INTERORGANIZATIONAL WORKFLOW IN THE MEDICAL IMAGING DOMAIN

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Abstract: Interorganizational Workflows are increasingly gaining relevance in enterprise information systems, particularly in developing internet-based applications. A process model has to be shared to enable work items to be managed in different workflow engines. This paper discusses the state-of-the-art for three interorganizational workflow models: capacity sharing, case transfer, and loosely coupled model. Furthermore, progress in workflow standardization in the medical imaging domain as well as its main concepts and software components are introduced. Key workflows, tasks, and protocols of the medical imaging domain are discussed. The presented interorganizational workflow models are then applied to the medical imaging domain and advantages of all models are discussed. Finally, the required infrastructure for a Web-service based design is discussed, conclusions for Web-service based implementations are presented, and further research areas are concluded.

1 INTRODUCTION

Interorganizational workflows can be thought of integrating different workflow models or modeling a consistent workflow for interorganizational processes. The medical imaging domain has been one of the first fields of standardization of workflows and is well suited to apply such models.

This paper first introduces basic concepts of interorganizational workflows as well as the workflow reference model and discusses basic concepts of the medical imaging domain. Three workflow architectures, the *Capacity Sharing Architecture*, the *Extended Case Architecture*, and the *Loosely Coupled Architecture* are discussed in more detail. The paper gives an overview of the major software components used within the medical imaging domain and the workflows they implement. Recurring tasks such as "Patient examination" or "Diagnosis and Reporting" are described in more detail. Also the integration of key technologies such as digital dictation and speech recognition are considered and special security requirements of the domain are defined. Furthermore common processes as defined by major medical imaging standards are described and their implementation in the software components is shown.

In section 4 we apply the three introduced architectural workflow models to the medical imaging domain. Seven tasks of this domain are introduced and associated to different architectural models. These tasks are supported by software products, implementing processes of patient worklists management, modality performed procedures, image acquisition and distribution, and medical report generation. Depending on the processes under consideration, different workflow models fit best to the business partners' interactions.

Based on the applied workflow models, software designers should be enabled to implement Web-service based products. Furthermore, the architectural models should allow for an evolutionary adaptation of the products using Interorganizational Workflow techniques. Suggestions for such implementations are given and further research areas are suggested.

2 INTERORGANIZATIONAL WORKFLOW

Interorganizational Workflows (IOWF) allow business partners to work together. All models introduced here are based on the workflow reference model of the Workflow Management Coalition (WFMC, 1995). In an interorganizational workflow, each business partner might maintain its own Workflow Enactment Service to instantiate tasks. Therefore the main architectural considerations are related to the Interface 4 of the WFMC-Reference Model where the interaction between Enactment Services is covered.

We will further cover client applications of the medical imaging domain as defined in the Interface 3 of the reference model. UML state chart notation (Fowler, 2000) will be used for the processes definition as suggested in (Aalst and Weske, 2001b), related work covering different modelling techniques with UML and Petri Net notations can be found in (Aalst and Weske, 2001a). For all workflow networks (WF-nets) presented the soundness criteria (Aalst and Weske, 2001a) is proven to provide a consistent model that can be chosen for an implementation. As suggested in (WFMC, 1995) the workflow client applications can be server or client-side and, depending on this, interacting with the workflow management system itself or a client-side worklist handler. Both are implementations of WFMC-Interface 3. All other interfaces, process definitions and monitoring tools are out of the scope of this paper.

2.1 Models of IOWF

Interorganizational Workflow architectures are described in detail in (Aalst and Weske, 2001b). They can be categorized in different levels of integration.

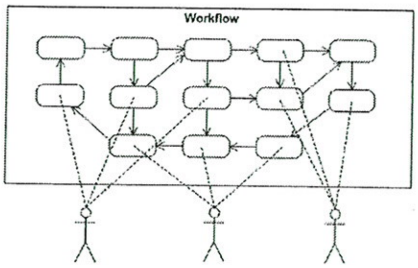

Figure 1: Capacity Sharing

The *Capacity Sharing Architecture* (Figure 1) requires a unified workflow; processes, work items and resources are shared throughout the domain. Two important characteristics of this architectural model are (a) the reduced complexity of a workflow process definition and (b) that the process execution is under control of a centralized workflow manager. It is difficult to implement changes to the process definition, because they influence all workflow client applications and make it even more difficult to maintain consistency between the workflow models. The business partners also have to share a common software infrastructure. We will use this workflow model for the processes of *remote speech recognition* and *remote imaging diagnosis*, presented in section 4.

