A Mediated Publish-Subscribe System for Inter-Institutional Process Support in Healthcare

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ABSTRACT

Inadequate availability of patient information is a major cause for medical errors and affects costs in healthcare. Traditional information integration in healthcare does not solve the problem. For chronic diseases and multimorbidity, the significance of patient information availability is yet increasing. Applying a document-oriented paradigm to a mediated publish-subscribe infrastructure allows to foster inter-institutional information exchange in healthcare. The goal of the proposed architecture is to provide information exchange between strict autonomous healthcare institutions, bridging the gap between primary and secondary care, following traditional paper-based working practice. In a distributed healthcare scenario, the patient has to maintain sovereignty over any personal health information. Therefore, the proposed mediated publish-subscribe architecture essentially decouples the roles of information author and information publisher into distinct actors.

Categories and Subject Descriptors

C.2.4 [**Computer-Communication Networks**]: Distributed Systems—*distributed applications*; D.2.11 [**Software Engineering**]: Software Architectures—*domain-specific architectures*; D.2.13 [**Software Engineering**]: Reusable Software—*domain engineering*; J.3 [**Computer Applications**]: Life and Medical Sciences—*medical information systems*

General Terms

Design, Human Factors

Keywords

Healthcare, information systems, inter-institutional, document-orientation, publish-subscribe, human mediation

1. INTRODUCTION

In a systems analysis of adverse drug events, 18% of the medical errors were associated with inadequate availability of patient information [1]. For improving the treatment quality and in order to avoid unnecessary costs, an effective information and communication technology is vital for the support of inter-institutional patient treatment. An IT infrastructure for healthcare networks must respect and consider the autonomy of preexisting systems in different institutions.

This paper describes a publish-subscribe architecture for healthcare supply chain scenarios. A short survey of fundamentals, current problems, and emerging requirements of integration and information exchange in healthcare is provided. The survey considerations directly relate to the design of the system. There are two distinguishable features of the proposed solution: to apply document-orientation as instrument of inter-institutional integration and to allow patients to control information distribution. To put a mediated publish-subscribe architecture into practice requires a systematic distinction of actors, roles, phases, and responsibilities in the distribution scenario. The proposed architecture essentially decouples the roles of information author and information publisher into distinct actors.

2. SUPPLY CHAINS IN HEALTHCARE

A short overview of the domain participants is given: The focus of the medical supply chain in Germany are the patients who are treated by office-based physicians foremost, collectively described as the *primary care*. The *secondary care* adds hospitals, laboratories, pharmacies, and ancillary medical institutions as participants of the medical supply chain. Accompanying participants are the health insurance funds and the associations of statutory health insurance physicians. Because data protection is essential for patient-related data, the patient has to maintain sovereignty over any personal health information. This provides a basic motivation for the mediation approach that will be applied to the publish-subscribe pattern.

Considering the comprehensive medical supply chain, functional integration and process integration between the autonomous information systems of the several participants is still unsolved in organizational and diagnostic-therapeutic processes [7]. Particularly chronic diseases like diabetes,

asthma, and cardiac insufficiency require a long-cyclic exchange of patient information between healthcare professionals from different institutions [3]. In order to foster the continuity of care, the inter-institutional cooperation needs to bridge the current gap between institutions of the primary and secondary care. Such effort must not instrument regional standards, as it is done in *regional healthcare information networks* (RHIN) [9], but *transregional standards*.

Information interchange by letters is the way of traditional cooperation – a referral from one institution to another delegates responsibility and liability of diagnosis or therapy to the other institution. Yet, genuine physician teams from different institutions are upcoming [6]. For some years now, in Germany, the treatment of breast cancer is organized by accredited in-station breast cancer treatment centers cooperating with manifold accredited partners like oncologists, radiologists, and the post-operative care. Collaborative treatment scenarios can be described as distributed medical treatment processes with physician teams from different institutions interacting closely meshed for treating complex chronic diseases and multimorbidity. For such collaboration the proposed architecture is based on digital information cards that are yielded from institutional *electronic health records* (EHR), e.g. [5], into a distributed publish-subscribe system that allows the patient to govern data interchange.

