

Towards a Flexible, Process-Oriented IT Architecture for an Integrated Healthcare Network

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ABSTRACT

Healthcare information systems play an important role in improving healthcare quality. As providing healthcare increasingly changes from isolated treatment episodes towards a continuous medical process involving multiple healthcare professionals and institutions, there is an obvious need for an information system to support processes and span the whole healthcare network. A suitable architecture for such an information system must take into account that it has to work as an integral part of a complex socio-technical system with changing conditions and requirements. We have surveyed the core requirements of healthcare professionals and analysed the literature for known problems and information needs. We consolidated the results to define use cases for an integrated information system as communication patterns, from which general implications on the required properties of a healthcare network information system could be derived. Key issues are flexibility, adaptability, robustness, integration of existing systems and standards, semantic compatibility, security and process orientation. Based on these results an IT architecture is being designed that is capable of addressing the requirements mostly on the basis of well-established standards and concepts.

Categories and Subject Descriptors

J.3 [Life and medical sciences]: Medical information systems; D.2.11 [Software architectures]: Domain-specific architectures

Keywords

Healthcare networks, evolutionary information systems, process orientation, systems integration, integrated care

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1. INTRODUCTION

1.1 Objectives

Today, health information systems play a significant role in supporting healthcare professionals and in improving the quality of healthcare. Their value has been shown in many studies. Among the demonstrated effects are better availability of medical patient data, prevention of adverse events, prevention of unnecessary duplication of tests, cost savings, and reduction of waiting times (e.g. [21, 15]). On the other hand, severe problems in health IT and lack of real progress have been described. It has even been stated that there is an ‘absence of real progress [...] towards applying advances in information technology to improve administrative and clinical processes’ [16]. To understand this discrepancy, both challenges and the potential of health information systems should be seen.

Currently, the situation of healthcare in Europe and in the U.S. is characterized by a process of transition, where isolated hospitals and individual practices are merging into networks of healthcare delivery [21]. This change is influencing health information systems, and major challenges have resulted. System integration and inter-institutional support of healthcare processes are massively needed. As a consequence, standards based on common ontologies need to be further developed. In addition, socio-technical issues have been much better understood as a central issue for successful health information system deployment [21, 1], and it has become clearer that systems have to be flexible and adaptable.

The potential of health information systems has been well understood. A series of studies focused on adverse events in medicine, their nature, and their preventability, e.g. [7, 24, 4, 41]. It was found that adverse events are not rare in healthcare, and that the preventability may be high. Analyses revealed that errors of omission play an important role in adverse events, that high complexity is a risk factor, and that information systems actually bear a high potential for preventing adverse events [3]. A number of highly successful implementations of health information systems demonstrated the positive effects of providing decision support at the point of care by presenting aggregated case specific information from the patient database, and by combining it

with domain-specific knowledge stored in knowledge bases. The spectrum of methods implemented is broad, including reminders, alerts, prompts, structured data entry, checklists, and presentation of aggregated and goal-oriented information (e.g. [2]). A fundamental insight has been that successful prevention efforts need to focus on root causes, i.e. on errors in the design and implementation of systems, not on the errors themselves.

Unfortunately, positive effects have only been demonstrated in a very limited number of installations, and the methods derived are clearly not in widespread use. Moreover, in healthcare networks currently emerging, IT systems are only loosely coupled or completely isolated. We found that discontinuity of healthcare is posing problems, and that IT solutions are missing.

Our objective has been to design and realize a flexible, process-oriented IT architecture for an integrated healthcare network. In our project, we have analysed the current state of health information systems not only from an IT-specific point of view, but by a deeper look at healthcare professionals' requirements. In our opinion, an information system should not only be a tool but rather an integral part of the healthcare process. Especially the problems to overcome semantic heterogeneity of disparate systems, which have often been disregarded, have been considered carefully. So our approach has been to derive the technical and functional requirements for a generic platform from a thorough requirements analysis of the application domain. Use cases have been formally described as communication patterns, and common elementary services have been identified. An architecture for an extensible and adaptable healthcare information system has been proposed on the basis of reusable elementary functional units and on special services supporting various degrees of semantic compatibility between separate information sources. This architecture is intended to serve as a framework for a set of tools that enable rapid implementation, adaptation, and deployment of process supporting applications within a healthcare network.

