9ª ed

MIM

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ORIENTADORES:
**Ricardo João Cruz-Correia**
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FEB | 2016

# Acknowledgments

I would like to express my deepest appreciation for the opportunity and advices offered by my thesis advisor Prof. Dr. Ricardo Cruz-Correia. You are a source of motivation and an example of dedication and success, but mostly important a good person to others. Once again, thank you for everything!

For the insatiability in motivating people, for the patience to endure and explain trivial situations, for your guidance, for the availability due to the late hours in development and essentially for the kind of person you showed to be, a friend. Thank you my thesis co-advisor PhD student Duarte Gonçalves Ferreira.

To Ricardo Ferreira, for the knowledge you continuously pass, for your availability and opinion when obstacles appear and essentially for your kindly disposition in helping and repeating. Thank you!

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I owe much of what I am today and will be in the future to my parents. Once again a stage in my life is passing and I'm happy you can be present for it. Love you both!

To my beautiful and lovely girlfriend for her support along the journey (...)!

*"Some believe it is only great power that can hold evil in check, but that is not what I have found. It is the small everyday deeds of ordinary folk that keep the darkness at bay. Small acts of kindness and love."*

***J.R.R. Tolkien***

# Abstract

**Introduction**: One of the main challenges of Medical Informatics nowadays is the lack of interoperability between healthcare information systems, that as a consequence affects the decision-making of it's users. As the technology produced by vendors of informations systems evolves, the control of interoperability over the many solutions deployed in a health institution decays. The result is a fragmented electronic health record all over the departments and institutions where the patient may have been, such as laboratories, imaging, dermatology and the problem is worse if we look at an national level because of the great number of health institutions. The solution to the problem may be the use of international standards that supplement specifications of how to improve the interoperability between heterogeneous systems. The improvement at the communication, storage of clinical data and process workflow of clinical practice levels, is respectively the responsibility of the Health Level Seven, openEHR and IHE methodologies.

**Objective**: The main objective of this project is to elaborate a solution that transforms the data from HL7 v2.x messages to openEHR compositions, in order to feed a unique repository of clinical data based on openEHR standards.

**Methods**: The development of the solution is divided in two stages. First we executed an analysis of the clinical context, testing the solution in a *laboratory* environment based on predefined variables. For the second stage the solution is deployed on the Health Institution to validate the variability presented on the daily clinical practice.

**Results**: The extraction of data from HL7 v2.x messages from the healthcare institution network, a mapping of the extracted clinical data to openEHR archetype slots, a set of templates that generates openEHR compositions, and the implementation of a prototype solution on a real healthcare workflow were the results of the thesis.

**Conclusion**: The prototype solution created with this thesis proved to be a useful tool with the transformation of extracted data from HL7 v2.x standard to openEHR compositions.

**Keywords**: Interoperability, HL7, openEHR, IHE, healthcare professionals, Health Institution.

# Resumo

**Introdução:** Um dos desafios atuais em Informática Médica é a falta de interoperabilidade existente entre Sistemas de Informação da Saúde, que como consequência afeta o processo de decisão para os seus utilizadores. Á medida que a tecnologia evolui produzida pelos fornecedores de sistemas de informação, o controlo da interoperabilidade sobre as diferentes implementações da instituição de saúde diminui. O resultado é um registo eletronico de saúde disperso por todos os lugares que o paciente possa ter estado, como laboratórios, imagiologia, dermatologia e a complexidade aumenta a nível nacional devido à grande quantidade de Instituições de Saúde existentes.

A solução para o problema pode ser a utilização de standards internacionais que fornecem especificações de como aumentar a interoperabilidade entre sistemas de informação heterógeneos. A melhoria a nível comunicacional, de armazenamento de dados clinicos e processos de workflow, é respetivamente o âmbito das ideologias Health Level Seven, openEHR e IHE.

**Objetivo:** O objetivo principal deste projeto é elaborar uma solução que transforme os dados provenientes de mensagens HL7 v2.x em composições openEHR, de modo a popular uma repositório clínico.

**Métodos:** O desenvolvimento da solução está divido em duas fases. Primeiro executámos uma análise do contexto clínico, testando a solução num ambiente de *laboratório* baseado em varíaveis predefinidas. Na segunda fase a solução é implementada na instituição de saúde, de modo a validar a capacidade de mapear a variabilidade de dados presente na prática clínica.

**Resultados:** A extração de dados provenientes de mensagens HL7 v2.x da rede da instituição de saúde para análise, o mapeamento dos dados clinicos extraidos para campos dos arquétipos openEHR, um conjunto de templates que origina composições openEHR, e a implementação da solução em workflows clinicos reais foram os resultados desta tese.

**Conclusão:** A solução protótipo criada ao com a tese provou ser uma ferramenta útil na transformação dos dados clínicos provenientes de HL7 v2.x para composições openEHR.

**Keywords**: Interoperabilidade, HL7, openEHR, IHE, profissionais de saúde, Instituição de Saúde.

# Preamble

It is a warm and good sensation the feel of accomplishing a personal goal, but the enlightenment lies on the path that led me there.

Some time before applying to college I was very reluctant if this was the best choice for me, as it was going to be the first time someone in my family pursued this path and I could easily let down people if I lost my way. My mind changed because I understood that further education could only raise my ambitions and satisfaction. Through my academic background in high school, I always followed the path that involved subjects regarding the healthcare domain.

So I chose a degree with a wide scope in its subjects but always related to healthcare. When I frequented the Biomedical Engineer licence's degree I came across the concept of programming. I enjoyed the tasks done at this class but because it was only a brief introduction and not the main scope of the degree, I started to learning more about it at home. I had discovered another interest that could be associated with the healthcare domain, little did I know that I knew absolutely nothing about this subject, Health Informatics.

So after the licence's degree I decided to narrow my field of interests to technology and healthcare. With that I applied to the Medical Informatics degree in Faculdade de Medicina da Universidade do Porto which is a prestigious academic masters degree that joined both my interests. With some persistence in the application process and confidence in the interviews, I was accepted. The master's degree program approached many of the Health Informatics areas of intervention, passing a considerable amount of knowledge, and many applications of it in healthcare scenarios. I got more attracted to the areas of interoperability and standards in health informatics along the masters degree, and thus it became the focus subject when deciding my thesis project.

Along this last year in developing the thesis, I had the opportunity to work as a research student for the CINTESIS group. By far the best experience for learning about the reality of technology in the healthcare domain and to empower my programming skills, as the work environment enabled me to interact in different healthcare projects that relied in technology. My research project was regarding the implementation of pharmacy-vigilance information system, but I was also able to work upon integration problems between health information systems to increase the decision power of the healthcare professionals, in the design of solutions, and more other projects.

This journey brought me a lot of work-experience and knowledge, but mostly important were the relationships created that enabled the exchange of knowledge and a healthy learning-environment.

In my honest personal opinion along this year I gave more value to the opportunity to work among people that willingly share their knowledge to help others, than to dedicate exclusively for the conclusion of the diploma.

As I said in the beginning, the enlightenment in on the path to the achievement of a personal goal.

# Scientific and Financial Results

The work described on this thesis as scientific outcomes managed to publish an article and deliver a prototype solution. Also, the time in the research grant enabled the submission of a paper.

- Oliveira, Raphael, Ferreira, Ricardo, Ferreira, Duarte, and Cruz-Correia, Ricardo (2016). Open-source based integration solution for hospitals. Computer Based Medical Systems (CBMS), 2016 IEEE International Symposium.[CBMS2016 - Published Article]
- Oliveira, Raphael, Dias, Claudia, Ferreira, Duarte, and Rodrigues, Pedro (2016). An online inference tool for Bayesian Networks in clinical settings. [HealthInf2017 - Submitted Article]
- CDOT - Prototype solution that enables the transformation of data from HL7 v2.x messages to openEHR compositions.
- Project “NORTE-01-0145-FEDER-000016” (NanoSTIMA) is financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF).

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# Acronyms

**AIM** Advanced Informatics in Medicine

**ADL** Archetype Definition Language

**ADT** Admission Discharge-Transfer

**AM** Archetype Model

**ANSI** American National Standards Institute

**AOM** Archetype Object Model

**AQL** Archetype Query Language

**API** Application Programming Interface

**CDA** Clinical Document Architecture

**CDOT** Clinical Document Online Translator

**CEM** Clinical Element Model

**CIDES** Department of Health Information and Decision Sciences

**CINTESIS** Center for Research in Health Technologies and Information Systems

**CIS** Central Information System

**CKM** Clinical Knowledge Manager

**DICOM** Digital Imaging and Communications in Medicine

**DSS** Despartment System Scheduler / Order Filler

**EHR** Electronic Health Record

**ESB** Enterprise System Bus

**FMUP** Faculty of Medicine of the University do Porto

**GEHR** Good European Health Record

**HELIOS** HELIOS

**HI** Health Institution

**HIS** Health Information Systems

**HL7** Health Level Seven

**IHE** Integrating the Healthcare Enterprise

**IS** Information Systems

**IRA** Integrated Routing Audit for HL7

**IPOP** Intituto Português de Oncologia do Porto

**JSON** JavaScript Object Notation

**LIS** Laboratory Information System

**MSA** Message Acknowledgement Segment

**MSH** Message Header Segment

**OBX** Observation Segment

**OMG** General Clinical Order

**OP** Order Placer

**openEHR** openEHR

**OPT** Operational Template

**ORG** General Clinical Acknowledgement

**ORU** Observation Result

**OSI** Open Systems Interconnection

**OWL** Web Ontology Language

**PMI** Patient Master Index

**REST** Representational State Transfer

**RIM** Reference Information Model

**RMIM** Redifined Message Information Models

**RM** Reference Model

**RIS** Radiology Information System

**SIU** Scheduling Information Unsolicited

**SM** Service Model

**SQL** Structured Query Language

**XML** eXtensible Markup Language

**XSD** XML Schema Definition

# Introduction

# 1. Introduction

The healthcare domain is constantly changing and adapting to different scenarios, in such a revolutionary way that on the last century the ideology of modern medicine started to focus more on a patient centred care approach [1]. Establishing the patient as the centre of the healthcare domain, made a huge difference in the healthcare professionals workflow.

It was now necessary to keep track of all the interactions between the patient and the healthcare services, meaning that we needed to store the clinical data for later use, thus appearing the patient health records [2]. The storage and exchange of information and clinical data between different healthcare professionals was simplified with the use of health technology solutions.

Technology became more usual among the HI, a new market was emerging, the development of HIS. Many technology vendors started to develop and implement health solutions to ease the process of storing clinical data.

Nowadays the healthcare professionals are highly attached to technology solutions that are implemented in their respective HI. In fact, the article by Ribeiro et al. [3] analyses data from a survey to a number of Chief Information Officer (CIO) of Portuguese hospitals and concludes that the number of applications increases with the size of the institution as well as the complexity of the integration's between them. The vendors are in an ongoing competition to implement their solution on the HI, therefore there are many differences from one HIS to another, generally if it is produced by a different vendor. Since the implementation of different solutions on a HI, that the concern is now at the communication level between the HIS. Putting two HIS manufactured by two vendors, is sometimes equal to have two persons who speak different languages. They will try to understand each other, but misinformation may be processed, compromising the conversation and therefore the clinical healthcare practice.

In healthcare, HIS must deal with critical data where having a quick access to the necessary information can often have an important impact in people's lives. Even though interoperability and information sharing in a HI is seen as a major element, in reality it is a feature that many clinical administrators and software providers easily forget about. There is no proper communication between these applications since most of the integrations are mainly made at the data or presentation layer [3]. Thus, applications typically gather or present the desired information by having direct access to some database or simply by embedding a user interface of another application.

One way to tackle against the lack of interoperability is by a communication interface. Most of the cases it is represented with a message oriented middleware and HL7 standard, that also needs a bilateral agreement on the message content which still keeps the integration complexity high. Such complexity in communications can sometimes be the cause of very unstable interoperable communications and cause a sense of distrust on the information offered to the final user.

Another way is to deal with these problems from the beginning, when storing the clinical data the HIS vendors should follow a standard, like openEHR (openEHR). The majority of HIS is sustained in relational databases, mainly due to the fact that IT healthcare professionals are tasked to create the model for storing clinical data. IT professionals are not the best professionals to decide the inputs in a clinical database, so they do it *a priori*, they gather the clinical variables and then create the model. This approach is not very friendly, one of the problems is the difficulty to alter such model after it is on production.

The openEHR approach delegates the clinical knowledge of concepts to the clinical healthcare professionals, who have a better knowledge of the clinical variables involved in the healthcare scenario [4]. One major benefit is that we can construct an HIS independently of content specifications, not needing to know before hand which clinical data will be processed. Another benefit is the simplicity to perform alterations in the concepts model when we have the HIS in production, because openEHR it's a dual model architecture, as explained in section 1.1.2 that separates the clinical knowledge from the technology model [5].

In order to foment the use of a standard way to store clinical data, we present on this thesis a solution that translates clinical data to the openEHR methodology. As today's HI do the communication mainly by HL7 between the HIS, the solution will gather the clinical data from there and map it to openEHR compositions, populating a clinical repository. This thesis is presented as it follows: Chapter 1 makes an introduction to concepts approached along the development, such as technologies and standards, followed by examples of related works and the objectives on sight. Chapter 2 presents the analysis done on *laboratory* to the HL7 messages from an HI, describing the mapping process and developments done to overlap the two standards (HL7 and openEHR). An analysis to the openEHR archetypes and templates used is also on this chapter. Chapter 3 describes the new processes made with the experience acquired from Chapter 2, as well as the implementation of the solution in the HI. Approaching new methodologies as IHE and a openEHR clinical repository.

## 1.1 State of the Art

### 1.1.1 The Electronic Health Record

There has always been a recognised need for those involved in the healthcare domain along the years to pass on details of procedures or therapeutic methods that proved to be successful when treating a patient. Those details were exchanged through written methods or simply by oral communication. An example of it are the *Ötzi Tattoos*, that were produced by fine incisions into which charcoal was rubbed on different parts of his body [6]. One of the theories that might explain the tattoos, is they were used as symbols of pain indicators during his lifetime due to degeneration or disease, thus turning is body into an health record. Another more recent example is the use of papyri from ancient Egypt describing prescriptions and intervention procedures, like for example the *Ebers Papyrus* [7].

In the beginning of the 20th century European and North American university medical schools advocated a scientific approach to medical education, encouraging healthcare professionals to keep a patient oriented-record [2]. The absence of standardized methods to record health information about the patient and in storing started to be noticed by the community of healthcare professionals. Therefore the topic

Figure 1.1: The *Ebers Papyrus*.
[8]

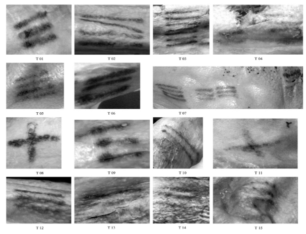


Figure 1.2: Illustration of some of the *Ötzi Tattoos*.
[9]

of storing clinical data regarding the patient began to appear often in conferences and meetings of the healthcare domain.

Forward to the 1950s, and a book published by *Michael Balint* [10] had a huge impact on the daily clinical practice, altering the bond of doctor-patient to health institution-patient. As a consequence the need for exchanging data regarding a patient between the different healthcare professionals became greater at each day. On the year 1969 Dr Lawrence Weed presented a problem oriented medical record (POMR) [11], introducing a method to structure the data with a problem list, a SOAP (subjective, objective, assessment and plan) progress note and more. Despite being very innovative in technology for the time, it proved to be very time consumptive for clinical practice [12].

In the following years as computers developed at fast pace and clinical practice became more complex, different HIS (*Lockheeds HIS* , *HELP Information Systems (IS)*) emerged on the healthcare domain, bringing variety of formats of structured data [13]. After the development of the early HIS that focused on structuring the clinical data, new challenges rose in exchanging data, thus interoperability is needed. Until today there is not a consensual definition of Electronic Health Record (EHR), instead based on Clement J. et al [13] five functional components are important to it.

**Integrated view of patient data** To provide an integrated view of all relevant patient data, accommodating a broad spectrum of data types.

**Clinician order entry** To enable the healthcare professionals in making clinical decisions and taking action, reducing the errors and costs.

**Clinical Decision Support** To deliver feedback on the actions made by the healthcare professionals and assisting in the decision making process.

**Access to Knowledge Resources** To offer knowledge resources to the healthcare professionals when taking actions.

**Integrated Communication Report** To guarantee the ubiquity and communication of the clinical data between multiple HI.

The European Union in 1988 established the Advanced Informatics in Medicine (AIM) initiative and in the early 1990s started the Good European Health Record (GEHR) project with the aim on developing an EHR architecture. As a core finding the professionals involved in the project noticed the importance in the distinction between knowledge and information as well as functional and semantic interoperability, presenting a dual model architecture of the EHR [14]. Later the results of the GEHR project were implemented around the world, thus originating the basis of the openEHR approach.

### 1.1.2 openEHR Foundation

After the GEHR project ended, it had became a focus of opposition within the healthcare domain, mainly by the HIS vendors [15]. Much because at the same type the rose of healthcare message systems, like HL7 v2.x were tackling the communication problems derived from most HIS claiming to be an EHR, even without meeting commonly agreed requirements. Nonetheless, the GEHR project left dedicated followers around the world, originating future project proposals based on the dual model architecture, like the Synapses EU project [16]. In 1998 at the end of the Synapses project, the healthcare professionals involved noticed the need for a clinically focused foundation to own the content domain, enabling clinical information management.

It was the premise to start the openEHR Foundation supporting the open research, development and implementation of a dual model architecture in EHRs, namely with openEHR specifications. The openEHR Foundation is a not for profit company established by the University College of London with the vision of achieving *"life-long interoperable electronic health records"* and *"computing on EHRs to improve the quality of healthcare and research"* [17].

openEHR

Figure 1.3: OpenEHR trademark logo.
[5]

The architecture of the openEHR is based on a two-level modelling, the Reference Model (RM) and the Archetype Model (AM). Respectively, one responsible for the structure of the health record itself and the other for the clinical data contained in the EHR. With the two-level modelling there is a separation of the technical issues from clinical data. Based on the two models, openEHR presents two more sets of information organization such as the openEHR templates, linked to the archetypes, and the cognitive user interface generated through the templates.

The RM describes the logic structures of EHR data. It defines the most basic technical concepts, representing a standardized data structure, enabling interoperability. With it there exists a set of specifications to explain it's variety and use.

1. **EHR Information Model** It defines the concepts regarding the major components of the EHR, such as the EHR itself, the Composition, the Section and Entry components [18].

2. **Demographics Information Model** Related to concepts connected with a Patient Master Index (PMI) system, such as contact addresses [19].

3. **Common Information Model** It defines various abstract concepts and design patterns used in

openEHR, as versioning of compositions, descriptive meta-data or referencing demographic entities [20].

4. **Data Structures Information Model** It presents the logic structures of the openEHR as list, trees, tables, and others [21].

5. **Data Types Information Model** Defines the various types of clinical/scientific data used to satisfy the functional requirements of the clinical practice [22].

