THE OPEN-SOURCE INTEGRATING THE HEALTHCARE ENTERPRISE (IHE)

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ABSTRACT

IHE has an increasingly great importance in delivering optimal patient care [1]. By pushing the integration of well-accepted standards in the healthcare domain, the IHE initiative improves interoperability between heterogeneous systems. The work described in this paper strives to give researchers enough information about open-source applied to IHE to get started with small-to-medium scale medical informatics research projects. In this context, we present free / open-source implementations of several IHE Profiles participating in the architecture of a very precise yet common motivation scenario: the medical document exchange. The objective of this work is to show that open-source applications may be successfully used in sensitive contexts such as healthcare, provided that scope and potential issues are well considered. Discussion at the end of this work informs on strengths and weaknesses of the presented frameworks as well as of the open-source model itself.

KEYWORDS

Integrating the Healthcare Enterprise, Healthcare, Open-Source, Document Exchange, e-Health, Interoperability.

1. INTRODUCTION

Integrating the Healthcare Enterprise (IHE)-enabled technologies have been gaining momentum [2]. IHE is an initiative led by the healthcare industry and professionals. It is sponsored by the Healthcare Information and Management Systems Society (HIMSS) and Radiological Society of North America (RSNA). IHE's objective is the support of optimal patient care, by solving interoperability problems encountered in the communication between heterogeneous healthcare systems. In order to make the integration of systems easier, IHE combines well-established standards, such as DICOM, HL7 and W3C standards, in specifications that intend to address specific clinical needs. Specifications are called Profiles in the IHE terminology.
There exist commercial-grade implementations for many IHE profiles, which can be found in IHE's product registry[1]. Since implementations are to make their way into the healthcare infrastructures, which have strong requirements in terms of security and liability, the IHE group proposes a way of checking the compliance of these solutions by testing them against other vendor implementations. This event is world-wide and is called "Connect-a-thon"[2]. The results of each Connect-a-thon are generally saved on a dedicated server by region (USA[3], Europe[4] …). Participants, which successfully passed the tests are given an IHE conformance certificate, called "Integration Statement". This statement can be a strong selling argument.

[1] http://product-registry.ihe.net/PR/home.seam (viewed 21 February 2011)
[2] http://www.ihe.net/Connectathon/ (viewed 21 February 2011)
[3] http://www.iheusa.org/ConnectConf2011.aspx#TestingEvent (viewed 21 February 2011)
[4] http://connectathon-results.ihe-europe.net/ (viewed 21 February 2011)

Aside from commercial implementations, IHE also found a way out into the open-source domain in the form of Free and Libre Open Source Software (F/LOSS) or Open Source Software (OSS) more generally. Many quality implementations are available today in public repositories[5]. This document provides a list of some popular free and/or open-source implementations and provides two feature matrices offering a per-actor and per-transaction view. The objective of this work is to show the benefits and issues of using open-source in a sensitive context such as medical informatics.
The next sections of this paper will provide some insight into research, which has already been done on open-source applied to medical informatics. A motivation scenario is then discussed as a basis for the selection of the open-source IHE implementations. Towards the end of this work, some popular implementations are presented along with a discussion about their benefits and potential issues.