1.2 Related work and existing standards

Currently, clinical communications use domain-specific messaging formats. In hospitals HL7 ('Health Level 7') is the usual data format, along with DICOM¹ and EDIFACT². Outside hospitals several formats are in use. In Germany the xDT family [20, 19] is a de-facto standard, containing different definitions depending on the purpose. Several new standards are being worked out at the moment that mostly utilize XML as representation format.

The new version 3 of HL7 is based on XML and comes along with a Reference Information Model (RIM) and extensions like the Clinical Document Architecture (CDA). CDA is a multi-level document-based architecture that allows to represent clinical documents on three semantic abstraction levels.

An implementation of CDA is being aimed at by the SCIPHOX project [35], initially a project to define a common format to bring together HL7 and xDT. Some applications have been specified (e.g. discharge reports), the current project phase is about to define the requirements for the needed security and transport mechanisms.

¹'Digital Imaging and Communications in Medicine'

²'Electronic Data Interchange For Administration, Commerce and Transport'

Examples for projects that rather focus transportation specifics are the German VCS [40] and D2D [23], whose purpose is mainly to bring data from one end to another in a healthcare network with the needed conditions.³ – Furthermore, many industrial solutions emerge for network communications, but they often try to bound communication to a proprietary format, rather worsening the heterogeneity problems.

The mentioned standards and projects have clearly demarcated applications' targets and thus do not primarily address general requirements like flexibility. This does the European Union's PICNIC project [33, 30], having a more general approach. PICNIC defines an architecture for a primarily flexible IT support delivered by exchangeable components, that are not constrained to a certain language, communication platform etc. Two levels of PICNIC services have been defined (derived from the former WISE project); domain-specific services accessing general services, that themselves rely on well-established transport mechanisms (W3C standards), forming the basis for medical applications.

2. REQUIREMENTS ANALYSIS

2.1 Literature review

We reviewed the relevant literature systematically. Needs, key issues, and challenges for health information systems, or particularly for computer-based medical record systems, have been analysed and presented for more than one decade, e.g. [10, 14, 26, 32, 21, 22]. Among the central issues are (1) integration with a need for open systems, common ontologies, and standardization, (2) adaptation to work processes with a need for adequate interaction design and system flexibility, and (3) a broad range of socio-technical aspects.

To illustrate specific problems in a healthcare network, we demonstrate some selected results here:

1. Discharge summaries were often missing when patients visited practitioners for follow-up treatment after hospitalization. The results ranged between an availability of this relevant information source in only 15% of visits [38] to 27% of cases [42] up to 77% [5] – which means large deficits in any case.
2. Patients for whom discharge summaries were available during follow-up visits had a significantly decreased risk of readmission [38].
3. Considerable deficiencies were found in discharge summaries, e.g. lack of information in a discharge diagnosis in 26% of summaries [39].
4. More than 50% of patients discharged had planned outpatient tests or procedures for unresolved medical issues, and about 49% percent of patients experienced continuity errors after discharge from a medical center. One of the three error types investigated (work-up error, medication continuity error, test follow-up error) was associated with a significant risk of readmission [27].

³Unification of the data is done by restricting the allowed data format to BDT (or currently developed XMLified versions).

2.2 Structured interviews with physicians

We interviewed a number of physicians which were either practitioners co-operating with our University Medical Center or physicians in our center. We could identify a number of key problems and of key needs which correspond to results from the literature.

2.2.1 Problems identified

Insufficient information flow between the hospital and the practitioners. This problem was identified from both sides: Practitioners complained of late, incomplete, unreadable, or missing data, reports, and discharge summaries. Hospital physicians reported on insufficient preparatory measures and insufficient information before and during hospitalization.

Insufficient coordination. Scheduling was found to be insufficient in several respects. Practitioners complained that patients were discharged without prior notification and that it was extremely difficult to get appointments for patients to be treated in the hospital. Within the hospital, insufficient coordination, difficulties in making appointments and lack of IT support for scheduling were described; IT modules for scheduling already available in several departments were highly appreciated.

Long waiting times. Complaints concerning waiting times resulted from the above. Physicians complained of waiting times when they wanted to make appointments, and of waiting times of their patients.

Problems with inter-personal communication. Practitioners saw a need of directly addressing responsible colleagues before, during, and after a hospital treatment of their patients, but found it very hard to find the responsible and informed colleagues.

2.2.2 Needs for IT support

Based on the above deficits, and based on proposals of physicians describing their own and their patients' needs, the following functionality was considered important in a healthcare network:

Scheduling. IT support for scheduling was considered important, both inter- and intra-institutional. While there was a certain preference to offer these modules to healthcare professionals, it was considered possible to offer them directly to patients, too.

