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IHE PROFILES
OPEN-SOURCE AND/OR FREE IMPLEMENTATIONS

(RCSO IHETOOLS Deliverable D.3.1)

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BUSINESS INFORMATION SYSTEMS TECHNICAL REPORT

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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. This work gives presents in detail 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.

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

Contents

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.

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,

[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)
[5] http://www.sourceforge.net (viewed 21 February 2011)

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.

3 Profiles

This section provides a brief insight into the different profiles, which are commonly found in most Electronic Health Records (EHRs), Personal Health Records (PHRs) and other healthcare IT systems leveraging IHE technologies. Pictures and information about these are taken directly from the IHE IT Infrastructure Technical Documents [16][17][18].

3.1 CT – Constant Time

3.1.1 Description

The Constant Time profile provides ways to maintain system clocks synchronized to a well known reference time. It has an utmost importance in maintaining the coherence of auditing information.

3.1.2 Actors

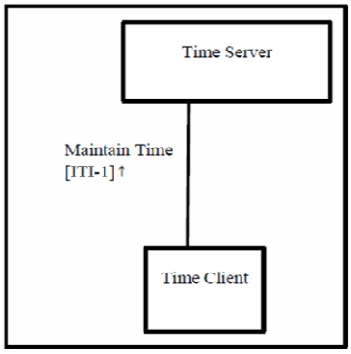

FIGURE 1. CONSTANT TIME ACTORS & TRANSACTIONS

Time Client. Uses Time Server responses to maintain the local clock synchronization.

3.2 ATNA – Audit Trail and Node Authentication

3.2.1 Description

Audit Trail and Node Authentication provides a specification for the characteristics of a basic Secure Node by:

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

1. Describing its security environment (identification, authorization, authentication, access control);
2. Defining its basic auditing requirements ;
3. Defining the basic security requirements for communications (TLS or equivalent)
4. Establishing the communication protocol between a Secure Node and an Audit Repository node collecting audit information;
5. Defining a Secure Application actor, which basically designates a product configuration that is not able to fulfill the specific requirements of a Secure Node.

Specific implementations of the ATNA profile may choose diverse additional options described in the Technical Framework.

3.2.2 Actors

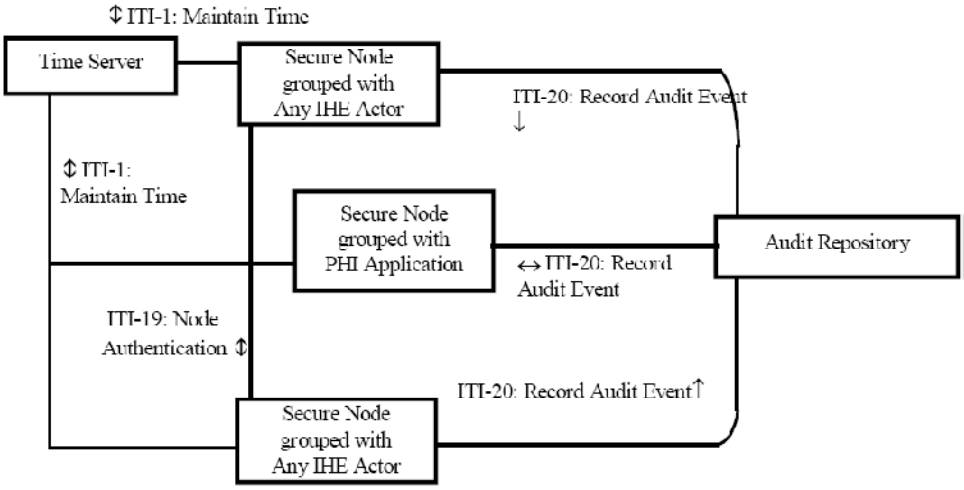

FIGURE 2. AUDIT TRAIL AND NODE AUTHENTICATION ACTORS & TRANSACTIONS

Audit Record Repository. Handles the reception and storage or audit records.

Secure Node. A node, which can establish a trust relationship to other nodes by using a mutual authentication mechanism, which is protocol specific (TLS for example).

Secure Application. A secure application uses the same authentication mechanisms as a secure node, but to a lesser extent. It only handles authentication and authorization at the application level, without taking care of the security level of the machine it is running on (operating system, network…).

3.3 PIX – Patient Identifier Cross-Referencing

3.3.1 Description

The PIX profile is a specification supporting the cross-referencing of patient identifiers across multiple Patient Identifier Domains. Cross-referenced identifiers allow clinicians to obtain a complete view on a patient, which may be known under different identifiers in other units.

3.3.2 Actors

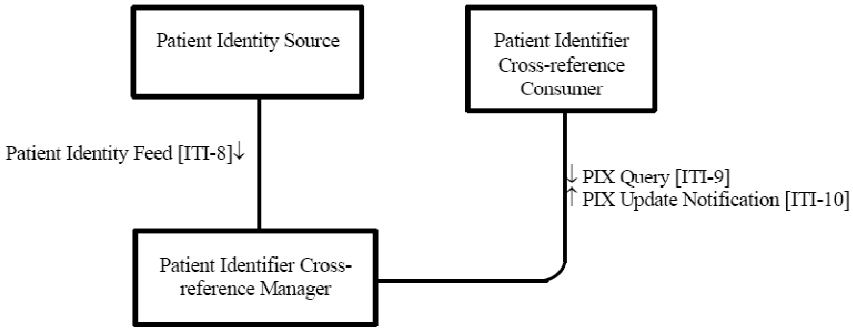

FIGURE 3. PATIENT IDENTIFIER CROSS-REFERENCING ACTORS & TRANSACTIONS

Patient Identity Source. Provides notifications to a PIX Manager about any patient identification related events.

