM general purpose worklist transaction to issue a query for a reporting worklist. The report manager generates a list of reporting tasks that satisfy the query and returns it. Examples of queries include a query for all interpretation tasks of a specific procedure type, or all verification tasks for a specific logged in user (Fig. 11). Tasks are identified by standard codes allowing the user to ask for a specific type of task, such as the dictation worklist or the verification worklist. Each workitem in the returned list includes references to input data (Table 1, work item information). For example, an interpretation task includes references to images, evidences and old reports that are the task input; similarly, a verification task includes a reference to the actual report instance to be verified. Therefore, when working on specific task, the input data needed to execute that task is known and can be displayed automatically, after retrieving if from the appropriate repository (Fig. 12).

Two transactions allow reporting status tracking. The report creator informs the report manager that it has

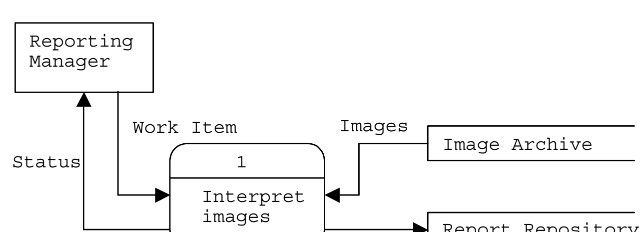

Fig. 12. Data flow diagram for the interpretation task.

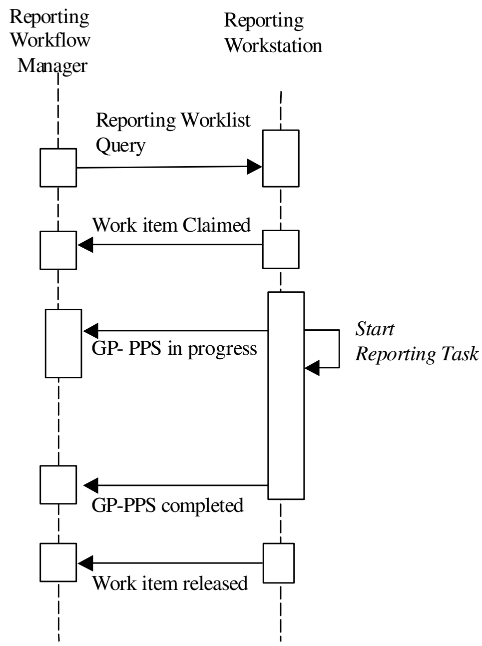

Fig. 13. Integrated reporting workflow with exclusive access to tasks.

started working on a specific task by sending a DICOM GP-PPS with a "in progress" status. Likewise, the report creator informs the report manager that it has completed working on a specific task by sending a GP-PPS with a "completed" status (Fig. 11).

By completing a task, the user may generate new results such as new documents. The output data are stored in a repository (Fig. 12). Additionally, the creator system informs the report manager about the results generated during task execution (Table 1, status information), by referencing the output data in the GP-PPS transaction. The output information is important because a workflow step result is usually the input of a subsequent workflow step. Consequently, the report manager, when informed about a specific step result, may use that information to specify subsequent steps input. The report manager manages the data flow along the workflow.

Moreover, since the report creator may carry out several reporting tasks in a single step, it informs the manager about the tasks that have been achieved. This is accomplished by listing all performed tasks codes in the GP-PPS transaction (Table 1, status information).

Furthermore, the report creator may suggest subsequent tasks to the report manager. This is achieved by providing codes for the requested subsequent tasks in the GP-PPS transaction (Table 1, status information). When informed about performed tasks and suggested subsequent tasks, the manager decides the next work item that needs to be performed toward achieving a final report.

Multiple report workstations may work with a single reporting workflow manager. Therefore, in order to prevent a user from working on a task that has been already started by another user, DICOM provides the general purpose scheduled procedure step (GP-SPS) transaction. This transaction is sent by the report creator to inform the report manager that it has started working on a task. This mechanism ensures an exclusive access to a specific task. Claiming a specific task prevents others from claiming the same task before it is released. The workflow manager can remove that task from its worklist and refuse any other claim related to it. The same transaction is used to release the task (Fig. 13). DICOM has defined several statuses for the GP-SPS. A "completed" transaction informs the workflow manager that the task is done; a "discontinued" transaction informs the workflow manager that the task cannot be completed at the moment, so it should be removed from the worklist momentarily or permanently. The workflow manager uses its own logic or may wait for other conditions to be met before putting back the same task on its worklist

Table 1
Exchange of information

Data flow	Information content	DICOM transactions
Work item	• Patient information such as patient name • Order and procedure information such as accession name and procedure description • Scheduled work item information such as description, date, performer • Reference to input data	GP-Worklist
Status	• Performed step information such as date, performer, description, and status (completed or in progress) • Suggested subsequent work item • Reference to output data	GP-PPS
Input data (depicted as Images in Fig. 12)	DICOM SOP instances such as images, presentation states or structured reports	Query/Retrieve (DICOM C-Find, C-Move)
Output data (depicted as Report in Fig. 12)	DICOM structured report or non-DICOM output such as audio file	Store (DICOM C-Store)

again. A "scheduled" transaction informs the workflow manager to keep the task on the worklist because it is not completed yet.