A second architecture is the *Case Transfer Architecture* which uses a case as a shared architectural component. Figure 2 shows a scheme for this model. Each business partner has a copy of a workflow process description. The process specification is replicated and the Cases reside at exactly one location. Transfer occurs to balance workload or because a specific location doesn't implement a process. In this paper we will use this model for a "Patient Case transfer" between two radiological departments using DICOM and non-DICOM functionality. In this case the model is used for organizational reasons. In contrast to the Capacity sharing Architecture, it is possible, to change software infrastructure, for example, between a radiolocal institute and a hospital department.

As the third workflow architecture model the *Loosely Coupled Architecture* will be examined. In this model, as depicted in Figure 3, each implemented process is cut in pieces and enacted decentralized.

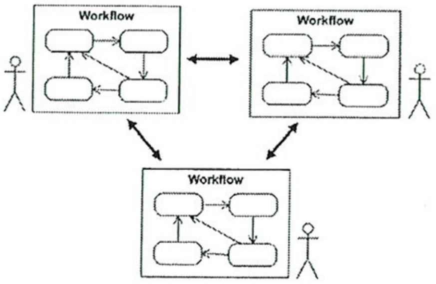

Figure 2: Case transfer

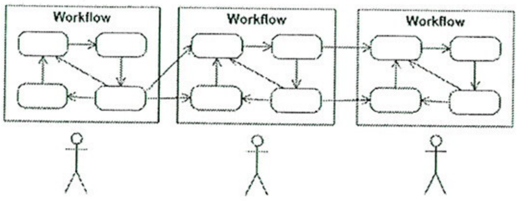

Figure 3: Loosely coupled Case

Execution may also be performed in parallel. Business partners implement their own workflows and interfaces (or protocols) to exchange process information are defined. The business partners act in a loosely coupled fashion. This model is suited for communications between different health care institutions. In this paper we will apply this model to an Internet-based application for scheduling, image-, and report distribution discussed in section 4. Further interorganizational workflow models such as *Chained Execution, Subcontracting*, etc. are described in (Aalst and Weske, 2001a, 2001b) and are outside the scope of the scenarios used in this paper.

3 MEDICAL IMAGING

In this section we discuss the main facilities and software systems that are used in the medical domain, and the workflows they cover as well as existing standards that are used for the implementation and enactment of the workflows. Two system categories RIS (Radiology Information System) and PACS (Picture Archiving and Communication system) will be discussed briefly. Both systems can be viewed as the backbone of current information systems in the medical imaging domain. They are used rather frequently, comparable to ERP (Enterprise Resource Planing) systems in the business domain.

3.1 RIS and PACS

Radiologists maintain a software system called RIS (Anzböck, 2001b), a patient-management system required for all organizational tasks of the medical institution.

Its first task it to examine the scheduling as well as the registration of patients. In this case all relevant visit and diagnosis data is gathered. Furthermore it produces workflow information for the examination facilities in form of patient worklists. Management data regarding the facilities can be attached to the patient's visit data. For the report generation the RIS integrates digital dictation equipment and speech recognition technology. The dictations are transcribed manually or automatically recognized and medical reports are generated and stored within the RIS. The reports can be exchanged with other health care facilities using fax or mailbox services. The visit data is further used for payments of the insurance companies. The RIS additionally implements financial and statistical functionality.

The second main software system radiologists' use is called PACS. These software products consist of several software components supporting all parts of image management. First the medical procedures are prepared by transferring patient management data of the RIS worklists to the examination facilities, called *patient worklist management*. A more detailed process step that can be implemented is the *scheduling and performing* of *medical procedure steps*. Further processes are defined for *sending*, *querying*, *retrieving* and archiving images. These are used to communicate image data between modalities, workstations, remote storages and archive hardware. Also included are creating *print jobs* and *exchange* image studies on CD-ROM.