Patient Identity Cross-reference Manager. Manages the cross-referencing of patients coming from a set of well defined patient domains (embodied by Patient Identity Source actors).

Patient Identity Cross-reference Consumer. Queries the PIX Manager for a list of of matching patient identifiers, if any is found.

3.4 PDQ – Patient Demographics Query

3.4.1 Description

The Patient Demographics Query profile provides means to query a patient information server for multiple patients, based on user-define criteria. This profile also enables the retrieval of demographic information about one or more patients.

3.4.2 Actors

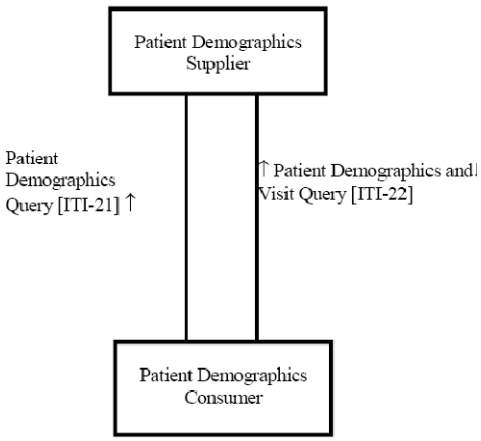

FIGURE 4. PATIENT DEMOGRAPHICS QUERY ACTORS & TRANSACTIONS

Patient Demographics Supplier. Returns demographic data for all patients matching the demographic criteria sent by the Patient Demographics Consumer actor.

Patient Demographics Consumer. Queries the Patient Demographics Supplier actor for a list of patient matching a specific demographic criteria (name, age, birth date, …). Returned entries attributes are populated with corresponding demographic data.

3.5 XDS – Cross-Enterprise Document Sharing

3.5.1 Description

The Cross-Enterprise Document Sharing profile organizes care units under a single domain (e.g., a community of care), enabling the cooperation in the care of the patient, by sharing clinical records. An XDS domain, also called XDS Affinity Domain is organized into federated document repositories revolving around a single document registry. XDS assesses the ebXML Registry and SOAP standards, allowing effectively the creation of longitudinal records and information sharing inside the same domain, or across enterprise boundaries.

3.5.2 Actors

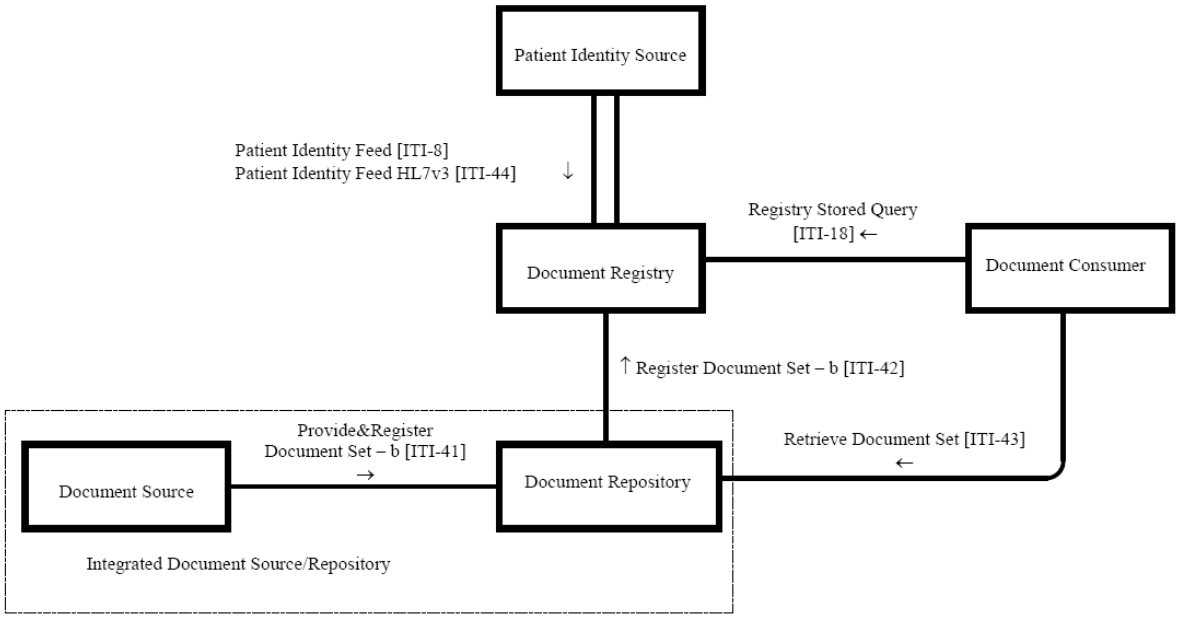

FIGURE 5. CROSS-ENTERPRISE DOCUMENT SHARING ACTORS & TRANSACTIONS

Document Registry. Secure Node maintaining metadata about each registered document in the XDS Affinity Domain. It can respond to queries issued by the Document Consumer actor to get metadata matching a certain criteria. It also can respond to a Document Repository in order to register metadata about a document.