Generation and communication of discharge letters and reports. IT support was considered necessary in the generation of letters and reports, including database access to reuse data already stored (e.g. laboratory values, but also previous diagnoses). An electronic communication of these letters and reports was considered helpful and important. Existing modules inside the hospital were rated positive.

Order Entry. IT-based order entry was considered important, both inter- and intra-institutional. Accompanying checklists, e.g. to check for preparatory measures, were rated valuable.

Access to knowledge bases. This feature, which is in frequent use within the hospital already, was rated important for all healthcare professionals and for patients as well.

Access to databases for physicians and for patients. The need of accessing databases with patient-specific information was considered extremely high for healthcare professionals. The interviewed physicians were

reluctant to offer the patients direct access to their data in the network, mainly because of privacy concerns.

Clinical pathways, disease management programs. A clear need of IT support for this field was seen. Actually, the hospital has started to introduce IT support in these fields already, which is planned to include a regional healthcare network, too.

3. FUNCTIONAL ISSUES

The requirements analysis summarized in section 2 highlighted the most frequently mentioned application requirements for healthcare networks today. Of course, these are neither complete – as new requirements might arise when political, social or legal conditions change or when new technological capabilities allow previously unknown applications – nor are they completely specified, as they are to be adapted to the specific conditions of concrete settings. The typical starting point for a healthcare network will be a landscape filled with numerous islands of information, based on different technologies and concepts, and embedded in different social environments, often with individually optimized work practices. An IT system intended to support healthcare networks should therefore be designed to and incorporate concepts for

- *Integration*, meaning to provide concepts for involving arbitrary participants into the network,
- *Adaptability* to different functional requirements in different settings,
- *Extensibility*, to be able to seamlessly add new functionality to a running system with a minimum effort and to be capable of evolving over time.

An information system's capability to evolve over time is primarily based on encapsulating functionality in more or less autonomous components, which can be added to a running system without affecting the rest of the system. To reduce the effort for system evolution it is highly desirable to incorporate generic components, that can be reused in different contexts. In order to identify reusable services for healthcare networks we derived communication patterns from the functional requirements. These communication patterns were iteratively refined by mapping similar steps to common generic elementary services.

3.1 Communication patterns

Starting from the core application requirements we have derived typical use cases, listed in table 1. Each of these use cases is described within a detailed 'communication pattern' comparable to the design patterns introduced by [13].

A communication pattern is a solution to a recurring problem [6] – it should not be tailored to the specific requirements in a local setting. In order to support a common understanding among developers and healthcare professionals they contain both a structured description of the context in which they are used (comprising contents, motivation, goals, participants, involved IT systems, variations, and a characterization) and a graphical representation (UML Activity Diagram). Figure 1 shows examples of such process diagrams.

Table 1: Use cases for a healthcare network information system.

D: Directed Communication
U: Undirected Communication
P: Patient-specific

#	Use case	D	U	P
Communication				
1	Appointment Arranging of an appointment date by the patient or a physician (usually for referral). Also intra-/interdepartmental scheduling of patients.	X	(X)	X
2	Discharge reports Providing a summary of medical data and progress report on discharge for post-clinical care.	X	(X)	X
3	Medical findings reports Any type of medical findings (text, picture, film, ...) to be provided to other physicians.	(X)	X	X
4	Order placement Ordering an examination at another institution etc.	X	(X)	X
5	Referral Referring a patient to another institution.	X	(X)	X
6	Online consultation Consultation of another physician with data exchange using the information system.	X		X
7	Result request Request a certain result from another participant.	X		X
8	Electronic prescription Enter, transmit and recall prescriptions.	X	(X)	X
9	Request checklist Request a checklist (e.g. for preparatory measures) from another participant.	X		
10	Various communication services like e-mail, talk, phone, ...	X		
11	Use electronic patient record Any type of access to the patient record.		X	X
12	Specify/release referral checklist Specify a checklist about requirements to other participants for referral preparations.		X	
13	Subscribe to event or notification E.g. request notification on discharge or result entry.			(X)
Other Functionality				
14	Process monitoring Any supervisory monitoring functions.		X	X
15	Clinical pathways Definition of clinical pathways.		X	X
16	Access to medical knowledge, information, guidelines, ... Provide/access medical information for healthcare professionals.		X	
17	Patient information services Provide/access medical information for patients.	(X)	X	