Each functionality is described as a part of the DICOM Standard and implemented in all available products. An introduction to PACS can be found in (Huang, 1998), more information also to the medical domain is available in (Kolodner and Siegel, 1998) and a product introduction is given in (Anzböck, 2001a and 2001b). PACS and RIS both implement a workflow model and cover implementations of the DICOM and HL7 standard, presented in the next section. Both systems have to be tightly integrated to perform tasks efficiently.

Depending on the cases and the number of involved partners different models of interorganizational workflows should be applied. Radiological institutions are business partners with a higher degree of required workflow integration because they additionally load balance task execution, while other institutions mainly use work items like Patient Records or Reports for additional processes.

In external locations a Radiologist can extend its infrastructure for remote execution of medical imaging tasks, for example Diagnosis or Report transcription. Insurance companies that interact in the settlement of medical service bills mostly implement national standards and are not covered here.

3.1.1 DICOM and HL7

The DICOM 3 standard covers a set of Client/Server communications over TCP/IP and OSI networks used to exchange Patient and Examination information. DICOM defines objects (what), services (how), and their combination as service object pairs in a client/server model. The standard covers objects like patients, visits, medical procedures, images, films, printers, and examination modalities. Additionally, notifications, data query, and exchange services based on these objects are defined. The HL7 standard is used for data exchange between healthcare providers and is more suited for non-radiological institutions. Some functionality overlaps with DICOM such as the scheduling process and the patient and result management. Other functionality such as the exchange of image data is not part of HL7. More detailed information on those standards can be found in Revet (1997) and in the HL7 standard (2000).

3.2 Medical Imaging Workflows

In the medical imaging domain mainly radiologists and other healthcare institutions are interested to speed up diagnostic processes and to distribute patient information reliably and securely. Each institution performs part of the medical imaging workflow. Figure 4 provides an overview on the main parts of the overall medical imaging workflow.

Seven different tasks are shown in Figure 4. First, a patient is scheduled by an assignment doctor for examination by a radiologist. The scheduling can be performed online or by telephone through a secretary. In the next step the patient's registration information is provided as soon as he arrives at the institution (or online) by the assigning facility. The patient is registered and prepared for the examination. The third task covers the examination itself performed by a radiological assistant. The fourth task consists of the patient's diagnosis and can be extended by a second professional opinion.

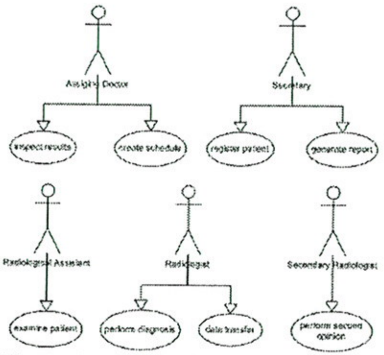

Figure 4: Medical Imaging Use Cases

The sixth task is the transfer of patient, image-, and report data between involved institutions. In most cases institutions maintain different archives for the data. The seventh task covers the inspection of the examination's results by the assigning doctor. This task is a minimal form of Task 6 where the data is not permanently stored. The assigning doctor participates in the workflow of the radiologist, while in Task 6, work item data is exchanged between different workflow systems.

The "create schedule" (Task 1) is supported by HL7 Scheduling. In the preparation phase DICOM supports patient examinations (Task 3) by worklist management as well as the query/retrieve service for image distribution and archivation. Tasks 4 and 5 can be supported by the DICOM query/retrieve service but have to be extended by HL7 patient management or proprietary functionality for the transfer of dictation and speech recognition data. Task 6 can be supported by all DICOM and HL7 work item management functions that are used to transfer data between business partners. DICOM is used for image data and between radiological institutions, and HL7 is used for other business partners. Task 7 can be implemented without any DICOM or HL7 support, if image data is required in the original format, then the query/retrieve service is used.