6. **Support Information Model** It describes the semantics of constants, terminology access, access to externally defined scientific units and conversion information for all other Information Models [23].

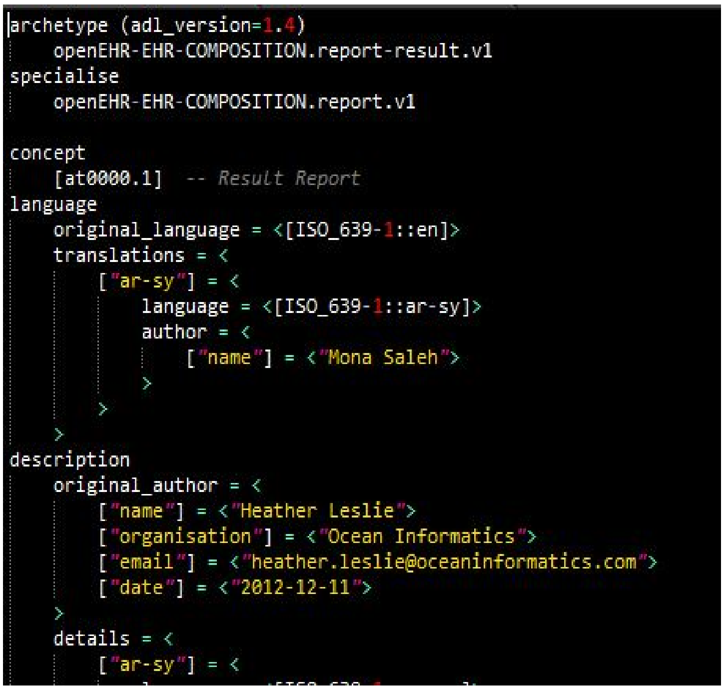
7. **Integration Information Model** It describes how to deal with external sources of data or legacy data [24].

8. **EHR Extract Information Model** This model formally defines the concepts of *'extract request'*, *'extract'*, various kinds of content including openEHR and non-openEHR, and a message wrapper [25].

The AM is the top level of the dual-modal architecture approach and it provides the semantics and structure of healthcare domain concepts. The archetypes are models that define arrangements of data that correspond to the logical data structure from the RM for the healthcare domain. A set of specifications or models are directly connected to the AM, that enable the identification or querying for example of archetypes, as shown below.

- **Archetype Identification** A specification that describes an identification system for versioning and lifecycle management of the archetypes and templates [26]. Archetypes are individually versioned because of the complexity presented in the data points, thus easing the concept revision. A clinical repository along time suffers revision on their archetypes due to the changes in clinical practice, so the versioning system applies to each one of the archetypes of the repository and not to the whole. The lifecycle management feature describes in which state the concept creation is at, until it's published.

- **Archetype Definition Language** It's an abstract syntax for definition of archetypes, templates and terminologies binding. Intended for software developers Archetype Definition Language (ADL) is an human-readable and computer-processing structure that expresses the archetypes [27]. Used to describe clinical concepts through the use of sentences of the syntax, making the process of creation and editing of archetypes future-proof. There are tools, such as the *Archetype Editor* and *LinkEHR Editor*, that allow the creation and edition of archetypes, because the ADL syntax is publicly available. Below on Figure 1.4 an example of the syntax described.



```
archetype (adl_version=1.4)
    openEHR-EHR-COMPOSITION.report-result.v1
specialise
    openEHR-EHR-COMPOSITION.report.v1

concept
    [at0000.1]  -- Result Report
language
    original_language = <[ISO_639-1::en]>
    translations = <
        ["ar-sy"] = <
            language = <[ISO_639-1::ar-sy]>
            author = <
                ["name"] = <"Mona Saleh">
            >
        >
    >
description
    original_author = <
        ["name"] = <"Heather Leslie">
        ["organisation"] = <"Ocean Informatics">
        ["email"] = <"heather.leslie@oceaninformatics.com">
        ["date"] = <"2012-12-11">
    >
    details = <
        ["ar-sy"] = <
```

Figure 1.4: Example of an ADL syntax of an archetype.

- **Archetype Object Model** It's a model that defines archetypes and templates, being independent of any syntax. Describes the semantics used in the object structures of archetypes and templates [28]. The model has a very similar purpose to the ADL, both used for building openEHR resources.

- **Operational Template** An Operational Template (OPT) is a document constituted by several archetypes. The templates have a direct relation with clinical forms and reports daily used in the clinical practice, because of the junction of different medical concepts represented in archetypes on to a single structure as the OPT [29]. The header of the template as similar to the header of a clinical report, is always an archetype of type Composition due to identifying the purpose of the document. The OPT structure also eases the process of implementation, implying the use of formats as eXtensible Markup Language (XML) or JavaScript Object Notation (JSON). Figure 1.5 displays an example of the syntax of OPT format.

```xml
<?xml version="1.0" encoding="utf-8"?>
<!--Operational template XML automatically generated by Ocean Template Designer Version 2.8.94Beta-->
<template xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  <language>
    <terminology_id>
      <value>ISO_639-1</value>
    </terminology_id>
    <code_string>pt</code_string>
  </language>
  <description>
    <original_author id="Original Author">Not Specified</original_author>
    <lifecycle_state>Initial</lifecycle_state>
    <other_details id="MetaDataSet:Sample Set ">Template metadata sample set </other_details>
    <other_details id="Acknowledgements"></other_details>
    <other_details id="Business Process Level"></other_details>
    <other_details id="Care setting"></other_details>
    <other_details id="Client group"></other_details>
    <other_details id="Clinical Record Element"></other_details>
    <other_details id="Copyright"></other_details>
    <other_details id="Issues"></other_details>
    <other_details id="Owner"></other_details>
    <other_details id="Sign off"></other_details>
    <other_details id="Speciality"></other_details>
    <other_details id="User roles"></other_details>
    <details>
      <language>
        <terminology_id>
          <value>ISO_639-1</value>
        </terminology_id>
        <code_string>pt</code_string>
      </language>
      <purpose>Not Specified</purpose>
    </details>
  </description>
  <uid>
    <value>4ac34777-de2b-4e86-a9a3-0aafa74405b4</value>
  </uid>
  <template_id>
    <value>RAD_ACK</value>
  </template_id>
```

Figure 1.5: Example of an OPT structure and syntax.

- **Archetype Query Language** Is a declarative query language developed specifically for expressing queries and retrieving clinical data found in archetype-based EHRs [30]. Archetype Query Language (AQL) varies from other query languages as Structured Query Language (SQL) due to expressing the queries at the semantic/archetype level and not at the data instance. Trough the use of the openEHR archetype path syntax, it's possible to locate the clinical statement or value within the desired data point of the archetype. It permits the utilization of operator syntaxes, such as matches, exists, in and negation, also supports arithmetic operations like other query languages [31].

```
SELECT c/content[openEHR-EHR-ACTION.imaging_exam.v1]/ism_transition/careflow_step/value as Fase_do_workflow, c/context/start_time as Time, c/name/value as Template_mapeado
FROM EHR [ehr_id/value = "7faf87bb-833d-40f8-9072-f0b47c83b8eb"]
CONTAINS COMPOSITION c
ORDER BY c/context/start_time DESC
```

Figure 1.6: Example of an AQL syntax for querying archetypes slots.

The openEHR specifications includes also a Service Model (SM) [32]. It is constituted by an API that enables web interaction with the EHR through Representational State Transfer (REST), and also with the Clinical Knowledge Manager (CKM) as a knowledge repository. On figure 1.7 it displays the openEHR architecture.

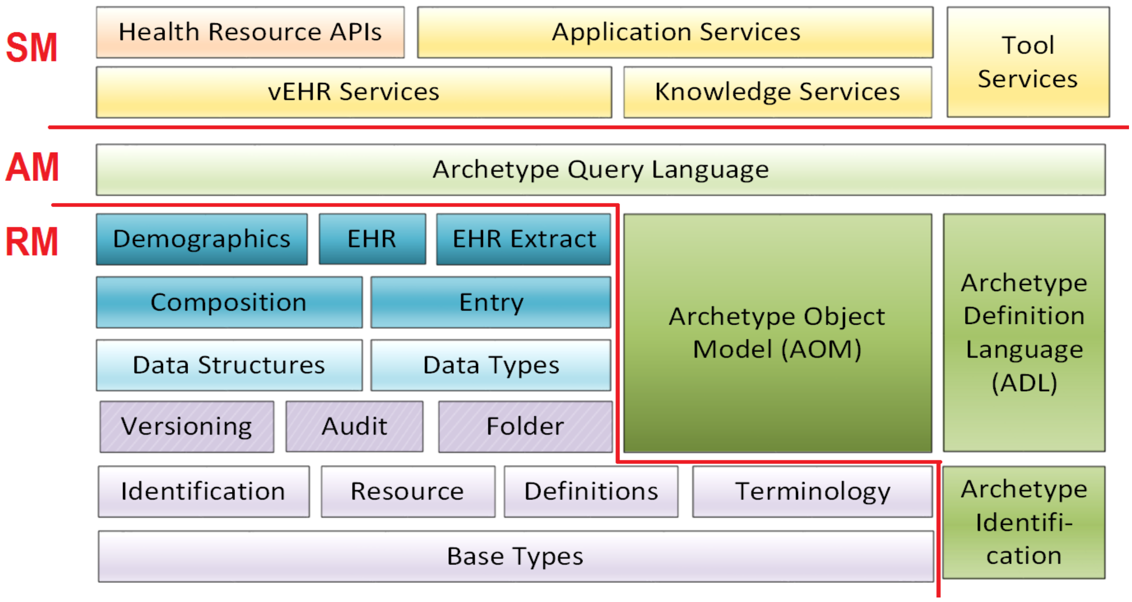



Figure 1.7: An illustration of the openEHR architecture and it's models.

**Clinical Knowledge Manager**

The CKM is a core utility of the openEHR approach, functioning as an international and open clinical knowledge domain to accomplish the sharing of clinical data concepts represented through archetypes [33]. It can be used to find and download already designed archetypes or templates that better suit our healthcare scenario. Most importantly it works as a collaborative tool, where it is possible to translate, update, suggest changes and interact with the openEHR community. The main purpose of the CKM is to enable a clinical repository where every HIS that uses the openEHR approach shall use the archetypes that exist in the CKM. If a desired medical concept is not in the CKM, the user shall create a new archetype and then submit it for review.

The openEHR approach rewards the user with a repository independent of content specifications, enabling future-proof EHRs who adapt according to new clinical concepts. It brings the clinical professionals to the development of new clinical concepts and revision of knowledge regarding the healthcare domain (Archetype Model). Delegating the technology of data structures and data types involved in the development process, to the IT professionals (Reference Model). To finish, the openEHR community has been growing year after year all around the world, showing that is successful to implement dual-model architectures EHR in clinical practice.

### 1.1.3 HL7

Founded in 1987 the HL7 is a not-for-profit American National Standards Institute (ANSI) accredited standards organization [34]. The number seven is an indication of the seventh application level of the Open Systems Interconnection (OSI) [35] reference model. The focus of the HL7 is on developing standards regarding the exchange of clinical data between the HIS. It is today an international standards organization, with human resources and implementations all over the world. As it continuously produces valuable standards to improve interoperability in the healthcare domain, as the HL7 v2.x, v3 and Clinical Document Architecture (CDA).

#### 1.1.3.1 HL7 v2.x

**HL7 v2.x** is the most widely used approach to exchange data in the healthcare domain. It has a total of seven versions from 2.1 to 2.7. Developed in 1989 quickly became the gold standard in data exchange due to its *'pipehat'* message structure. Developed to support a central HIS and also a distributed environment where clinical data resides in departmental HIS [36]. The figure 1.8 illustrates an example of the HL7 v2 message structure.

```
MSH|^~\&|BAR|HI|FOO|HI|20160405120112||ADT^A10|24b26fa2-5faa-455e-aa81-9882bc529fd6|P|2.3
EVN|A10|20160405120112
PID|1||123456^^^SONHO^SN||NomeFamilia^NomeProprio^NomeEmFalta||19970205|M|||||||||654321^^^SONHO^PN
PV1||URG|10000^^^^^^^^UlsmUrgGeral||||||15008||||||||123456789|||||||||||||||||||||||20160405115203
OBX|1|RP|111^URL_OBS||http://Servidor/ReportServer/Pages/ReportViewer.aspx?%2fResumoObs&numeroEpisodio=123456789&rs:Format=PDF|
OBX|2|NM|222^Idade_Gestacional||25|semanas||||F|||20160405120112||10000^ApelidoUser^NomeUser
OBX|3|TX|333^Resumo_OBS||informacao do resumo|||||F|||20160405120112||10000^ApelidoUser^NomeUser
```

Figure 1.8: Example of HL7 v2.x message structure and data.

#### 1.1.3.2 HL7 v3

**HL7 v3** is based on the Reference Information Model (RIM) reference model, that was developed in order to diminish customization of messages. The RIM model describes all aspects of a healthcare clinical and administrative information. The HL7 v3 enabled an object oriented approach to the HL7 messaging standard [37]. Not so widely used as the previous version, it inspired the creation of the next HL7 version.

#### 1.1.3.3 HL7 CDA

**CDA** is built upon the RIM through representation in reusable templates. The HL7 CDA is defined as an object that supports clinical information based on RIM and can include multimedia content. The CDA structure is XML based, enabling the concept of incremental semantic interoperability. It supports features as persistence, stewardship, potential for authentication, context, wholeness, and human-readability [12].

Nonetheless the main problems of the HL7 standard comes with the wide range of possible implementation scenarios in which it can be applied. The flexibility in HL7 implementations makes it a widely used tool to exchange data among developers. This flexibility also has a downside, as developers are different and find their own way of using the HL7 standard. A more familiar comparison would be that most of HL7 implementations presented in real use cases are accents from the original language. This difficulty mainly has to with, the complexity presented in the daily practice habits from healthcare professionals and with the effort and knowledge used by the different vendors in the process of interoperability.

### 1.1.4 IHE

Nowadays, to the best of our knowledge, the information shared between HIS in a HI, lacks efficiency regarding the access of healthcare professionals to all relevant information of a patient. One of the major reasons comes from the unawareness of the healthcare enterprise, such as vendors and healthcare professionals, to understand the full potential of medical informatics as a great benefit to reduce medical errors and improve the overall quality of patient care [38].

Raising the awareness of software vendors and healthcare professionals all over the world to this subject was the premise to form the IHE initiative. IHE promotes the share of information between HIS based on established standards, such as Digital Imaging and Communications in Medicine (DICOM) and HL7, and produces frameworks with best practices on how to implement these standards and integrate the multiple HIS [39]. IHE is organized by clinical and operational domains, each domain is hierarchy structured with a palning and technical committee responsible for the development and documenting of solutions published in technical frameworks.

The members of the domains are diverse in terms of role in the healthcare enterprise (vendors, healthcare professionals, information technology professionals and healthcare administrators), contributing in unity for the different obstacles presented to deliver an optimal patient care. The Technical Frameworks are organized documents respectively to each domain, which guide the implementation of integration profiles using transactions (exchanges of clinical data based in established standards), between various actors (HIS that produce, manage or act on clinical data) to achieve higher levels of interoperability in a HI. These are reviewed and maintained regularly by the committee of each domain [40].

In summary IHE provides the tools to improve the interoperability in a HI, making the integration between HIS faster and more efficient using existing standards and technology.

On figure 1.9 we present a diagram that explains the development process of the technical frameworks published by each domain of the IHE initiative.

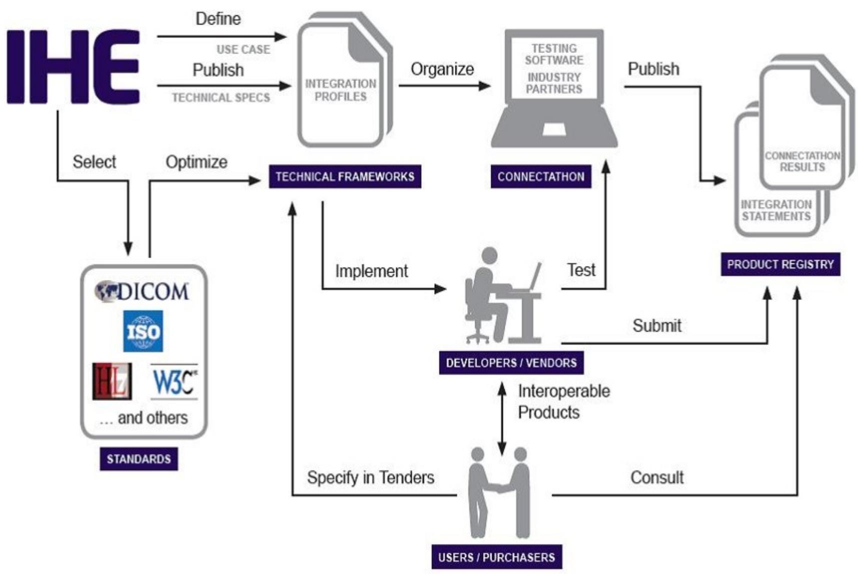



Figure 1.9: Illustration of the IHE methodology process.
[41]

### 1.1.5 Healthcare Data Integration Engine

The complexity of the healthcare domain is such that HIs see themselves forced by healthcare professionals to have unique HIS depending on the Department. The exchange of data between the different HIS, majorly uses the HL7 standard communication and it can be accomplished by two ways [42]:

1. **Point-to-point communication**, where each HIS talks independently of others. In this way, applications that are going to communicate must have an export and import endpoint designed

specifically to interface with the other application. The number of export and import endpoints varies depending upon the type of communication required between the applications.

2. An **interface engine** can be placed between all HIS aiding in the information exchange, working as a Enterprise System Bus (ESB).

There are several challenges to build an HL7 interface engine, it requires a sending and receiving module. These can be created by the software vendors, meaning that different HIS may use the HL7 message format, but they rarely agree on the specific format in use. To mitigate these differences that occur, an interface engine can be used in the middle to transform the messages format and tackle inconsistencies.

**Mirth Connect**

The Mirth Connect solution aims to transform the healthcare informatics domain by making high-value information technology tools available to the healthcare community on an open source basis. Mirth's professional grade, service-backed open source offers break through cost barriers to achieve more rapid health information technology dissemination, and enables users to create a safer and more effective health care delivery system [43]. Mirth Connect is an healthcare data integration engine that enables bi-directional sending of all the basic standards of the healthcare industry (HL7, DICOM and others) and supports multiple protocols (Web Services, SOAP, REST, etc.). It is a platform that connects HIS so they can exchange clinical and administrative data. The solution works based on a channel architecture, were it is possible to filter, transform and route healthcare messages as HL7 for example.

## 1.2 Related work

The translation from data exchange protocols to a storing protocol is described as an ontology mapping by Elkund, Peter in [44]. The article presents the mapping of two ontologies, HL7 v2.x and HL7 v3 to openEHR. First the authors explain the mapping from the HL7 v2.x structure to the HL7 v3, affirming that both models have similar structures supported by an XML data structure. The translation from HL7 v3 clinical data to openEHR compositions, is done by a bidirectional mapping to ensure that the meaning of the clinical data is preserved. As a case study example, the authors suggest the use of the HL7 v3 Observations Redifined Message Information Models (RMIM) as it has a very similar clinical concept description with the openEHR archetypes used.