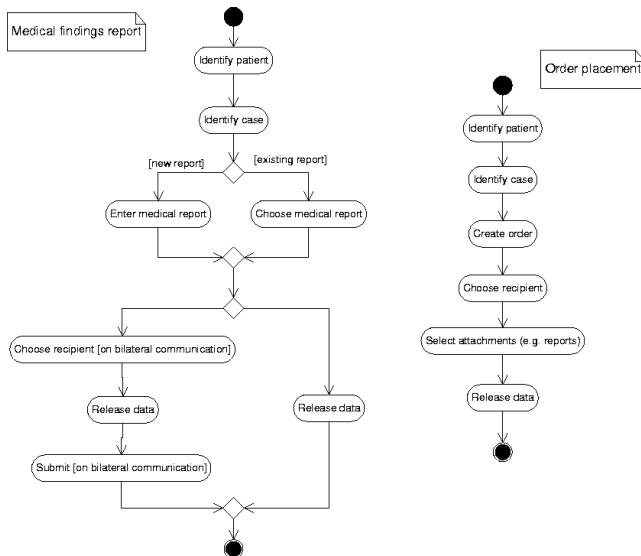


Figure 1: Graphical process description as UML Activity Diagrams

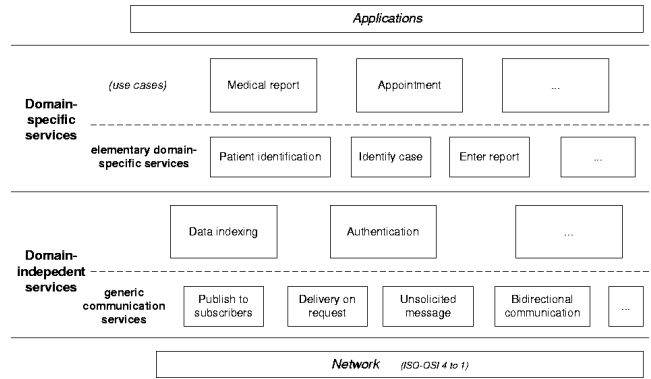


Figure 2: Architecture draft

3.2 Generic services

As the diagrams already indicate, there are elementary healthcare-specific services (like ‘identify patient’ in fig 1) which occur in multiple communication patterns. In addition, most of the communication patterns utilize the same basic communication mechanisms.⁴ Thus, in order to be able to reuse these typical services for reconfiguration of communication patterns (specialization and adaptation) and specification of new patterns (extensibility), it is helpful to choose a layered approach: An architecture should provide a basic layer of reusable, elementary healthcare-specific communication services, on which the single components can be built. An analysis of the healthcare-specific elementary services shows that these services, in turn, are based on a small set of domain-independent generic communication services. We found that most of the communication needs can be implemented on the basis of the following generic services:

Publish to subscribers A subscriber registers to receive a notification if a certain event occurs.

Delivery on request A sender requests instant delivery of certain data.

Unsolicited message A sender initiates a message without expecting a response.

Bidirectional communication A symmetric connection for telecommunication in both directions.

3.3 Component architecture

Our approach is a component-based architecture as sketched in fig 2. Its components provide the services needed, structured into several layers according to their abstraction degree. The top level services correspond to the identified use cases. These use common elementary domain-specific services provided on the next layer, which access domain-independent services. A basic layer provides generic communication services according to the communication concepts identified, using established technical standards.

The component architecture concept allows us to add new services, replace existing ones, and also scale and adapt the

⁴e.g. release information to subscribers ($\hat{=}$ interested and authorized participants)

system to the concrete settings' prerequisites. It follows a generic approach open to various application scenarios, but it is likely to be managed at a central place like a hospital. We are planning to implement the specified architecture in our regional healthcare network (e.g. for disease management).

3.4 Configurability

With a process-oriented approach and the complexity and changeability in healthcare emerges the need for an easily configurable system. The specification of e.g. processes requires knowledge about the application domain, so domain experts should be enabled to edit these specifications themselves, which requires a suitable modelling component with a user interface. A graphical solution supports communication between developers and employees in the healthcare network. These specifications are to be stored in a processable format, so that process or converter configuration can be automated.

Employing such a modelling tool allows for specialization of the abstract communication patterns to explicit process descriptions for concrete use cases and locations. The modelling tool we use in our approach [18] is based on the concept of perspective-oriented modelling originally designed for workflow management concepts [17].

