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# INFORMATION SYSTEMS AND HEALTHCARE XX: TOWARD SEAMLESS HEALTHCARE WITH SOFTWARE AGENTS

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**ABSTRACT**

Healthcare processes are frequently fragmented and often badly supported with IT. Inter- and intra-organizational communication and media frictions complicate the continuous provision of information according to the principle of information logistics. Based on extensive literature review, we present the vision of seamless healthcare with horizontally and vertically integrated healthcare processes enabled by seamless IT support. Its implementation requires the establishment of a communication infrastructure and the deployment of adequate standards in healthcare. There are already comprehensive approaches for dealing with integrating heterogeneous information systems. However, they lack a common communication infrastructure and do not support proactivity and flexibility which are dominant characteristics in healthcare. We propose a software agent-based approach for realizing the vision of seamless healthcare. We present a corresponding implementation for integrating heterogeneous information systems in the context of the German Health Telematics Infrastructure. Based on the concept and the implementation, we show that the modular approach is capable of supporting a wide range of different applications. We furthermore outline which facets of an agent-based solution could be implemented in an operative real-world environment. In closing we derive implications for IT decision makers in healthcare and show directions for future approaches for reducing information logistics related shortcomings in healthcare.

**Keywords:** healthcare information systems, information logistics, standards, software agent.

## I. SPECIFICS IN HEALTHCARE

Current issues in healthcare focus on the improvement of the quality of treatment and patient satisfaction. In order to reach these goals, this paper is geared to the Design Science [Hevner et al. 2004] methodology as a framework, which allowed us to analyze the needs for an integrated healthcare solution by an extensive literature review, to design and implement an agent-based artifact, and to evaluate its results and possible impacts.

Through information technology, it could be possible to improve efficiency in healthcare by using adequate systems for support. Indeed, information systems can improve the availability [Elson et al. 1997], completeness [Tang et al.1999], reduce failures [Bates et al. 1994], and enhance the orientation of comprehensive documents [McDonald and Tierney 1988; Garrett et al. 1986; Lenz et al. 2005]. In the following section we will show that the number of participants within the healthcare process, their local distribution, inter- and intra-organizational communication, media frictions, and both heterogeneous communication standards and infrastructures are aspects in healthcare that make leveraging the potentials of IT very difficult.

### INTRA AND INTER ORGANIZATIONAL COMMUNICATION

Healthcare is characterized by a broad spectrum of different actors such as service receivers, service providers, and health insurance agencies. Patients receive services which are provided by numerous individuals and institutions and include healthcare professionals, hospitals, outpatient care services, rehabilitation services, and drug stores. Within hospitals, the services provided can be further broken down as there are highly specialized actors in disciplines such as cardiology and dermatology who provide specialized services. In addition to intra-disciplinary specialties there are also inter-disciplinary healthcare workers such as nurses and physical therapists working in hospitals. In order to provide accurate diagnoses and effective treatment, these heterogeneous working groups need to be controlled and their activities need to be coordinated using good communication. The distribution of work implicates the existence of a distributed and sometimes even isolated information systems' landscape. This effect is reinforced by the fact that the respective service providers usually act autonomously and independently from each other. This can lead to an inability of the different groups or different departments to attain the desired goal which is effective and efficient diagnosis and treatment of the patient, i.e. management of the ill person.

Various types of media are to be found in hospitals. A lack of congruous media is caused not only by the parallel usage of both paper-based and digital documents, but also by the usage of different digital data structure formats which leads to inconsistencies of the data collected [Mikkelsen and Aasly 2001]. Although Mikkelsen and Aasly identify in their study significant differences between the information that is recorded on paper-based and digital media, the amount of faulty documents is relatively small in relation to the total number of documents under investigation. The potential consequences of wrong information are assessed to be more severe than the consequences of completely missing data. Another consequence of media discontinuity is the error-prone transmission of data to the target medium. As a result, wrong information, as identified in the study by Mikkelsen and Aasly, can potentially be generated but should be avoided as it is closely correlated with a high potential for poor decision-making. Failures in the treatment process reduce the quality of administered treatments. Several sources of errors within the diagnostic process, the first step in the treatment process, have been identified [Bhasale 1998]: Error-prone assessment of information, especially when proposing and evaluating hypotheses; errors in the transfer of information; inaccurate patient records; inadequate communication between patients and service providers; and inadequate communication between various service providers. The identification and correction of failures could increase the quality of the treatment process in hospitals [Bates et al. 1994].

The strict division of service providers and thus the existence of different information systems imply heterogeneous data formats [Sunyaev et al. 2006]. Since there is no tendency toward a uniform and comprehensive standard for semantic and syntactic data exchange to be expected, the need for transformation between the established standards can be observed [Haeber and Dujat 2004].

The described phenomena related to intra-institutional communication can be equally transferred from the hospital domain to the general healthcare system. The distribution and discontinuity in the process of providing treatment is even more distinct if the treatment process takes place in different institutions. Deficits in terms of cross-institutional treatment processes have been demonstrated [Forster et al. 2004].