Document Repository. Secure Node maintaining a persistant storage of the registered documents. It is furthermore responsible for forwarding registration requests to the Document Registry of the XDS Affinity Domain.

Document Source. Actor which produces documents for submission and registration.

Document Consumer. Actor which consumes documents and metadata from both actors: Document Registry and Document Repository.

3.6 XDS-I – Cross-Enterprise Document Sharing for Imaging

3.6.1 Description

The Cross-Enterprise Document Sharing for Imaging provides a solution for publishing, finding and retrieving specific imaging documents across a single domain (XDS Affinity Domain).

3.6.2 Actors

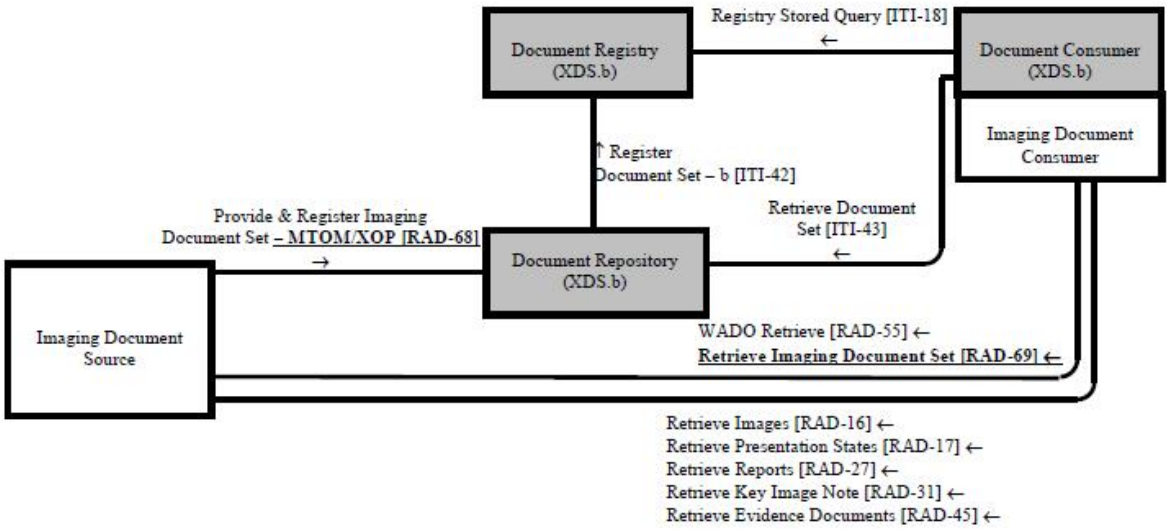

FIGURE 6. CROSS-ENTERPRISE DOCUMENT SHARING FOR IMAGING ACTORS & TRANSACTIONS

Document Registry. *see Cross-Enterprise Document Sharing Registry.*

Document Repository. *see Cross-Enterprise Document Sharing Repository.*

Imaging Document Consumer. Retrieves the published information from the Document Repository and identifies the available imaging information returned queries to the Document Registry.

Imaging Document Source. Shares an imaging report by embedding it in a PDF/CDA and sending it to the Document Repository.

3.7 XDR – Cross-Enterprise Document Reliable Interchange

3.7.1 Description

The Cross-Enterprise Document Reliable Interchange provides document interchange using a reliable messaging system. This profile is used to directly exchange documents between medical actors (EHRs, PHRs and other healthcare IT systems), when no XDS Registries or Repositories are present. XDR leverages the metadata of the XDS profile.

3.7.2 Actors

Document Source. Submits documents and associated metadata to a recipient.

Document Recipient. Receives a set of documents and chooses either to view it or integrate it in the EHR system.

3.8 XCA – Cross-Community Access

3.8.1 Description

The Cross-Community Access Profile provides ways to access patient medical data held by other communities (in the sense defined by the XCPD section below). XCA bridges two domains by letting a user access to data in another domain.