The different perspectives are the following:

- Functional perspective: Description of process types or activities. Process types on a higher level can consist of process types and so on. This enables a flexible de- and composition.
- Behavioral perspective: This gives us the information how the steps within the treatment process are linked together. The control flow is modelled within this perspective.
- Informational perspective: This provides the information, which data items are needed at one process step and which information is produced. The data flow models the way the information must be transported by the system (and possibly transformed).
- Organizational perspective: Derives the different roles and groups taking part in treatment processes. Each process step is assigned to a role, substituted by a real participant at run-time.
- Operational perspective: Models the systems involved in the distributed treatment process. The data described in informational perspective must be transported from the system to another system.

These perspectives allow us to flexibly model the whole data logistics (What data is needed when and where?) and control flow (What alternatives must be executed by a system under which conditions?). The modelling tool automatically creates a description in XML. An XML Schema representation of a process has been developed. The XML process descriptions are to be used for configuring our architecture.

4. INTEGRATION ISSUES

In addition to the functional issues discussed in the previous section integration issues are to be considered, as the

information to be shared within the healthcare network is typically captured in disparate autonomous systems at the participating sites. To integrate these subsystems into a comprehensive healthcare network different aspects of integration have to be considered:

4.1 Data integration

The core problem of data integration is semantic heterogeneity, which is a result of the design autonomy of different vendors [36, 9, 25]. The goal is that information produced in a source system can be transferred to and 'understood' by a target system. This requires different aspects of compatibility:

1. Data structure and encoding (syntactical compatibility)
2. Type level semantics (ontological compatibility)
3. Instance level semantics (terminological compatibility)

To some degree these incompatibilities can be handled by means of typical ETL (Extraction/Transformation/Loading) functionality offered by most EAI⁵-tools, such as MoM⁶-type integration engines.

4.1.1 Syntactical compatibility

Different systems might use different encoding rules to represent data. A syntactical transformation is required to handle this. For internal data representation XML will be best suited. This extensible structuring language along with its manifold extensions (like XML Schema for structural definitions or XSLT for transformation) provides powerful facilities for data management and conversion without constraining exchangeability and platform independence.

4.1.2 Ontological compatibility

Semantic heterogeneity on the type level occurs when semantics is 'hardcoded' into an application, e.g. by encoding concepts into a database schema. This ontological commitment might result in incompatible database schemas: A posteriori matching of semantically heterogeneous database schemas is a fundamental problem in systems integration which cannot be fully automated [12, 31] and in some cases is not even possible without modifying at least one of the database schemas [9]. This kind of semantic heterogeneity can only be reduced if different vendors agree on common ontologies by adhering to healthcare-specific standards. In hospital settings, HL7 is a well established message-based standard which contributes to reduce semantic heterogeneity to some degree [34]. HL7 is based on a comprehensive catalog of message triggering events and the associated message formats. The standard particularly specifies the semantics of the data that are to be exchanged. Unfortunately, HL7 is not a plug-and-play standard: Most vendors only implement a subset of the most frequently required events in their HL7 interface. The standard also allows a variety of integration strategies (e.g. both push strategy and pull strategy can be implemented using HL7 messages) and user-specific

⁵Enterprise Application Integration

⁶Message-oriented Middleware. Integration tools that ease the mapping of disparate interfaces by supporting the specification of rules for message transformation.

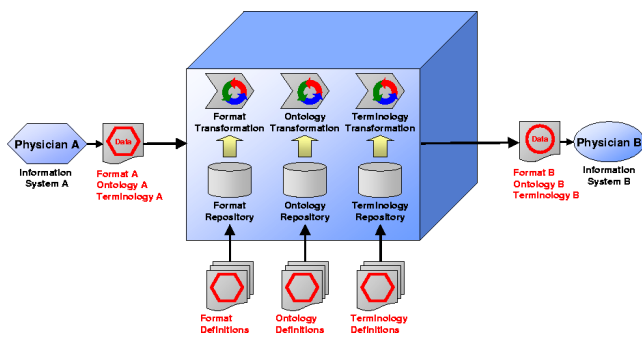


Figure 3: Basic concept for syntax, ontology, and terminology integration

adaptations of message formats via user defined fields and segments.