The main Roles used in the domain are Patient, Radiologist and Assigning medical institution. Important work items used throughout the tasks are associated to Patient, Schedule, Assignment, Examination, Image, Report, and Dictation. Those hold most information of the medical imaging domain and are also modeled in the DICOM and HL7 standards. As suggested in (WFMC, 1995) server-side workflow manager and client-side worklists are used for the execution of tasks. This Interface 3 definition also fits to client/server based models of DICOM and HL7. In section 4 we will examine the tasks in detail by applying the three different interorganizational workflow models explained in section 2.

4 APPLYING IOWF TO MEDICAL IMAGING

In this section we describe medical imaging tasks and apply the interorganizational workflow models presented in section 2 to the medical domain. For each of the architectural models we discuss a use case, where the boundaries of business partners' workflows are taken into consideration. The radiologist maintains the central workflow in this domain; the assigning doctors and second opinion radiologists participate or constitute their own workflow. Most important from this point of view is the assignment of patients, the second opinion diagnosis and the transfer of patient and all related data to other healthcare facilities subsequently and after the diagnosis is finished. We will examine further 3 different workflow models, as introduced in Section 2.1, specific for a task described above.

First remote speech recognition and diagnosis as part of task 4 is described as a capacity sharing workflow model. A radiologist in a different location performs the whole or parts of the diagnosis and reporting workflow and uses the same workflow interaction mechanisms of client applications as in the main location. The centralized control of one workflow manager is exercised by the radiologist's information system, where also the unpartitioned workflow is maintained.

Second, the exchange of patient, image-, and report data between radiological institutions (Task 6), is described in terms of the Extended Case transfer workflow model. One scenario for such an exchange is the remote diagnosis (Task 5) as discussed for the first example. Additionally a radiologist exchanges data with an institution that further processes or stores the data during a medical treatment or data is exchanged assignment because of the patient changing between healthcare providers or from one location to another. In both cases the work item data can be exchanged and used within different workflow systems that recognize DICOM or HL7 work items. The Case transfer model also simplifies the enactment service interaction. But the model requires a vertical partitioning of the work-flow. The diagnosis or further treatment of the patient in another location with a different workflow implementation suggests a case exchange after the patient examination or after the patient diagnosis and report generation.

Thirdly, the Loosely Coupled workflow model is chosen for the functionality of Internet-based patient assignment and image and report data inspection as described in task 1 and 7. Both tasks mark the endpoints of the medical imaging Use Cases. All workflow implementations before and after these processes are out of the scope of this paper. The model allows for local definition of subprocesses and only requires a protocol for data exchange. HL7 scheduling messages and XML descriptions for patient and image data are used for data exchange. This model requires horizontal partitioning between different workflow models. The separation points are also endpoints of the medical imaging workflow as suggested in Figure 1; no special consideration for pre- or post-processing, other than providing the relevant information, is given. Beside the interpretation chosen here to inspect models of interorganizational workflows, many other task model pairs can be examined. For example, towards standardization of XML based DICOM and HL7 communication, extension of the standards for digital dictation and speech recognition and widespread implementation of further parts of the standards, tighter workflow integration models will have to be taken into consideration. For proprietary functionality and interfaces a loosely coupled environment will persist.

4.1 Applying the capacity sharing architecture

We first provide a model for tasks 4 and 5, remote diagnosis and reporting. Figure 5 shows the corresponding UML state diagram. In this model a radiologist performs a diagnosis (see also Figure 1) and creates a dictation or speech recognition document. First the patient and image data that has to be reviewed is chosen from the RIS and the PACS and loaded onto the diagnostic workstation. The image data is automatically arranged by a locally performed algorithm. The radiologist starts its diagnosis by reviewing the image material and performing modifications and comments on image data. In the next step, one of two alternatives can be chosen. First a digital dictation can be created allowing a later transcription of a report; second online speech recognition can be initiated creating a report text document. All generated information is archived and the diagnosis is finished.

This model is now extended to provide capacity sharing functionality. The process can therefore be executed in parallel and load balanced between locations. The diagnosis duration can be reduced and radiological resource assignment is more effective also reducing the costs of an examination. Figure 6 shows the extended state diagram for remote diagnosis and reporting.