Another example of translation between different data models is approached by Carmen, María in [45]. In this case, the authors explain the process of transformation from Clinical Element Model (CEM) to openEHR archetypes. The transformation process is based on defining mappings between the two models resorting to common representation formalism, available with the Web Ontology Language (OWL). According to the authors such transformation process with the help of OWL, can be executed also with the HL7 data structure. The work presented in the paper exploits the utility of the OWL methodology in supporting transformation processes.

Regarding the use of the IHE methodology in conjunction with the openEHR there have been recent advances in the subject. The presentation [46] by Gornik, Tomaz clearly states that both ideology's can coexist. It states benefits of the IHE across the dual model architect of openEHR. For the RM data structures the IHE presents complete data sets for the clinical data and describes data structures used.

The possibility of generating XML structures of the openEHR OPT can be used in CDA supported by IHE. The coexistence of IHE and openEHR supports the federated model.

An implementation of an openEHR based HIS with the use of IHE was implemented by an international vendor Marand [47]. According to the author in article [48], the IHE approach enabled a *"fast, secure and efficient connectivity to various devices"*, and support in all clinical processes of healthcare professionals.

## 1.3 Research Questions

The work documented on the thesis was based on the following question:

*Can a unique clinical repository get populated, using a healthcare data integration engine, with the exchange of data done at the HI network in order to centralize clinical data and avoid product and vendor lock-in?*

**Problem**: To avoid dependencies of the clinical data and possess a secondary source of data.
**Intervention**: Development of a solution to enable the transformation.
**Comparison/Control**: How is the exchange of data done at the HI network.
**Outcome**: The main goal is to centralize clinical data.

## 1.4 Objectives

The main objective of this project is to elaborate a solution that transforms the data in HL7 v2.x messages to openEHR compositions, in order to feed a unique repository of clinical data.

As secondary objectives we aim to conclude the following tasks:

- Mapping of the clinical workflows of the healthcare scenario in analysis, through the audit to the HL7 vv2.x messages.
- Identify wrong clinical workflows in production on the healthcare scenario.
- Enable the storage of the translated clinical data to an openEHR clinical repository.

# Study A

# 2. Study A

## 2.1 Introduction

On the healthcare domain, clinical workflows are a reflection of the daily clinical practice habits made by healthcare professionals, changing according to the resources available. The process of communication and transmission of clinical data between the various healthcare professionals has been shaping the quality of healthcare [49].

In nowadays technology continuously increases in the healthcare domain, becoming a great tool for healthcare professionals to base their clinical decisions on. As a consequence the communication and transmission of clinical data is now made between multiple HIS. According to [3], the bigger the capacity of a HI, the more HIS tend to exist, and so increases the complexity of the integrations between systems.

Along this chapter we will show a way to tackle the interoperability problems, through an analysis to the first study regarding the implementation of the clinical document online translator. Starting with a brief introduction of the healthcare scenario, followed by an explanation to the technical development and methods used, finishing the chapter with the presentation and discussion of the results obtained.

## 2.2 Methods

In order to have a better understanding of the healthcare scenario, an interpretation of the interoperability context is first presented in this section. Supported by a display of the variety of HL7 message types and clinical data transmitted between the different HIS.

We first analysed and understood the interoperability context, then a mapping of the clinical data that flows in the HI network is presented on section 2.2.1. The mapping of the clinical data is one of the key factors to the translation process.

Secondly we focused on the openEHR archetypes and templates, which the clinical data will populate. These were chosen by their purpose, and should correspond with the intent of the interactions that occur in the healthcare scenario along this section.

Lastly, the relationship between the two different data models and the final phase of the translation process are explained. Furthermore, the connection between the clinical data obtained in the HL7 v2.x messages and the chosen openEHR archetypes is illustrated.

### 2.2.1 Analysis of the interoperability context

The Health Institution analysed in this study is the Instituto Português de Oncologia do Porto, a region-based Oncology Hospital. the first step we made in the translation process was to understand the various integrations between the multiple HIS present in the HI. After, we performed an audition to the communications made by the HIS using an extraction tool to gather the HL7 messages that flow in the HI network. With the results of the extraction of HL7 messages, represented along the tables of section 2.2.1.2, sets of information regarding the workflow of all HL7 integrations in the HI is presented.

Lastly, on subsection 2.2.1.3 is a detailed analysis of the Radiology Department, and the workflow of the current healthcare scenario. The desired outcome in this study is the representation of a detailed diagram, representing the various interactions between the HIS present in the Radiology Department.

#### 2.2.1.1 Extracting the HL7 v2.x messages from the HI

All the HIS present at the Radiology department are connected to the HI network, and use this network to exchange HL7 messages. We extracted the HL7 messages from the HI network, using the Integrated Routing Audit for HL7 (IRA) solution first presented in the following paper [50].

IRA as described in the article, has five different modules that work independently of each other. It takes advantage of the integration techniques done between the software vendors, such as being prepared to comprehend the HL7 standard that is used by most HIS.

The sniffer module is responsible for passively extracting IP network packets from the HI network, reassemble HL7 messages and then store them in log/data files or send them to a processing module. We used the sniffer module to extract the HL7 messages, recording a total of 4,197,134 hits. The time range of the process of extraction were three months, March, April and May of the year 2015.

In the mean time an upgrade for the previous discussed solution IRA has been developed [51], easing the global analysis. One of the major changes, is the Audit Services module that performs a bird's eye view over the clinical data exchanged on the HI network, acting as a processing module. It is fed by the sniffer module, enabling a detailed visualization of the clinical data exchanged in the healthcare scenario in a simpler way. The upgrade also contains some changes in the technology used in the modules of the previous solution.

#### 2.2.1.2 Global HL7 analysis of the HI

In order to understand the healthcare scenario and inherent clinical workflows of the HI, we used the IRA updated tool that enables a global analysis of all HL7 messages in circulation.

A total of 4,197,134 HL7 v2.x messages were collected as showed in table 2.1.

Table 2.1: Extracted HL7 v2.x messages from all departments of the HI

| Department Name | Total of HL7 Messages | Percentage |
|---|---:|---:|
| Radiology | 380 046 | 9.0% |
| Radiotherapy | 779 800 | 18.5% |
| Laboratory | 3 013 091 | 72.0% |
| Others | 24 197 | 0.5% |
| TOTAL | 4 197 134 | 100% |

The majority of HL7 traffic occurring on the HI network, is related with the Laboratory Department. The Radiotherapy Department is responsible for almost a fifth of the HL7 traffic and the Radiology Department generates around a tenth of all the HL7 traffic, that occurs in the HI network.

The HL7 organization produces specifications that describe the structure of the many types of HL7 v2.x messages. According to the HL7 specifications, the general information about the messages source, destination and the intent are defined in segment Message Header Segment (MSH). This segment is mandatory in all HL7 messages, giving a general briefing of the HL7 message content.

On table 2.2 we present a deeper view of the communications, were we have information about the clinical data exchanged between the different HIS of the various Departments of the HI

Table 2.2: Overview by HIS of the different types of HL7 messages and quantity exchanged.

| Source | Destination | Type | Total Messages |
|---|---|---|---|
| Radiology Information System | Central Information System | OMG | 105,912 |
| | | ORG | 35,255 |
| | | ORU | 8,028 |
| | | | |
| Laboratory Information System | Central Information System | OML | 1,277,334 |
| | | ORU | 500,245 |
| | | ORL | 485,891 |
| | | | |
| Radiotherapy Information System | Central Information System | SIU | 559,546 |
| | | ADT | 170,525 |
| | | DFT | 25,2263 |
| | | | |
| Central Information System | Radiology Information System | ORG | 113,417 |
| | | SIU | 50,131 |
| | | OMG | 49,219 |
| | | ADT | 18,084 |
| | | | |
| | Laboratory Information System | OML | 749,621 |
| | | | |
| | Radiotherapy Information System | ADT | 24,466 |
| | | | |
| | Others | ADT | 1,025 |
| | | ORU | 8 |

Table 2.2 shows the existence of one specific HIS by Department and a Central Information System (CIS). Each HIS receives and sends messages according to it's purpose and the HL7 standard. As such OMG and ORG messages are specific to the radiology department and only the applications that belong to that department use these types of messages.

The purpose of the HL7 message, is described in the HL7 field Message Type (MSH.9). As healthcare professionals notice different healthcare scenarios in the clinical practice, different actions are used to tackle them. The purpose of each HL7 message used in the HI is related to the healthcare professional action purpose. The HL7 message types used are described below, listed by Department.

Radiology

- **OMG** - *General Clinical Order Message*

  Initiation of the transmission of information about a general clinical order that uses the OBR segment.

- **ORG** - *General Clinical Order Acknowledgement Message*

  Response to an OMG message. An ORG message is the application acknowledgement to an OMG message.

- **ORU** - *Unsolicited Observation Message*

  For transmitting laboratory results to other HIS.

- **SIU** - *Schedule information unsolicited*

  To facilitate the communication of scheduling requests and information between applications.

- **ADT** - *Admission Discharge Transfer Message*

  Provides for the transmission of new or updated demographic and visit information about patients.

Laboratory

- **OML** - Laboratory Order Message

  Used to communicate any step of the order, as initiations, changes and cancellations.

- **ORL** - General Laboratory Order Response Message to any OML

  Response to an **OML** message. An **ORL** message is the application acknowledgement to an OMG message.

- **ORU** - Observational report - unsolicited

  For transmitting laboratory results to other HIS.

Radiotherapy

- **SIU** - Schedule information unsolicited

  To ease the communication of scheduling requests and information between applications

- **ADT** - Admission Discharge Transfer Message

  Provides the transmission of new or updated demographic and visit information about patients.

- **DFT** - Detail Financial Transactions

  Used to describe a financial transaction transmitted between systems.

#### 2.2.1.3 Radiology Department HL7 Circuit Analysis

On this subsection we approach a more detailed view of the HL7 messages involved at the Radiology Department. It is likely that the clinical data present in the HL7 messages, will enable the mapping of all states of a daily clinical workflow.

First off, we present a general review of the HL7 message types exchanged between the two HIS, along with their purpose and information about the method how HL7 messages can be grouped by order request to construct the structure of a clinical workflow. Lastly with the knowledge acquired from the HL7 messages, we designed a diagram of the Radiology Department HL7 Circuit.

Table 2.3: Overview of HL7 messages statistics by HIS of the Radiology Department. Different types of HL7 messages and total count.

| Source | Destination | Type | Total Messages | Accumulated |
|---|---|---|---|---|
| Radiology IS | Central IS | OMG | 105,912 | 149,195 |
| | | ORG | 35,255 | |
| | | ORU | 8,028 | |
| | | | | |
| Central IS | Radiology IS | ORG | 113,417 | 230,851 |
| | | SIU | 50,131 | |
| | | OMG | 49,219 | |
| | | ADT | 18,084 | |

Table 2.3 is a general view of the HL7 communication done at the Radiology Department. As said before, the HL7 message type meaning has to do with the action's purpose. The differences between the actions of both HIS, is associated to the SIU and Admission Discharge-Transfer (ADT) message type.

The ADT HL7 message is only issued by the CIS, meaning that the CIS is responsible for the transmission of patient demographics. The same applies to the SIU HL7 message, where the CIS is charged with the scheduling information about the order process. Note that the Radiology Information System (RIS) does not issue any of this message types. Nonetheless, both HIS have in common the issuing of HL7 message types related to the order management (OMG and ORG).

The HL7 specification standard defines the actions made by the HIS. On the Message Type field of the HL7 messages, there is information about the purpose of the triggered action. For example, an ADT message type has information related to patient demographics, more specifically the trigger A08 means an update on the patient demographics information. So an HL7 message that is supposed to transmit the new address of a patient, will have the following in the Message Type field *"ADT-A08"*.

Table 2.4: Overview of the HL7 v2.x messages exchanged in the Radiology Department, ordered by message type

| Type | Trigger | Source | Destination | Accumulated |
|---|---|---|---|---|
| OMG | O19 | RIS | CIS | 105,912 |
| | | CIS | RIS | 49,219 |
| ORG | O20 | RIS | CIS | 35,255 |
| | | CIS | RIS | 113,417 |
| ADT | A08 | CIS | RIS | 18,04 |
| | A34 | CIS | RIS | 44 |
| SIU | S12 | CIS | RIS | 34,851 |
| | S13 | CIS | RIS | 13,913 |
| | S15 | CIS | RIS | 1,367 |
| ORU | R01 | RIS | CIS | 8,028 |

Table 2.4 shows all of the actions triggered by the HIS at the Radiology Department. The columns Type and Trigger are the Message Type field of the HL7 messages exchanged between the HIS in the Radiology Department. Table 2.4 also shows that the CIS is responsible for the use of SIU HL7 messages, concretely with three actions related to scheduling information and have the following purpose:

**S12** - Notification of New Appointment Booking

**S13** - Notification of Appointment Rescheduling

**S15** - Notification of Appointment Cancellation

The CIS is also responsible for the ADT message type. The ADT message type has two triggers associated at the Radiology Department.

**A08** - Update Patient Information

**A34** - Merge Patient Information - Patient ID Only

We noted the existence of a exclusive HL7 message type transmitted by the HIS, named as ORU. It only possesses one trigger.

**R01** - Unsolicited Observation Message

There are two HL7 message types that remain, and are mutual to both HIS. They are related to the order management, meaning it communicates data required for the correct flow of a clinical order. The OMG message type indicates there is an action that will alter the flow of the clinical order, like a cancellation or admission.

**019** - General Clinical Order Message

The response to the OMG message is an ORG message type, with the purpose of providing feedback to the desired action, was it accepted or not.

**020** - General Clinical Order Acknowledgement Message

The HL7 message types OMG, ORG and ORU are related to the Order Management. Only the ORU message type is exclusively used by the RIS to provide the final report of the order, according to the executed message analysis. Earlier we noted that the ORG stands as a response (Processed correctly or with errors) to the OMG message type. However the OMG message type is used in all steps of the Order Management by both HIS, for example yo announce the admission of the patients, cancellation of orders, end of activity, and others. These differences in the purpose of each OMG message are not identified in the Message Type field, but in the fields that represent the message status.

The different status represented in the OMG message types are described in the following HL7 fields:

- **Order Control** (ORC.1) - Determines the function of the order segment.
- **Order Status** (ORC.5) - It specifies the status of an order.

With the help of the documentation provided by the HI regarding the integrations of the Radiology Department with the CIS and with the auditing of OMG messages, we listed the different actions identified and the correspondent message status. Representing all the actions involved in the process of Order Management of the Radiology Department.

Table 2.5: Listing of the all message status within the order workflow.

| HIS | Type and Trigger | O. Control | O. Status | Count | Action |
|---|---|---|---|---|---|
| RIS | OMGÔ19 | NW | | 31,322 | Request a new order |
| | | CA | | 1,243 | Cancel an Order |
| | | SC | CA | 1,154 | Cancel an executed exam |
| | | | CM | 72,192 | Exam executed |
| | ORGÔ20 | UA | | 48 | Corresponding message processed with errors |
| | | OK | | 113,254 | Corresponding message processed correctly |
| | ORUR01 | SC | CM | 8,028 | N/A (Sending of final report) |
| CIS | OMGÔ19 | XO | | 12,383 | Changes to Scheduling and Exams |
| | | SC | IP | 34,325 | Register of a patient for an examination (one-time) |
| | | | HD | 1,921 | Cancel of an Registration of a patient |
| | ORGÔ20 | OK | | 113,254 | N/A (Message received with success) |
| | | UA | | 156 | N/A (Message not received) |
| | | XO | | 3 | N/A (Errors?) |
| | | SC | IP | 2 | N/A (Errors?) |

The researcher analysed table 2.5 verifying which are the responsibilities of the HIS at the Radiology Department. The RIS can request new orders, cancel orders, cancel in progress orders and notify order completion. It is also responsible for providing the final report that includes a link to a directory resource containing the image data, using the ORU-R01 message.

About the CIS, it can change scheduling and orders, notifies when a patient enters the HI for the examination and it can cancel the registration of a patient.

A recap in the responsibilities of each HIS at the Radiology Department can be described as following:

**Actions of HIS**

---

**RIS** - Radiology Information System

***Order Management*** :

Request new order

Cancels orders

Cancels in progress orders

Notifies order completion

***Report Management*** :

Provides the final report

---

**CIS** - Central Information System

***Order Management*** :

Changes orders

Admit patient in the HI

Cancel admission of patient in the HI

***Patient Demographics*** :

Update patient information

Merge patient

***Scheduling*** :

New appointment schedule

Reschedule appointment

Cancel appointment schedule

---

An interaction is a set of actions that correspond to an general topic. The responsibilities are grouped by interactions, having then various actions for the same type of interaction. There are four different interactions at the Radiology Department, as for the actions the total is thirteen. The researcher noted that the RIS has two interactions and five actions, and the CIS has three interactions and eight actions. Interaction Patient Demographics is not related to the workflow of the order, so it was discarded.

In order to create a workflow out of the HL7 messages, there must be an identifier that relates the HL7 messages to a specific order. Each HIS is responsible of creating their unique identifier for the order, thus having a pair of unique keys to identify which order the HL7 message refers to. According to the HL7 specification, the fields **Placer Order Number** and **Filler Order Number** are intended to be used as unique identifier of the order by HIS.

- **Placer Order Number** (ORC.2 || OBR.2) - Represents the unique identifier attributed to the order by the HIS that requires the orders.
- **Filler Order Number** (ORC.3 || OBR.3) - Represents the unique identifier attributed to the order by the HIS that receives the orders.

The audit to the HL7 Radiology Circuit, with the documentation provided by the HI and the responsibilities of each HIS of the Radiology Department, were sufficient resources to design an HL7 Circuit. The researcher has now the detailed view of the communications that flow along the Radiology Department, by possessing information about the different actions and actors of the healthcare scenario and also about the clinical data exchanged.

Each interaction and action between both HIS generates a status change on the Order. For an action to trigger another one, the states must be defined in a careful and connected way. Considering the list of responsibilities of the HIS, the interactions used to map the workflow of the order and help with the definition of states, were the Order Management, Report Management and Scheduling.

We defined a total of five states accordingly to the knowledge obtained through the audit of HL7 Radiology Circuit.

1. **Order** Represents the generic initial state of the clinical order process, when an order is required by a healthcare professional (Request new order). It also aggregates the changes done to an order that was not yet scheduled (Change Order). An order that has seen their schedule cancelled also comes here (Appointment Cancellation).
2. **Schedule** It’s the second state in the order workflow. It can work as the initial state in some cases where there is a direct scheduling of the order or comes from the previous state (Appointment Schedule). When the order has a reschedule of appointment or a change it stays in this state (Appointment Reschedule). If an admission cancellation comes through, the order returns to this state (Cancel admission of patient in the HI).
3. **Admitted** The third state starts when the patient enters the HI (Admit patient in the HI). In case a order suffers a change it maintains is state (Change Order).
4. **Cancelled** The fourth state and one of the terminal states. The cancellations of an order come all to this state, representing the end of the order. The states enabled to make cancellations are the Order and Admitted.
5. **Completed** The fifth state and the last terminal state. When the report with the observation results is issued, the represented state is this one.