3. APPLYING DOCUMENTS AS EVENT TYPE

There are two prime objectives of the proposed solution. The first is the abdication of any central server. The second is the application of document-oriented integration with lightweight interfaces instead of service-oriented integration with semantically rich interfaces.

Documents are coarse-grained, self-contained, and viable. A document carries its own context information and can exist independently from the system it stems from. Changes are not propagated by update information, but by creating an updated document that replaces its predecessor. The *document-oriented integration* focuses on available information, and the integration method affects the semantic scalability of document models, using standardized and minimal interfaces for hand-over. Redundancy in data distribution is not critical with documents because, due to the self-containedness, a synchronization in the classical sense is not required. Likewise are data consistency checks confined to the scope of the document.

Any new standards should respect the ones already in practice for backwards-compatibility and to achieve and maximize acceptance. In conclusion, the event type of the proposed mediated publish-subscribe system will be based on the HL7 v3 CDA standard: The relatively new HL7 v3 standard is based on the HL7 v3 *reference information model* (RIM). It allows for new types to be derived from a limited number of core classes, enabling RIM-based systems to handle even unknown message-types in a generic way. A conceptual change from messages to documents is provided by the HL7 v3 *clinical document architecture* (CDA) substandard. CDA allows for XML-structured medical documents. HL7 v3 CDA provides semantic scalability for healthcare documents, both because this has been an inherent feature of the underlying RIM and because CDA is particularly structured in three levels of semantic abstraction. For example, CDA level 1 simply ensures the ability to display a document like a PDF file. Any CDA document can be accepted without immediate support for processing. Advanced semantic processing support of CDA level 2 or 3 can be added to the system, seamlessly enhancing the information value of already stored CDA documents.

The *deferred system design* principle of evolutionary systems [4] requires semantic decisions not to be frozen in an interface schema because they are hard to revise. HL7 v3 CDA supports deferred system design by its semantic scalability. Applying a document-oriented approach improves the adaptability of the systems by deferring schema decisions from design-time to deploy- or run-time [2].

4. PROPOSED SOLUTION

The proposed solution architecture, the *distributed electronic patient file update system* (DEUS), applies the document-oriented idea in form of DEUS *digital cards*: digital cards are self-contained and viable containers of information. A digital card is authored by an information provider (first part of the digital card ID; e.g. a physician) and it concerns a person (second part of the digital card ID; e.g. a patient). Because an author can provide several digital cards about a concerned person, the author provides an additional discriminator as third part of its identifier. The digital card as information container is subject to PKI signatures, as it will be detailed by the DEUS scenario description. One DEUS digital card contains, for example, a diagnostic finding, clinical evidence, a diagnosis, a therapeutic measure, an order, or a prescription.

4.1 Interaction Scenario

The basic DEUS scenario is outlined in Fig. 1. The patient ("Alice") has recently visited a healthcare professional ("Dr. Higgins") and the obtained information has to be shared to other involved parties (inter alia "Prof. Bob"). The local *healthcare information system* (HCIS) of Dr. Higgins, the author of the obtained information, bundles the information into a digital card. This digital card is electronically signed by its contributor and becomes the subject of information distribution. Subsequently, it is contributed into the node's local DEUS system extension.