2. RELATED WORK

Numerous papers have been written about open-source frameworks applied to medical informatics. These works typically fall in one of these categories: framework surveys, studies on usage of open-source in medical informatics, open-source maturity/quality measurement.
First, the number of surveys and studies related to clinical applications suggest that open-source in mainstream developments has definitely attracted interest from the healthcare sector [3]. A relatively recent study [4] confirms the existence of an active OSS development community focusing on health and medical informatics, yet hospitals seem slow to follow [5]. Numerous surveys about existing frameworks and standards have been published [6][7].
Although open-source in medical informatics is taking attention, its adoption rate varies greatly across the globe. The very sensitive nature of the healthcare IT primarily raises questions about liability. A study published in 2007 shows that open-source software adoption in Quebec by health care organizations has still many barriers to overcome [8], supposedly due to lack of proper information and internal political pressures. Another study shows that in UK, the future of open-source software implementation in the public sector is uncertain [9]. Even if there is evidence that a change is occurring, a major shift from current outsourcing deals doesn't seem to be happening anytime soon. In the U.S, where the health expenditure is the biggest in the world, open-source electronic health record systems seem to be at the center of the discussion [10]. Another very serious study [11] suggests that F/LOSS-related services in Europe could reach a 32% of all IT services by 2010. Unfortunately, we do not have corroborating data to verify this. So, even if there is evidence through studies, that open-source is taking off in the public sector and healthcare, it is not yet clear what to expect in the future.
Finally, this work would be incomplete without a word on maturity models in open-source. According to its definition, the open-source maturity model (OSMM) is a formal methodology for assessing the maturity of a given open-source software. OSMM from Capgemini[6] is a practical method based on two axes and two levels. OSMM from Navica has been exposed in [12], but the Navicasoft's website[7] seems to be down for a long time. The Method for Qualification and Selection of Open Source Software (QSOS) described in [13] is a four step iterative evaluation process based on criteria split into three axes: functional coverage, risks for the user's perspective and risks from the service provider's perspective. Open Business Readiness Rating (OpenBRR[8]) is an assessment methodology aiming at the integration of company constraints. A comprehensive comparison between QSOS and OpenBRR has been published in [14]. Finally, the QualiPSo Open Source Maturity Model (OMM) described in [15] is also based on three levels, each one requiring the software to comply with different elements of trust.
Ultimately, the research in this paper does not intend to supersede any of these previous works (surveys), but indeed complement it. Our focus is finding a concrete case in medical informatics where open-source tools are particularly well suited.

[5] http://www.sourceforge.net (viewed 21 February 2011)
[6] http://www.osspartner.com/portail/sections/accueil-public/evaluation-osmm (viewed 21 Feb. 2011)
[7] http://www.navicasoft.com (viewed 21 February 2011)
[8] http://www.openbrr.org/ (viewed 21 February 2011)

3. MOTIVATION

Some situations may arise, where large commercial infrastructures may not suit the very particular needs of some healthcare deployments. Since they represent major investments in terms of time, resources and infrastructure, their use is often restricted to highly sensitive applications both in terms of patient safety and security.
On other hand, some deployments often require limited resources and fast response, because they are limited in scope and simple in application. This holds particularly true in medical informatics research projects. In this context, the medical data exchange scenario [16] fits particularly well within this type of limited-scope deployment. It is conceptually simple, all actors are known in advance and require relatively few resources to deploy and test.
A rapid analysis of this scenario shows that the medical document exchange involves the participation of one or more source actors (typically hospitals) injecting medical documents into a repository, one or more consumers consuming them (hospital units or general practitioners) and a central repository managing document entries. The picture below illustrates this scenario.

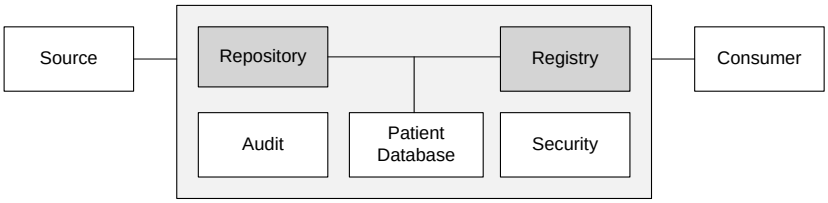

Figure 1. Typical Document Exchange Scenario Actors

This scenario has already been extensively described in the IHE IT Infrastructure Technical Framework [17][18][19] both in terms or IHE Profiles and Transactions. The figure below, taken from the Technical Framework, shows exactly the same deployment based on IHE actors.