3.8.2 Actors

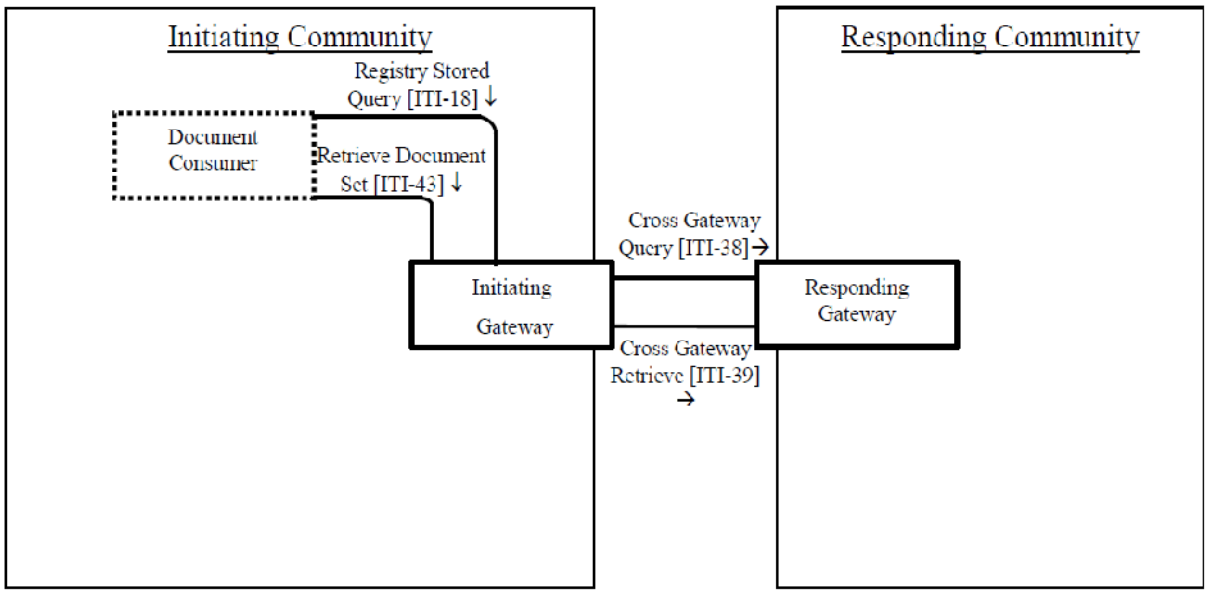

FIGURE 7. CROSS-COMMUNITY ACCESS ACTORS & TRANSACTIONS

Initiating Gateway. Actor initiating the request and supporting outgoing inter-community communications. This actor is necessary in order to support synchronous transaction messaging. This actor can also be grouped with a document consumer when supporting a XDS Affinity Domain (*defined in XCA profile options)*.

Responding Gateway. Actor responding to requests from the Initiating Gateway and supporting incoming inter-community communications.

3.9 XDM – Cross-Enterprise Document Media Interchange

3.9.1 Description

The Cross-Enterprise Document Media Interchange provides document interchange. This is achieved by specifying a common file and directory structure, which is used over several standard media types. XDM can support multiple patients in a single transfer. This profile is useful for people carrying health personal data on a particular medium, like an USB pen drive.

3.9.2 Actors

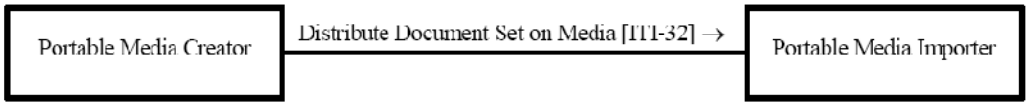

FIGURE 8. CROSS-ENTERPRISE DOCUMENT MEDIA INTERCHANGE ACTORS & TRANSACTION

Portable Media Creator. Author of the content that is responsible for its storage on the media to be distributed.

Portable Media Importer. Actor responsible for reading the submission set on the distributed media and for its importation.

3.10 XUA – Cross-Enterprise User Assertion

3.10.1 Description

The Cross-Enterprise User Assertion specifies a way of communicating claims about the identity of an authentication principal (user, application, system …) in transactions, which may cross enterprise

boundaries. The objective of the XUA profile is to provide accountability in transactions that cross enterprise boundary, but identifying the requesting principal in a way that enables the receiver to make access decisions and generates the proper audit entries.

3.10.2 Actors

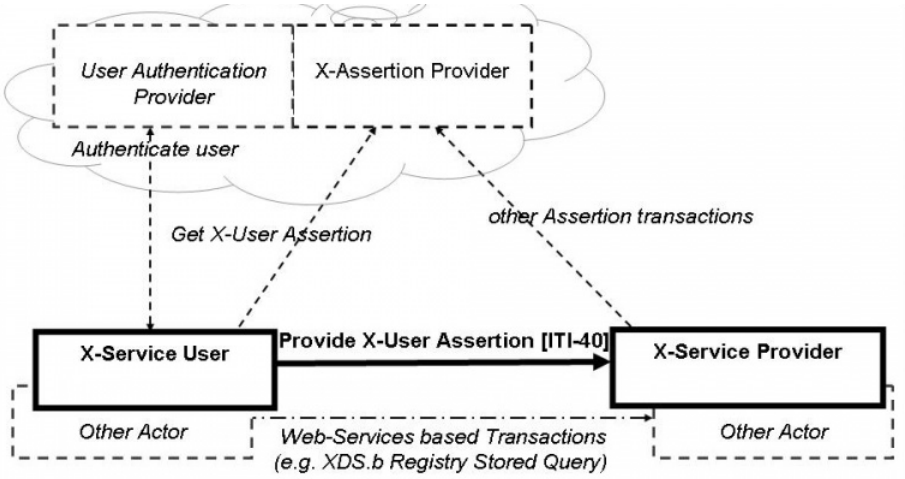

FIGURE 9. CROSS-ENTERPRISE USER ASSERTION ACTORS & TRANSACTION

X-Service User. User requiring a security assertion to connect to a service.

X-Service Provider. Service providing a security assertion for a transaction, which requires it.