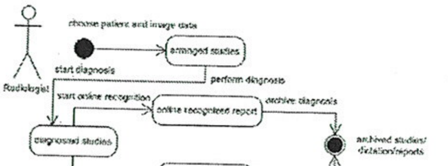

Figure 5: Remote diagnosis and reporting

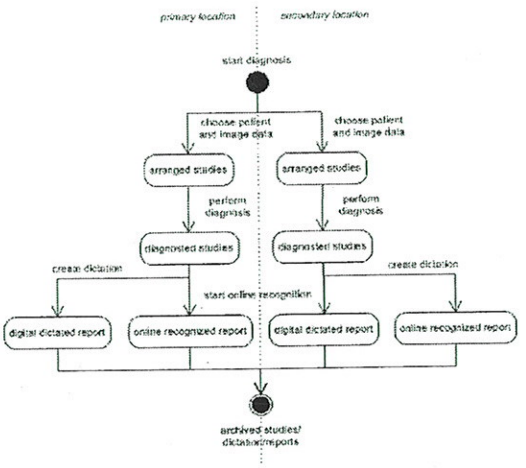

Figure 6: Workflow net with Capacity Sharing

In the first step a diagnosis task is instantiated and assigned to a specific radiologist. All further process steps are executed equally independent of other process instances. In the last step the results of the process are again incorporated into the workflow management system and tasks after diagnosis are processed transparently. Usually a primary location is defined where most tasks are executed; secondary locations are used for load balancing. Also symmetric sharing models can be implemented.

As shown in (Aalst and Weske, 2001a) the workflow model is sound. It can easily be seen that the output location can be reached with one token in place. There is no token left behind because no AND relation is used that produces more tokens. No dead tasks can be produced; there are no loops in the workflow net.

4.2 Applying the extended case architecture

As the next model the Extended Case transfer is discussed and applied. As a sample Task 6, the exchange of patient data, is chosen. Figure 7 provides an overview of the export process.

The radiologist chooses a patient record to export from his archived data. The patient initial data is provided, some in form of standard data, some still to be converted. In the next step, the DICOM or HL7 formatted data is created and the data is exported using the supported network transport mechanism (see section 3.1.1). The DICOM and HL7 formats allow exporting different work items. HL7 covers patient, visit, and result data. DICOM additionally exports study and image data.

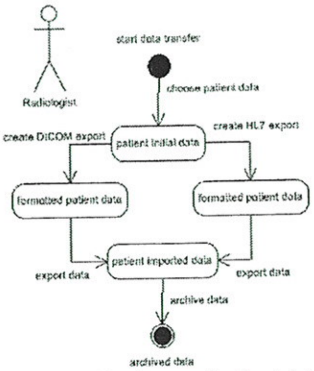

Figure 7: Exchange of patient data

Internally both protocols work different, for simplification this is hidden in the export data action. For example the DICOM standard uses the Query/Retrieve Service Class that covers the transfer of Image, Patient, and Result data between DICOM nodes.

The Case Transfer model requires the same process definition at both locations; however, it is assumed that the interaction takes place as shown in Figure 8, because of the overall workflow of the medical imaging domain and the interface definition of the imaging standards. The focal points therefore, are the exchanged work items, which are uniformly defined throughout the workflow. The synchronisation point of archived patient data (finished patient examination) provides a vertical partitioning of the workflow. The transfer is extended in terms described in Aalst and Weske (2001a) because of the possible local variations of the workflow.

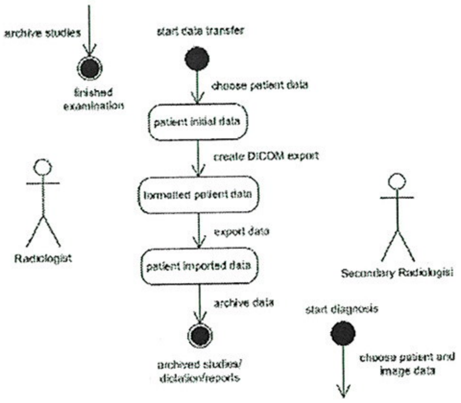

Figure 8: Workflow-net, Extended Case transfer

The export process can now be used in different parts of the workflow. To better distinguish between the first two models, the task provided here, is the examination of a patient and the transfer of all relevant data to a second radiologist who performs further diagnosis on the data. Figure 8 shows the Extended Case transfer in more detail.