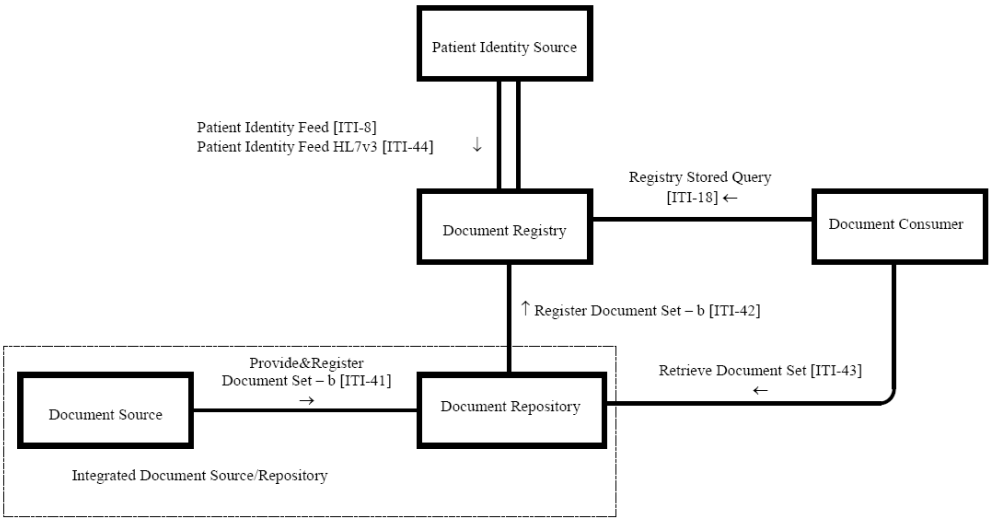

Figure 2. IHE Document Exchange

In terms of IHE profiles, the medical data exchange scenario illustrated above involves a registry and repository, which are responsible for the management of the document entries. The IHE Cross-Enterprise Document Sharing (XDS) profile provides that kind of functionality. Furthermore, in order to associate

patients described in the documents to entries in a patient index, IHE provides the Patient Identity Cross-Referencing (IHE PIX) and the Patient Demographics Query (IHE PDQ) profiles. The first bridges identifiers from different domains (usually hospitals) for the same patient and the latter provides demographics. Finally, the Audit Trail and Node Authentication (IHE ATNA) profile handles security and audit logging. Those profiles may also have dependencies on other profiles, such as Constant Time (CT) or Cross-Enterprise User Assertion (XUA), which handle time synchronization and user assertions respectively.
Since many free implementations exist for individual IHE Profiles, the medical document exchange scenario provides thus a good motivation scenario. First of all, the modularity of its architecture makes for a higher probability of finding related implementations. It is obviously more complicated to find a "do-it-all" solution, than finding the implementation of a single profile. Second, since actors and transactions are translated by IHE in terms of specifications (IHE Profiles are based on specifications), it is somewhat certain that different implementations will communicate almost seamlessly. Finally, since the scope of this deployment is rather small and usually limits to a few hospitals and a few care providers, the cost-effectiveness of an open-source solution is a major motivation.
The following sections present some popular IHE implementations that provide the necessary building blocks necessary to architect this scenario (partially or fully) or are complete implementations of it. Two reference feature matrices are provided that give some information the implementation status for the tested platforms.

4. OPEN-SOURCE IHE IMPLEMENTATIONS

The provided open-source implementations proposed below are part of a selection provided by an extensive, but non-exhaustive compilation from several sources[9][10]. There exist many other free and open-source alternatives, but to date, those listed below seem to be the most popular and some of them are used in large-scale healthcare deployments, although no specific criteria has been used in their choice.

IHEOS. IHE Open Source (IHEOS) is an implementation of the Cross-Enterprise Document Sharing (XDS) profile developed by the National Institute of Standards and Technology (NIST) for the testing of certain IHE Profiles.

O3-XDS. Open Three Cross-Enterprise Document Sharing (O3-XDS) is an open-source initiative from the Open Three (O3) Consortium. This project was activated by the SSIC-HECE & DEEI in cooperation with the Dipartimento di Scienze Medico Diagnostiche e Terapie Speciali and the Unitersità degli Studi di Padova in Italy. O3-XDS provides a modular and portable XDS registry and repository actor implementation.