The interactions are performed through the HIS actions at the Radiology Department, originating state changes, as illustrated in fig 2.1.

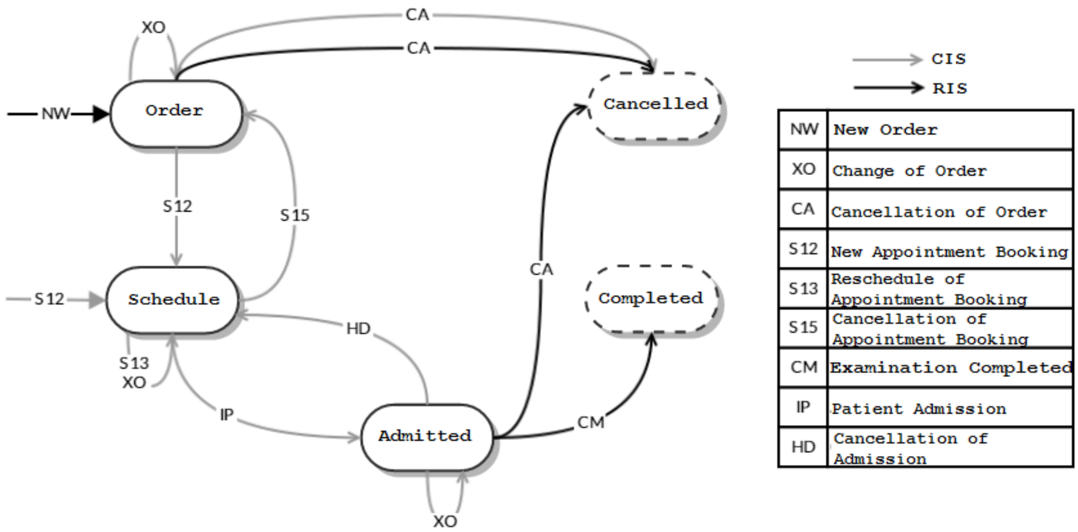



Figure 2.1: Radiology Department HL7 Circuit diagram regarding the order workflow.

The HL7 Radiology Circuit starts with RIS issuing a New Order (NW). This leaves the order in the Order status. At this state we have the following state changes as corresponding actions:

- **Change of Order (XO)** - It can be changed by both HIS, thus remaining in the same state.
- **Cancellation of Order (CA)** - It is possible by the two HIS, changing to state Cancelled.
- **New Appointment Booking (S12)** - If the order proceeds to be schedule by the CIS, it will go to state Schedule.

Another way to start the HL7 Radiology Circuit is when CIS, creates a direct scheduling without an order request from the RIS. From this state we can reach the following states with the corresponding actions:

- **Reschedule of Appointment Booking (S13)** - It is only used by the CIS, remaining in the same state.
- **Cancellation of Appointment (S15)** - The cancellation of appointment, will have the order go back to state Order.
- **Patient Admission (IP)** - When the scheduled date for realization of the order comes, the patient enters the HI, and triggers the order to state Admitted, sent by the CIS.

The Admitted (Admitida) state is reachable from the state Scheduled(Agendada) with the action (IP) which tells the system that the pacient has reached the department and is ready for the examination. At this state the CIS may decide to cancel the registration of a patient, and thus moving the order back to state Scheduled. Through the audit of HL7 messages we noticed that that when a change occurs (XO) the order doesn't change state. After the notification of patient entry (IP) the RIS can issue an order cancellation action(CA)., moving the order to state Cancelled. In the case of order completion by the RIS, the order goes to state Completed.

When an order is cancelled by one of the HIS it goes to state Cancelled. Reaching this state, means the end of the Radiology Department HL7 circuit.

The last state is named Completed, it also ends the Radiology Department HL7 circuit. It indicates that the examination is successfully, thus ending the patient visit to the department.

### 2.2.2 HL7 to openEHR

On this subsection (2.2.2) the translation method from the standard HL7 v2.x to openEHR archetypes and the details of the key factors for obtaining a correlation between both standars is described.

#### 2.2.2.1 HL7 significant fields

On section 2.2.1.2 we analysed the HL7 message types used at the Radiology Department, but now the focus is at the clinical data that they carry and its relevance for mapping. The HL7 v2.x standard specification indicates the structure of each HL7 message type, but generally vendors adapt their message structures accordingly to the healthcare scenario and their needs. These slight modifications done by the vendors in their implementations, are one of the reasons to diminish the interoperability in an HI causing the need to verify the appropriate use of the segments.

The segments are an aggregation of HL7 fields and subfields, each with a defined usage. Generally vendors distribute documentation with the software that explains this changes to the standard but it is not always up to date with the software version that is implemented on the HI.

First we mapped the HL7 message types to the interactions present at the Radiology Department, as pointed in table 2.6. Then, we identified the use and relevance of the HL7 segments and fields by interaction at the Radiology Department.

Table 2.6: Correlation between HL7 message types and defined interactions of the Radiology Department.

| Type | Interaction |
|---:|---:|
| OMG | Order Management |
| ORG | Acknowledgement |
| SIU | Schedule |
| ORU | Report |

For the **Order Management** interaction, the correspondent message type is OMG. The HL7 segment structure of this message type is indicated on table 2.7.

Table 2.7: Segment structure of a OMG message type at the Radiology Department.

| **Segment** | **Description** |
|:---:|:---:|
| MSH | Message Header |
| PID | Patient Identification |
| PV1 | Patient Visit Information |
| ORC | Common Order |
| OBR | Observation Request |

The segment structure contains data about general communication information, patient demographics, visit information and order details. On table 2.8 are represented the relevant fields analysed in the OMG messages in production at the Radiology Department.

Table 2.8: Relevant HL7 fields obtained from the segment analysis of the message type OMG-O19.

| **Segment** | **Field** | **Description** | **Use** |
|---|---|---|---|
| MSH | 3 | Sending Application | Source IS |
| | 4 | Sending Facility | Source HI |
| | 5 | Receiving Application | Destination IS |
| | 6 | Receiving Facility | Destination HI |
| | 7 | Date/Time of Message | Moment of message sending |
| | 9 | Message Type | Type and trigger of message |
| | 10 | Message Control ID | Unique message ID |
| | 12 | Version ID | Version of HL7 standard |
| | | | |
| PID | 3 | Patient Identifier List | Number of Patient record |
| | | | |
| PV1 | 19 | Visit Number | Number of Patient visit |
| | | | |
| ORC | 1 | Order Control | Status of message |
| | 2 | Placer Order Number | Unique ID provided by a HIS |
| | 3 | Filler Order Number | Unique ID provided by a HIS |
| | 5 | Order Status | Status of message |
| | 9 | Date/Time of Transaction | Moment of common order request |
| | 12 | Ordering Provider | ID of the ordering provider |
| | | | |
| OBR | 2 | Placer Order Number | Unique ID provided by a HIS |
| | 3 | Filler Order Number | Unique ID provided by a HIS |
| | 4 | Universal Service Identifier | ID and name of the examination |
| | 6 | Requested Date/Time | Earliest date requested for completion |
| | 8 | Observation End Date/Time | Latest date requested for completion |
| | 13 | Relevant Clinical Info | Notes and comments |

The **Acknowledgement** interaction is related to the HL7 message type ORG. On table 2.9 are represented the correspondent segment structure of the ORG message type in analysis.

Table 2.9: Segment structure of a ORG message type at the Radiology Department.

| **Segment** | **Description** |
|---|---|
| MSH | Message Header |
| PID | Patient Identification |
| MSA | Message Acknowledgement |
| ORC | Common Order |
| OBR | Observation Request |

The **Acknowledgement** interaction, stands as a confirmation for the Order Management interaction. The implication is that all OMG messages, have a respective acknowledgement represented with the message type ORG. The information present in segments related to order details (**ORC** and **OBR**), is a repetition from the segments presents in the respective OMG message. The value in mapping this type of messages comes with the Message Acknowledgement Segment (MSA) segment, which provides the unique identification of the respective OMG message, for which the acknowledgement is applied. On table 2.10 it shows the significant fields present on the HL7 messages.

Table 2.10: Significant HL7 fields obtained from the segment analysis of the message type ORG-O20.

| **Segment** | **Field** | **Description** | **Use** |
|---|---|---|---|
| MSH | 3 | Sending Application | Source IS |
| | 4 | Sending Facility | Source HI |
| | 5 | Receiving Application | Destination IS |
| | 6 | Receiving Facility | Destination HI |
| | 7 | Date/Time of Message | Moment of message sending |
| | 9 | Message Type | Type and trigger of message |
| | 10 | Message Control ID | Unique message ID |
| | 12 | Version ID | Version of HL7 standard |
| | | | |
| PID | 3 | Patient Identifier List | Number of Patient record |
| | | | |
| MSA | 1 | Acknowledgement Code | Type of acknowledgement |
| | 2 | Message Control ID | Unique message ID of related HL7 message |
| | | | |
| ORC | 1 | Order Control | Status of message |
| | 2 | Placer Order Number | Unique ID provided by a HIS |
| | 3 | Filler Order Number | Unique ID provided by a HIS |
| | 12 | Ordering Provider | ID of the ordering provider |
| | | | |
| OBR | 2 | Placer Order Number | Unique ID provided by a HIS |
| | 3 | Filler Order Number | Unique ID provided by a HIS |
| | 4 | Universal Service Identifier | ID and name of the examination |

Another Interaction present on the HL7 messages is related to the **Schedule**. The Schedule messages differ at the trigger level but have the same message type (SIU). This interaction is responsible for scheduling purposes, thus possesses a different structure of the other interactions we analysed until now. The segments inherent to this message type are shown in table 2.11.

Table 2.11: Present segments of a SIU message type at the Radiology Department

| Segment | Description |
|---|---|
| MSH | Message Header |
| SCH | Scheduling Information Unsolicited |
| PID | Patient Identification |
| PV1 | Patient Visit Information |
| RGS | Resource Group |
| AIS | Appointment Information |
| AIP | Appointment Information Personnel |
| NTE | Notes and comments |

The most relevant HL7 fields in this interaction, are the ones related to schedule information. This message defines the desired schedule date for the examination, the duration for the observation and the event reason within the SCH segment. Relevant fields mapped on SIU messages are represented on table 2.12

Table 2.12: Significant HL7 fields obtained from the segment analysis of the message type SIU.

| Segment | Field | Description | Use |
|---|---|---|---|
| MSH | 3 | Sending Application | Source IS |
| | 4 | Sending Facility | Source HI |
| | 5 | Receiving Application | Destination IS |
| | 6 | Receiving Facility | Destination HI |
| | 7 | Date/Time of Message | Moment of message sending |
| | 9 | Message Type | Type and trigger of message |
| | 10 | Message Control ID | Unique message ID |
| | 12 | Version ID | Version of HL7 standard |
| | | | |
| PID | 3 | Patient Identifier List | Number of Patient record |
| | | | |
| PV1 | 19 | Visit Number | Number of patient visit |
| | | | |
| SCH | 1 | Filler Appointment ID | Unique ID provided by a HIS |
| | 6 | Event Reason | Code to the respective event |
| | 11 | Appointment Timing/Quantity | Duration of appointment, start and end date |
| | 26 | Placer Order Number | Unique ID provided by a HIS |
| | 27 | Filler Order Number | Unique ID provided by a HIS |
| | | | |
| AIS | 3 | Universal Service Identifier | ID and name of the examination |
| | | | |
| AIL | 3 | Location Resource ID | Point of Care and room associated to the order |

The last interaction to be analysed is **Report Management**, the HL7 message type that satisfies this interaction is the ORU. It has a very similar structure with interactions Order Management and

Acknowledgement, and is represented in table 2.13

Table 2.13: Present segments of a ORU message type at the Radiology Department

| **Segment** | **Description** |
|---|---|
| MSH | Message Header |
| PID | Patient Identification |
| PV1 | Patient Visit Information |
| ORC | Common Order |
| OBR | Observation Request |
| OBX | Observation |

The HL7 fields to map are basically the same as in the Order Management interaction. An extra segment and its fields are also very valuable for the mapping, the Observation Segment (OBX) segment. This is the final interaction, directly related to the order workflow.

Table 2.14: Significant HL7 fields obtained from the segment analysis of the message type ORU.

| Segment | Field | Description | Use |
|---|---|---|---|
| MSH | 3 | Sending Application | Source IS |
| | 4 | Sending Facility | Source HI |
| | 5 | Receiving Application | Destination IS |
| | 6 | Receiving Facility | Destination HI |
| | 7 | Date/Time of Message | Moment of message sending |
| | 9 | Message Type | Type and trigger of message |
| | 10 | Message Control ID | Unique message ID |
| | 12 | | |
| | | | |
| PID | 3 | Patient Identifier List | Number of Patient record |
| | | | |
| PV1 | 19 | Visit Number | Number of Patient visit |
| | | | |
| ORC | 1 | Order Control | Status of message |
| | 2 | Placer Order Number | Unique ID provided by a HIS |
| | 3 | Filler Order Number | Unique ID provided by a HIS |
| | 5 | Order Status | Status of message |
| | 9 | Date/Time of Transaction | Moment of common order request |
| | 12 | Ordering Provider | ID of the ordering provider |
| | | | |
| OBR | 2 | Placer Order Number | Unique ID provided by a HIS |
| | 3 | Filler Order Number | Unique ID provided by a HIS |
| | 4 | Universal Service Identifier | ID and name of the examination |
| | 6 | Requested Date/Time | Earliest date requested for completion |
| | 8 | Observation End Date/Time | Latest date requested for completion |
| | 13 | Relevant Clinical Info | Notes and comments |
| | | | |
| OBX | 5 | Observation Result | Path to image directory |

Possessing the clinical data transmitted in each action done by the healthcare professionals.

Now that we have the mapped the relevant HL7 fields from each message we can proceed with the mapping process. It should be noted that due to the existing differences between the HL7 used on this systems and the standard, using this mapping in other HI would need some extra work.

#### 2.2.2.2 openEHR archetypes and templates

The aim of this section is to describe the openEHR archetypes we chose, that better suit the healthcare scenarios in study and that later will be used to construct the openEHR templates used on the mapping.

The construction of the openEHR templates is related with the interactions defined for the Radiology Department on section 2.2.1.3, table 2.6. As templates are based on interactions, it is critical to define the archetypes that correspondent to the actions of the interaction in analysis.

**Order Management**

First off, the Order Management interaction is a set of actions that are related to the order workflow, which map to the HL7 v2.4 messages of type OMG. These actions, described in section 2.2.1.3 have identical clinical data and only differ on the status, represented by the fields (Order Status and Order Control). On table 2.5 we can see the different status possible on the Radiology Department. These are mapped to an archetype that has the capacity of representing the five states presented in figure 2.1. The researcher needs an archetype that supports most of the HL7 significant fields, approached in 2.2.2.1, relatively to the OMG message type.

According to the openEHR specification, the archetypes that indicate a request of an action are defined by the name **Instruction**. We looked at the CKM repository for all the archetypes of type Instruction and selected the **Imaging Examination Request**. The purpose of this archetype as cited is *"To request an imaging examination to be performed and convey supporting clinical details."* We can observe by figure 2.2, that the contents of this type of archetypes include Activities and Protocol.

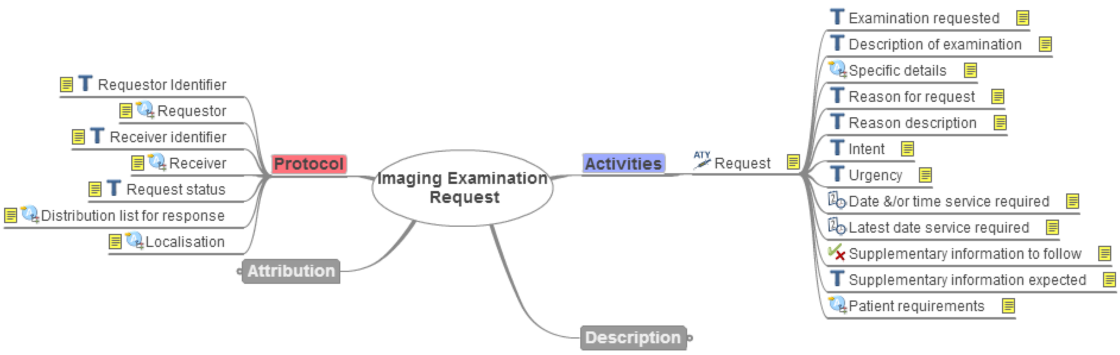



Figure 2.2: Mindmap of the Imaging Examination Instruction Request Archetype.[33]

For the Order Management interaction to be fully mapped we needed an archetype to represent the different actions, enabling the user to know in which state their order is on. Archetypes of type **Action** have a structure that has a content named **'Pathway'**, it provides a way of mapping the steps of any process. The contents of these type of archetypes includes description of the activity (**Description**), the workflow of the order progress (**Pathway**) and the protocol (**Protocol**). In CKM an archetype that matched the requirements was found named **Imaging Examination**.

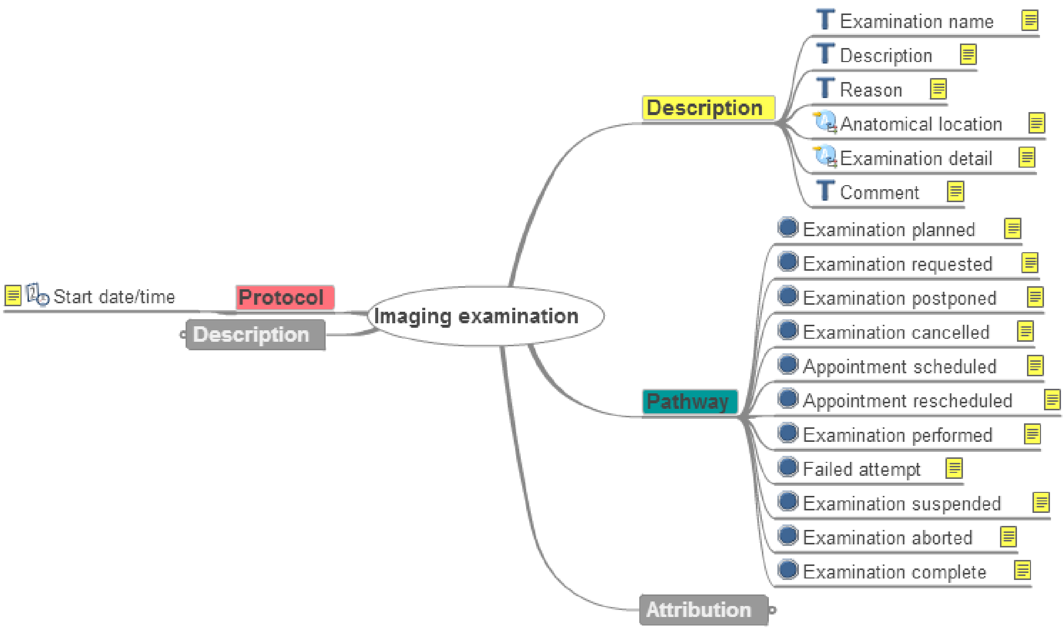



Figure 2.3: Mindmap of the Imaging Examination Action Archetype.[33]

We also edited the archetypes content in the **'Pathway'**, to the reality of the Radiology Department in analysis. Altering the attributes described in the **Pathway** content to the actions involved in the order processing, described in figure2.1.