Significant deficits in terms of information logistics resulting from the factors mentioned above can be identified. To correct these deficits, the right information needs to be provided at the right point of time, in the right quantity, at the right location, and in the right quality [Augustin 1990]. Correct and appropriate flow of information is especially important in healthcare [Anderson,1997]. There are, however, aspects of the healthcare industry which prevent the correction of known deficits which, as a consequence, compromises the ability of this industry to improve the quality of the services offered.

## TOWARD A VISION: SEAMLESS HEALTHCARE

The vision of seamless healthcare can be summarized as comprising horizontally and vertically integrated healthcare processes enabled by seamless IT support. The provided health services are capable of adapting to the variable and individual situation of the patient over time. Therefore, this paradigm focuses on an effective and efficient provision of patient-centered healthcare, independent of time and location. This implies the interconnectedness of all information systems and basing information exchange on data formats for semantic and syntactic unification. Several studies [Fowles et al. 2004; Pyper et al. 2004; Ross et al. 2005] have come to the conclusion that patients are explicitly interested in their personal medical information. This interest in medical information could potentiate compliance with the treatment process [Essex et al. 1990] and improve the outcome of treatment [Cimino et al. 2001; Ball and Lillis 2001].

The described integration of information and resultant patient empowerment takes place in several steps. Five levels of digitalization [Waegemann 1999] flow into a comprehensive electronic patient record. This record is an integration of data from different and locally distributed institutions and enables the patient to monitor their own medical data and, possibly, to add his own e.g. wellness-related data.

Deploying the vision of seamless healthcare can increase the quality of treatment since all relevant data can be made available to healthcare providers according to the principle of information logistics. This reduces the risk of errors. As all information is stored together, there is little risk of inadvertent omission or misplacement of data. The availability of digital data and automatic translation between different digital data formats provides ease in transferring data between various media thereby reducing possible errors and the need for manual handling of data. Storage of data in a comprehensive electronic patient record could help to reduce healthcare costs although this aspect of electronic data storage has not been fully investigated.

# II. INTEGRATED IT-SOLUTIONS FOR SEAMLESS HEALTHCARE

In order to enable the implementation of the vision of seamless healthcare, a basic communication infrastructure needs to be established. Once this network infrastructure is set up, the interoperability at the syntactic and semantic level can be advanced.

## A NATIONAL FRAMEWORK: THE GERMAN HEALTH TELEMATICS INFRASTRUCTURE

Advances in the basic communication infrastructure have aided the introduction of the electronic patient card in Germany. A telematics infrastructure forms the basis for an electronic patient card which is mandatory for patients within the public health insurance system. In general, the telematics infrastructure aims at connecting existing information systems of various service providers and health insurances via a common network. The requirements for the development of this infrastructure are derived from legal constraints, current standards, and the requirements of the participating stakeholders.

### Health Telematics Infrastructure

Figure 1 depicts an overview of an abstract architecture of the solution architecture for the forthcoming telematics infrastructure in Germany. Primary systems of service providers (i.e. general practitioners or hospitals) are connected to the communication infrastructure by a special component. This connector communicates with primary systems and card terminals for the electronic patient card and the secure module card (SMC). The communication between the connector and the card terminals is transparent to the user and is encrypted automatically. The connector is connected to a VPN box. The connection to the communication structure is established via an access gateway. Access gateways allow only registered users to access the communication infrastructure. A certificate within the used access node enables the mapping to the appropriate VPN. With the mapping to a dedicated VPN a special user role is associated. The service gateway holds a list for the mapping between possible roles and the rights for using application services. These grants specify which services of the user's VPN can be used. Access gateways and service gateways communicate via a trusted backbone, mutually authenticate themselves, and are connected via a VPN. These measures allow only those users the execution of application services, which invoke services via access gateways. Dedicated VPN are capable of calling infrastructure services.