Outside hospital settings HL7 is uncommon and other standards are used (in Germany xDT standards are quite common). To map xDT to HL7 it is necessary to translate between the underlying ontologies. Such an ontological transformation can also be supported by typical ETL functionality. However, mapping heterogeneous ontologies is essentially the same as mapping heterogeneous database schemas, so it might occur that some concepts cannot be translated without a modification of the participating systems.

4.1.3 Terminological compatibility

While semantic heterogeneity on the type level corresponds to database schema, semantic heterogeneity on the instance level corresponds to database contents (cf. [28, 21]). Semantic incompatibilities occur at both levels, but the basic problem to be solved in the context of systems integration is the type level heterogeneity. Terminological incompatibilities usually emerge at runtime, when different users enter semantically incompatible data into the system. A typical approach to avoid this kind of heterogeneity is to use a controlled terminology, standard catalogs, or classifications like ICD⁷ and ICPM⁸ in order to give the end user a terminological reference – medical entities dictionaries and terminology servers are to be mentioned in this context (cf. [8, 29, 21]). Translations between disparate terminologies can also be done by common ETL translation mechanisms. However, incorporating a meta-thesaurus like UMLS⁹ and associated tools might be supportive for this purpose.

Components for the various kinds of ETL functionality needed for data transformation and mapping are to be integrated into our system architecture, because data transformation is an elementary step within the communication patterns that are to be supported. This is illustrated in fig 3.

4.2 Levels of integration

An important quality of a healthcare network is that arbitrary sites can participate in the network. It would be fatal to force the participating local systems to adhere to a complex common ontology. Instead, it should be possible to participate in the network with a minimum integration ef-

fort. This will necessarily require to start with compromise solutions, in order to interconnect sites with conceptually incompatible systems. To achieve this we propose to distinguish different levels of semantic compatibility. The Clinical Document Architecture (CDA, a part of the HL7 Version 3 definition; cf. [11]) supports this levelling as it includes a hierarchic set of document specifications. It can be seen as a set of hierarchically related XML document type definitions with three different levels of abstraction: Level 1 does not restrict structure or contents, but a document as a whole is characterized by its context data (e.g. document identification, confidentiality status, encounter data etc.). Level 2 specifies the document's contents on a high level of abstraction (a level 2 template may, for instance, specify that a document of a certain type must contain a section 'vital signs'), while level 3 includes additional detailed mark-up derived from the HL7 Reference Information Model (RIM). The advantage of utilizing this approach is that the XML document can at least be displayed at the recipient's site, using an appropriate style sheet, and interpreted by a human beholder, even if the contents of the document are not 'understood' by the recipient's local system.

4.3 Record linkage

Despite the usage of CDA, it is still necessary to achieve agreement on a minimum set of context data in order to be able to properly link data (such as clinical documents) to their context data. The core functionality required for this purpose is a Master Patient Index (MPI), which allows to uniquely identify a patient. The MPI is also necessary to establish an electronic patient record containing links to various kinds of patient-related information. This information may either be stored at a central site or remain at its source location. The latter would be called 'virtual electronic patient record'. For further discussion of data distribution issues we refer to e.g. [10, 37].

5. DISCUSSION AND CONCLUSION

The ongoing process of hospitals and individual practices merging into networks of healthcare delivery, along with high rates of medical errors resulting from insufficient information logistics, creates a strong need to extend the use of information systems from hospital settings to cover the whole healthcare network. We surveyed the literature and interviewed local practitioners and hospital physicians, in order to determine the core requirements for an information system to improve the delivery of healthcare within a healthcare network.

In addition to the functional requirements, we found extensibility, adaptability, and integrability to be core requirements that influenced the design of a system architecture. We classified the functional requirements and derived reusable communication patterns, which were analyzed to derive typical common elementary services that are reused in multiple scenarios. We have introduced an extensible system architecture to comply to the complex and evolving structures in healthcare, based on a multilevel component concept. The layered approach facilitates a high degree of reusability and supports adaptability to changing or new requirements.

To enable arbitrary sites to participate in the healthcare network we proposed to distinguish different levels of semantic compatibility and allow compromise solutions for

⁷International Classification of Diseases

⁸International Classification of Procedures in Medicine

⁹Unified Medical Language System

integration accordingly. This is facilitated by using CDA-conformant documents as the unit of information interchange. This approach at least enables a human beholder to display an electronic document even if the contents cannot be recognized by the local computer system.

A prototype of the healthcare network architecture is currently being implemented and various types of available software products are tested whether they are suitable as an implementation platform or as internal component to provide reusable generic services.

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