OpenEHR archetypes are seen as LEGO bricks, and the 'brick' which purpose is to be the base of the construction is an archetype of type Composition. This type of archetype is filled with other types of archetypes, such as **Instruction**, **Observation**, **Action**, etc. It functions as the header of all aggregated archetypes, varies according to their purpose, and it can be perceived as a persistent document, it will serve as a reference for future informations. In CKM we found the archetype of type Composition named *Request for Service*, which has the best fit to our scenario. Citing it's purpose, *"To request advice, a specified service or transfer of care from a healthcare provider or organisation about the subject of care."* Figure 2.4 presents the structure of the chosen archetype.


Figure 2.4: Mindmap of the Request for Service Composition Archetype.[33]

In the end grouping of these three archetypes, the researcher created a template in order to map all the clinical data that goes through the HI network by HL7 messages of type OMG or according to the interaction Order Management.

**Acknowledgement**

The second template that we created is regarding the clinical data that goes through the HL7 messages of type ORG. On section 2.2.2.1, there is a description of the HL7 fields used in this type of message. As noticed during the audit, the clinical data contained in this case is minimal mostly because these type of message work as a response to the OMG type of message.

The types of archetypes used for the construction of the template regarding the interaction Acknowledgement were the **Composition** and **Action**. The **Composition** archetype is the same as the one used in interaction Order Management represented in figure 2.4, named **"Request for Service"**, due to the similarity in the purposes of the two interactions in analysis.

Also the same archetype of type **Action** is used in both interactions (Order Management and Acknowledgement) represented in figure 2.3, named as **Imaging Examination**. It's utility comes with the fact we can map the state of the order workflow, because of the **'Pathway'** content.

**Report**

This interaction is used in the HI network on the HL7 messages of type ORU. The purpose of this interaction is to transmit the observation results. The construction of the template must follow the context of the interaction, the report management.

First, the **Composition** archetype and base for the template is the *Result Report*. It's purpose fulfils the requirements of the interaction, citing *"Generic container archetype to carry information about the result of a test or assessment."*. Figure 2.5 presents the structure of the **Composition** archetype.


Figure 2.5: Mindmap of the Result Report Composition Archetype.[33]

As it relates with the order workflow, interaction Report Management must also possess a way to map the states. For it, we will continue to use the archetype of type **Action**, named **Imaging Examination** represented in figure 2.3, which provides the **Pathway** content.

To conclude, the template for the **Report Management** interaction, we needed an archetype capable of carrying clinical data related to observation results. The archetypes of type **Observation**, have their usage related to the storage of observation results, including imaging results. The archetype we chose is the **Imaging Examination Result**. Figure 2.6 presents the structure of the archetype in analysis.

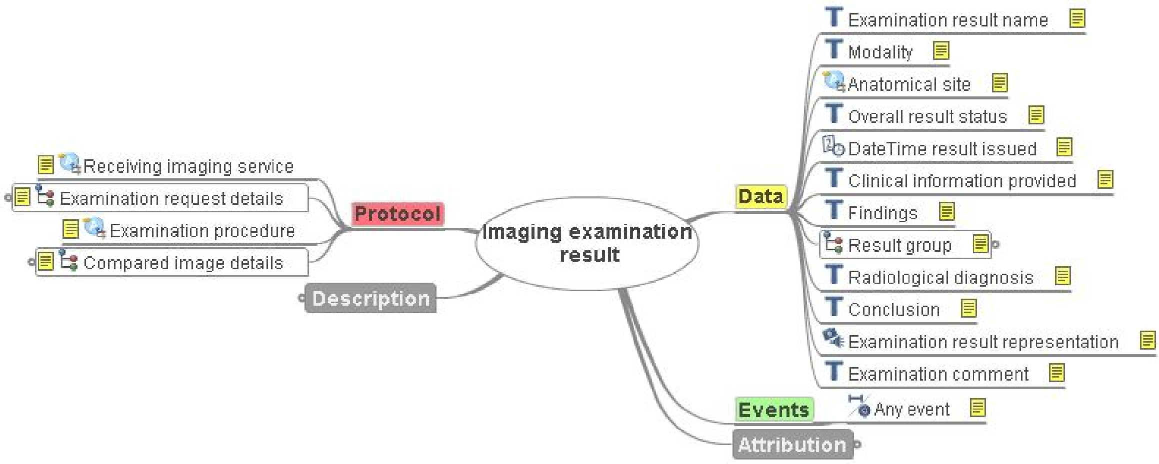



Figure 2.6: Mindmap of the Imaging Examination Result Observation Archetype.[33]

In the end, the openEHR template for interaction Report Management possess three archetypes, one of type **Composition**, one of type **Action** and one of type **Observation**.

**Schedule**

The last interaction that we need to map to a template is the Schedule interaction, represented by the HL7 messages of type SIU. The scheduling of an appointment to execute the examination requested in the order. So it is also related with the order workflow, meaning a slight difference will be noticed when constructing the respective openEHR template for this interaction.

The **Composition** archetype is the same as the one used in interactions Order Management and Acknowledgement represented in figure 2.4, due to the interaction's purpose that is related with the request of appointments.

To map the states in which the order is, we used the same **Action** archetype, named **Imaging Examination**, due to the content of **'Pathway'** present in this type of archetype.

The difference comes in the last archetype, the interaction deals with requests of new, modifications, or cancellations of appointments. The chosen archetype is named *Procedure Request*, and is of type **Instruction**. Citing the purpose of the archetype *"Generic framework for a request for a procedure to be performed by a healthcare provider or agency."*. Figure 2.7 presents the structure of the chosen archetype.

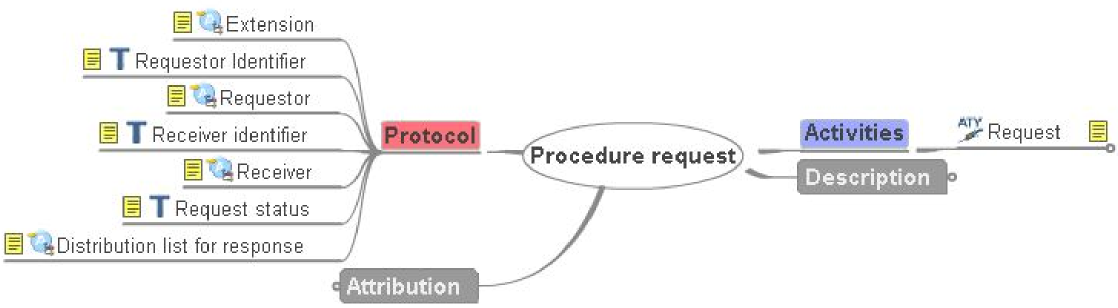



Figure 2.7: Mindmap of the Procedure Request Instruction Archetype.[33]

The openEHR template for interaction Schedule has three archetypes, one of type **Composition**, one of type **Action** and the last of type **Instruction**.

In the end, we found archetypes for all the interactions and actions done on the Radiology Department. Having a total of six archetypes, were one of them (Action) is present in all openEHR templates used to map the states of the order workflow. We ended up with four openEHR templates.

#### 2.2.2.3 Mapping of HL7 and openEHR

On this section we describe the translation process used, from HL7 clinical data obtained on subsection 2.2.2.1 with the archetypes chosen in subsection 2.2.2.2.

For the Order Management openEHR template, the clinical data to map comes from the HL7 message type OMG. It is composed by one composition archetype, one action archetype and one instruction archetype. Since the composition archetype works as a header for the template, it was edited to enable the mapping of certain HL7 fields from the MSH segment, that act as a header for the HL7 message. The action archetype named **Imaging Examination**, was also edited to accommodate general information regarding the order identifier, such HL7 fields are mainly present in the **ORC** segment. More editions were made to the contents of the archetype's pathway, to carry the different states from the Radiology Department HL7 Circuit. The instruction archetype did not get any editions, and is used as the original version from CKM. The correspondence is illustrated in figure 2.8.

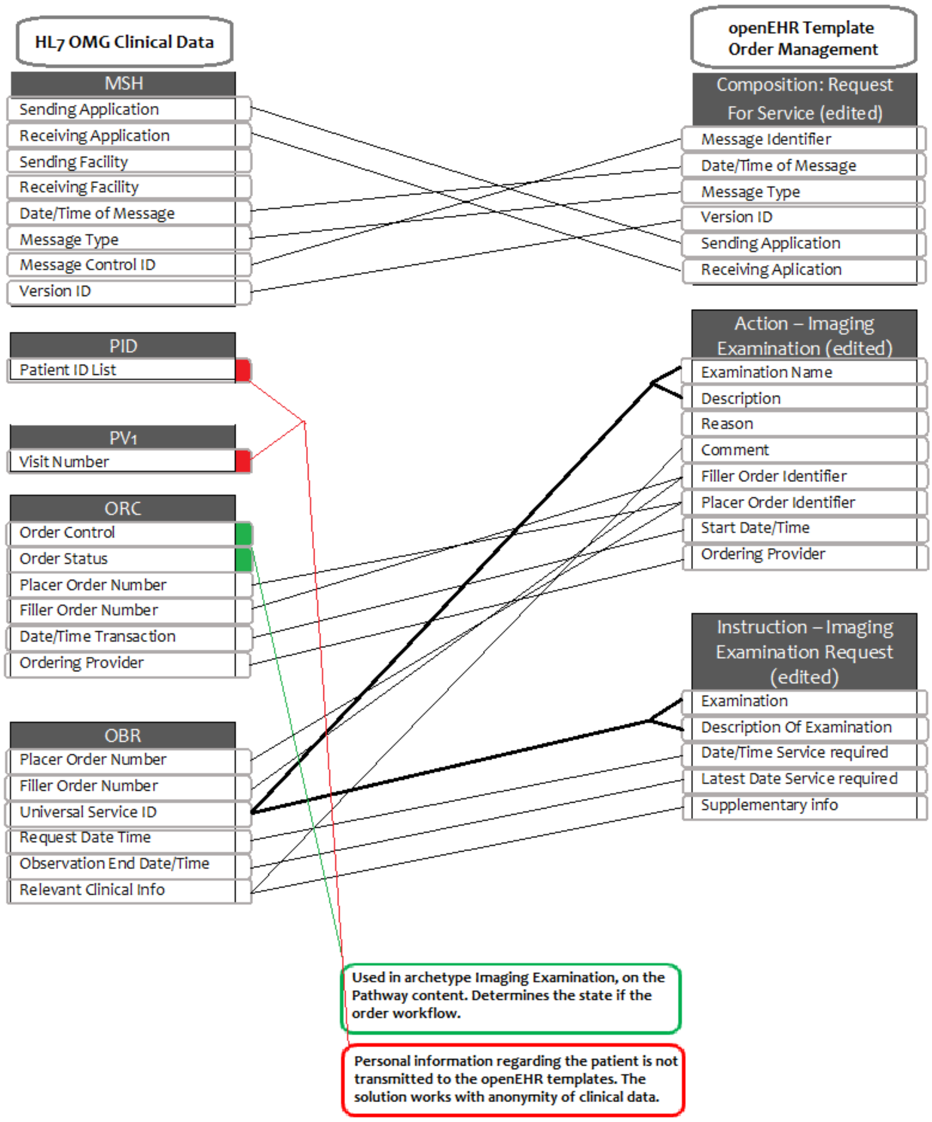



Figure 2.8: Mapping of clinical data from the HL7 OMG message type to the Order Management Template.

The HL7 patient demographics fields present in segments **PID** and **PV1**, are not used to map any field of the archetypes, but are pre-processed by the integration engine **MirthConnect** in order to anonymize the clinical data. The HL7 fields Order Control and Order Status, are mapped to the pathway content of archetype action **Imaging Examination**, defining the state of the order.

For the Acknowledgement openEHR template, the clinical data is translated from the HL7 message type **ORG**. This template is formed by a composition archetype and an action archetype, respectively the *Request for Service* and *Imaging Examination*. For this interaction a new archetype of type cluster was created to carry the information that is present in the **MSA** an **ERR** segment, relating to data from acknowledgements and possible errors of the HL7 message. Figure 2.9 presents the correlations between HL7 and openEHR.

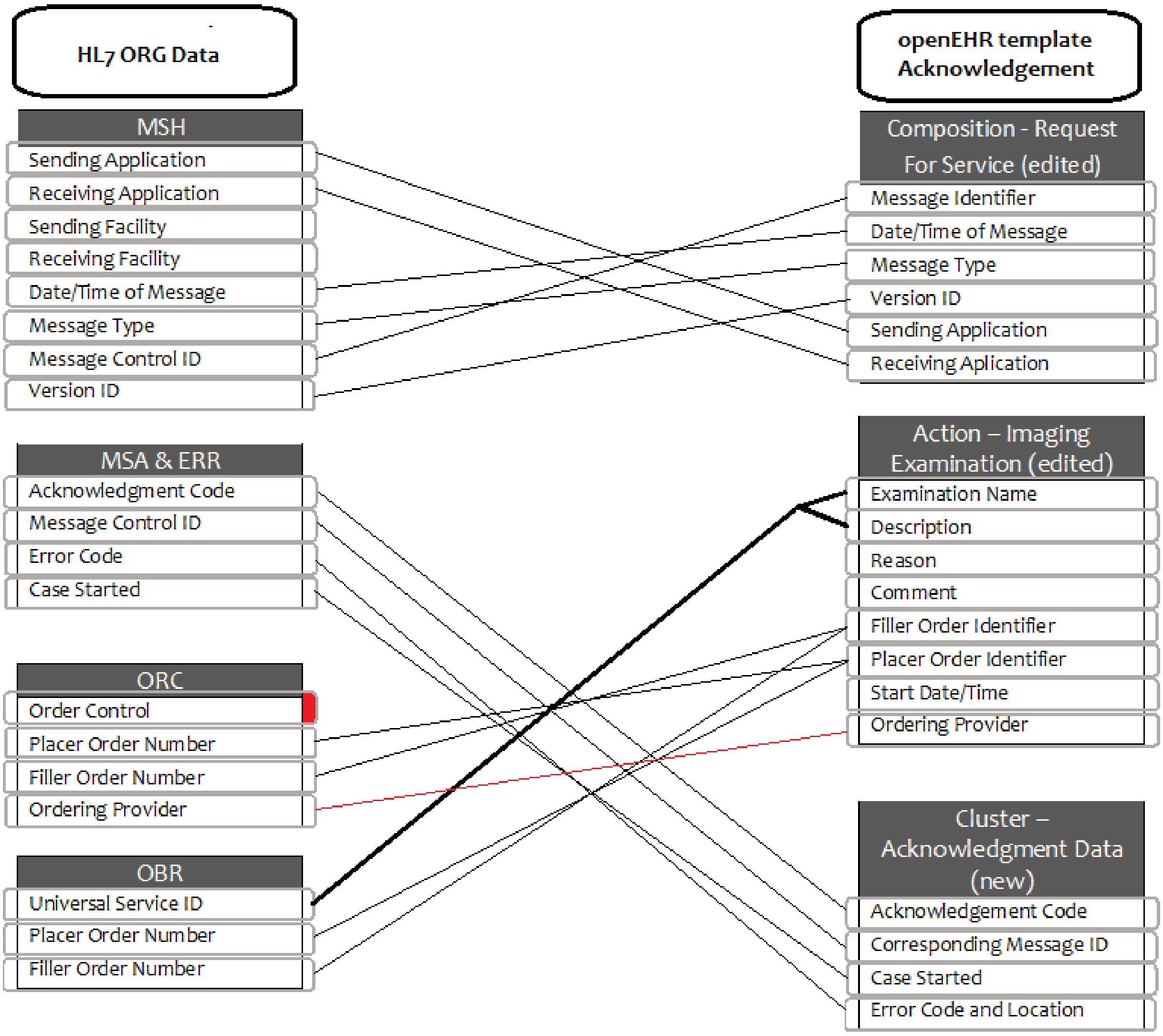



Figure 2.9: Mapping of clinical data from the HL7 ORG message type to the Acknowledgement Template.

The segment of patient demographics (PID) in the **ORG** message, is not mapped to any openEHR archetype, instead they are pre-processed earlier as said before, to anonymize the data. On this scenario, the Order Control HL7 field is used to guarantee that the message was successful processed or if it contains errors. Thus, not being directly connected with the order workflow, but acting as a validation to another HL7 message.

For the Schedule openEHR template, the clinical data is translated from the HL7 message type SIU. Identical to the previous templates showed, it possesses the same composition archetype and action archetype, named *Request for Service* and *Imaging Examination*, plus an instruction archetype called *Procedure Request*. This last archetype is used in it's original form, directly from the CKM. On this scenario, the HL7 message type and trigger is used to map the state in which the order workflow is, used at the pathway of the action archetype. In figure 2.10, an illustration of the mapping is presented.