3.11 XCPD – Cross-Community Patient Discovery

3.11.1 Description

The Cross-Community Patient Discovery (XCPD) profile provides a means to locate communities holding relevant patient health data. The XCPD also defines how to provision patient identity translation between communities. Communities, which are roughly equivalent to XDS Affinity Domains, are identified by a globally unique id called homeCommunityId. An enterprise may be member of more than one community.

3.11.2 Actors

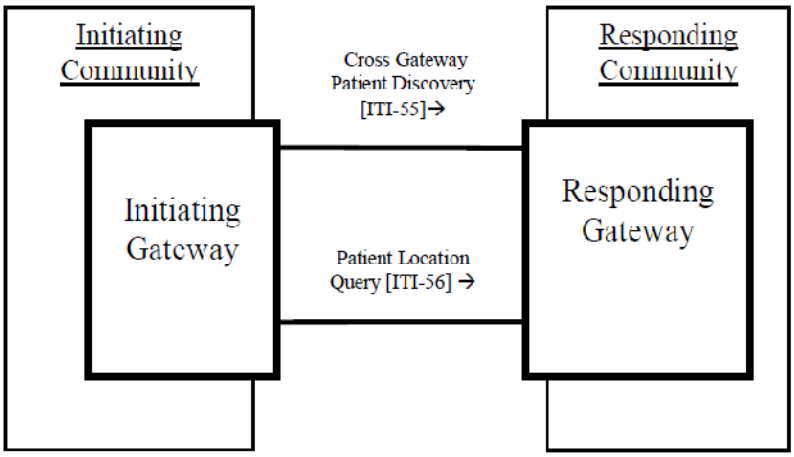

FIGURE 10. CROSS-COMMUNITY PATIENT DISCOVERY ACTORS & TRANSACTIONS

Initiating Gateway. Actor initiating the request and supporting outgoing inter-community communications. This actor is necessary in order to support synchronous transaction messaging.

Responding Gateway. Actor responding to requests from the Initiating Gateway and supporting incoming inter-community communications.

3.12 MPQ – Multi-Patient Query

3.12.1 Description

The Multi-Patient Query profile defines an extension of the Stored Query transaction [ITI-18] allowing handling multiple patients, folders or catalogs. The need for such special cases is often common in the QRPH (Quality, Research and Public Health), where data needs to be combined before the application of patterns.

3.12.2 Actors

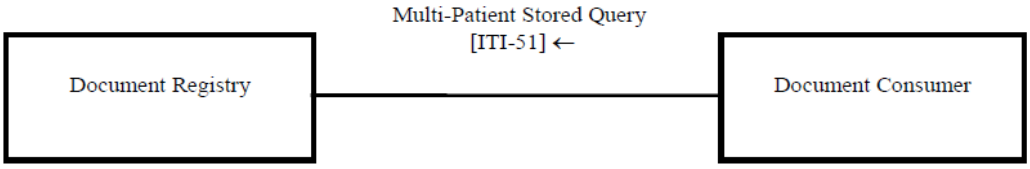

FIGURE 11. MULTI-PATIENT QUERY ACTORS & TRANSACTION

Document Registry. *See Cross-Enterprise Document Sharing Registry Actor*

Document Consumer. Actor issuing aggregated queries about multiple patient for data analysis scenarios.

4 Server-side implementations

4.1 Selected 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 are the most popular and some are used in large-scale healthcare deployments.

Some basic information is provided for each entry in the list. Attributes are explained in the table below:

License	License under which the project is provided to the developers
Implementer	Company, foundation or other responsible for the project
Language	Main language used in the code, documentation and interfaces
Documentation	5 out of 5 possible stars designating the level of documentation available and its pertinence.
Programming Language	Programming language the library/framework is developed in
Platform	Indicates the operating system/infrastructure the solution runs on
Interface	Indicates whether the library/framework is meant to be integrated in an existing application or is manipulated through a web-interface
Database	Database and database connector for underlying persistent storage
Release	Current release or release used in the last IHE Connect-a-thon
URL	Website of the project or implementer
Integration Statement	Document attesting that the solution was tested in an official IHE Connect-a-thon event

4.1.1 IHE Open Source (IHEOS)

[9] http://www.medfloss.org/
[10] http://motorcycleguy.blogspot.com/p/open-source-standards-implementations.html

IHE Open Source 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.

License	Public domain
Implementer	National Institute of Standards and Technology (NIST)
Language	English
Documentation	
Programming Language	Java
Platform	Cross-platform
Interface	Web-based
Database	JDC
Release	6.09 (2009-10-23)
URL	http://www.nist.gov
Integration Statement	None provided

4.1.2 Open Three (O3) Cross Enterprise Document Sharing (XDS)

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.

License	GNU General Public License (GPL)
Implementer	Open Three (O3) Consortium
Language	English, Italian
Documentation	
Programming Language	Java, PHP
Platform	Cross-platform
Interface	Web-based
Database	JDBC
Release	
URL	http://o3-xds.sourceforge.net
Integration Statement	None provided (results are available at connecthaton-results.ihe.net)

4.1.3 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.