In a first step the radiologist finishes the examination task and archives patient data. From here the data transfer process starts as described above. The export ends when the patient data is archived at the secondary radiologist's location. From there a diagnosis task can be executed. This interaction can be implemented between all institutions performing examination and diagnosis tasks and supporting the DICOM query/retrieve service.

Again the workflow-net soundness criterion has to be proven. For Task 6 the soundness is satisfied, because the AND relationship that produces two tokens corresponds to two linear processes where in the next step the two tokens are merged again. Therefore we can substitute the two formatting steps with one parallel step resulting in a linear process. For the linear process the output location can be reached with one token in place. No dead tasks can be produced; there are no loops in the workflow net. For Task 7, a linear process, the criteria is satisfied.

4.3 Applying the Loosely Coupled architecture

The third sample covers two tasks of Figure 1. As a first step, Task 7 is modeled where an assigning doctor inspects studies and reports from the Radiologist. Figure 9 shows an overview of this task. The assigning doctor, interested in analyzing reports, uses a Web-browser interface to choose from a list of diagnosed patients.

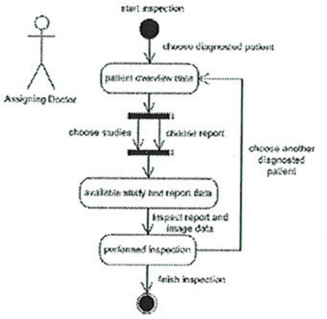

Figure 9: Inspecting Studies and Reports

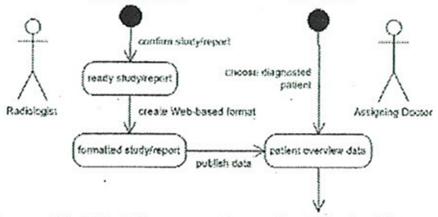

Figure 10: Workflow-net, Loosely Coupled (Inspection)

He first receives patient overview data to reduce data transfer and chooses which reports and studies to inspect in more detail. As the next step, the Web-converted (html, jpeg) patient data is transmitted and can be inspected by the doctor. The loosely coupled model of this task (Figure 10) shows the interaction of the radiologist to provide the information in this case.

The inspection task is extended with a release task on the radiologist side. He first confirms readiness of studies and/or reports. Then a Web-based format is created, this step can be omitted if the patient examination and report generation tasks end with an automatic conversion, storing different formats in parallel. In the third step the Web-formatted data is published to make them available for external inspections. The third step is necessary to allow radiologists to perform an explicit release step. This might be necessary if internally a second opinion task is executed. The soundness of task7 is satisfied because the process is linear with one loop that can only lead to an extended linearity. The number of examinations is limited to practically 10 examinations and therefore reachability can be maintained and deadlocks can be avoided.

Secondly, the scheduling of a patient is covered where an assignment doctor requests appointments from a radiological facility. Figure 11 shows the scheduling task from the assigning doctors' perspective.

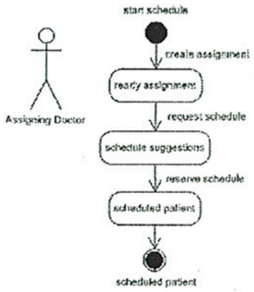

Figure 11: Scheduling

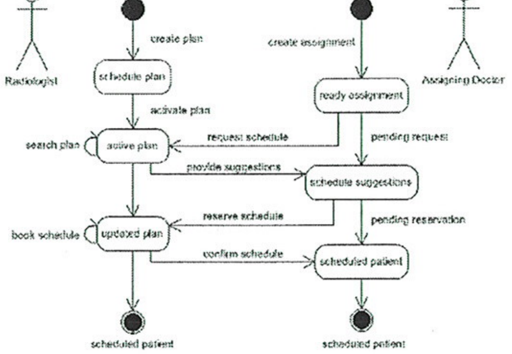

Figure 12: Workflow-net, Loosely Coupled (Scheduling)

Secondly, the scheduling of a patient is covered where an assignment doctor requests appointments from a radiological facility. Figure 12 shows the scheduling task from the radiologists and the assigning doctors' perspective. The task is split in a part that is executed by the assigning doctor and the other by the radiologist. The latter maintains an appointment database and provides an interface through a scheduling workflow client application. The schedule request is sent to the secretary and the schedule plan is searched for possible appointments. Suggestions are responded containing possible schedules. The assigning doctor chooses the appropriate one and makes a reservation (schedule). The schedule plan of the radiologist is updated and a confirmation is sent back to the assigning doctor. Reservations are made right before the confirmation is generated.