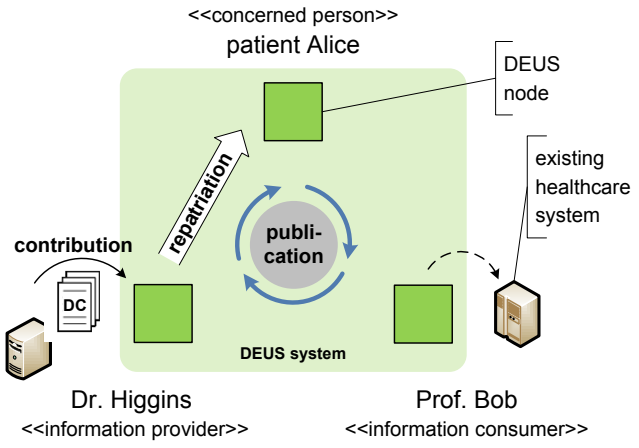

Figure 1: The DEUS scenario as mediated publish-subscribe system

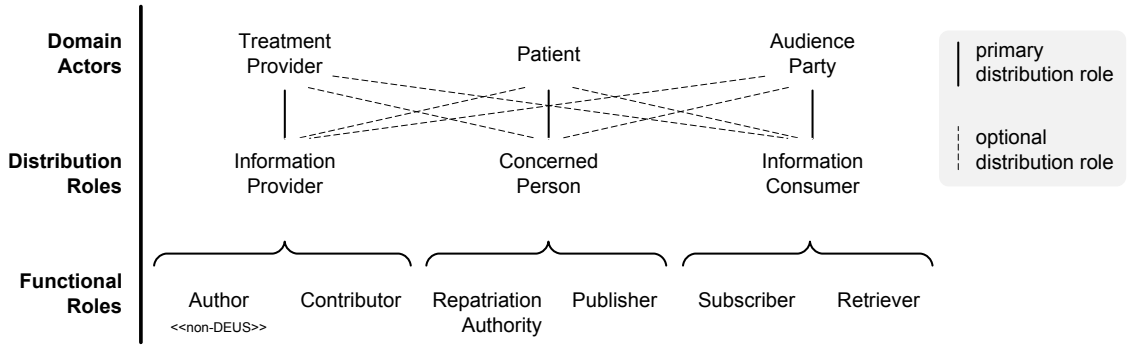

Figure 2: The DEUS roles of healthcare participants

The exported digital card is subsequently transfered to the account of patient Alice who is the person being concerned by the medical information. The patient as sovereign of information distribution decides whether the information is accepted into the pool of digital cards that builds his or her *personal patient file*. The process of transfering a digital card from the contributing DEUS system to the patient's DEUS system together with the patient's decision about the acceptance of the digital card is named *repatriation*. Subsequently, the digital card is published to any subscriber DEUS systems, like Prof. Bob. He will consume the information later, for example when Alice is visiting next time.

Each DEUS participant owns a DEUS account. A DEUS node is a healthcare information system with an installed DEUS extension. A DEUS node can host multiple DEUS accounts. For the mediated publish-subscribe interactions, it is transparent whether an account resides on the same or another DEUS node.

The distribution of patient-related information requires a human authority over any inter-institution-ally shared information, so that the induced transparency of patient information by electronic interchange does not erode doctor-patient confidentiality. The only appropriate healthcare participant for publication control is the patient as the concerned person. If the patient lacks the abilities to sovereign his or her healthcare information, it is possible to delegate this role to a legitimate proxy person or institution, possibly a general practitioner. The mediation of HCIS-to-HCIS communication by the patients' DEUS accounts reintroduces interception and control by a conscious human in an electronic environment for gradually automated information interchange.

4.2 Actors and Roles

The three basic participating actors and their different roles in the DEUS information interchange are summarized in Fig. 2. Each actor has its dominant role in the distribution process, visualized as straight vertical lines between the layer of *domain actors* and the layer of *distribution roles*. However, each actor can assume, by its DEUS account, each distribution role as it is visualized by the clashed lines: For example, the patient can act as information provider about himself, providing information like allergies or legacy paper documents that he contributes in transcribed or scanned form. On the other hand, a treatment provider can use its DEUS account in the role of a concerned person to provide and publish business card information or consultation hours information. Even associations of statutory health insurance physicians could participate by contributing certificates like the ones required for accredited in-station breast cancer treatment centers, and health insurance funds could contribute the patient master data.