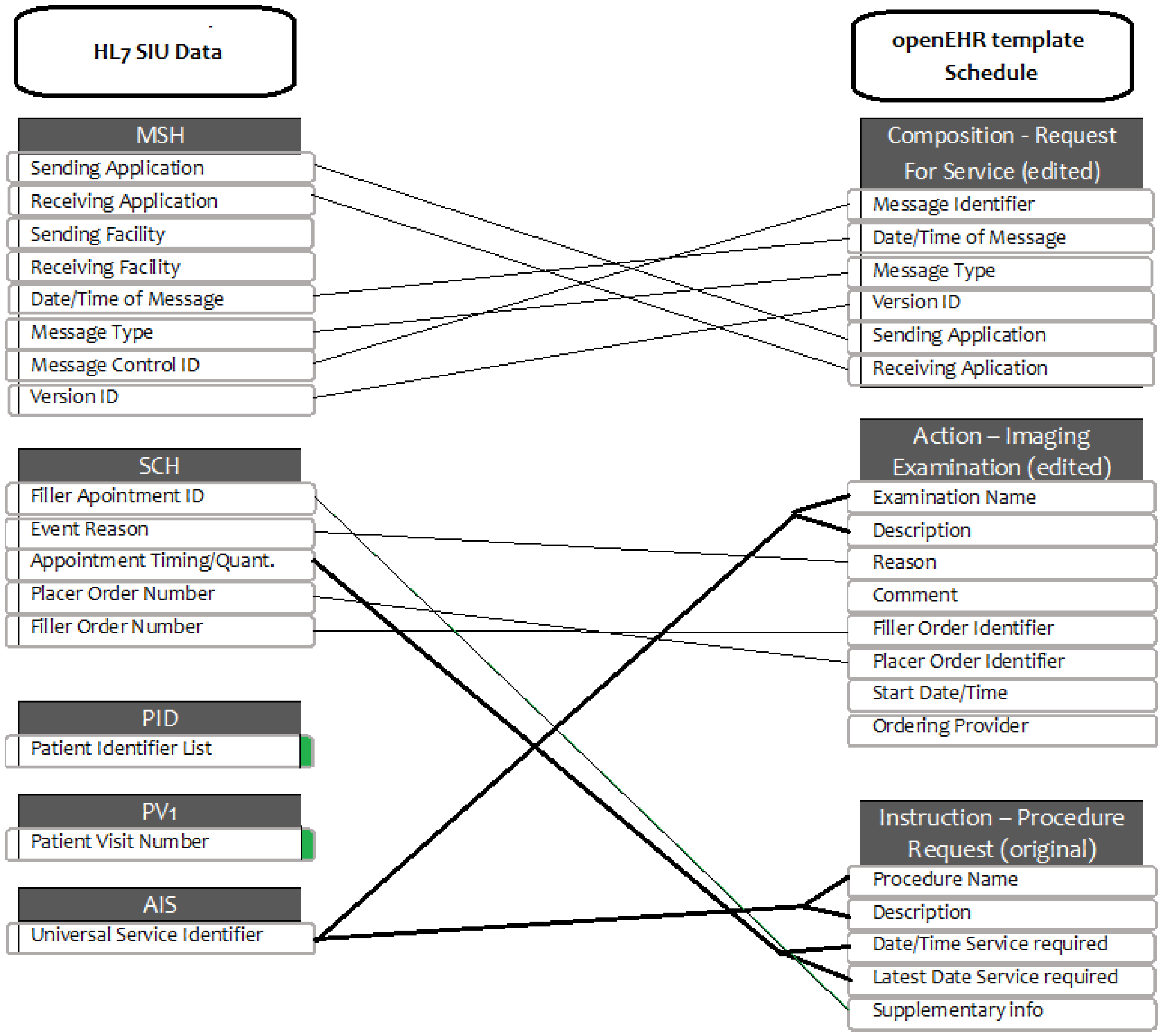



Figure 2.10: Mapping of clinical data from the HL7 SIU message type to the Schedule Template.

For the Report Management openEHR template, the clinical data is translated from the HL7 message type ORU. The template has the same action archetype as the others described earlier, named **Imaging Examination** with the purpose of mapping the state of the order workflow through the **Pathway** content. Figure 2.11 presents the correlations between HL7 and openEHR.

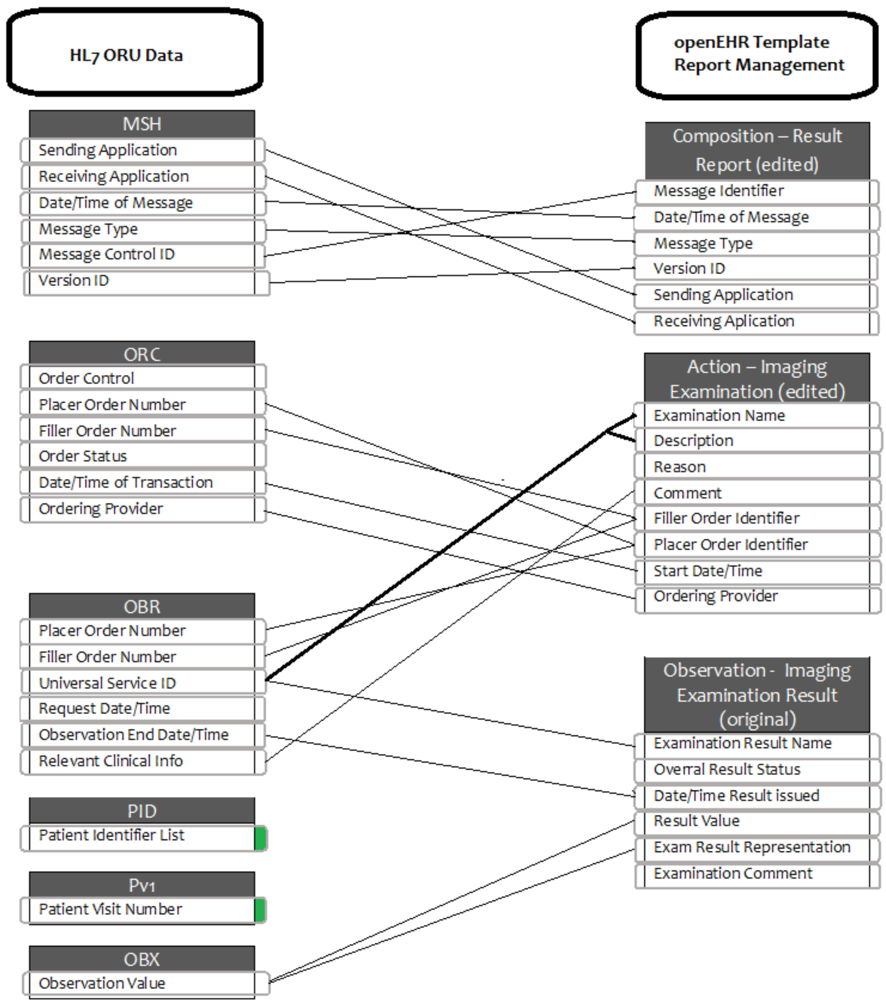



Figure 2.11: Mapping of clinical data from the HL7 ORU message type to the Report Management Template

After this work the researcher can extract the data from HL7 v2.x messages and populate the openEHR templates to feed an repository.

## 2.3 Results

### 2.3.1 Analysis of the interoperability context

The global analysis of the interoperability context in the HI based on section 2.2.1, enabled a better comprehension of the healthcare scenario. We found that the HI has a central information system, with presence in all Departments, and that it deals majorly with patient demographics and scheduling of orders. All the HL7 messages are coded in the 2.4 standard. Using the Audit Services module, the researcher had a birds-view of all communication between HIS, and subsequently a clear view of the number of orders processed, number of episodes, and patients that cross the HI.

Regarding the task of extracting IP packets from the HI network with the purpose of analysing the HL7 messages that go through it, the sniffer module used had a very reliable performance in production.

The audit performed on the Radiology HL7 Circuit with the help of documentation regarding integrations between the HIS, enabled the design of a diagram matching the reality of the actions made by healthcare professionals in the daily clinical practice. The diagram represented in figure 2.1 shows all the actions that compose a correct workflow of the order. On section 2.2.1.3 the list of actions by HIS is a key factor to understand the responsibilities of each at the Radiology Department, helping on the design of the Radiology HL7 Circuit.

The most common workflow encountered, is composed of the following actions:

1. Initial order requisition made through the RIS.
2. Acknowledgement response executed by the CIS.
3. Appointment Scheduling done with the CIS.
4. Admission of the patient in the HI, triggered by the CIS.
5. Acknowledgement response executed by the RIS.
6. Confirm activity of the order, if completed or cancelled, done by the RIS.
7. Send Report with final results to CIS, by RIS.

Nevertheless, it was also possible with IRA to verify that some orders did not follow the 'normal' workflow of the Radiology Department. Such as having confirmation of finished activities before an admission of the patient in the HI or also cancellations of orders and subsequent modifications. These are direct inconsistencies with the diagram designed in 2.1, violating the priority of the states and correct process of an order workflow.

### 2.3.2 HL7 to openEHR

The process of translation from one type of data model (HL7) to a different one (openEHR) is described on sections 2.2.2.2 and 2.2.2.

Through the analysis to the Radiology Department HL7 Circuit, we verified the HL7 structures used for communication between the HIS. Comparing such structures with the respective HL7 v2.x specification, some inconsistencies are identified. For example, the low incidence of data in HL7 messages regarding the healthcare professional who required the order and also from who approved the results report. Such syntactic problems come with the integration done by the different vendors involved. Nevertheless, data regarding the examination name, unique identification and realization dates is available.

For the choice of openEHR archetypes, we took advantage of the online repository CKM. The archetypes were chosen through their purpose in use, and by verifying the correspondence with the HL7 fields specified in tables from section 2.2.2.1. The major connection between the four openEHR templates created for the Radiology Department comes with the archetype chosen to store the data regarding the state of the order workflow, in this case the action archetype. The action archetype used is the **Imaging Examination**, which contains a structure that enables the task of mapping the order state. Regarding the composition archetype, three of the four templates have the same (Request for Service), but as the Report Management deals with observation results it has a different one (Result Report).

Each template possesses a unique archetype, due to the difference in their purposes. For the Order Management template, as it is responsible for all the requisitions, modifications and cancellations of orders through all the workflow, it has an archetype of requisition of an imaging examination in it's original structure from the CKM.

The Acknowledgement template deals with data for validation of previous HL7 messages. To store data related to errors regarding validation of content or others, we created a new archetype of type cluster, named Acknowledgement Data. It is used as an extension of the composition archetype *Request for Service*.

The Schedule template purpose is to identify all data regarding the process of scheduling the date for the examination. The unique archetype in the template is the Procedure Request, that is also used in it's original structure from the CKM.

The Report Management template deals with the final stages of the order workflow, and as such the observation results. It has a different composition archetype, but it was also edited to store the data regarding the header of the HL7 message like with the other composition archetype (Request for Service). For storing data from the observations results segments of the HL7 message, the researcher chose the Imaging Examination Result.

The composition archetypes were edited to store general information about the exchange of data between the HIS. Adding some extra fields in the archetype enabled the mapping of such information to the openEHR ideology.

Another edition made was in the action archetype that is present in all templates. The researcher altered the content of pathway from the Imaging Examination archetype, to the states identified in figure 2.1 and section 2.2.1.3.

## 2.4 Discussion

The analysis made to the sample and the existing documentation, enabled us to understand the HL7 message interactions that were compliant to the documented workflow, but most importantly identified the misfits, the ones that would not fit in the agreed workflow by the vendors, causing confusion with the HIS. To better understand the number of misfits, a deeper analysis with the vendors shall be conducted to verify the magnitude of the problem.

The mapping of the correlation between the two models is dependent of the openEHR methodology, and as such is a very thorough process.

Nonetheless, the correlation between the two is possible as showed along this chapter, mainly because we are concentrating only in a particular healthcare scenario. Adapting such methodology of translation to another Department or HI, would require a redo of all the previous steps indicated.

The solution may be in supporting the translation process with an existing methodology of clinical workflows.

# Study B

# 3. Study B

## 3.1 Introduction

With the knowledge acquired through the developments and decisions described on Chapter 2, we automatized the transformation process of the clinical data. First on this Section we will introduce the developed solution, including the functional requirements and system architecture. After a detailed analysis to the implementation the solution on the HI is presented and we end with a discussion of the work done.

### 3.1.1 CDOT

The CDOT solution aims to provide the means to transform clinical data from HL7v2.X messages into openEHR compositions. The main objective is that those compositions can be used to populate a unique openEHR repository. In order to implement the solution, we used an installation of the Mirth Connect integration engine and JSON data structures for communication. Through the IRA solution detailed in Section 2.2.1.2, the CDOT solution receives the incoming HL7 v2.X messages and parses the contents of each message so that relevant clinical data can be mapped into a JSON data structure. After, the JSON will work as an intermediary structure, in order to populate the openEHR compositions. The compositions that feed the unique repository are based on the openEHR templates created by the author, described in section 2.2.1.3, that better suit the clinical context in which the CDOT solution will be implemented. In the end the solution empowers the user with the ability to have clinical data in a openEHR composition, which can then be sent to an application that accepts such format or to an unique clinical repository.

### 3.1.2 Use Cases

In this section we will describe some use cases regarding the role of the CDOT solution in a real healthcare scenario. As the solution passively inspects the communication between the HIS, it has no influence on the healthcare professional workflow, but enables possibilities that can directly impact the end-user at the short and long term. For example, at the short-term the adoption of a shared EHR with the integration of all HIS will mean an unique EHR per patient, that will possess all the information produced in the HI in one instance. The CDOT is the solution to the integrations between the HIS and the shared EHR. At the long-term the persistence of the clinical openEHR templates will enable the persistence of clinical data and its availability in the future, thus the healthcare professionals may lose the fear of vendor lock-in and embrace a *future-proof* EHR.

The first use case is related to an episode in an intra-institutional healthcare scenario.

`Use case 1 - A patient is admitted in the emergency department of Hospital X, due to an adverse reaction. The physician prescribes an anti-histaminic to the patient and issues the discharge. After the apointment the physician suspects the adverse reaction has to do with substance Z and wants to notify it to the national association responsible for storing adverse reactions notifications, that supports the ideology of a shared EHR, using a openEHR clinical respository. The physician notifies the adverse reaction on the HIS and the CDOT solution integrates with the national openEHR clinical repository of adverse reactions.`

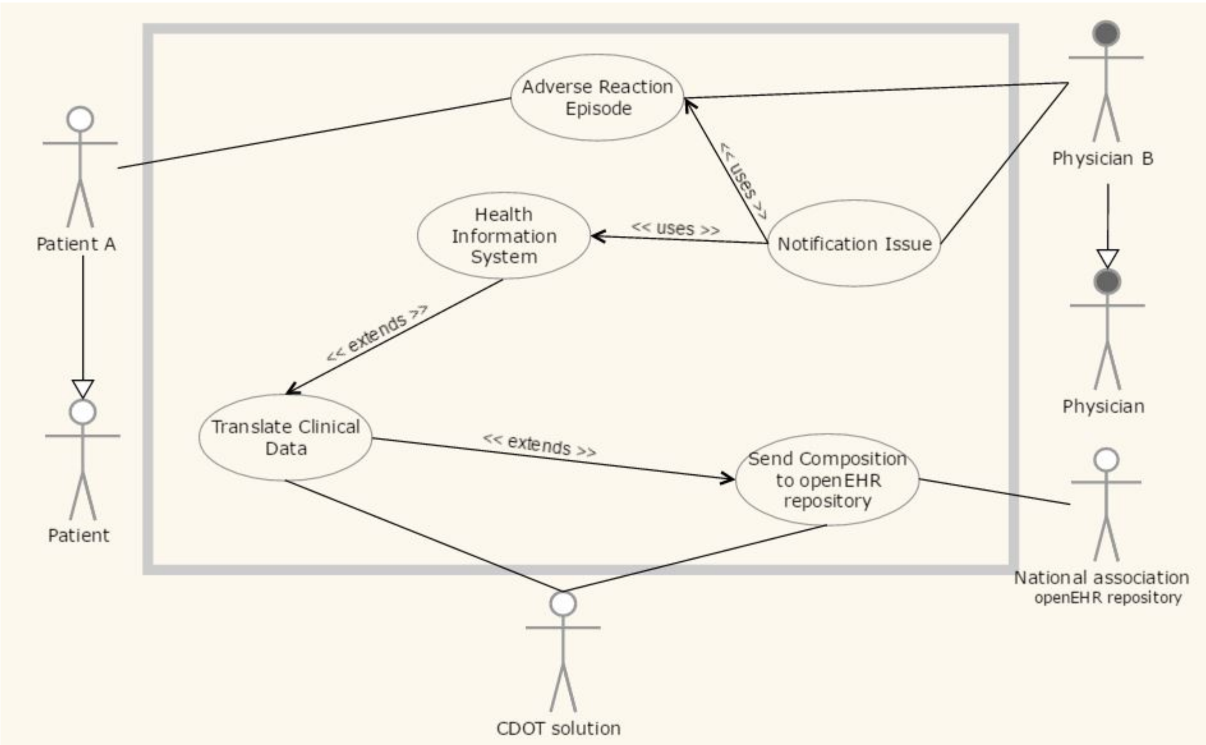



Figure 3.1: Use case related to an episode of an adverse reaction.

The second use case is related to episodes in a intra-institutional healthcare scenario along time.

`Use case 2 - A patient enters the Orthopedics Department of Health Institution X, due to a pain in the forearm. The patient is examined by Physician C who then sends him to perform an imaging examination. The patient's imaging examination reveals a broken radio. Physician B casts the forearm and discharges the patient using HIS Y. OpenEHR compositions are created based on the HL7 communications done at the HI network level. Twenty years later the same patient enters the emergency department of Hospital X due to a fall from a ladder. Now Physician D uses HIS Z, that is openEHR compliant to search previous episodes of the patient, and finds clinical data related to an discontinued HIS Y used to request a imaging examination. As Health Institution X adopted the CDOT solution, imutable and persistent openEHR compositions were always created based on the communications done at the network level. Making the clinical data independent of HIS` and therefore vendors.

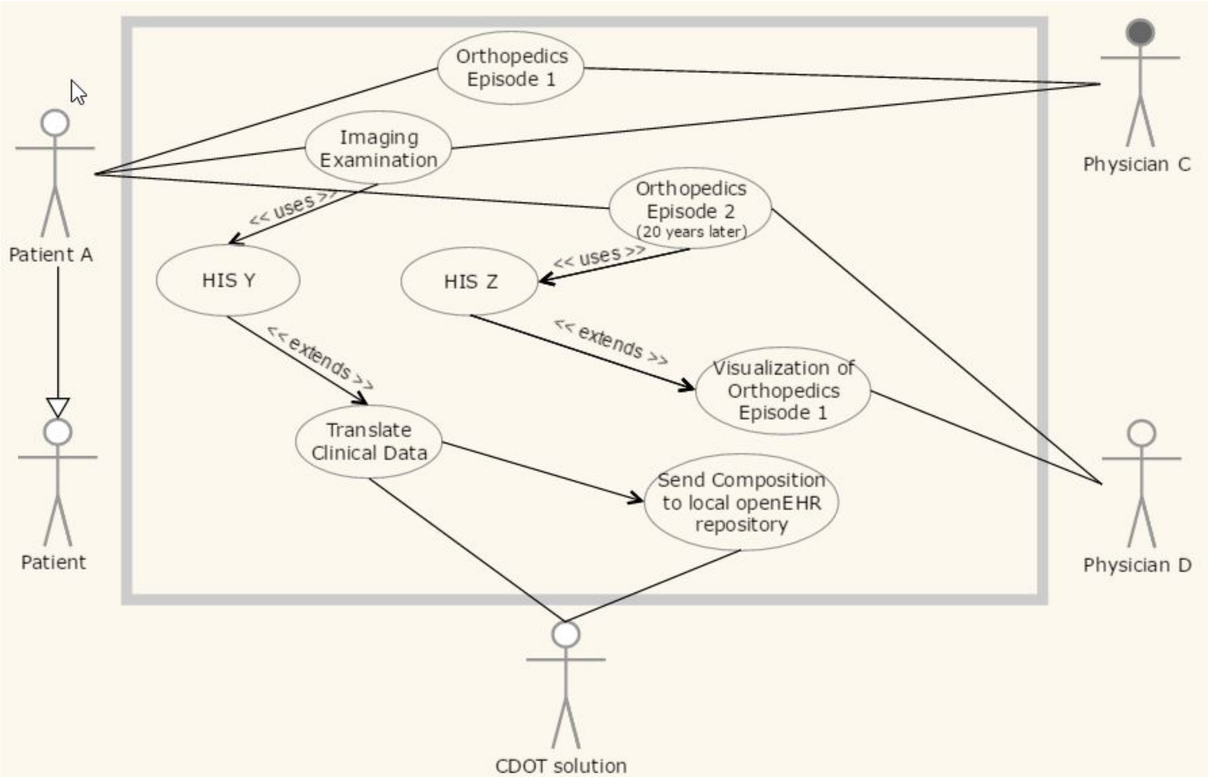



Figure 3.2: Use case related to an episode in the present time and in the future.