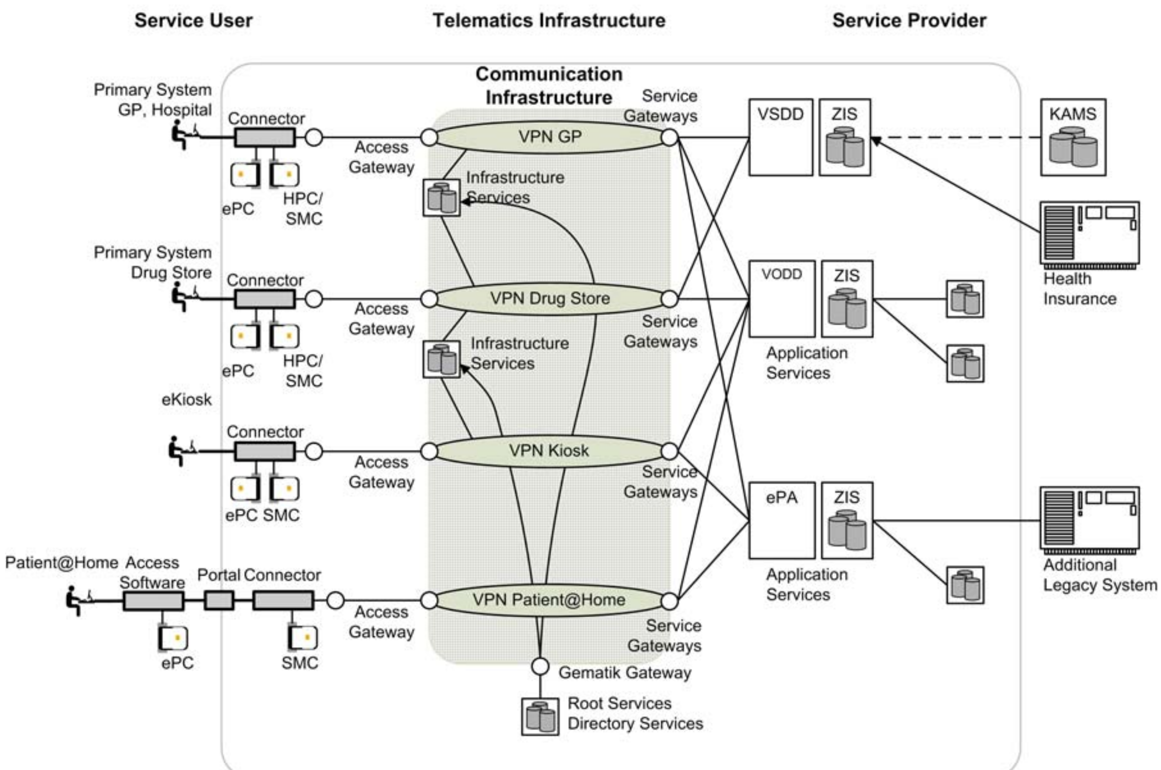


Figure 1. Health Telematics Infrastructure for the German Electronic Patient Card [Projektgruppe FuE-Projekt "Loesungsarchitektur" 2005]

Application services, such as the access to the electronic patient card (ePA), prescription data service (VODD), or insurance data service (VSDD), can be called via service gateways. Application services access relevant data via a common access and integration layer (ZIS). This layer implements a common rights management for the access to data which allows for mapping of appropriate rights to users. The ZIS layer also hides the actual distribution of data and implements storage transparency. This encapsulation facilitates the future extension for the integration of external systems since the interfaces of the application services do not need to be adapted. The gematik gateway allows access to root and directory services which are necessary for the administration of the network.

**Enhancement of the Basic Health Telematics Infrastructure**

The electronic patient card, as a central part of the telematics infrastructure, can provide access to multiple forms of information and can store data locally. These data can be classified as being mandatory or faculty. Mandatory data comprises basic administrative patient data like name, date of birth, or health insurance information. In addition, the implementation of an electronic drug prescription is an obligatory element of the electronic patient card. A further element provides German patients the right to medical services in other European countries.

Besides the storage of data on the electronic patient card, other applications for use are possible. These applications are facultative and require patient permission. These applications include: drug order documentation, electronic physician letters, treatment cost receipts, emergency case data, general patient data, and an electronic health record. Facultative applications allow for improvements in the treatment process and the integration of the patient as an active participant in his return to a state of wellness. Apart from that, these applications potentiate increase in efficiency and effectiveness [Bernnat and Booz Allen Hamilton GmbH 2006]. Therefore, these need to be introduced to the patient by the service providers in healthcare.

The described telematics infrastructure enables a basic communication structure that is needed for a cross-institutional information flow. Only administrative information and data for obligatory applications are to be stored on the electronic patient card, the location of data storage of the other distributed applications is left open and could be stored either centrally or non-centrally. In order to prevent the storage of redundant data, the electronic patient card could be an enabler for establishing a virtual patient record. For this purpose, relevant data could be aggregated at runtime and retrieved out of the locally distributed information systems. In order to have the information about the location of the data storage, the following process could be implemented: The patient card stores links to all treatment data that is stored in distributed information systems. The link information does not need to be stored necessarily on the patient card, but could also be stored centrally on a server of the telematics infrastructure and can then be accessed by the patient or the service provider. Using this approach, in case of loss of the patient card, the data is not lost as it is stored centrally. These links contain the information of where the data is stored and enables the retrieval of all relevant data, regardless of where it is located. This idea enhances the mandatory elements of the patient card and transforms it into the prerequisite for an electronic patient record which integrates distributed information systems. This scenario takes into account the notion of an empowered patient and is implemented in the described prototype for seamless healthcare.