The distribution roles are related to the specific role that a DEUS account assumes in an overall distribution scenario. The *functional roles* are responsibilities that are deduced from a distribution role.

The information provider acts as author of the information, which takes place inside the HCIS and is not part of DEUS. The information provider acts as contributor by exporting a digital card and handing it over to the actual DEUS account. The concerned person acts as repatriation authority by deciding about the validity of a repatriated digital card. The concerned person acts as publisher by applying the selection of subscribers and performing the publication transfer. The information consumer acts as subscriber by establishing subscriptions to the account of the concerned person and by accepting published digital cards. Finally, the information consumer acts as retriever by accessing the information pool.

5. DISTRIBUTION OVER CENTRALIZATION

A risk in instrumenting a central content storage, like German D2D[1] or Google Health[2], is an information leak that potentially involves all patients. This is not comparable to any possible abuse scenario in today's paper-based infrastructure: No current healthcare institution hoards information about so many patients as will do any centralized solution for inter-institutional scenarios. The distributed approach mirrors the current state in paper-based working practice: The patient information is available only to the directly involved healthcare systems. As a result, the consequences of a security breach are limited to a fraction.

Yet, even the smallest security breach still remains fatal due to the criticality of the involved information. Hospital infrastructure commonly hosts electronic patient information and already applies profound security measures, e.g. [8], but primary care participants might not be accustomed to the required security standards. Therefore, a distributed approach has to allow proxy institutions to professionally and securely host accounts, i.e. for primary care participants or

[1]Doctor to Doctor, `http://www.d2d.de`, based on PaDok cryptographic infrastructure
[2]`http://www.google.com/health`

for patient participants. In conclusion, participating peer systems in the globally distributed healthcare environment are required to locally adhere to a multi-tenant data architecture as it is provided by DEUS.

6. RELATED WORK

Standards for electronic information exchange between the *practice management systems* of the primary care and the hospitals and institutions of the secondary care are rare. No universal exchange protocol and format exists for interchange of referral vouchers and discharge letters. In Germany, the governmental project "Elektronische Gesundheitskarte" (eGK) has not provided a solution for the issue since the project's outset in 2002. Effective platforms like D2D require a central server for document handover.

Solving the information exchange in healthcare in a document-oriented fashion seems to be targeted by IHE XDS which allows for distributed document repositories and access delegation. Yet, in order to find documents in such a repository, a single central document registry is specified, reusing ebXML registry methodology to provide a centralized method of indexing documents. The central registry is a global system node that allows queries and that delegates the access to referenced documents to the original document repositories. Such architecture targets complex hospitals with associated ancillary systems and is even applicable to regional integration efforts, but fails for nationwide application due to its centralized approach.

7. CONCLUSION

The DEUS architecture achieves a document-oriented process support between strict autonomous institutions following the paper-based work practice as reference model. For this purpose, DEUS applies document-orientation based on a publish-subscribe design. The essential argument for document-oriented integration over interface- or message-oriented integration lies in its capacity to support deferred system design. Deferred system design is necessary for healthcare information systems due to their evolutionary character.

The DEUS architecture appoints the patient as integral participant of the information supply chain. The warranty of data protection, imperative in healthcare, requires PKI integration on technological level but additionally requires a repatriation phase with end-user interception capability, resulting in a mediated publish-subscribe architecture. The DEUS architecture supports local autonomy, platform independence, and loose coupling.

The initial goal of the proposed DEUS architecture is to foster the availability of patient information in order to bridge the gap between institutions of the primary and secondary care. It supports closely meshed inter-institutional physician teams and allows for patient-centered document management. As subject of interchange digital cards maintain the self-contained and viable character of a document, accentuating a finer information granularity than paper-based document practice. The patient account can be involved in multiple distinct physician teams fostering trans-sectional, life-long, patient-centered healthcare documentation.

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