License	Other License
Implementer	
Language	English
Documentation	
Programming Language	Java
Platform	Cross-platform
Interface	Web-based
Database	JDBC
Release	1.2 (16-02-2010)
URL	http://sourceforge.net/apps/mediawiki/hieos
Integration Statement	http://sourceforge.net/projects/hieos/files/Vangent_HIEOS_IHE_Integration_Statement.pdf/download

4.1.4 Open eHealth Integration Platform (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.

License	Apache
Implementer	Open eHealth Foundation
Language	English
Documentation	★★★★★
Programming Language	Java, Groovy
Platform	Cross-platform
Interface	Web-based
Database	JDC
Release	2.1.0 (01-04-2010)
URL	http://repo.openehealth.org/confluence/display/ovw/Home
Integration Statement	http://www.medetel.eu/download/2010/parallel_sessions/presentation/day3/Implementing_IHE.pdf (claims, but not official)

4.1.5 OpenXDS

OpenXDS is the document sharing component of the OpenExchange[11] platform. It provides an implementation for the Cross-Document Sharing Registry and Repository actors, as well as an implementation for both the Cross-Community Access (XCA) actors.

License	Public domain
Implementer	Misys Open Source Solutions – Cardiff University
Language	English
Documentation	★★½
Programming Language	Java
Platform	Cross-platform
Interface	Web-based
Database	JDC
Release	1.0 (2-10-2010)
URL	https://www.projects.openhealthtools.org/sf/projects/openxds/
Integration Statement	https://www.projects.openhealthtools.org/sf/docman/do/downloadDocument/projects.openxds/docman.root/doc1182

4.1.6 OpenPIXPDQ

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

License	Public domain
Implementer	Misys Open Source Solutions – Cardiff University
Language	English
Documentation	★★★
Programming Language	Java
Platform	Cross-platform
Interface	Web-based
Database	JDBC
Release	1.0 (03/12/2009)

[11] https://www.projects.openhealthtools.org/sf/projects/openexchange/

URL	https://www.projects.openhealthtools.org/sf/projects/openpixpdq/
Integration Statement	http://openpixpdq.sourceforge.net/IHE%20Integration%20Statement.pdf

4.1.7 OpenATNA

OpenATNA is the audit management component of the OpenExchange platform. It provides an implementation for the Audit Record Repository of the ATNA profile.

License	Apache
Implementer	Misys Open Source Solutions – Cardiff University
Language	English
Documentation	★★★
Programming Language	Java
Platform	Cross-platform
Interface	Web-based
Database	JDBC
Release	1.0 (02-10-2010)
URL	https://www.projects.openhealthtools.org/sf/projects/openatna/
Integration Statement	https://www.projects.openhealthtools.org/sf/docman/do/downloadDocument/projects.openatna/docman.root/doc1201

4.1.8 CONNECT

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

License	BSD
Implementer	U.S Department of Health and Human Services
Language	English (American)
Programming Language	Java
Documentation	★★★★½
Platform	Cross-platform
Interface	Native
Database	JDBC (mySQL)
Release	6.09 (2009-10-23)
URL	N/A
Integration Statement	None provided

4.1.9 Microsoft XDS.b Reference Implementation (MS-XDS.b RI)

Microsoft XDS.b Reference Implementation is the 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.

License	Microsoft Public License (Ms-PL)
Implementer	Microsoft Corporation
Language	English
Programming Language	C# / .NET
Documentation	★★★½
Platform	Windows
Interface	Windows service
Database	MS-SQL Server
Release	Post Connecthaton NA2010 Release (18-10-2010)

URL	http://ihe.codeplex.com/releases/view/40388
Integration Statement	http://download.microsoft.com/download/0/5/B/05B752A6-00B0-404D-B915-8A9F6FC3290E/IHE_Integration_Statement.pdf

4.1.10 IHE Profiles (OHT iheprofiles)

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.

License	Microsoft Public License (Ms-PL)
Implementer	Open Health Tools
Language	English
Programming Language	Java
Documentation	★★★
Platform	Cross-Platform
Interface	Eclipse/OSGi plugins
Database	N/A
Release	1.1.0 (30-06-2010)
URL	https://projects.openhealthtools.org/sf/projects/iheprofiles/
Integration Statement	https://projects.openhealthtools.org/sf/docman/do/downloadDocument/projects.iheprofiles/docman.root/doc1495

The process includes mandatory steps, i.e. steps you **have** to follow prior to publishing the technical report, and optional steps that you should follow. The mandatory steps are kept minimalistic to reduce the burden and constraints.

4.2 Implemented actors & transaction

The tables below present respectively the implemented actors and the implemented transactions. A dot at the intersection between an implementation and an actor/transaction means that this solution implements the associated actor/transaction.
The CONNECT project is a special case in both tables in the sense that it is made to be highly adaptive, due to its modular structure. It was not possible to find concise information concerning the precise nature of the implementations, because the documentation is too extensive and mainly composed by NHIN specifications.

						OpenExchange					
Profile	**Actor**	**IHEOS**	**O3**	**HIEOS**	**IPF**	**OpenXDS**	**OpenATNA**	**OpenPIXPDQ**	**CONNECT**	**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 12. IMPLEMENTED IHE ACTORS

						OpenExchange					
Profile	**Actor**	**IHEOS**	**O3**	**HIEOS**	**IPF**	**OpenXDS**	**OpenATNA**	**OpenPIXPDQ**	**CONNECT**	**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 13. IMPLEMENTED IHE TRANSACTIONS

5 IHE and HL7 related libraries

The section below presents some popular tools, which are generally directly related to IHE implementations. Part of these tools is directly used in implementations.