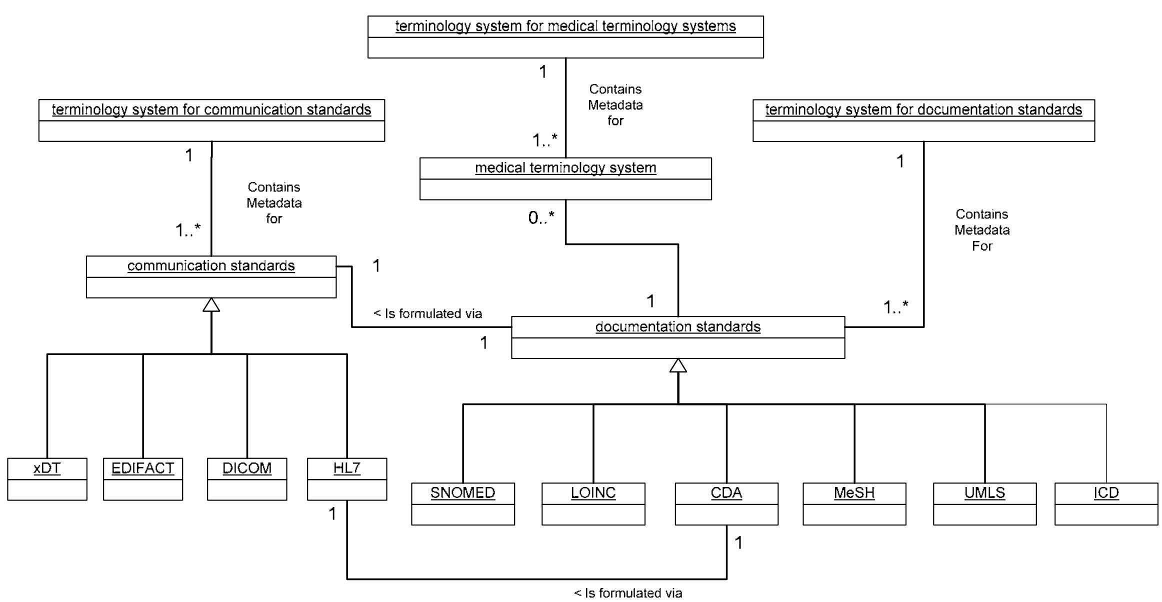

Figure 2. Medical Communication and Documentation Standards [Sunyaev et al. 2008]

## REQUIREMENTS FOR AN INTEGRATED IT-SOLUTION

The described integrated telematics solution is based on standardized communication mechanisms. Standardized communication enables the exchange of data between all participating healthcare information systems [ Healthcare Information and Management Systems Society 2006]. Interoperability processes in healthcare and the medical market require generally accepted standards [Sunyaev et al. 2006] in order to achieve the following: efficient and effective combination of distributed medical systems, increase competition and reduce costs, easily update or replace healthcare IT products, and reduce errors to make healthcare services safer [WHO 2006; CEN/TC 251 European Standardization of Health Informatics]. IT standards in the healthcare sector can be divided into two groups: syntactical and semantic standards. For an overview of current and worldwide accepted healthcare IT standards, see Figure 2. Sunyaev provides a comprehensive discussion of accepted IT standards in healthcare [2008].

The correct transmission of medical and administrative data between heterogeneous and distributed medical information systems is based on syntactical standards. These are mainly HL7/CDA [Health Level Seven Inc. Ann Arbor MI 2005; Dolin et al. 2001; Dolin and Behlen 2006], DICOM [NEMA], and EDIFACT [EDIFACT 2006]. The German standard xDT, promoted by the National Association of Statutory Health Insurance Physicians [KBV (Kassenaerztliche Bundesvereinigung Deutschland]) focuses on data transfer in the German healthcare system.

Semantic standards on the other hand ensure correct interpretation of the content of the electronically exchanged data. Established standards are LOINC [LOINC 2006], SNOMED [SNOMED International 2005], ICD [DIMDI 2006; WHO 2006 ], MeSH [UMLS 2006], and UMLS [UMLS 2006].

The current standardization situation in the healthcare sector has been described as being unsatisfactory [Institute of Medicine of the National Academies 2001]. Until there is a generally accepted standardization of syntactic as well as semantic standards, all advantages listed previously cannot be exploited [Haux 2005]. To improve health services, reduce costs, and gain the vision of seamless healthcare, the problem of standardized software solutions must first be solved. As it can be assumed that there will not be a global standard for the integration of semantic and syntactic data, an integration solution has to be capable of dealing with different established standards. That is why the proposed agent-based solution for the integration of healthcare information relies on established standards such as HL7, CDA and LOINC.

Numerous initiatives described in the following section can be identified which support the previously outlined vision of seamless healthcare and efforts have been undertaken to transform this concept into reality. There are, however, problems that remain unsolved that prevent the implementation of seamless healthcare.

## OTHER APPROACHES FOR INTEGRATING THE DIGITAL HEALTHCARE ENTERPRISE

There are many approaches which enable information integration in healthcare. These contribute to the present status for information systems and their integration. Some prominent examples are described in Table 1. All of these, except the SCIPHOX-approach, include an electronic health record. The described approaches share the idea of using established standards for the integration. But all of them are similar to isolated solutions, since they do not take into account a standardized telematics infrastructure and therefore cannot provide value added services on top of it. Furthermore, they lack the integration of heterogeneous information systems. In order to deal with these deficits, we propose an agent-based approach described in the next section.