## 3.2 Requirements

### 3.2.1 Functional Requirements

Here we describe the functional requirements of the CDOT solution, defining situations that it should support. These requirements need to be balanced with the reality of the healthcare domain.

- It should have the ability to receive HL7 traffic, without interfering with the HI network.
- The solution has to separate the clinical data from the patient demographics information.
- The solution must be capable of producing data structures that are after validated by a designated XML Schema Definition (XSD) to form openEHR compositions.
- It should have the feature to exchange clinical data with HIS compliant with the openEHR standard.

### 3.2.2 System Architecture

It defines the conceptual model of the solution and behaviour of it with other systems. It involves the components that make the solutions, and all other variables needed to implement the overall system.

Figure 3.3 shows a general view of the CDOT solution with the surrounding infrastructure. It shows the source of the data and it's path of transformations until the commitment of the clinical data.

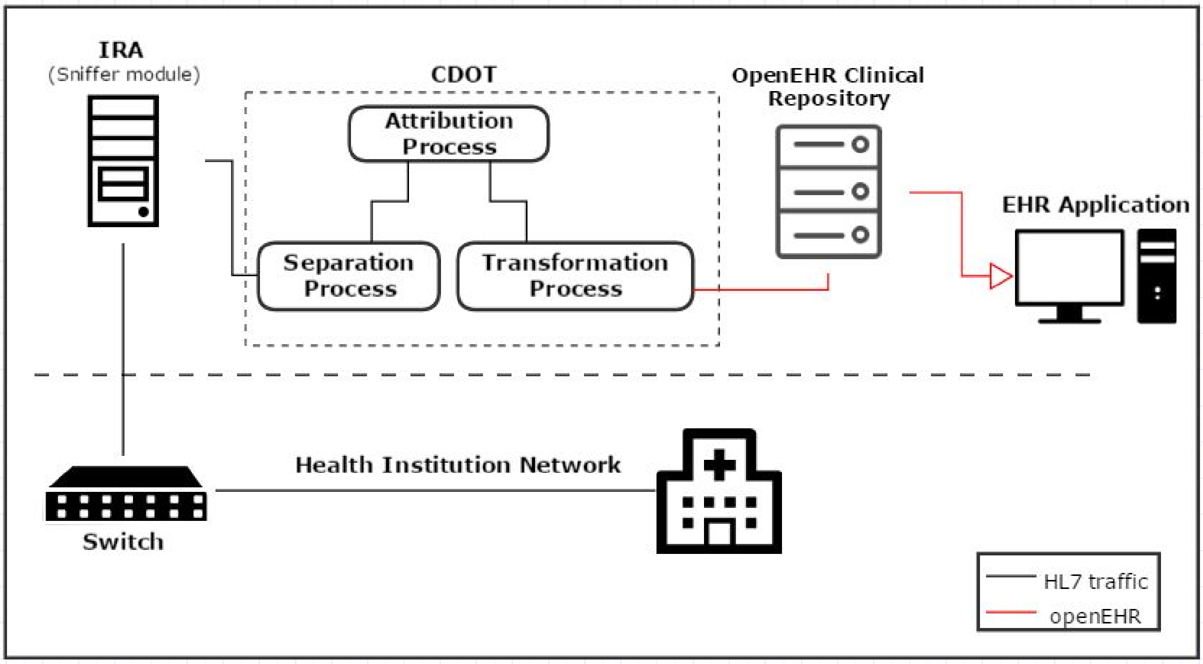



Figure 3.3: Design of the System Architecture of the CDOT and surrounding infrastructure.

Foremost the HI network is tunnelled using a network switch, allowing the IRA solution to gather the HL7 traffic. Then, it sends the data to the CDOT solution, where it will suffer three distinct process, the Separation Process, the Attribution Process and the Transformation Process. After the transformation the clinical data is ready to feed a clinical repository, starting the commitment process. Lastly, we used an EHR application to visualize the clinical data committed from HL7 v2.x messages. These two last components are based on a existing open-source solution, that acts as an EHRServer and as an EHR Application [52].

Table 3.1: Technical requirements of the CDOT solution

| | |
|---|---|
| **Operative System** | Ubuntu 14.04.4 LTS |
| **CPU** | Dual Core 2.4GHz |
| **Memory** | 4Gb RAM |
| **Disk** | 55Gb |
| **MirthConnect Version** | v3.4.1.8057 |
| **OpenEHR Clinical Repository** | CaboLabs EHRServer v0.7 |
| **OpenEHR Application** | CaboLabs EHRServer v0.7 |

## 3.3 Implementation

The implementation process of the CDOT solution is simple, practical and adaptive to the different healthcare scenarios in which it is deployed. The solution is based on international standards that guide the workflows of daily clinical practice, which are in nowadays the *gold-standard* to exchange clinical data in and between HIs. Like for example, if a HI possesses the communications between HIS accordingly to the IHE profiles methodology, the CDOT solution will identify directly the desired HL7 fields and map them to the correspondent openEHR composition.

On this section, we will explain the purpose of the Mirth Channels regarding the anonymization of patient demographics and clinical data withdrawal from the HI network. As the transformation process used on this study is explained, a description of the steps taken to sustain and validate the majority of healthcare communications done in the HI is presented. Ultimately an explanation of the openEHR repository used and how it can be queried is given by the authors. More details regarding the commitment of clinical data to the openEHR repository are described along the section.

### 3.3.1 Mirth Channels

The first process of the workflow of the CDOT is the reception of extracted HL7 messages. These messages are extracted from the HI network using the IRA solution, who then diverts the traffic to the CDOT.

The second process is the separation of the clinical data from the patient demographics. We used a healthcare data integration engine, a **MySQL** database and a EHR repository with API to execute the process. The identification number of the patient and some patient demographics are extracted from the HL7v2.x message. Then the number is verified with the PMI, responsible for maintaining a central database with patient demographics, if it has a match it will return an EHR identifier to use forward. If the patient identifier is not in the PMI, it will redirect to an API from an openEHR repository, in order to associate the patient identifier to an EHR identifier. After it registers the patient with the PMI and proceeds to the transformation process. Figure 3.4 shows highlighted in blue the process described earlier.

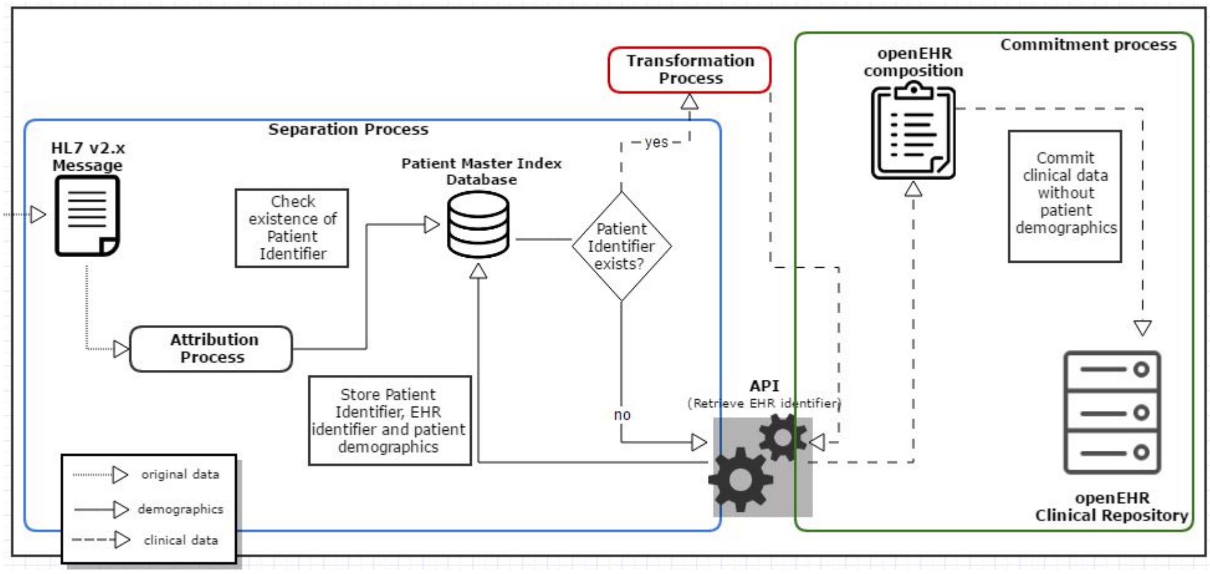



Figure 3.4: Representation of the five process involved in the CDOT-

The arrow that comes from outside the box represents the reception process. The blue square represents the Separation Process. The red square represents the transformation process. the green square represents the commitment process. The black square represents the attribution process.

The third process is the separation of HL7 v2 messages by their purpose, as explained in section 2.2.1.3. Each message will have a correspondent openEHR template in which it will be mapped, according with their intent in use. The implementation of the CDOT solution on the HI, as described in section 2.2.2, originated four openEHR templates and consequently four sets of HL7 message types.

The fourth process is the transformation based on IHE that is detailed forward in the section 3.3.2. We used the transformers at the source level of the Mirth channels to perform the changes needed for the process. In the end, the composition is created and ready to be sent.

The final and fifth process uses the connectors of Mirth to interoperate with an API. The openEHR repository has a RESTfull API, enabling the use of HTTPS submissions using the POST and GET methods.

### 3.3.2 Transformation based on IHE

The variety of clinical workflows in the Radiology Department are mainly defined because of healthcare professionals daily practice habits. And as technology continuously increases in the healthcare domain, becomes part of healthcare professionals habits. Increasing the metadata collected from the healthcare professionals use of the technology, such as logins, requests, prescriptions, enables a easier mapping of all the steps involved in a clinical workflow. This information will be valuable to pressure the adaption of HIS that support workflow standards such as IHE

IHE integration profiles enables HIS to integrate accordingly to predefined standards, optimizing clinical workflows. As our work was related with a Radiology Department, as described in section 2.2.1.3, we followed the guidance of the Radiology Domain of IHE and respective Technical Frameworks published. In more detail the analysis done earlier deals with the order workflow (Order Management, Report Management, Acknowledgement and Schedule), referred in section 2.2.2.3. According to the IHE Radiology domain the corresponding profile for the situation must be of type workflow. There are three more types named Content Profiles, Presentation Profiles and Infrastructure Profiles but are not within the purpose of the project.

- **Workflow profile** - Responsible for the management of the order workflow, involving the supply of work lists, and report/monitor of progress and conclusion of work items.

There are various Workflow profiles with well defined intents of use, as represented in Figure 3.5.

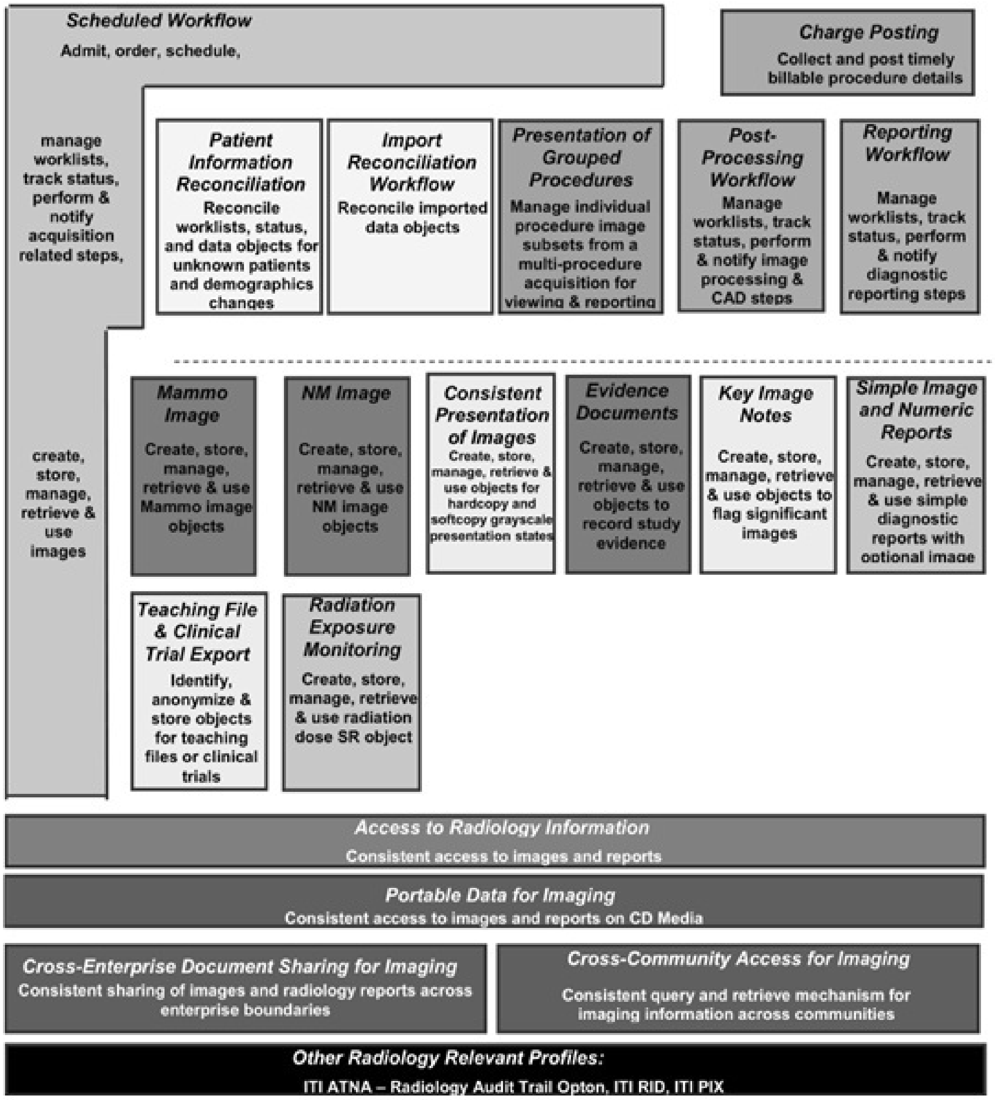



Figure 3.5: Representation of the different Workflow Profiles from the IHE Radiology Domain. Taken from Technical Framework Volume 1 (IHE RAD TF-1).

The profile most suited for our purpose, order workflow and schedule management, is the **Scheduled Workflow**. The Scheduled Workflow establishes the continuity and integrity of clinical data, specifies a set of transactions that maintain the consistency of patient and ordering information and provides the scheduling and imaging acquisition procedure steps It manages the workflow from the request of the order to the issue of the report, including appointments.

**IHE Actors and Transactions**

Integration profiles define sets of actors who can be involved in more than one transaction. A transaction is the correspondent to an general set of actions performed by a healthcare professional, like for example Schedule Tasks set involves the actions new appointments, reschedule appointments and cancellation of appointments.

Earlier we analysed all the actions involved in the Radiology Workflow of the HI, described in section 2.2.1.3 and now we identify the IHE transactions and actors with the same intent in use as the actions performed on the Radiology Department of Intituto Português de Oncologia do Porto (IPOP).

The IHE actors involved for actions related to order workflow, scheduling and patient demographics are:

- **ADT - Admission Discharge Transfer -** An HIS responsible for information regarding patient demographics and episode.

- **OP - Order Placer -** Central HIS that manages the order requests and distributes tasks for each Department.

- **DSS/OF - Department System Scheduler/ Order Filler** A specialized HIS, like RIS or Laboratory Information System (LIS). Involved from the process of order request to the final report.

Each IHE actor may interact in more than one transaction. Table 3.2 shows the chosen interactions that best suit the actions of the Radiology Department.

Table 3.2: IHE Actors and Transactions indicated to suit the Radiology Department actions.

| Actor | Transaction |
|---|---|
| ADT Patient Registration | Patient Registration [RAD-1] |
| | Patient Update [RAD-12] |
| | |
| Order Placer | Appointment Notification [RAD-48] |
| | Patient Registration [RAD-1] |
| | Patient Update [RAD-12] |
| | Placer Order Management [RAD-2] |
| | Filler Order Management [RAD-3] |
| | |
| Department System Scheduler/Order Filler | Patient Registration [RAD-1] |
| | Patient Update [RAD-12] |
| | Placer Order Management [RAD-2] |
| | Filler Order Management [RAD-3] |
| | Procedure Scheduled [RAD-4] |
| | Procedure Update [RAD-13] |
| | Appointment Notification [RAD-48] |

We identified general interactions related to the order request (RAD-2 and RAD-3) and appointments (RAD-1 and RAD-12). For each transaction there are multiple actions associated, more details are found in the Technical Frameworks published periodically by the IHE Radiology Domain. For example, transaction **RAD-2** (Placer Order Management) includes four actions. The actions are: request of an order, cancelling of an order, change of an order and cancelling of an examination in-progress. All the transactions identified on table 3.2, have a set of actions associated that is more detailed later on section 3.4.1

After doing the mapping of the IHE actions with the Radiology Department actions, we can proceed to follow the guidelines of the Technical Frameworks, and follow the IHE implementation process of clinical workflows, using international standards such as the HL7. Each action is defined in IHE through the representation of a HL7 v2.x message structure, meaning that in the end we will have openEHR templates mapped directly from the HL7 fields specified in the IHE Radiology Domain Technical Frameworks for each set of actions. All the HIs that comply with IHE Radiology methodology, will use the same openEHR templates and thus obtaining interoperable openEHR compositions.

### 3.3.3 openEHR Repository

The final implementation step is the commitment of the created compositions to an openEHR clinical repository.

We used an existing solution to be our openEHR clinical repository.

The **EHRServer**[53] is an open source, service-oriented, openEHR clinical data repository, developed by Dr.Pablo Pazos[54] from CaboLabs[55].

Among the many qualities of the EHRServer, its ability to support XML and JSON structures, the REST API feature, the support of rich documentation and being able to query the clinical data are among the requirements desired for the commitment process [55].

First the method GET was used to obtain the identification token, in which the user who is submitting the clinical data will be identified. Then the CDOT solution sends to the EHRServer API a POST request containing the created openEHR composition in a XML format and an identification token.

After the XML structure is validated against an XSD [56] that is compliant with the openEHR standard. The XSD validates the submitted composition against the openEHR dual methodology reference model, to not corrupt the clinical repository. It also possesses a versioning mechanism to provide corrections or amendments to openEHR compositions.

In the end, the clinical data contained in the composition is mapped to the desired archetypes slots of the created openEHR template.