HIEOS. Health Information Exchange Open Source (HIEOS) is an open source implementation of Integrating the Healthcare Enterprise (IHE) Cross-Enterprise Document Sharing (XDS.b) and Cross Community Access (XCA) integration profiles, enabling longitudinal records. HIEOS' core services can be used in federated, hybrid or centralized model scenarios.

IPF. The Open eHealth Integration Platform (IPF) is an extension of the Apache Camel routing and mediation engine. IPF provides domain-specific languages (DSLs) for implementing general-purpose as well as specific Enterprise Integration Patterns, such as HL7-specific integration solutions. These DSLs are extensible via Groovy's meta-programming features. IPF may be easily embedded into Java applications and also provides support for deployments inside OSGi environments. In addition to its many features, IFP also provides failure recovery and high-availability features support.

OpenXDS. The Open Cross-Enterprise Document Sharing (OpenXDS) project is the document sharing component of the OpenExchange[11] platform. It provides an implementation for the IHE Cross-Document

[9] http://www.medfloss.org/ (viewed 21 February 2011)
[10] http://motorcycleguy.blogspot.com/p/open-source-standards-implementations.html (viewed 21 February 2011)
[11] https://www.projects.openhealthtools.org/sf/projects/openexchange/ (viewed 21 February 2011)

Sharing Registry and Repository actors, as well as an implementation for both the IHE Cross-Community Access (XCA) actors.

OpenPIXPDQ. The Open Patient Identity Cross-Referencing and Patient Demographics Query (OpenPIXPDQ) project is the patient identification management component of the OpenExchange platform. It provides an implementation for the IHE Patient Identifier Cross-reference (PIX) Manager and Patient Demographics Query (PDQ) Supplier actors.

OpenATNA. The Open Audit Trail and Node Authentication (OpenATNA) project is the audit management component of the OpenExchange platform. It provides an implementation for the IHE Audit Record Repository of the ATNA profile.

CONNECT. Initially developed by U.S federal agencies to support their health-related missions, CONNECT is a software solution for healthcare applications. Now available to all organizations, CONNECT has become an open-source solution providing Health Information Exchange (HIE) at both local and national levels. CONNECT uses the Nation-wide Health Information Network (NHIN) standards and governance.

MS-XDS.b RI. Microsoft XDS.b Reference Implementation is Microsoft's implementation of the IHE XDS.b Document Registry and Repository actors. It also provides implementations for client-side ATNA logging, Secure Node actors and is available only for the Microsoft Windows™ platforms.

IHE Profiles. IHE Profiles is a comprehensive set of Eclipse/OSGi plugins implementing the client-side of many IHE profiles. The project was initiated in the context of Open Health Tools, an association of influent actors in the healthcare sector. IHE Profiles provides support for the following profiles: ATNA, MPQ, PAM, PIX, PDQ, SVS, XCA, XDR, XDS and XUA.

Feature matrices

The feature matrices below show a synthetic view of the differences between implementations. The first matrix highlights the actors implemented by the different frameworks. The second shows the implemented transactions. The data shown below in the matrices was collected from statements available from the Connect-a-thons. Not all frameworks were tested in the laboratory. For some frameworks, no Connect-a-thon statement is available (CONNECT project) or is available only partially (IPF). This comparison does not give any measure on the quality or maturity of the solutions.