5.1 Mirth Project

Mirth is an open source cross-platform HL7 interface engine that enables bi-directional sending of HL7 messages between systems and applications over multiple transports. It is divided in three subprojects:

- **Mirth Connect**: Specifically designed for HL7 message integration, Mirth Connect provides the necessary tools for developing, testing, deploying, and monitoring interfaces.
- **Mirth Results**: Mirth Results is an open source clinical data repository that can organize and aggregate clinical data across multiple sources. No information is given on its relationship with the IHE XDS profile.
- **Mirth Match**: Mirth Match is an open source plug-in based master patient index (MPI).

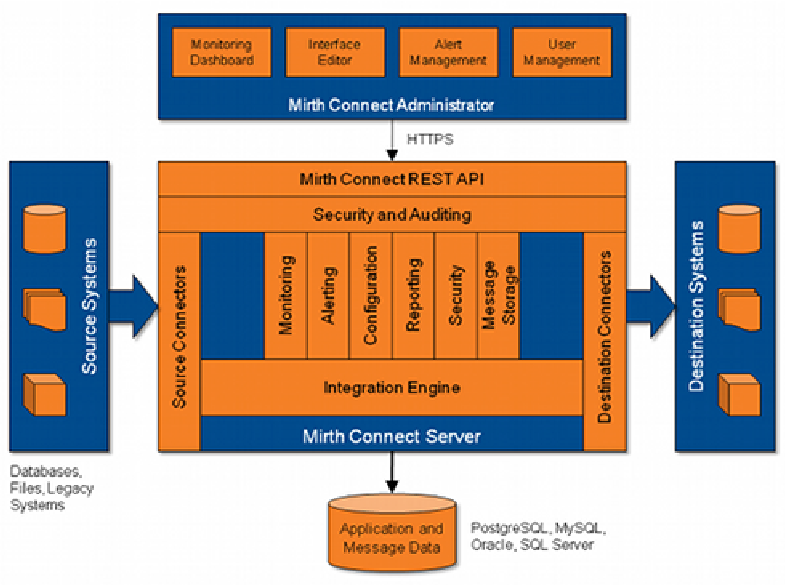

FIGURE 14. MIRTH CONNECT ARCHITECTURE DIAGRAM

License	BSD, MPL
Implementer	Mirth Corporation
Project	Mirth Project
Language	English
Primary Function	HL7 Communication Engine
Programming Language	ASP.NET
Documentation	★★★★
Platform	Cross-Platform
Packaging	Binary for Mac & Windows
Interface	Web-based
Database	Microsoft SQL Server
Release	1.1.8
URL	http://www.mirthcorp.com/community/overview

5.2 Open Enterprise Master Patient Index (OpenEMPI)

OpenEMPI is an open source implementation of an Enterprise Master Patient (EMPI). It consists in a repository, which maintains a registry of all patients across an enterprise. Benefits of an EMPI include:

- Central registry for all patients along with their demographics. Each patient is assigned a unique identifier
- Duplicate patient entries resulting from changes in demographics are eliminated, as well as data entry errors during patient registration, or missing demographic information.

An EMPI has the ability to identify matching patient registration records and link them together as they represent information about a single entity. It is able to perform this record linkage even in the presence of errors and missing attributes. This linking ability is provided by a matching algorithm. Matching algorithms exist in a wide variety, but can be split in two distinct categories.

- **deterministic algorithms** that search for an exact match between attributes
- **probabilistic algorithms** that search for an approximate match between two records

OpenEMPI provides an HL7 endpoint allowing communication with other open-source tools, amongst which: OpenPIXPDQ. The figure below presents the layered architecture of OpenEMPI.

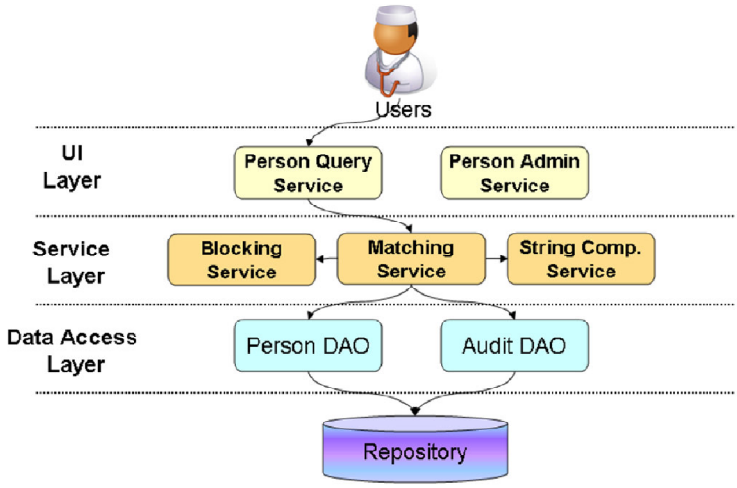

FIGURE 15. OPENEMPI LAYERED ARCHITECTURE DIAGRAM

License	Apache
Implementer	Sysnet International
Project	Project Kenai
Language	English
Primary Function	Master Patient Index
Programming Language	Java
Documentation	★★★
Platform	Cross-Platform
Interface	Web-based / Standalone
Database	Microsoft SQL Server
Release	2.1.0
URL	http://openempi.kenai.com/

5.3 Open-DM-MI Open Master Index Project

Mural is an open source community project that aims at developing a foundational data management infrastructure. It will provide a basis of Master Data Management (MDM - MPI, PIM, …) and more

traditional data warehousing and business intelligent initiatives. The Mural project leverages OpenESB and Netbeans communities.