The framework described so far enables a reporting workflow implementation between heterogeneous systems using the DICOM standard. However, since the interpretation process goal is to generate the radiology report, many preliminary versions of that report may be produced and transformed before generating the final one. Consequently, the various workflow tasks create or modify the preliminary report versions towards its final form. These documents, preliminaries and final, are usually multimedia documents [28]; they may contain references to radiology images, audio and text content; they should be stored, displayed, and communicated in a standard way between various systems involved in the workflow. DICOM provides a standard encoding for the multimedia radiology report [17]. Alternative standards for diagnostic report content encoding are also available such as CDA [29]. Although the described framework is not limited to DICOM content, managing other formats requires the ability to query and transfer other contents with standard well-defined protocols. While, this is not possible for document formats that only specify content such as MS-Word, DICOM has provided the same querying and transferring mechanisms for reports as for images. Therefore, a reporting framework involves two additional actors: a repository that is responsible for providing the report storage and for answering queries and retrieves requests, and a reader that is responsible for rendering diagnostic reports and issuing queries and retrieves requests.

6. Conclusion

Information technology improves patient care by reducing errors. When information is entered at one system, then transferred and shared between multiple systems, typographical errors are eliminated and data consistency ensured. However, information technology can fundamentally reshape the way healthcare is provided. It is much more than an automating force or a tool to share information. In fact, collections of individual or functional tasks can be broken down into processes. Consequently, information technology has a major role in enabling healthcare process redesign in order to achieve maximum efficiency and effectiveness.

But, processes need to be understood and modeled before they can be reengineered or redesigned. Therefore, in this paper, we have identified and modeled the radiology interpretation process. Radiology interpretation implies several actors, steps, and information flows. We have identified the actors involved in reporting. We have also identified the tasks performed on a single report before it becomes a final result. To better frame the interpretation process, we have depicted an overall process map, identified the interpretation process boundary and positioned it with respect to other radiology processes. Furthermore, we have modeled several common interpretation workflows. Even though, little variations in interpretation workflow may exist between institutions, there are simple common workflows such as the traditional one that involves a dictation, a transcription and a verification steps. There are also more complicated workflows, but yet very common, such as the one that involves a radiology student or that include delaying steps. Our model for the various workflows is essential for implementing efficient and effective interpretation management systems.

Reporting may involve heterogeneous systems. We have discussed and compared various integrated interpretation environments. More specifically, we have presented and discussed the IHE reporting framework that is based on standard network transactions to allow various workflow implementations. Our workflow model can be implemented between different systems by using the IHE reporting framework.

But, IHE did not define any specific information flow, and did not include any specific workflow model. And since workflow modeling is crucial for process implementation and redesign, our work contributes to IHE by providing a workflow model that can be implemented with the framework. Furthermore, by providing a complete workflow model, we help the understanding of IHE transactions technical and complex details.

Process improvement is a continuous effort and process redesign is dynamic [3]. It should be constantly investigated whether it is possible to carry out a process in a new improved way. Also, information technology is continuously evolving and forthcoming technologies will certainly have a substantial impact on healthcare of next decades. This recursive relationship between information technology and business process redesign suggests that healthcare organizations oversee continuing redesign and tuning as well as ensure that information systems support process flows.

Accordingly, process improvement requires analysis, and then accurate measurements are needed to assess present and future enhancements. This paradigm is completely new in healthcare, and process measurements are yet to be specified and recorded [30–33]. General measurement examples include cost reduction, time reduction, output quality, and quality of work life. In radiology, these general measurements translate into reduction of referring physician waiting time for result, reduction of patient presence time within the department, reduction of wasted time between interpretation, transcription, and verification, reduction of time before firing billing claims, reduction of billing errors, increased quality of care, increased quality of work life, and increased professional retention. This measurement list is not exhaustive; a more comprehensive and analytical study about measurements will certainly help pioneers of healthcare process redesign to record and share their failures and successes.

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Rita Noumeir is a professor at the Department of Electrical Engineering of the University of Quebec, Ecole de Technologie Superieure in Montreal. Her main research interest is the Healthcare Information Technology, specifically, Interoperability, Electronic Patient Record, Security, Information Confidentiality, and Image Processing.

As a member of both Technical and Planning International IHE Radiology Committees, Dr. Noumeir took part over the last 4 years in developing many IHE Integration Profiles in Radiology such as the Reporting Workflow Profile, and in organizing several Integration Demonstrations. She is a co-founder of IHE Canada and a co-chair of its steering committee.

Dr. Noumeir contributed to many Research and Development projects in collaboration with several Canadian and international companies in Medical Imaging and Healthcare Information. Currently, she collaborates with the Diagnostic Imaging Team of Canada Health Infoway to define the Principles and Architecture for sharing imaging information between multiple Healthcare Institutions. She plays a leading role in the development of this solution that is published as an IHE Integration Profile for which she is the editor.

Rita Noumeir holds a PhD and a Masters degree in Biomedical Engineering from Ecole Polytechnique of Montreal specializing in Medical Imaging. She is member of numerous Canadian and international scientific associations.