Table 1. Overview of Current Approaches for Integrating the Digital Healthcare Enterprise [Sunyaev et al. 2008]

| **Initiatives for information integration in healthcare** | **Characterization and Goal** | **Approach and assignment of internationally accepted standards** |
|---|---|---|
| Integrating the healthcare enterprise [IHE, Hornung et al. 2005] | IHE is an international initiative, driven by healthcare professionals and industry, to improve the communication of medical information systems and the exchange of data. | IHE's approach for the information integration is based on propagation and integration/usage of HL7 and DICOM standards. IHE promotes and advances these standards as a suggestion for standardizing bodies. |
| Professionals and citizens network for integrated care [PICNIC, Danish Center for Health Telematics 2003] | PICNIC is a European project of regional healthcare providers in a public private partnership with industry to develop the new healthcare networks and to defrag the European market for healthcare telematics. | The development is an open source model, i.e. an open and interoperable architecture with exchangeable components (aim is an easy and simple integration of external products). All components must be based on established standards, such as HL7/CDA. |
| Open electronic health record [openEHR 2004] | OpenEHR foundation is dedicated to develop an open specification and implementation for the electronic health record (EHR). OpenEHR advances the experiences of GEHR-projects [GEHR 2006; Blobel 2006] in England and Australia. | The project works closely with standards (e.g. HL7). However, it does not adopt them verbatim but tests, implements and improves their integration and application while giving feedback to the standard bodies. |
| Standardization of communication between information systems in physician's offices and hospitals using XML [SCIPHOX 2006; Gerdsen 2005] | SCIPHOX is a German initiative with the aim to define a new common communication standard for ambulant and inpatient healthcare facilities. | The basis for the information exchange is the XML-based HL7/CDA standard. SCIPHOX adapts and improves this global standard for local (German) needs. |
| www.akteonline.de [Ueckert et al. 2002; akteonline 2006] | akteonline.de is German state-aided project to develop a Web-based electronic healthcare record. | akteonline.de developed dynamic Web pages, which can be accessed via internet and look similar to physicians and hospital software. The project is based on the common communication standards (DICOM and HL7/CDA). |

## III. SOFTWARE AGENT ENABLED APPROACH

As previously described, current approaches to the integration of healthcare information are feasible, but the capacity to be not only reactive, but also proactive in initiating necessary behavior for the adequate support of healthcare teams as well as patients is missed. Using the proposed approach, information can be provided in advance which ensures that necessary information is available when needed. Furthermore, software agents can be used as information brokers which aggregate and transform locally distributed patient data. The advantage of these software agents is that they are flexible and able to react to changing environmental characteristics.

## THE CONCEPT OF SOFTWARE AGENTS

Software agents can be defined as being small computer systems which exhibit the following characteristics [Wooldridge and Jennings 1995]:

- *Autonomy:* Agents act without the direct intervention of human beings and control their actions and their internal state.
- *Social Ability:* Agents interact with other agents or possibly human beings using a special agent communication language in order to reach particular common goals.
- *Reactivity:* Agents are capable of perceiving their environment and reacting flexibly to changes.
- *Proactivity:* Agents do not only react to changes in their environment, but also possess goal-oriented behavior which becomes manifest in the agents' own initiative for actions.

It seems that software agents as described above are especially suited as an implementation approach for the paradigm of seamless healthcare. In general, healthcare can be adequately modeled as a complex, adaptive system [Tan et al. 2005; Plsek 2001]. Both approaches, complex, adaptive systems and agent systems, share common characteristics like distribution or autonomy in reaching certain goals. Therefore, implementing future information systems as agent based systems seems to be an adequate approach. Furthermore, a number of scientific results [Czap and Becker 2002, 2003; Zachewitz 2004; Heine and Kirn 2004; Heine et al. 2005; Paulussen et al. 2003; Moreno et al. 2003; Kirn et al. 2006] have been published that support our belief that software agents are indeed a means for solving issues in healthcare.

## SEAMLESS HEALTHCARE BASED ON THE PARADIGM OF SOFTWARE AGENTS

Current information systems in healthcare would clearly benefit from the deployment of software agents. To achieve this purpose, software agents are associated with an authority like a patient, physician, or a nurse. Apart from these associations, software agents can also represent facilities like medical devices or an entire institution. There are a number of reasons why this mapping is valuable. First, patients would appreciate the autonomy in being able to make appointments. Software agents can also act proactively by reminding the patient of a pending appointment. Second, from a physician's point of view, the autonomous retrieval of relevant information for the treatment of a patient would improve decision-making. Third, agents representing resources could enhance the efficiency of the devices or departments they represent. Since agents represent different actors, they must cooperate with one another to match needs with available services (e.g. match the availability of an open appointment slot with a date that best suits the patient). Software agents are capable of this type of social behavior. If, for example the scheduled appointment time needs to be changed due to unforeseen circumstances, then the corresponding agents can react flexibly to this situation by negotiating a new appointment.