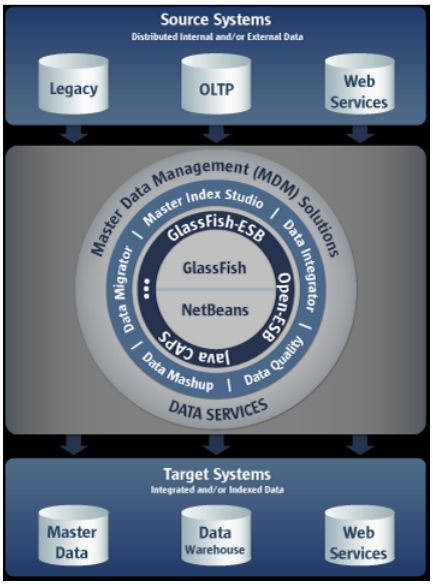

FIGURE 16. MURAL PROJECT ARCHITECTURE DIAGRAM

The Open Master Index (MI) subproject (DM – MI) presents interesting features, like the ability of creating any domain-specific master index, including the ability for representing Patient Indexes. The Open Master Index project has the following high-level features:

- Sub-component of Mural community that allows the creation of any domain specific master index, including Master Patient Indexes.
- Provides the capability to match, de-duplicate, merge, and cleanse data from various sources.
- Creates a three-tier, J2EE indexing application based on a business object definition.
- Provides flexibility through configuration.
- Provides a pluggable framework for incorporating industry-specific business logic.

Although this project looks promising, it has not reached a sufficient maturity level to be deployed in sensitive environments, like in healthcare. The figure below illustrated the instantiation mechanisms (design time to run time infrastructure).

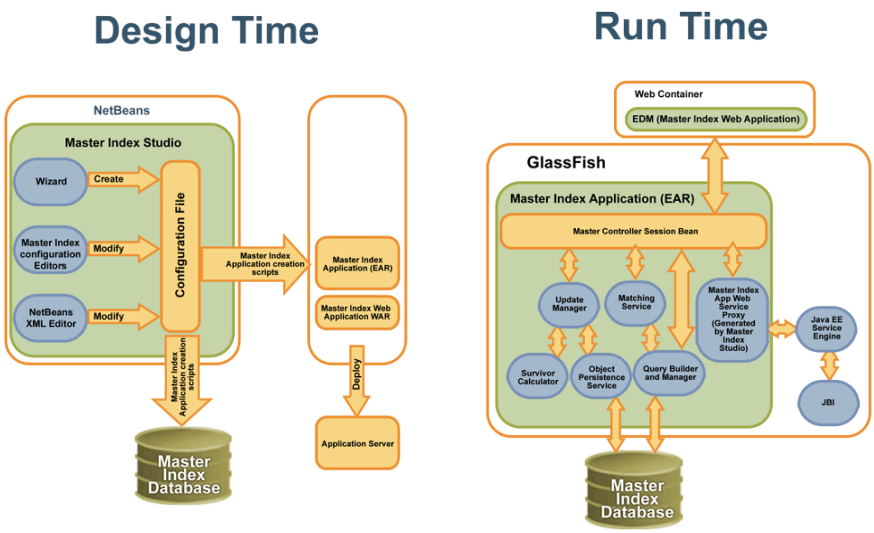

FIGURE 17. OPEN-DM-MI ARCHITECTURE DIAGRAM

License	CDDL

Implementer	Oracle
Project	Mural Open Master Data Management Community
Language	English
Primary Function	Master Patient Index (Data Aggregation Systems)
Programming Language	Java
Documentation	★★★★
Platform	Cross-Platform
Interface	Web-based
Database	JDBC
Release	1.1.0 (30-06-2010)
URL	https://open-dm-mi.dev.java.net/

5.4 HAPI

HAPI (HL7 Application Programming Interface) is an open-source, object-oriented HL7 2.x parser for Java, which is used in several healthcare open-source appliances. The project was initiated by University Health Network (a large multi-site teaching hospital in Toronto, Canada).

License	MPL, GPL
Implementer	University Health Network
Project	HAPI Project
Language	English
Primary Function	HL7 2.x Parser and Encoder
Programming Language	Java
Documentation	★★★
Platform	Cross-Platform
Interface	OSGi
Database	N/A
Release	1.0.1
URL	http://hl7api.sourceforge.net/whatsnew.html

6 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 (medical data exchange) is concerned, HIEOS, CONNECT, IPF, OpenExchange and Microsoft's Reference Implementation can be used as reference implementations for

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

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 [19][20].

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 “Related work” section).

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).

7 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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