						OpenExchange				
Profile	Actor	IHEOS	O3	HIEOS	IPF	OpenXDS	OpenATNA	OpenPIXPDQ	MS-XDS.b RI	IHE Profiles
CT	Time Client	•	•	•	•	•	•	•	•	
ATNA	Audit Record Repository	•	•				•			
	Secure Node	•	•	•	•		•		•	
	Secure Application					•		•	•	
PIX (and v3)	Patient Identity Source				•					•
	Patient Identity Cross-Reference Manager				•			•		
	Patient Identity Cross-Reference Consumer				•					•
PDQ (and v3)	Patient Demographics Supplier				•			•		
	Patient Demographics Consumer									•
XDS.a	Document Registry		•		•					
	Document Repository		•		•					
	Document Source		•		•(1)					•
	Document Consumer		•		•(1)					•
XDS.b	Document Registry	•		•	•	•			•	
	Document Repository	•		•	•	•			•	
	Document Source				•(1)					•
	Document Consumer				•(1)				•	•
XDS-I.b	Document Registry	•		•		•			•	
	Document Repository	•		•		•				
	Image Document Source									•
	Image Document Consumer		•							
XDR	Document Source	•								•
	Document Recipient	•								•
XCA	Initiating Gateway	•		•		•				
	Responding Gateway	•		•		•				
XDM	Portable Media Creator		•							
	Portable Media Importer									
XUA	X-Service User					•				•
	X-Service Provider	•		•		•				•
XCPD	Initiating Gateway	•			•					
	Responding Gateway	•			•					
MPQ	Document Consumer			•						•
	Document Registry			•						
(1) No Connect-a-thon statement available										

Figure 3. Feature matrix by actor

						OpenExchange				
Profile	Actor	IHEOS	O3	HIEOS	IPF	OpenXDS	OpenATNA	OpenPIXPDQ	MS-XDS.b RI	IHE Profiles
CT	ITI-01 Maintain Time		•	•		•	•	•		
ATNA	ITI-19 Authenticate Node		•	•	•	•	•	•		•
	ITI-20 Record Audit Event		•	•	•	•	•	•		•
PIX	ITI-08 Patient Identity Feed		•	•	•	•		•		•
	ITI-09 PIX Query		•		•			•		•
	ITI-10 PIX Update Notification				•			•		
PIX HL7 v3	ITI-44 Patient Identity Feed v3			•	•			•		•
	ITI-45 PIX Query v3				•			•		•
	ITI-46 PIX Update Notification v3				•			•		
PDQ	ITI-21 Patient Demographics Query				•			•		•
	ITI-22 Patient Demographics and Visit Query				•					
PDQ HL7 v3	ITI-47 Patient Demographics Query v3				•			•		•
XDS.a	ITI-16 Query Registry		•		•					•
	ITI-15 Provide & Register Document Set		•		•					•
	ITI-14 Register Document Set		•		•					
	ITI-17 Retrieve Document		•		•					•
XDS.b	ITI-18 Registry Stored Query (a and b)			•	•	•			•	•
	ITI-41 Provide & Register Document Set - b			•	•	•			•	•
	ITI-42 Register Document Set -b			•	•	•			•	
	ITI-43 Retrieve Document Set			•	•	•			•	•
XDS-I.b	RAD-16 Retrieve Images		•						•	
	RAD-17 Retrieve Presentation States		•						•	
	RAD-27 Retrieve Reports		•						•	
	RAD-31 Retrieve Key Image Note		•						•	
	RAD-45 Retrieve Evidence Documents		•	•	•				•	
	RAD-55 WADO Retrieve		•		•				•	
	RAD-54 Provide and Register Imaging D.Set		•		•				•	
XDR	ITI-41 Provide & Register Document Set - b									•
XCA	ITI-38 Cross-Gateway Query			•						
	ITI-39 Cross-Gateway Retrieve			•						
XDM	ITI-32 Distribute Set On Media		•							
XUA	ITI-40 Provide X-User Assertion			•		•				•
MPQ	ITI-51 Multi-Patient Stored Query			•						•
XCPD	ITI-55 Cross-Gateway Patient Discovery									
	ITI-56 Cross-Gateway Patient Location Query									