The paradigm of seamless healthcare requires also the integration of existing information systems into the agent-based approach. For that purpose, relevant information is extracted from distributed information systems. Non agent-based systems can be incorporated into an agent-based system by deploying special wrapper agents [Jennings 2001]. These transform incoming agent requests into proprietary service calls to legacy software systems. The results of the service call are translated into an agent communication for further processing.

The proposed agent-based approach needs also be built upon the previously described telematics infrastructure in Germany. As a result, the described agent system can provide additional value-added services.

Agent-based systems are per se distributed, decentralized, and reflect the status of the healthcare system and its actors. To conclude, there is a natural mapping between the healthcare domain and the paradigm of software agents at the software engineering level.

## CONCEPT FOR AN AGENT-BASED INTEGRATION SOLUTION

For the cross-institutional information integration for the support of the information logistics principle, the concept of an active medical document [AMD, Schweiger et al. 2005] is deployed. Such documents are compiled at run-time and can be prepared according to the user's needs by supporting different views. These documents are comprised of both internal service agents and coordinative, administrative, and medical data, i.e. the patient record. Internal service agents handle additional services like information provision and information compilation. Available information systems are integrated into the agent system by dedicated wrapper agents, which transform agent messages into calls to the actual information system and vice versa. Active, medical documents are designed such that the integration of several other information systems can be carried out via a single entry point (Figure 3). The communication with these information systems is enabled by the previously described telematics infrastructure for the electronic patient card in Germany. Mobile devices allow for an adequate implementation of the principle of information logistics, since these can be carried to the places where information actually is needed, for example at the bedside in a hospital. Therefore, the AMD has been successfully ported to a Personal Digital Assistant [PDA, Schweiger et al. 2006a; Schweiger et al. 2006b]. Since Web services are an established notion of a service-oriented architecture's implementation and the idea of service delivery can be found both in agent-based systems and Web services, a mapping between these approaches is rather straightforward. An extension of the well-known and FIPA[1] compliant agent-platform JADE[2] is deployed for building a patient platform. The communication between the AMD and the patient platform is enabled by standardized Web services. The platform can be used to aggregate the patient's data and provide these to the patient via a Web browser.

To conclude, the construct of an active, medical document can be used to integrate heterogeneous application scenarios. The AMD is part of the reference implementation, which is described in the next section.

[1] For further information see the Web site: http://www.fipa.org/ (current March 22, 2007).

[2] For details about the agent platform JADE see http://jade.tilab.com/ (current March 22, 2007).

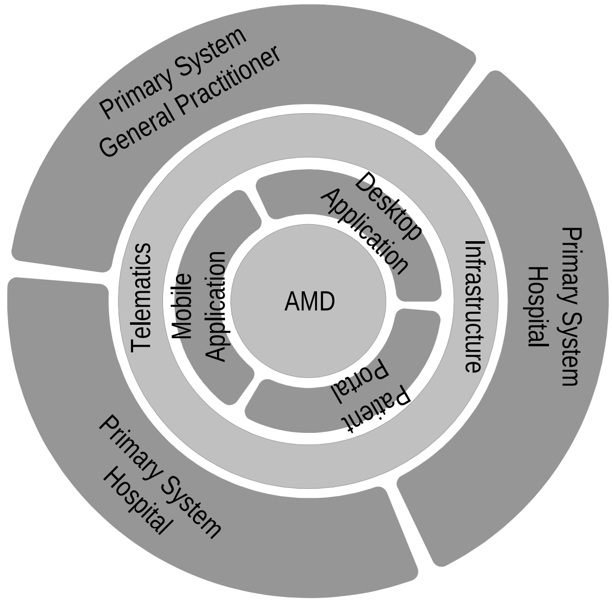


Figure 3. Active, Medical Documents at the Center of Other Applications in an Integration Scenario

## AN AGENT-BASED REFERENCE IMPLEMENTATION

Figure 4 illustrates an overview of the implementation for an agent-based system, which can be enhanced for further application scenarios. The implementation focuses on the integration of heterogeneous information systems. For prototyping reasons, parts of the systems to be integrated are simulated. This can be applied to the chosen hospital information system (HISSim), the general practitioner information system (GPIS), and the anesthesiology information system (AIMSSim). The latter provides parameter values which are recorded.