To prove the soundness of the loosely coupled interorganizational workflow model (LC-IOWF) timelines and message sequence charts have to be introduced and the workflow net has to be extended with additional places for the connection points.

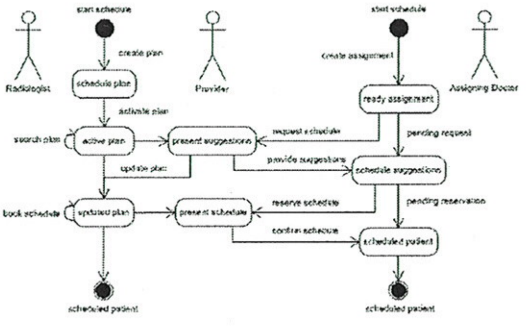

Figure 13: Provider based model (Scheduling)

The soundness then has to be proven for the extended workflow net as described in (Aalst and Weske, 2001a).

4.4 Provider based models

All models presented cover processes as peer-to-peer communications of medical institutions. Additionally to the models presented it should be possible to centralize workflow implementations in a common place at a service provider. Figure 13 shows the scheduling task in such a configuration.

As an extension to the scheduling task, a provider presents suggestions and presents schedules reserved by assigning doctors. As a major advantage the assigner has the possibility to choose between different service providers. In further refinements of this model the provider has the ability to extend the scheduling service over several medical institutions and present the "best" schedules for a requested medical procedure. Compared to other tasks presented in this paper the loosely coupled workflow model seems to be best suited for such a provider configuration. A better decoupling of the workflow dependencies can be reached by using hierarchical structure as suggested in (Kreger, 1999). Also other scenarios, such as outsourcing the "report generation" task using speech recognition, are possible.

4.5 Web-service based design

We finally introduce a first possible loosely coupled design for the implementation of the scheduling task as a Web-service. Web-services are self-contained, modular applications (components), accessible via the Web, that provide a set of functionalities to businesses or individuals. A good introduction to Web-services can be found in (Kreger, 1999).

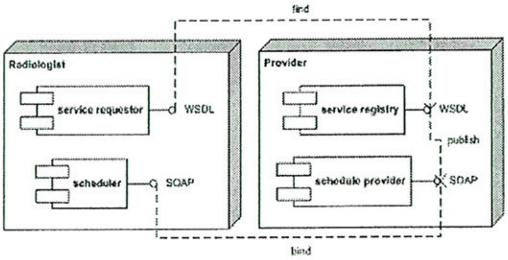

Figure 14: Web-service (scheduling task)

We consider the provider-based configuration and outline requirements for the Web-service registration infrastructure. Figure 14 shows the interfaces for the communication partners. The Web-service infrastructure requires a service requestor at the radiologist and a service provider at the provider site, implementing WSDL interfaces for finding and publishing Web-services. On the service-level the scheduler and the schedule-provider implement a SOAP interface that is binded to service requests of the provider.

It can be seen that Web-services fit to loosely coupled models because of the contract based interaction of distinct workflows. Further research is necessary to clarify whether implementation of other workflow models is possible and feasible.

5 CONCLUSION

We have provided an introduction to inter-organizational workflow architecture models and basic concepts and systems in the medical imaging domain. Furthermore we applied three inter-organizational workflow architectural models - capacity sharing, case transfer, and loosely coupled models - to the medical imaging domain and described common medical imaging tasks in relation to workflow models. Depending on the tasks and the involved business partners' different workflow models we suggested various interorganizational workflow models; however there is no "one-to-one relationship" between a task and an architectural model. Our future work consists of implementing workflow based Web-services in the medical domain based on the loosely coupled interorganizational workflow architecture model presented in this paper.

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