Figure 4. Feature matrix by transaction

5. DISCUSSION

IHEOS is a testing platform, but its source-code is valuable for system implementers. O3-XDS seems rather simple to install, however the lack of proper documentation and the long inactivity (unreachability) of its associated website allows for emitting only reserved judgments. HIEOS provides an extensive documentation and a rather solid implementation of the XDS.b IHE Profile. IPF comes with A-grade documentation, a rock-solid implementation of many profiles and extensibility though the Apache Camel routing and mediation engine. It is packed with lots of features, but looks quite hard to deploy. The subprojects of the OpenExchange platform (OpenXDS, OpenPIXPDQ and OpenATNA) provide a good implementation, share the same core interfaces and are made to work together seamlessly. They are really simple to deploy, but the documentation somewhat lacks in detail. Client-side interfaces are provided under the Open Health Tools (OHT) IHE Profiles[12] subproject. The CONNECT project is huge and was first developed as a support platform for Nation Wide Health Information Networks (NHINs). As good at it is, it may not be suited to small research projects. Microsoft's reference implementation is a solid IHE XDS implementation for Windows. It was successfully deployed by our team in one medium scale project. This project uses the less permissive Microsoft Public License (Ms-PL). Finally, IHE Profiles, a subproject of the OHT initiative provides a very solid implementation of many client-side IHE actors for a wide range of profiles (amongst which XDS, PIX, PDQ, ATNA, XUA …).

As far as the motivation scenario is concerned, HIEOS, CONNECT, IPF, OpenExchange and Microsoft's Reference Implementation can be used as reference implementations for the repository and registry, since all of them support the Document Registry and Repository actors and provide implementations for transactions ITI-41, ITI-42, ITI-43 and ITI-18. However, only IPF, OpenExchange and CONNECT may be used as complete platforms, since others do not provide an implementation for IHE PIX and PDQ server-side actors. The integration between MS-XDS.b RI and IHE Profiles OHT project (OHT Bridge) has been successfully tested in a real case scenario, Medicoordination, as described in [20][21].

Performing an objective comparison between different implementations is very difficult and often dangerous. Some frameworks are straight implementations of particular use cases along with dependencies (document sharing framework for example), while others like CONNECT are large-scale platforms that support Nation Wide Health Information Networks (NHINs). Although a comparison is not directly feasible; the previous matrices may still be used as references. Difficulties encountered when trying a straight comparison between different implementations raise interesting questions. What should be used as a comparison base? How should we compare different open-source solutions providing the same services? These are rather sensitive points and have been devoted lengthy discussions in other papers (see Section 2).

Using open-source frameworks for medical applications does present some issues and disadvantages. Firstly, it is often difficult to measure their maturity / quality objectively. The Connect-a-thon statements used in this survey merely assert that vendors are IHE-compatible in some profiles; they are not a measure of their quality. To make this study more complete, these solutions should have been analyzed through the lens of open-source maturity/quality measurement methods like the ones described earlier. Furthermore, unlike commercial solutions where the support is directly provided by an independent company or by the vendor itself, a team of programmers may have to be hired just for the deployment and maintenance of the open-source platform. Finally, the image of open-source is not sufficiently clear at this time. Often people are more likely to trust commercial solutions, because they indirectly associate a high production cost with quality.

Fortunately, there are strong benefits in leveraging open-source solutions. In the motivation scenario described in the paper, the fact that different implementations exist for the same IHE profile is beneficial. Using implementations from different vendors in the same project reduces the dependency of a particular actor towards a vendor (vendor lock-in), resulting thus in risk (if the company goes bankrupt) and transience (if the company changes direction of business) mitigation. Moreover, open-source frameworks make source-code available to the developers. As soon as problems or bugs are detected, they can be directly tracked and patched; the framework can thus be updated and shared back with the community, improving its liability over revisions. Finally the reduced cost, generally limited to associated exploitation costs, is a major asset for projects where reduced resources are a requirement (typical in applied research projects).

[12] https://www.projects.openhealthtools.org/sf/projects/iheprofiles/ (viewed 21 February 2011)

6. CONCLUSION

As discussed previously, the use of open-source implementations in healthcare applications is generally good, provided that the scope of its application is limited and risks are correctly measured. Modularity, control and reduced costs are certainly a major added-value for any research project.
Unfortunately, open-source is not always associated an enjoyable image in the context of very sensitive healthcare applications. Documentation is very often incomplete or hard to understand and the infrastructure is sometimes really painful to deploy and maintain. Moreover, implementers often do not provide models for the maturity or even quality of their projects, making it difficult to unravel the good from the bad.

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