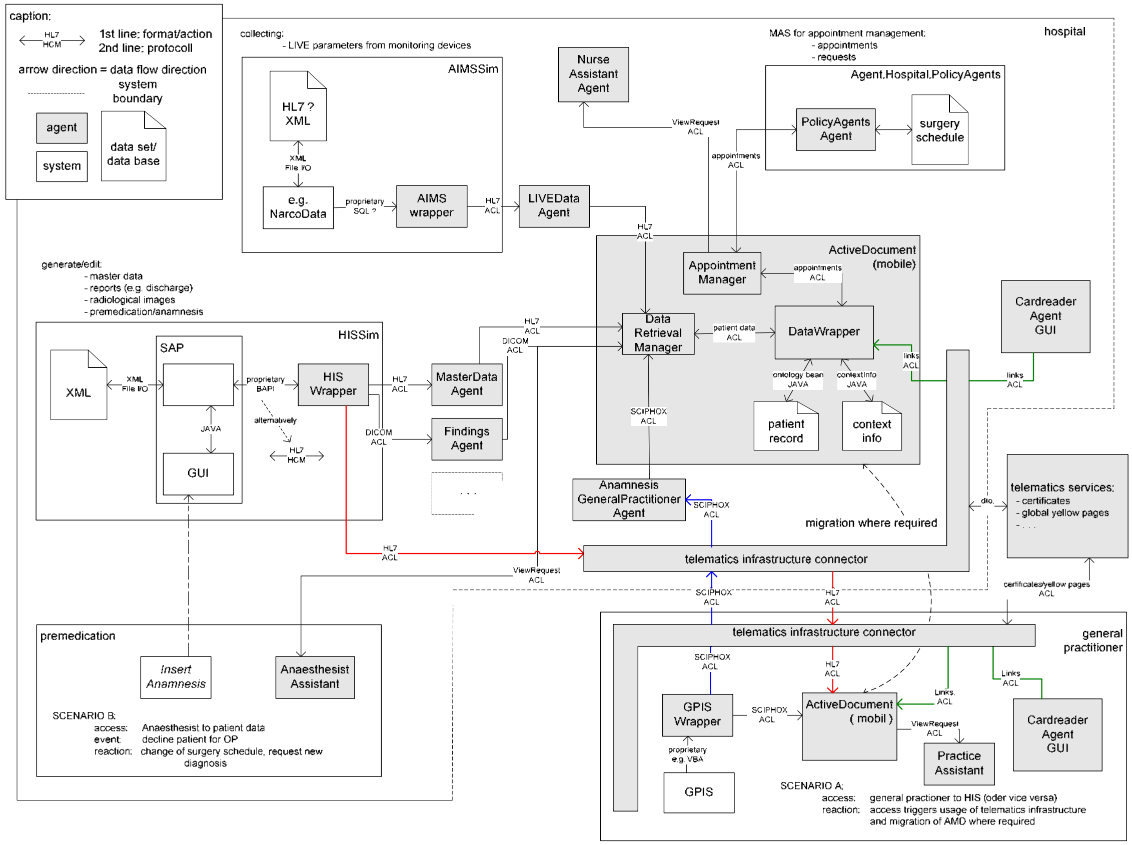


Figure 4. Reference Implementation for an Agent-based System [Schweiger et al. 2005]

For accessing the remote general practitioner information system from within the hospital, the previously described telematics infrastructure is implemented prototypically. If the patient permits access to these data, they can be retrieved via the telematics infrastructure. Links to these data are stored on the electronic patient card. Patient cards are read by a simulated card reader (CardReaderAgentGUI).

The following scenario demonstrates the basic functionality of an AMD, which is embedded in a hospital. An anesthesiologist would like to consult the virtual patient record before making the decision if a patient's current health status allows for a surgical intervention. To make this decision, all previous documents on the patient's health status need to be retrieved. The user interface of the personal assistant of the anesthesiologist provides the interface to the virtual electronic patient record. This agent formulates a request to the AMD of the patient and the request for the aggregation of the patient's data is forwarded via the DataRetrievalManager to the DataWrapper. The latter receives the links to the data locations from the card reader (CardReaderAgentGUI) which are stored on the patient card and subsequently grants access according to the pre-determined access rights. After a successful inspection of the access grants, the DataRetrievalManager is responsible for the creation of subtasks and their delegation to task agents. One of these agents extracts parts of the patient data stored at the remote general practitioner's information system (GPIS). Since this information system is located on a different location, a secure connection via the telematics infrastructure is established. For that purpose, dedicated connectors are deployed to enable digital signatures and encryption. Once the connection is established, the GPISWrapper can be contacted. Extracted data are translated into an HL7 format and assigned with a sample LOINC code. Another task agent extracts the radiology findings from the local hospital information system.

Once all findings arrive at the DataRetrievalManager they are visualized at the AnesthesistAssistance user interface. According to these aggregated data, the anesthesiologist is able to provide a decision on the patient's suitability for surgery. If the decision to operate is made, then the patient is scheduled for surgery. If surgery is not appropriate, an AppointmentManager is notified to reschedule the planned surgery. Hence, the structure of the AMD allows for the integration of scheduling tasks as well. These are especially important in the healthcare domain as unforeseeable events often cause changes in previously arranged surgery schedules. Scheduling and re-scheduling tasks are currently carried out manually by the medical and nursing personnel and are sources of high overhead costs. To reduce these costs, Paulussen et al. [2001] describe a distributed agent-based scheduling algorithm. This algorithm is embedded into the described AMD and allows for the integration of a flexible scheduling approach. The latter is capable of dynamically and flexibly taking into account changes in the environment.