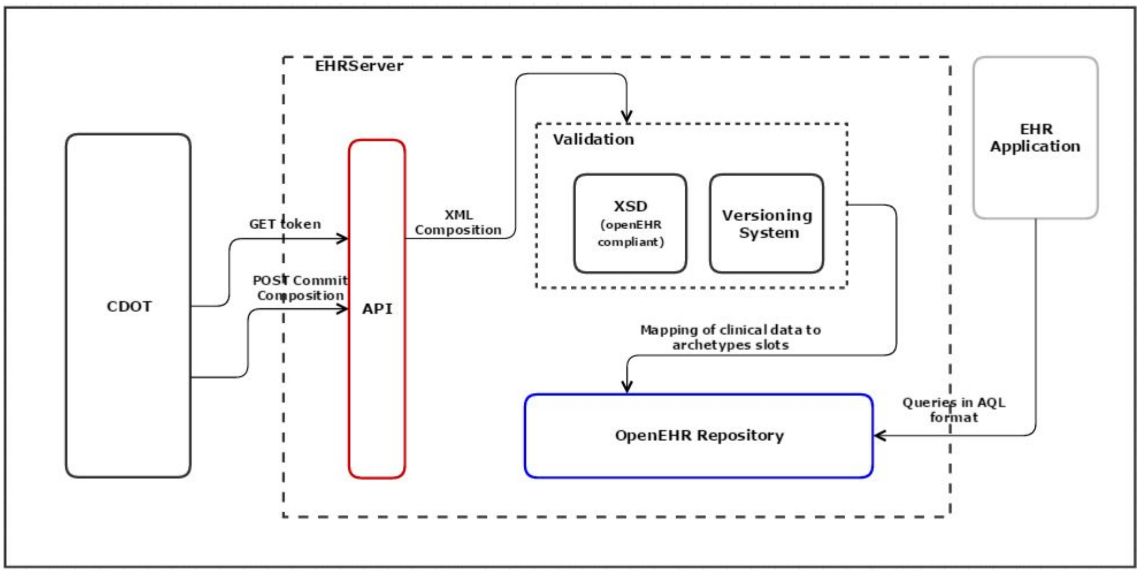



Figure 3.6: The fifth process, commitment of the clinical data in XML compositions. Validation and querying.

#### Querying the data using Archetype Query Language

Once the clinical data is on the archetype slots it can be queried for clinical documents or data values. The EHRServer uses the AQL syntax to query the openEHR clinical repository. It provides a query builder to adapt the information display accordingly to the healthcare professionals needs.

```
SELECT c/content[openEHR-EHR-ACTION.imaging_exam.v1]/ism_transition/careflow_step/value as Fase_do_workflow
FROM EHR [ehr_id/value = "7faf87bb-833d-40f8-9072-f0b47c83b8eb"]
CONTAINS COMPOSITION c
ORDER BY c/context/start_time DESC
```

Figure 3.7: Query to determine the workflow phase of a defined EHR.

## 3.4 Evaluation

### 3.4.1 Mapping of IHE Actions and IPOP Actions

#### Mapping of actions related to patient demographics information

Described in section 2.2.1.3 are the set of actions of each HIS involved on the Radiology Department (RIS and CIS). CIS is responsible for patient demographics information and episode management, the same purpose fits the IHE actor ADT.

The actions executed by the CIS on the Radiology Department, involving patient demographics information and episode management are:

- **ADT - A08** -> Patient Information Update
- **ADT - A34** -> Patient Information Merge
- **OMG - O19** -> Admission of a patient in the HI.
- **OMG - 019** -> Cancellation of a patient admission in the HI

These identified actions are in production on the Radiology Department and their purpose relates to identical IHE actions. Nonetheless, their current implementation does not follow totally the IHE methodology.

To announce the admission of a patient in the HI, the CIS sends a HL7 message of type OMG-O19 to the RIS, with the fields ORC.1 = "SC" and ORC.5 = "IP". Transaction **RAD-1 - Patient Registration**, enables the HIS to announce the admission of a patient in the HI using action **Registration of an outpatient for a visit of the facility**. For the cancellation of an admission of a patient in the HI, the CIS sends a HL7 message of type OMG-O19 to the RIS, with the fields ORC.1 = "SC" and ORC.5 = "HD". Again, transaction **RAD-1 - Patient Registration** covers the situation with action **Cancel Admit Patient**.

Regarding the other two actions that CIS performs in Radiology Department, patient update information and merge patient info, are already according the IHE methodology. In transaction **RAD-12 - Patient Update**, we have the IHE action **Patient information update** which has the same purpose and structure of the identical named action on the Radiology Department **Patient Information**

**Update**. Also in the same transaction, the IHE action **Patient Merge** is identical to the Radiology Department action the **Patient Information Merge**.

Figure 3.8 shows the agreement between IHE actions and Radiology Department actions.

| Action | Type and Status | New Type | Correspondent transaction and action | IHE Compliant |
|---|---|---|---|---|
| Notification of an patient entry in the healthcare facility for an examination | OMG^O19 ORC.1 = SC ORC.5 = IP | ADT^A04 | Patient Registration [RAD-1] “Registration of an outpatient for a visit of the facility” | |
| Cancelation of an patient entry in the healthcare facility for an examination | OMG^O19 ORC.1 = SC ORC.5 = HD | ADT^A11 | Patient Registration [RAD-1] “Cancel Admit Patient” | |
| Update patient information | ADT^A08 | ADT^A08 | Patient Update [RAD-12] “Patient information update” | |
| Merge patient information | ADT^A34 | ADT^A34 | Patient Update [RAD-12] “Patient merge” | |

Figure 3.8: Mapping and agreement of IHE actions and Radiology Department actions related to patient demographics information.

#### Mapping of actions related to order management and report management

For the mapping of IHE actions executed by the Order Placer (OP) and Despartment System Scheduler / Order Filler (DSS), we had to assume some definitions: using the purpose of the actions which actors of the HIS of the Radiology Department

- Actor **Order Placer** is from the IHE radiology domain point of view a CIS that manages the request for the corresponding Department.
- Actor **Department System Scheduler/Order Filler** is defined as an exclusive HIS for a hospital speciality, like Radiology. It also can manage the request of orders and is responsible for scheduling.
- The documentation provided by the IT healthcare professionals of the HI, indicates that the CIS has the responsibility of scheduling orders and is transversal to all the HI.
- It indicates that RIS is exclusively used on the Radiology Department. Being responsible for the communication of images with actor of image management using the DICOM standard.
- The HL7 message analysis done on the Radiology Department, revealed that the CIS requests orders directly trough the scheduling of it, changes orders request, deals with scheduling tasks and admission of patient in the HI.

- Regarding the RIS, the HL7 message analysis shows that is responsible for the management of the order, cancelling of an order or an order in-progress and report management.

Figure 3.9 shows the agreement between IHE actions and Radiology Department actions of the two HIS.

| HIS | Action | Current Type and Status | New Type and Status | Correspondent Transaction and Action | IHE Compliant |
|---|---|---|---|---|---|
| RIS | Request a new order | OMG^O19<br>ORC.1 = NW | OMG^O19<br>ORC.1 = SN | Filler Order Management [RAD-3] "New Order from Order Filler" | |
| | Change an order | None | OMG^O19<br>ORC.1 = XX | Filler Order Management [RAD-3] "Change Order from Order Filler" | |
| | Cancel an order | OMG^O19<br>ORC.1 = CA | OMG^O19<br>ORC.1 = OC | Filler Order Management [RAD-3] "Order Cancelled by the Order Filler" | |
| | Cancel an in-progress order | OMG^O19<br>ORC.1 = SC<br>ORC.5 = CA | OMG^O19<br>ORC.1 = SC<br>ORC.5 = OD | Filler Order Management [RAD-3] "Order Status Update by the Order Filler" | |
| | Order Completion | OMG^O19<br>ORC.1 = SC<br>ORC.5 = CM | OMG^O19<br>ORC.1 = SC<br>ORC.5 = CM | Filler Order Management [RAD-3] "Order Status Update by the Order Filler" | |
| | None existing Use -> (Order is in progress) | None | OMG^O19<br>ORC.1 = SC<br>ORC.5 = IP | Filler Order Management [RAD-3] "Order Status Update by the Order Filler" | |
| CIS | Change an Order | OMG^O19<br>ORC.1 = XO | OMG^O19<br>ORC.1 = XO | Placer Order Management [RAD-2] "New/Change Order from Order Placer" | |
| | None existing Use -> (New Order) | None | OMG^O19<br>ORC.1 = NW | Placer Order Management [RAD-2] "New/Change Order from Order Placer" | |
| | None existing Use -> (Cancel Order) | None | OMG^O19<br>ORC.1 = CA | Placer Order Management [RAD-2] "Cancel Order by Order Placer" | |

Figure 3.9: Mapping and agreement of IHE actions and Radiology Department actions related to order management and report management.

All the Radiology Department actions described on table 3.9 have an identical IHE action.

For the actions executed by the RIS, it is the equivalent in **IHE SWF** profile to the actor **Department System Scheduler/ Order Filler**. For the actions executed by the CIS and mostly by it's position as a central system, it is the equivalent in **IHE SWF** profile of actor **Order Placer**.

**Mapping of actions related to scheduling**

The responsibility of scheduling an appointment to an order request, according to the IHE is in the responsibility of the actor **Department System Scheduler/Order Filler**. Nonetheless, with the HL7 message analysis done we can clearly state that this role on the Radiology Department is being executed by the CIS.

This situation brings a conflict between reality and the IHE methodology, as we verified the Radiology Department CIS is the corresponding IHE actor OP, nonetheless this task should be done by the DSS. Changing such responsibilities from CIS to DSS would be very hard to implement, affecting the daily clinical practice of healthcare professionals and probably reducing the quality of care during the change. As the IHE methodology is intended to be used as guidelines to achieve a better interoperability between HIS, it also indicates that it should be plastic enough to allow some changes accordingly to real use case scenario. In this case, the schedule transaction **RAD - 48 Appointment Notification**, will be the responsibility of the actor OP, the Radiology Department CIS.

| HIS | Action | Current Type | New Type | Correspondent Transaction and Action | IHE Compliant |
|---|---|---|---|---|---|
| CIS | New Appointment Booking | SIU^S12 | SIU^S12 | Appointment Notification [RAD-48] "New Bookings" | |
| | Rescheduling Appointment Booking | SIU^S13 | SIU^S13 | Appointment Notification [RAD-48] "Reschedule Bookings" | |
| | Cancel of Appointment Booking | SIU^S15 | SIU^S15 | Appointment Notification [RAD-48] "Cancel Bookings" | |

Figure 3.10: Mapping and agreement of IHE actions and Radiology Department actions related to schedule information.

## 3.5 Discussion

Chapter 3 Study B details how the knowledge acquired from Chapter 2 Study A is applied on the development of the CDOT solution. As for example using the description of IPOP actions presented in section 2.2.1.3, and also with the definition of openEHR templates and correspondent HL7 fields, described in section 2.2.2

The development of the CDOT solution brings to discussion the requirements regarding its functionality and architecture appointed in section 3.2. The capabilities of the solution are described on the functional requirements and represents the actions it performs on the healthcare scenario. Also the system architecture defines the different processes done with the CDOT solution and illustrates it's association with the IRA and the EHRServer, as showed on section 3.2.2.

The implementation describes in detail the different processes done by the CDOT solution to the clinical data and patient demographics info and explains the purpose in using the IHE methodology and the **EHRServer**.

Finally as an outcome of analysing the Radiology Department HL7 Circuit and associate the result with the IHE Radiology Domain actions we can suggest modifications to the HI IT infrastructure to then pass it to the vendors to implement.

The CDOT solution is a product that through its implementation on a healthcare scenario outcomes the mapping of the communications done by the vendors and empowers the IT healthcare professionals with knowledge towards the standardization of the exchange of data.

# Discussion

# 4. Discussion

As the developments done for the thesis are now over and stated along the earlier chapters, we can check with how much precision we accomplished the objectives.

The main objective of the thesis was to elaborate a solution that transformed the data in HL7 v2.x messages to openEHR compositions in order to feed a unique repository of clinical data. Although the literature regarding the overlap between the two standards mentioned is scarce due to the HL7 v.2x message structure not being ideal for a clinical document format, we used a third standard (IHE) to make the bridge. We translated HL7 messages that have an intend action in a IHE profile that relates with a clinical document in openEHR. After the research and development made through out the thesis we obtained the knowledge to accomplish the main objective and created the CDOT solution that enables the HI to achieve such purpose. Nonetheless we identified some requirements for the deployment of the CDOT solution in a healthcare environment, such as the existence of communications between HIS using the HL7 v2.x standard. We also need an extraction tool to gather the HL7 v2.x messages from the HI network or a ESB that can clone the HL7 traffic and send it to the solution. Lastly, in order to guarantee a unique repository of clinical data the CDOT solution took advantage of the **EHRServer**, based on the openEHR methodology.

## 4.1 SO.1 - Mapping of clinical workflows

For the first secondary objective we aimed to map the clinical workflows of the healthcare scenario in analysis through the audit of the HL7 v2.x messages. Understanding the clinical context regarding the exchange of clinical data in the HI, is the first key situation onto the implementation of the CDOT solution, so we can state this objective as been fulfilled.. If the healthcare environment has a non-standard workflow of communication, it is necessary to perform a detailed analysis to the interoperability context, so we can map the actions of the workflow. In this thesis analysing the HL7 Circuit of the Radiology Department helped in the mapping of the actions of the healthcare professionals, and to construct clinical order workflows based on the exchange of data. More, the actions defined the general phases that occur on the Radiology Department network, such as Order Management, Report Management, Schedule and Acknowledgement. Chapter 2 (Study A) shows the process of how to map the clinical data exchanged between different HIS. The primary stage of understanding the healthcare scenario is needed when there is not certainty in the compliance of the integrations with defined standards. In order to skip the analysis of the interoperability context for each time a implementation is done, the integrations must be compliant with some interoperability standard regarding clinical workflows, such as IHE. Our intention is to en-force IHE workflows across different HI, to enable the sharing of the same openEHR operational templates.

## 4.2 SO.2 - Noticing erroneous workflows

The second secondary objective of the thesis was to identify the wrong clinical workflows in production on the analysed healthcare environment. This objective was accomplished during the analysis of the interoperability context, but is also possible to identify ”wrong” workflows during the transformation process of the clinical data. In order to accomplish such objective we need to have a set of specifications related to clinical workflows on which we can base our definition of a ”wrong” workflow. On this case we took the IHE Radiology Domain Technical Frameworks as guidelines to define clinical workflows. The clinical workflows are a set of HL7 v2.x messages, that represent a story that took place on the HI, and IHE is a methodology that indicates how these stories should be told. As the Radiology Department HL7 Circuit was a non-standard workflow, we analysed and illustrated the actual scenario on section 2.2.1.3. We identified the misfits workflows with the help of a script that checked the HL7 message states for each order and compared it to the illustrated scenario in figure 2.1. For healthcare environments that posses a standard workflow, such as IHE profiles, the identification of missfits is done when transforming the data to feed the unique clinical repository.

## 4.3 SO.3 - Populate a unique repository of clinical data

The final secondary objective was to enable a way to store the transformed clinical data to an openEHR clinical repository. This secondary objective was accomplished because the CDOT enables the HI to connect using **REST**, **SOAP** and other methods to an EHR API, and we used pre existing and edited openEHR archetypes to construct the templates. For the clinical openEHR repository we decided to use the **EHRServer**, it provided an incorporated EHR API with the project enabling the connection with the CDOT solution. In order to ensure the openEHR methodology, as the objective states, the created templates for the IHE workflow profiles must comply to a openEHR validation schema. After the template is validated and the connection between the CDOT solution and the API EHR is made, the storage of transformed clinical data from HL7 v2.x messages into a openEHR clinical repository is possible.

In a more personal note, I believe that the standardization of the clinical workflows of the many different healthcare scenarios is the path to an interoperable HI. For this to happen the administration responsible for such subjects must compromise itself and oblige the different vendors to respect such methodologies.

In the national interoperability healthcare scenario the best solution to implement such ideologies in my opinion is, the assignment of a government institution to define national clinical workflows based on the IHE profiles and past national experiences. This National clinical workflows could be used to produce a framework to regulate national clinical workflows and how their integrations should work, the government institution should financially encourage and legally force such changes across the national healthcare domain. Another step that should be taken to harmonize integrations between different HI across a national scenario is the mapping of the clinical data to a predefined storing methodology, as the openEHR. This step assures that all the clinical data will be available on the future, even if a software vendor changes.

# Conclusion And Future Work

# 5. Conclusion And Future Work

## 5.1 Conclusion

Along this thesis, we showed that it is possible to transform the clinical data from HL7 v2.x messages and transform it to be used onto openEHR compositions, validating our main aim objective.

We first presented a description of the concepts related to an HI interoperability context, such as the EHR, most frequent obstacles and different integration methodologies. Then a brief presentation of different international standards or methodologies to tackle the interoperability problems of HIs, providing a good initialization of how to surpass the incoming obstacles when integrating HIS. It also indicates advantages of using such tools and how are they structured.

We analysed the interoperability context of the Radiology Department of IPOP, by auditing the communications done using the HL7 v2.x standard. Inspecting the exchange of data between different HIS nurtured our knowledge about the vendors reality regarding integrations, which most of the time is non-existent and based on one case scenario integrations.

We produced a bird's eye view of the current state of the Radiology Department HL7 Circuit, illustrated by a diagram in figure 2.1. Another outcome was the listing of all the actions done on the Radiology Department by the healthcare professionals, through the use of HIS as showed on section 2.2.1.3. We also got to group by purpose each IPOP action listed into a general interaction, as represented in table 2.6. This set of interactions enabled the relation between the HL7 standard and openEHR, by picking openEHR archetypes from the CKM which fitted the intended purpose of each interaction or by editing them.

Upon implementing the CDOT solution on the Radiology Department, we stated its architecture and purpose in the healthcare scenario as described in sections 3.1.1 and 3.2.2. The CDOT solution acts as middleware to translate the clinical data from HL7 v2.x messages to openEHR compositions. The translation process was based on IHE profiles and their specifications regarding integrations using the HL7 v2.x standard. The relation between the IHE action and IPOP actions is compared in section 3.4, identifying the inconsistencies and agreements between the two. In the end we reached the aim of populating an openEHR clinical repository, with the possibility to query the respective clinical data through the archetype slots.

The interaction with an open-source openEHR clinical repository, as described in section 3.3.3 provided to us a deeper understanding of the openEHR dual methodology-architecture and about its data structure. Also, the Application Programming Interface (API) provided by the **EHRServer** to interact with the clinical repository, made us develop code specifically to our healthcare scenario and also contributions to the open-source project, available at [53].

The healthcare domain is very complex and is consequently changing, as such the HIs cannot close themselves and apply band aids in most integrations done at their infrastructure, because in the future, we will have a different set of HIS that can't process the previous integrations done, and subsequently lose clinical data.

## 5.2 Future Work

For future work, we want to add to the CDOT solution the support for translation from other data standards to the openEHR methodology, for example the DICOM standard to enable the collection of more information related to an order. Also the IHE supports clinical workflows based on communications using the DICOM standard.

More work related to the query of the clinical data should be implemented, such as a development to enable the real-time tracking of patient workflow based on the openEHR compositions committed to the openEHR clinical repository.

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