The described scenario serves as a basis for integrating several other applications such as a Web-based patient portal, and mobile devices [Schweiger et al. 2006a; Schweiger et al. 2006b]. This embedding allows for the transfer of agents' benefits to mobile devices and patient portals. A case study [Schweiger et al. 2006b] at a university hospital in Germany demonstrated that agents can also serve as information brokers in domains where heterogeneous media are deployed. Our experiences with this case study underpin our understanding that a common syntactical standard helps to further process extracted data. Using this approach, it has been shown, that agents are a valuable approach in terms of bridging heterogeneous data formats and media.

The previously described scenario is prototypically implemented as it represents actions which can be observed almost exclusively in healthcare environments and deals with the identified deficits in healthcare.

### DEPLOYMENT IN OPERATIVE ENVIRONMENT

Agent-based systems have not been widely-used [Heine 2005]. One can identify two main reasons for this fact. Missing robustness of agent-platforms and adequate development methods [Luck et al. 2004; Dam and Winikoff 2003; Cernuzzi and Rossi 2002]. Thus, the deployment in an operative environment requires the advancement of agent technology in terms of suitable development processes and robustness. The described scenario makes us confident that agents can be deployed advantageously in order to provide seamless healthcare once the previously identified technical deficits are corrected.

The prototypical implementation shows a basic notion of seamless healthcare. Some missing elements still need to be developed before the paradigm of virtual patient records can be advanced into the modular active medical document. In order to provide information according to the principle of information logistics, relevant information needs to be provided automatically and in advance. An agent-based approach for anticipating the physician's needs and which takes into account the data given in the electronic patient record already exists [Wiesman et al. 2006] . This approach can be integrated into the described AMD as both of these concepts are agent-based. Furthermore, the concept described by Wiesman et al. allows for the integration of data from the patient record that can be constructed out of all previously collected patient data. As a result, the anticipation of information need can be supported to its maximum. There have also been agent-based processes implemented that track treatment procedures and trigger the search for information or the negotiation for a new appointment as required.

## IV. CONCLUSIONS AND OUTLOOK FOR FUTURE RESEARCH

### MANAGERIAL IMPLICATIONS

Complexity in the healthcare system is increasing due to various causes including advances in informatics. Existing architectural solutions are likely to be incapable of handling and processing information logistics both within and between institutions. The essential advantages of agent-based systems are their decentralized, adaptive, and intelligent coordination possibilities which provide services and the availability of data in fragmented and heterogeneous settings. These agents have the potential to allow automization, optimization, and initiation of completely new applications in new areas such as scheduling, dynamic and proactive resource allocation, and decision support for medical staff and patients. Decision-makers in the healthcare arena should carefully consider the potential these agents present and consider agent software as more than a software engineering vision but rather as an opportunity for improving performance and quality in healthcare enterprises.

## OUTLOOK

The future is bright for applications for agent-based systems in healthcare. Since data are highly distributed, the enforcement of data privacy is of high priority. Agents are capable of encapsulating patient data and providing a single point of access to data. Therefore, ensuring the privacy of data in a distributed environment seems to be feasible. This approach can also be used for dealing with archiving and managing access to data.

Software agents are capable of finding alternative routes to stored information within the distributed communication structure. Thus, software agents help to ensure the availability of data in healthcare and can be used to support processes, for example, information retrieval. Although advances have been made in terms of scheduling timetables, a need still exists to integrate these results into an established information system. The connection of the described agent-based prototype to the selected hospital information system is incomplete and needs to be enhanced by broadening the interface between the systems. To sum up, software agents can provide valuable services for seamless healthcare, even on any device. Porting information systems to different devices allows for the usage of applications on heterogeneous platforms and for advancing the principle of information logistics, since mobile devices can be easily brought to the locations where data is needed.

## SUMMARY

We focused on information integration as a requirement for seamless healthcare. To achieve this goal, we suggest the concept of active medical documents which supports the idea of an integrated, virtual patient record designed to aggregate all previous medical documents from locally distributed information systems. Established standards could also be integrated into the prototype, showing that agents are capable of dealing with heterogeneous standards. In this way, different media formats can be handled by software agents acting as information brokers. Furthermore, future approaches are to be based on adequate communication infrastructures such as the German telematics infrastructure. Once the described deficits in agent engineering are corrected, software agents will be able to provide valuable support for information logistics in distributed healthcare. Agents can be suitably deployed for information integration in healthcare and can become an enabler for the vision of seamless healthcare. The reference architecture we described is capable of being extended for the integration of Web-based patient portals, for using mobile devices, and for scheduling algorithms. This modular approach allows for the integration of further applications. In particular, agents potentiate the provision of proactive and flexible services.

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